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ENERGY-EFFICIENT ARCHITECTURE, I.E. A COMBINATION OF FUNCTIONALITY AND ENVIRONMENTAL ASPECTS

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Abstract
The paper presents the concept of energy-saving architecture as a way to increase the use of renewable energy sources in the energy economy and increase the level of eco-innovation in Poland. Solutions leading to the minimisation of costs of energy supply and consumption in the internal building system are presented. The paper shows basic forms of building optimization and the possibility of their adjustment to the existing directives and regulations of the European Union using modern technologies. The reflections have been supported by examples of good practice in the field in Europe and worldwide.

Keywords: energy-saving architecture, optimization, "ZEB" buildings, eco-innovations, renewable energy sources

Introduction

The concept of functionality is the basis for the design and construction of modern buildings, but increasingly often there are also ecological and economic aspects. In order to reduce the negative impact of human beings on the environment and to meet the requirements imposed by the European Union in the field of energy-efficient construction, a variety of technologies are used which exploit renewable energy sources and allow the costs of producing energy to be reduced.

The aim of this paper is to show the best practices of energy-efficient construction, which in the future may become widely used to achieve not only self-supply of individual buildings with energy obtained from renewable energy sources, but also global benefits resulting from the reduction of fossil fuel consumption and minimization of carbon dioxide emissions. The paper presents legal requirements in the field of energy-efficient construction, and examples of technologies used, as well as economic aspects of implementation of new systems in architecture.

Definition of terms:

a) Eco-innovation – this is a term that links ecology with innovation, i.e. phenomena related to the implementation of ever more modern eco-technologies aimed at improving human health, as well as maintaining the natural order. The scope of activities is focused on environmental protection and maximizing the benefits of RES use.
b) ZEB (Zero-Energy Buildings), nZEB (Net Zero Energy Buildings) – buildings in which the applied technology makes it possible to produce an amount of energy from renewable sources that at least covers the energy demand of the building. The aim of sustainable construction is to achieve a balance between energy demand and production. Currently, nZEB buildings are considered to be the most beneficial long-term projects in terms of environmental efficiency (Sowa 2017).

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Directives and Regulations

The regulations governing energy efficiency standards are: Directive 2006/32/EC of the European Parliament and of the Council of 05.04.2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, and also Directive 2002/91/EC of the European Parliament on the energy performance of buildings. On the basis of both the directive of 1 January 2009 and of the construction law, the requirement to prepare an energy certificate has come into force. Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (Official Journal of the European Union L 153 of 18.06.2010, p. 13). The main objectives of this directive were to reduce energy consumption and the use of energy from renewable sources, and to adopt standards such as "keeping the global temperature increase below 2 °C and the commitment to reduce by 2020 – total emissions of greenhouse gases by at least 20% below 1990 levels and by 30% in the event of an international agreement, and to reduce the Union's energy consumption by 20% by 2020" (European Council meeting in March 2007) and to achieve 20% energy efficiency by 2020 and to reduce greenhouse gases (Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009).

The year 2014 was a breakthrough legal year for energy-efficient construction through the newly binding Ordinance of the Minister of Infrastructure of 12 April 2002 (and subsequent amendments) on the technical conditions to be met by buildings and their location. The Regulation of the Minister for Infrastructure contains, inter alia, new requirements for thermal insulation of building envelope, i.e. specific requirements (mainly U_{MAX}) and general requirements (e.g. EP) for non-renewable primary energy, in addition to requirements for the design and, at a later stage, construction of such buildings in order to reduce the risk of overheating in summer. The Regulation also specifies the requirements for the use of general mechanical ventilation systems or in air conditioning systems with an efficiency of 500 m^3/h or more, devices which will be aimed at recovering heat from the extracted air with a minimum temperature efficiency of 50%, or the use of recirculation where this is allowed.

The Regulation of the Minister of Infrastructure of 6 November 2008 concerns the methodology of calculating the energy performance of a building and a residential unit or a part of a building constituting an independent technical and usable unit, besides both the method of preparing and templates of energy performance certificates.

This Regulation implements Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (Official Journal of the European Union L 1 of 04.01.2003, p. 65; Official Journal of the European Union Polish special edition, Chapter 12, Volume 2, p. 168). The Regulation of the Minister of Infrastructure and Development on the methodology of determining the energy performance of a building or part of a building and energy performance certificates of 27 February 2015. (Official Journal Dz.U., 3025, item 376). The Act of 29 August 2014 on the energy performance of buildings on the basis of Directive 2010/31/EU of the European Parliament and of the Council of 19 May

2010 on the energy performance of buildings (recast). In Poland, the given standard will apply to all buildings as of 1 January 2021, while for buildings occupied by public authorities, which are their property, it will be applied from 1 January 2019.

Concepts and assumptions of plus-energy construction and its impact on the environment

Nowadays, traditional residential buildings are beginning to be replaced by "zero-energy" or "plus-energy" buildings, not only in terms of functionality, but above all in terms of ecology and economy. The main objective of introducing this type of building is to reduce the depletion risk of renewable energy sources. One of the most important assumptions is maximum energy efficiency with minimal energy consumption and costs. Energy construction has many goals. The most important is to protect the environment and strive for its sustainability, while at the same time benefiting health by reducing negative and dangerous phenomena occurring in the atmosphere. An example of actions leading to the implementation of this assumption is the reduction of the number of coal-fired furnaces and boilers, which results in the reduction of the amount of pollutants emitted to the atmosphere. However, the reduction of the use of renewable raw materials is an important aspect – well-thought-out construction and wall sealing allows for the preservation of heat, which in turn leads to a reduction in the design heat load.

Energy-efficient architecture plays an increasingly important role in the Polish construction industry due to the regulations and directives introduced by the European Union, which require Member States to maintain appropriate procedures, concerning not only the method of construction itself, but also the initial design process, taking into account the economic and ecological aspects. As a result, not only are modern eco-housing estates built from scratch, but steps are also being taken to rebuild and modernise existing facilities such as the Beddington Zero Energy Development – Bed ZED in London, which has been rebuilt from a sewage treatment plant to one of the most efficient eco-housing estates.

In countries such as the United Arab Emirates and Germany, energy-efficient construction is well known and promoted, while in Poland projects are beginning to be implemented especially in places where energy efficiency can help to rebuild the local environment. One example of world-class technology implementation is the Klimaty housing estate in Kraków, which is an energy-efficient and ecological type of construction, consuming only 27.5 kWh/m² annually (completion of construction in 2017). Heating costs vary, at around 450 PLN per apartment with an average area of 120m^2 and a height of more than 3 metres. This is possible thanks to the use of innovative technology using renewable energy sources by means of heat pumps. These apartments are only 5.5 km away from the city centre, but they are distinguished by the surrounding greenery, silence and protection against the annoying smog, which is an inherent problem for the inhabitants of Kraków. Meanwhile, the energy consumption at the "Sielanka" housing estate in Tarnowskie Góry (Lower Silesia) amounts to 40 kWh/m^2/year. It consists not of apartments, as in the case of the Klimaty estate, but of single-family houses with an area of 92 to 186 m^2 (completion of the first stage of construction in 2012 – 26 energy-saving houses).

The houses are located at a distance of 22 to 27 metres from each other, and the whole estate is located only 4 km from the city centre, which provides full access to public transport with other parts of the city or the surrounding area. On the other hand, passive houses are becoming more and more popular in Poland, thus ensuring minimum heat consumption – which amounts to only 15 kWh/m² due to the use of thermal insulation walls with appropriate sealing (U-value for walls is below 0.15 W/(m²K)), and also because of the use of mechanical ventilation with heat recovery (recuperator) and appropriate construction of the building and location in relation to light.
In newly-built residential buildings, a number of technological solutions are applied, leading to the highest possible amount of energy from RES. The following technologies are used for this purpose: solar collectors, photovoltaic cells, small and micro wind turbines, compressor heat pumps, biomass-fired installations, and cogeneration.

In the use of renewable energy sources, particular attention should be paid to biomass, the share of which in the fuel balance of renewable energy is still growing. It is currently the most widely used renewable energy source (Sala 2017). This is due, among other things, to the possibility of direct combustion in the form of solid biofuels (wood, straw, pellets), gaseous fuels (biogas) or after conversion into liquid fuels (oil, alcohol).
Water also plays an important role. It is the longest used renewable energy source in Poland, although, due to unevenly distributed annual rainfall, small land falls and high soil permeability, it is not very effective.
Solar energy is the least used. This is due to the uneven distribution of solar radiation over the year (about 80% of the annual amount of sunshine falls in the spring-summer season, i.e. less than six months). However, this allows the use of collectors for heating water in single or multi-family houses and public buildings.

Effective ways to optimise buildings. Presentation of local energy production capacity

Public buildings have the largest share in reducing energy consumption costs and increasing the level of eco-innovation in Poland. However, due to the lack of profitability, it is not possible to convert them completely into ZEB buildings. The opportunity to meet the requirements of the EU and government in the field of energy-saving architecture is in their partial reconstruction and the installation of specialised installations.

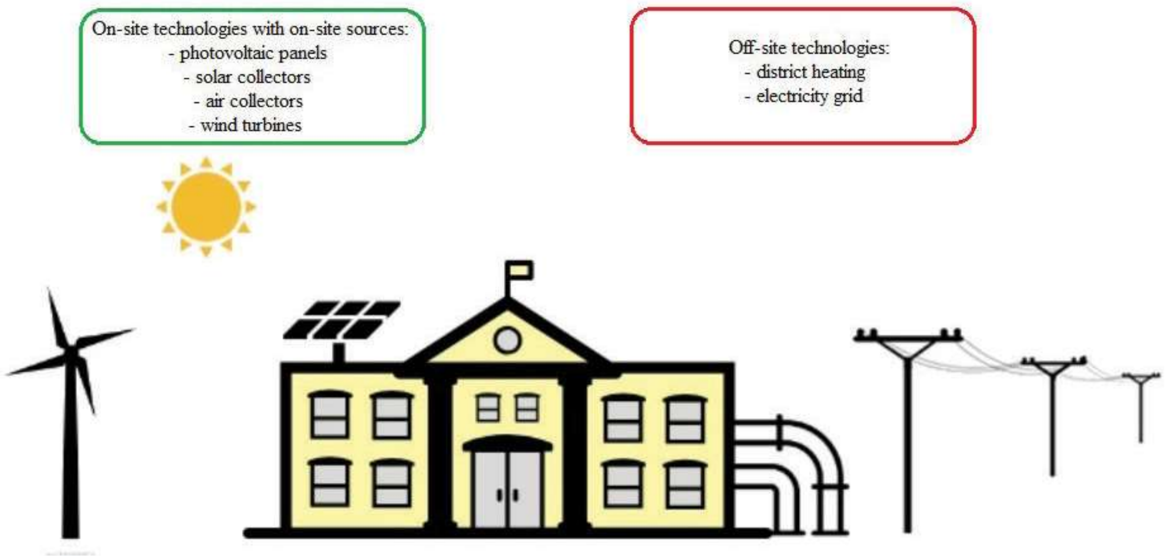
One of the ways to optimise buildings, using the potential of solar energy, is to rebuild the building so that it is exposed to light as long as possible and the heated air is maintained due to the use of modern technologies in sealing walls and windows. However, each redevelopment requires individual consideration and evaluation, so that all implemented energy-saving systems bring the greatest possible benefits without incurring any losses (accumulation of an adequate amount of heat and, in the case of possible surpluses, management for other energy-consuming sources).

Examples of effective ways to optimise the energy performance of buildings are based on selected buildings from around the world and Poland. The choice was not determined by a specific criterion, but only by popularisation and innovation among energy-plus architecture.

The application of the following solutions contributed to the achievement of the effect of energy efficiency: a recuperation system, which is based on the recovery of heat from the reconstruction of the mechanical air ventilation system. An example of using this system is the Klimaty housing estate in Kraków, which not only provides energy efficiency but also protects residents from urban smog, as well as heat pumps, using renewable energy sources. Minimisation of thermal energy consumption in passive buildings – passive kindergartens in Slovenia in the municipality of Preddvor, which were put into operation in 2012. The annual energy demand is 61 kWh/m²/year. Among other things, the following were used: a ventilation system with heat recovery at the level of 80%, a biomass boiler that provides heating for kindergartens, and photovoltaic panels on the roof with an output of 96.7 kW; which is a mechanism tracking the daily course of the sun – this is an example of the first building that maximises the absorption of natural light, and such a project was first developed in Germany in 1994. A "heliotrope" can produce 6 times more energy per sunny day than it consumes.

The concept of zero-energy architecture assumes that the energy needs of buildings should be covered by the energy produced within the building's balance sheet limits. This can take place using on-site technology, i.e. on the premises of a given building, or off-site, i.e. with the use of fuels located on its premises or supplied from outside. It is also possible to combine these two technologies through devices such as heat pumps that draw energy from external sources (e.g. grid electricity) and internal (e.g. ground).

Figure 1. Types of devices using on- and off-site technology. Source: own elaboration



Economic aspects of building renovation

Upgrading public buildings to nearly zero-energy building standards requires capital expenditure, which needs to be properly assessed in order to be able to identify the sources of financing.

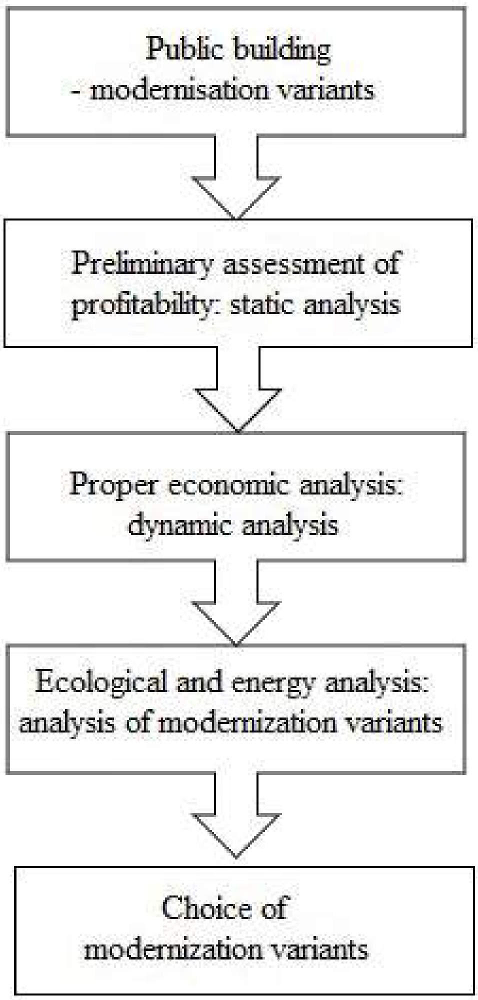
In the initial phase of calculation, the investment costs include: energy audit and technical design, obtaining permits, technical supervision, purchase of materials, and salary costs. An important element of the cost estimate is also the financial reserve, which will protect the budget against unexpected expenses.

In addition to investment, the costs of operating the building should also be determined, which are different in each case and should be determined after taking into account the configuration of the system, local energy costs, the location of the building and its financing sources. The components of operating costs include:

- purchase of: fuel or heat, electricity, and other utilities,
- environmental charges,
- maintenance and consumables,
- wages and salaries.

In order to determine the profitability of the planned investment, a static economic analysis (at the initial stage of project planning) and a dynamic analysis (to determine the actual profitability of the investment, taking into account the change in the value of money over time) are carried out.

Figure 2. Schema of valuation and selection of the building modernisation variant. Source: own elaboration



Static analysis indicator:

– Formula 1: Simple return time:

SPBT - simple return time,
I – investment outlays incurred in the base year,
K – the economic effect, i.e. the sum of profits (i.e. savings resulting primarily from a reduction in the costs of purchasing energy carriers and revenues from the sale of electricity generated) less tax, depreciation and costs of financing investments at base year prices,
R – possible increase in maintenance and repair costs in base year prices.

Dynamic analysis indicators:

– Formula 2: Real discount rate:

r_r – real discount rate,
r_{dep} - rate of return on risk-free investments,
r_i - inflation rate.

– Formula 3: Discount rate of increase in energy prices:

r_e – discount rate of increase in energy prices,
r_r – real discount rate,
r_{per} – energy price increase index.

– Formula 4: Net present value

NPV – net present value,
n – year of operation of the investment,
N – economic life of the investment,
K – the economic effect in specific periods, i.e. the sum of profits (i.e. savings resulting primarily from a reduction in the costs of purchasing energy carriers and revenues from the sale of electricity generated) less tax, depreciation and costs of financing investments at base year prices,
R – possible increase in maintenance and repair costs in individual periods,
I – investment outlays in individual periods,
r – discount rate.

– Formula 5: Net updated value:

NPVR – net updated value,
NPV – net present value,
t – period of incurred expenditures,
N – economic life of the investment,
I - investment and replacement outlays in individual periods,
r – discount rate.

– Formula 6: Profitability ratio:

PI – profitability ratio,
n – year of operation of the investment,
N – economic life of the investment,
I – investment and replacement outlays,
K – the economic effect, i.e. the sum of profits (i.e. savings resulting primarily from a reduction in the costs of purchasing energy carriers and revenues from the sale of electricity generated) less tax, depreciation and costs of financing investments at base year prices,
R – possible increase in maintenance and repair costs in individual periods,
r – discount rate.

Benefits from the buildings modernization by the example of the thermo-modernization program for Poland

According to experts from the Buildings Perfomance Institute Europe (BPIE), the potential reduction of greenhouse gas emissions by 2030 (compared to 2010) can reach 8-59%. It will be achieved as a result of thermal modernization of buildings. Air pollution will also decrease significantly due to reduced combustion of low quality solid fuels in domestic inefficient furnaces. As a result of thermo-modernization, it is also possible to reduce the emission of harmful substances. The table shows the estimated social benefits from the program.

Table 1. Estimation of the social benefits of thermo-modernization. Source: Own elaboration based on "Strategia modernizacji budynków: mapa drogowa 2050"

	PLN billion
Energy saving	185
Health benefits	185
Benefits for power grids	185
Economic stimulus	277
Environmental benefits	18
Total benefits (gross)	849
Minus total investment	122
Net social benefit	227
Saving for consumers (net)	63

Next table presents results of research on thermo-modernization of buildings in Poland by 2030 conducted by the Buildings Perfomance Institute Europe. It shows the results of the most effective solution including fast and free decarbonization.

Table 2. Results of research on thermo-modernization of buildings in Poland by 2030. Source: Own elaboration based on "Strategia modernizacji budynków: mapa drogowa 2050"

Description	Value	Unit
Annual energy saving in 2030	75	TWh / year
Savings in 2030 as % of present values	26	%
Investment costs (present value)	122	PLN billion
Savings (present value)	185	PLN billion

Net savings for the consumer	63	PLN billion
Net savings for society - without external effects	828	PLN billion
Net savings for society - with external effects	920	PLN billion
Internal rate of return	13,2	%
FAST DECARBONIZATION		
Annual CO_2 savings in 2030	65	Mt CO_2 / year
CO_2 saved in 2030 (% of 2010 values)	59	%
Cost of CO reduction	-131	PLN/ t CO_2
FREE DECARBONIZATION		
Annual CO_2 savings in 2030	32	Mt CO_2 / year
CO_2 saved in 2030 (% of 2010 values)	28	%
Cost of CO_2 reduction	-516	PLN/t CO_2

Advantages and disad

Every new idea or new construction process implemented involves positive and negative aspects, which are not always predictable, but after a certain period of time, there is a certain pattern through which the already existing methods can be improved. Plus-energy building is discovering increasingly streamlined solutions every year; however, despite this, there are still drawbacks or underefinements, which do not necessarily depend on the originator but on a wider group of individuals. A special case is the desire to reduce the number of coal-fired stoves and boilers. An individual inhabitant of a housing estate or city, after replacing a heating source, will not minimise the emission of pollutants into the atmosphere through coal-fired buildings located around them. Therefore, some problems need to be resolved on the macro scale. On the other hand, the application of systemic solutions for a whole housing estate or city will promise significant effects, which will be felt not only by the whole society, but additionally will mainly contribute to the reconstruction of the environment, which with every next century is facing an increasing number of threats. The introduction of such a solution is particularly necessary for cities threatened by smog. Another profitability is the reduction of heat energy consumption, which results in a reduction of heating costs. However, regardless of the introduction of modern technologies, there is the risk of equipment failure, which entails repair costs. An example of solving the problem of failure, although used only in some facilities (e.g. hospitals) due to high costs, is the construction of two sources of heat. When one of them fails, the other one is used. On the other hand, a cheaper and more frequent method is the introduction of devices with high reliability and guaranteed undisturbed operation, which do not assume failure rates.

Conclusion

The implementation of detailed legal requirements imposed by the European Union concerning energy-efficient construction is a big challenge for state policy. At the same time, however, it causes an increase in interest in this field among Polish architects, who are trying to implement innovative technologies in public and residential buildings. Thanks to appropriate calculation of investment profitability ratios, it is possible to select solutions in such a way as to minimise the costs of energy generation, while at the same time achieving the expected results. The use of energy-saving techniques initially in individual buildings gives an opportunity for their large-scale implementation, which will bring us closer to achieving energy balance not only in the country, but perhaps even in the world.

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