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The way to limit emission – energy efficient buildings. The example of the largest facility in Poland in nearly Zero Energy Building standard

Key words: carbon dioxide impact, nearly zero-energy building, energy consumption, renewable energy

Introduction

The concentration of gases responsible for the development of global warming has been steadily rising for decades. Global energy-related CO_2 emissions grew by 1.7% in 2018 to reach a historic high of 33.1 Gt CO_2 (IEA, 2019). It turns out, that it's biggest contribution can be accredited to urban areas. Although they occupy only 3% of the area of our globe, they are responsible for over 70% of emissions. According to American estimations, the on-going trend of population migration from rural areas to cities will still transpire in the decades ahead. While today 55% of the world's population lives in cities, it is estimated that in 2050 it will be 68% (UN DESA, 2018). In the EU 70% of the population already are city inhabitants. The progressing urbanization and population growth may cause main metropolises to contribute to the further increase of greenhouse gases emissions in the world, if one does not take any remedial steps. The major sources of urban emissions at present are residential houses, office buildings and other buildings, which generate over half of all greenhouse gases emitted by these agglomerations. On the EU scale the entire municipal-household sector produces approx. 36% of CO_2 emissions, and it's development is connected to the further increase in demand for energy (Report COM(2013) 483 final/2). According to the Ecofys report (Wong, Jager & van Breevoort, 2016), buildings in Poland consume as much as 40% of all energy used in the country, 70% of which is accounted for heating. Right at first sight one can recognize, that it is this sector where considerable savings can be sought.

Emissions from buildings are contributing not only to the issue of global warming. The external air quality is important for the natural environment and human health. It is known, that the air pollution in urban agglomerations, which generate smog, comes mainly from individual heating devices used in the municipal-household sector. In order to reduce the emissions, apart from implementing technologies utilizing renewable energy sources, the EU promotes and puts into action energy efficiency and smart buildings. The last one is the reaction to the recent development of the computer systems: building management system (BMS) and building and energy management system (BEMS).

In 2010 together with the revision of the Directive 2002/91/EC energy performance in buildings directive (Directive 2002/91/EC; Directive 2010/31//EU), the EU introduced as a goal "Nearly zero-energy buildings" and requires implementing this standard for a building in newly erected facilities from January 2021 onwards in all member countries. As an important building type to diminish energy use and greenhouse gas emissions in the construction industry, NZEB has attracted much attention since 2006 already (Christian, Richards, Atchley, Childs & Moon, 2006). An overview of definitions and energy-efficient measures of NZEB is presented in detail in Deng, Wang and Dai (2014). The low amount of energy that NZEB require comes mostly from renewable energy sources. Beginning on 1 January 2021 in Poland a building which is to be considered nearly zero energy needs to fulfil the requirements of heat protection of buildings included in the 2017 technical conditions (Regulation of the Minister of Infrastructure and Construction of 12 April 2002). For public buildings, it means that the value of the non-renewable primary energy indicator *EP* for heating, preparing hot water, cooling and integrated lighting or the one ensured by the auxiliary equipment in these systems cannot exceed 95 $kWh \cdot m^{-2} \cdot year^{-1}$ for buildings without a cooling system and 120 $kWh \cdot m^{-2} \cdot year^{-1}$ for buildings with a cooling system.

The above-mentioned EU directives have recently been changed as part of the "Clean energy for all Europeans package". Also, after this EU amendment in 2018 (Directive (EU) 2018/844), the planning of buildings in accordance to the NZEB standard, which integrate renewable energy sources, becomes mandatory.

The enumerated EU directives are a very significant instrument for enforcing actions, that will help in achieving highly efficient and decarbonised building resources by 2050.

Due to the above mentioned requirements many new and modernized buildings are currently being built in Europe in NZEB standard (Attia, Polyvios, Xeni & Morlot, 2017; Brambilla, Salvalai, Imperadori & Sesana, 2018). One of them is the Posejdon complex in Szczecin, Poland.

Analysed object

The Posejdon service complex (Fig. 1) is the largest facility in Poland with low energy consumption (NZEB). It is situated in the very centre of Szczecin

FIGURE 1. Visualisation – A partial view on the historic facade of the Posejdon building (author: Federacyjne Biuro Architektoniczne)

and consolidates the existing building of the former department store with a completely new part which together will constitute one functional unit. The existing building was erected on 28 November 1928 and was opened to the public the following year as the department store DeFaKa (Deutches Familien-Kaufhaus). After the war, the preserved part of the building was restored – but in a different shape from the original and in a less embellished form. Already in 1951 the building was opened again to the public as the universal department store and had been in business until 2009. Since 2015 the owner of the city block, in which the store had been located, has been the Szczecin Porto company, which received a building permit in October 2016 and the investment is planned to be completed at the end of 2019.

The complex will include an office building with an area of nearly 20,000 m^2, a conference centre for approx. 1,000 people and two hotels belonging to the Marriott chain – courtyard by Marriott and Moxy – which together will offer 255 hotel rooms. The compound will encompass a publicly available patio on the first floor of the office part where a vertical wall of green, several meters high, will be created (Fig. 2). This living green external wall acts as extra insulation with a layer of air between the plants and the wall. It also reduces noise levels by reflecting, refracting as well as absorbing acoustic energy. Like all plants, green wall plants remove carbon dioxide from the air and release oxygen. This air filtering process of the most significant greenhouse gases is certainly a remarkable improvement to air quality. Achieving BREEAM Excellent status was one of the primary objectives for this project and one contributory factor to realising this was the specification of a green wall solution.

The Posejdon complex in Szczecin will self-sufficiently generate most of the necessary heat and cooling. It will be

FIGURE 2. Visualisation – the vertical wall of green of the Posejdon patio (author: Federacyjne Biuro Architektonicze)

equipped with, among others, a modern HVAC installation based on RES technology, powered by photovoltaic cells situated on the roof of the building and a rainwater system for toilets, and devices characterised by very high energy efficiency.

Installations in the Posejdon NZEB

A huge ground heat exchanger was constructed under the building and therefore it will be possible to derive energy from the ground. The exchanger consists of 46 vertical boreholes, each 300-meter deep, situated under a foundation slab in the area of the underground garage (Figs. 3–4). The installation is filled with 28% ethylene glycol. It's design temperatures will amount to 12/8°C in winter and 26/30°C in summer. The medium from ground exchangers is directed to two exchangers – water/glycol (power of

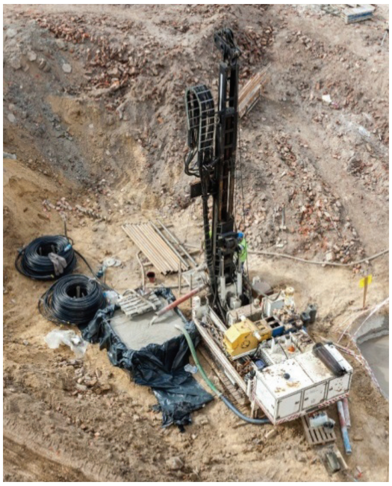

FIGURE 3. Drilling for the ground heat exchanger (source: www.posejdoncenter.pl)

2 × 400 kW) working for the water loop heat pumps (WLHP) system. In case the temperature at the outlet from the heat pump loop reaches its minimal value (6°C), the system starts operating with water/glycol exchangers supported by a reserve heat pump. In the summertime, the cooling system is to be backed up by

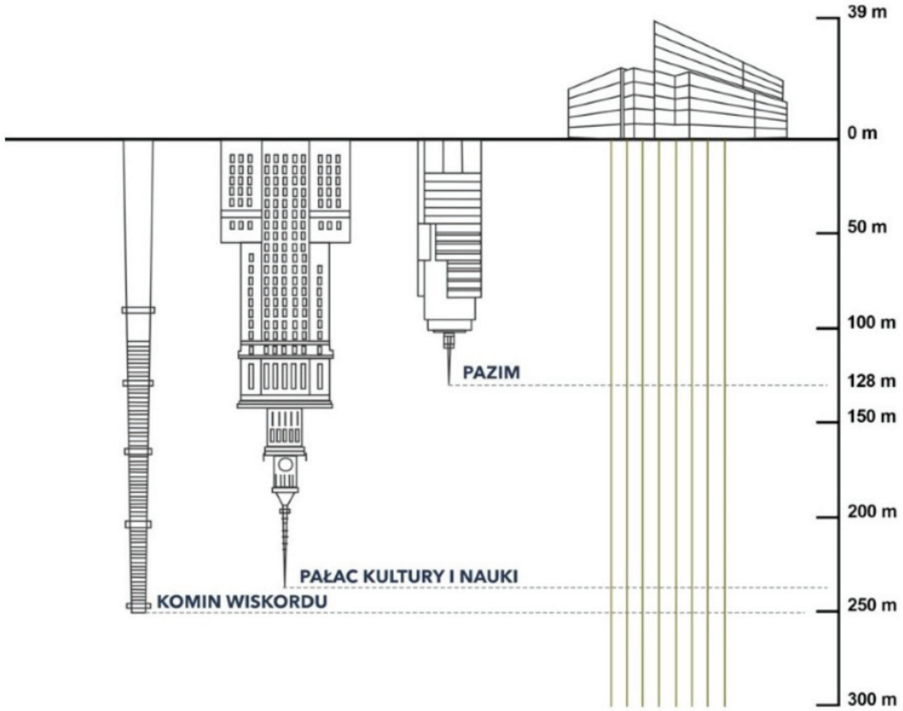

FIGURE 4. The comparison of the depth of the ground heat exchanger with the highest buildings in Szczecin and the Palace of Culture and Science in Warsaw (source: www.posejdoncenter.pl)

two evaporator-cooling towers built on the roof of the building.

Energy extracted from the ground will be used to heat the facility by means of high-efficiency local heat pumps (WLHP) in the office and service areas and also for the needs of producing domestic hot water for the hotel. On the other hand, in summer, cooling derived from the ground will be used for air-conditioning of the office and service areas also thanks to the local heat pumps (WLHP). For this purpose, the office and service part of the complex was equipped with 910 inverter heat pumps units (WLHP) placed under the ceiling, which will be responsible for maintaining the required temperatures in the rooms. The energy efficiency class of the applied units in ventilation and air-conditioning systems is A+ both for heating and cooling.

The primary heat source for the system of producing domestic hot water will be the district heating substation with hot water storage tanks. Additionally, hot water will be preheated using energy from ground heat exchangers. It was estimated that 50% of the demand for domestic hot water will be generated from the district heating substation, whereas the remaining 50% from the RES system. Cooling achieved in this way by use of the heat pump will decrease the water temperature in the water loop.

Electric energy necessary to supply auxiliary energy in HVAC installations, circulation pumps in the RES system and pumps in the district heating substation, DHW electric heaters (intended for the office part) and internal lighting will be taken from the PV panel system with a total power of approx. 102.6 kWp (kWp is the peak power of a PV system). The installation will be constructed on the roof of the building and will consist of 342 photovoltaic monocrystalline modules. The planned annual production of electric energy from the PV roof panels system amounts to approx. 81,880 kWh.

Artificial lighting in rooms where users are in temporarily (bathrooms, staircases, an underground car park) will be controlled by motion sensors. The application of motion sensors allows to obtain relevant savings resulting from rational electric energy consumption.

The building will be equipped with LED lamps. Due to low energy needs, they contribute to the decrease of energy production which directly affects the reduction of carbon dioxide emission harmful for the environment.

In the building many solutions to limit water use have been envisaged. Treated rainwater (a grey water system) is supposed to be used for toilet flushing, watering green roofs and a green wall. Consequently, a separate installation of treated water run to bathrooms of the office part and to water the greenery on a publicly available patio situated over the ground floor has been designed.

Heating and cooling of the office-service part

In the office-service part mainly air heating and cooling systems have been provided. On the roof of the building and in technical rooms there are air handling units equipped with a high efficiency heat recovery system based on rotary or crossflow heat exchangers. The units for the office part are additionally equipped with coolers running on an ethylene glycol solution. The air handling units supply air, which will be humidified to a humidity of 40%. The air distribution system will be equipped with CAV controllers. The ventilation system has been designed with consideration for the variable flow rate depending on the internal air quality and controlled by the automation and BMS systems. The ventilation flow rate will be decreased to a minimum, when users are not present in the building. The introduced solutions should substantially reduce the energy consumption of the ventilation and air-conditioning systems.

The heating and cooling of the office and service area will be carried out by means of the water–air heat pumps, so-called water loop heat pumps (WLHP), which are also denoted in literature as water system heat pump (WSHP) systems and are the alternative to conventional air conditioning with heating systems. In the Posejdon office-service complex part there are 910 such pumps. The main feature of the system is generating heating and cooling energy directly in the location where it is used (thus, the system is decentralised), which has a positive impact on energy efficiency. However, the system needs a central heat and cooling source. In the case of Posejdon, the ground is the main heat source. When the demand for heat is maximal, glycol/water exchangers can be supported by a reserve heat pump. The cooling source is also the ground exchanger backed up by cooling towers (Fig. 5).

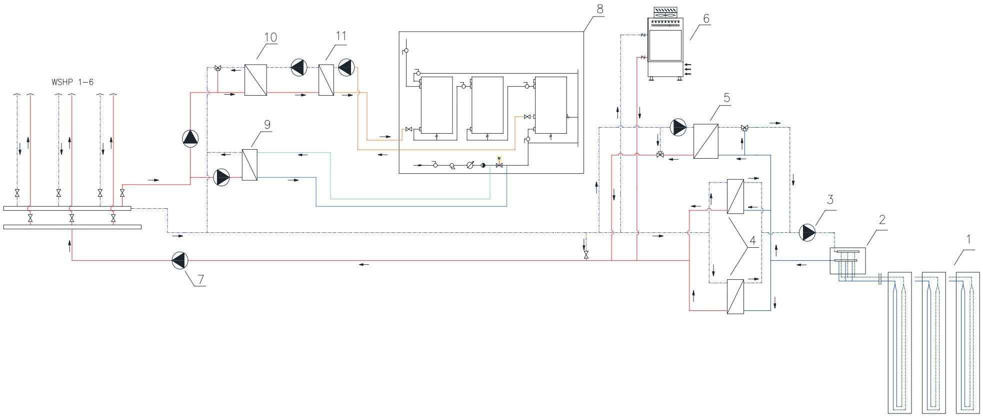

FIGURE 5. The diagram of the heat source: 1 – the ground heat exchanger (48 vertical boreholes with double-*U* geothermal probes); 2 – manifold wells; 3 – the pump set (three pumps adapted for operation in 2 + 1 system); 4 – water/glycol exchangers (with power of 2 × 400 kW); 5 – the reserve heat pump; 6 – two evaporator-cooling towers built on the roof of the building; 7 – the set of circulation pumps (three pumps adapted for operation in 2 + 1 system); 8 – the two-step district heating substation in a serial-parallel connection with hot water storage tanks for the hotel part; 9 – the water/water exchanger for preheating tap water; 10 – the water/water heat pump for heating warm water; 11 – the flow heat exchanger for heating water in load circulation of hot water storage tanks, WSHP 1-6 – 910 local heat pumps creating six two-pipe loops diagram of the heat source (author: Dorota Leciej-Pirczewska)

Single heat pumps have the certificate of high energy efficiency class (A+) with ratings: *COP* > 4.1, *EER* > 5.9, LW_{max} < 37.5 dB_A. They are responsible for maintaining the required temperature in the office and commercial-service rooms. Each of the 910 heat pumps will be connected to the installation by a piping system with a control valve, a sieve filter and shutoff valves (Fig. 6). Due to the variable needs for cooling and heating by the rooms being operated by the water loop, it is essential to apply a very accurate flow regulation. Because

FIGURE 6. The heat pump (WLHP) connected to the water installation by the pipe system with the control valve, the sieve filter and shut off valves (author: Dorota Leciej-Pirczewska)

of that, modern balancing ABQM valves with the newest NovoCon® digital drive of the Danfoss company have been chosen as control valves.

In order to constitute a coherent and well-functioning unity with all building energy systems, the building will operate the building management system (BMS) – an advanced system of automatic regulation and control complemented by the functionalities allowing to manage energy consumption.

The standard of the HVAC and electricity systems in Posejdon goes far beyond currently existing norms. Additionally, applied technologies allowed to obtain the prestigious BREEAM ecological certificate in the latest version New Construction 2016 on the level "Excellent".

Environmental impact: CO_2 emissions savings in analysed object

In accordance with the previously mentioned EU directives, reference is made to the importance of the reduction of CO_2 emissions in the generation of energy associated with buildings. Consequently, the most important objective of this paper is to characterize the CO_2 building emissions and savings in CO_2 emissions achieved thanks to the operation of all technologies installed in the renovated office-service part of the Posejdon building.

Methodology of research

The amount of CO_2 emission generated by the grid for heating, obtaining hot water, air conditioning, ventilation and room lighting is directly affected by the energy performance of the building. The emissions are obtained after calculation of energy use in accordance with Polish and European regulations using climatic conditions taken from a Polish meteorological database for the region Szczecin-Dąbie. The heat consumption was verified according to the regulation on the methodology of determining the energy performance of a building (Regulation of the Minister of Infrastructure and Construction of 20 December 2016) valid in Poland. The general calculations of the energy demand for heating, cooling and ventilation are based on methods from CEN standards (EN ISO 13790:2008). Emission factors for electricity are taken from the report of National Centre for Emission Management (KOBiZE, 2018). Emission rate for the district heat, a value in accordance to the regulation on the methodology of determining the energy performance of a building (Regulation of the Minister of Infrastructure and Construction of 27 February 2015), was assumed, because of a lack of data from the supplier. On that basis, CO_2 emissions were calculated. The energy consumption necessary to fulfil the building's energy demands were compared for a WLHP system together with the described below combination of auxiliary heat sources and a conventional district heating substation, which was used for the energy supply of the building before modernisation.

Results

The calculated index of annual demand for final energy for heating and ventilation of the analysed office-service building before renovation is EK_H = = 201.71 kWh·m^{-2}·year^{-1}. The improvement of the energy performance due to the renovation results in a reduction of approx. 85% of building energy demand referring to final energy for heating in the modernised building. This means the value of EK_H decreases to EK_H = 29.28 kWh·m^{-2}·year^{-1}. As Figure 7 shows, heating, ventilation, and air-conditioning (HVAC) consume most of this energy, followed by lighting. This building presents little demand for domestic hot water (DHW). Indoor heating accounts for approx. 36% of the energy demand, whereas 12% of the total energy consumption is to meet cooling requirements.

In the case of electrical energy that is taken from the grid a reduction of 81,880 kWh·year^{-1} results from the application of photovoltaic panels, which will cover approx. 36% of the required electrical energy that concerns the energy performance of the building in question (Regulation of the Minister of Infrastructure and Construction of 20 December 2016). According to this regulation it applies to indoor lighting, auxiliary energy, running devices of the HVAC system and heating domestic hot water.

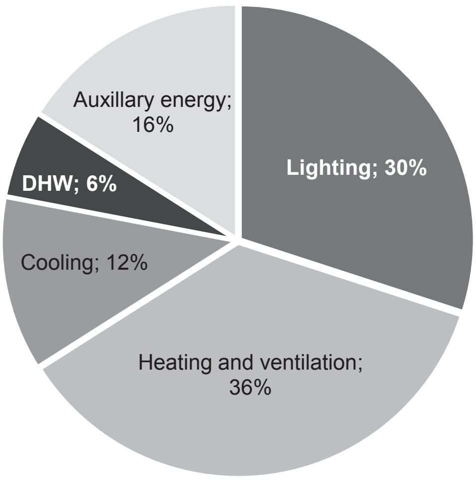

FIGURE 7. Percentages of the consumed final energy in the analysed office building after renovation

It was calculated by (KOBiZE, 2018), that the average CO_2 emissions for electricity in Poland are approx. 778 g CO_2·kWh^{-1}. Using this specific CO_2-factor for electricity in the Posejdon building, savings from the photovoltaic installation amount to 64.7 t of CO_2·year^{-1}.

Figure 8 shows the improvement of the thermal characteristic of the building envelope after the renovations. The results show that the implementation of these strategies as well as using renewable energy sources and ensuring a high energy efficiency of the installed systems, instead of conventional solutions before building renovation, could reduce CO_2 emissions up to 752.7 t·year^{-1} (Fig. 9), thus minimising the environmental impact. This constitutes a reduction of CO_2 emission on the level of 90%.

As a result, in this modernised building it was possible to achieve a very low CO_2 emission factor related to the usable area of the building. It is on the level of approx. 5.35 kg CO_2·m^{-2}·year^{-1}. In both cases, before and after renovation, there is no emission directly from the building, but released indirectly through the district heating and power plants.

It was calculated in Communication COM/2011/0112 that in order to reach the EU's 2050 target CO_2 reductions of 80%, a reduction of emission of approx. 90% in the building stock would be sufficient. The presented building meets these requirements.

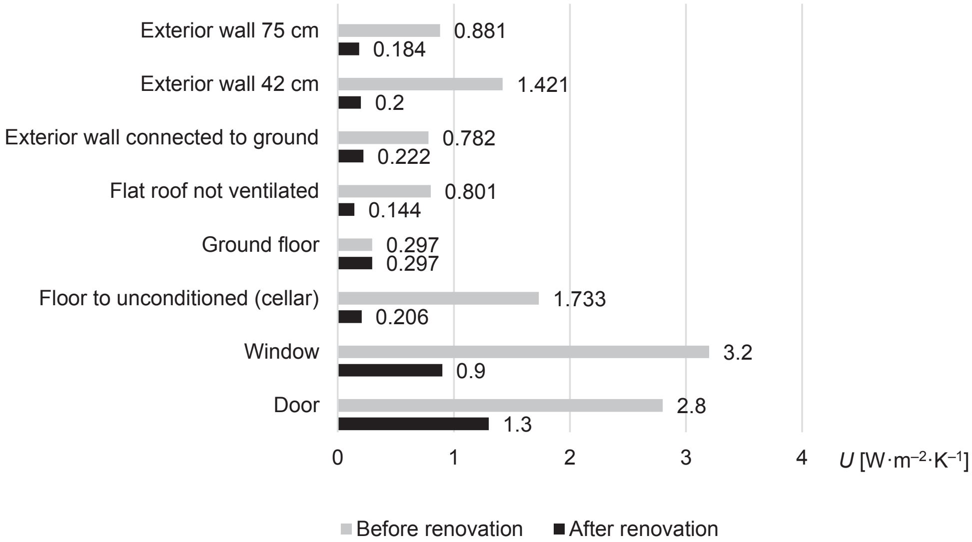

FIGURE 8. Thermal transmittance (*U*) of the building envelope before and after renovation

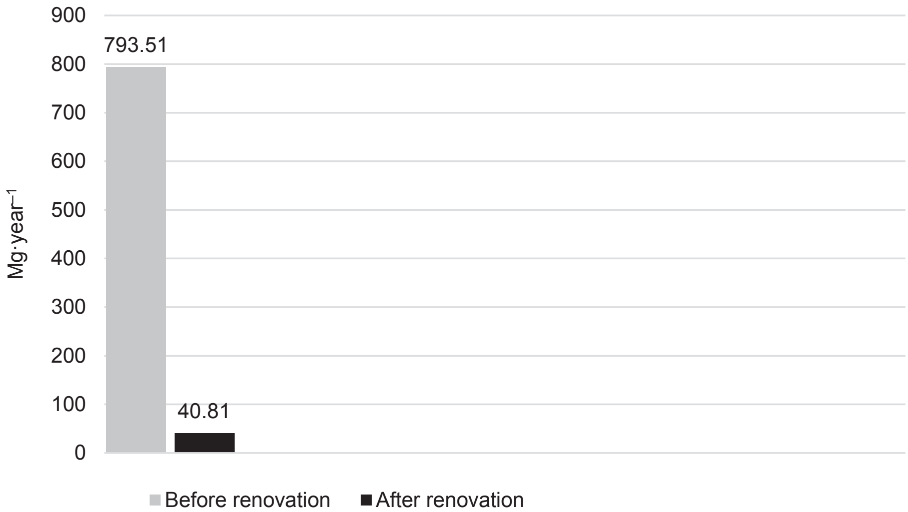

FIGURE 9. Carbon dioxide emission savings in office-service part of the Posejdon building

Conclusions

From the example of the modernised building Posejdon it can be concluded, that the energy performance, CO_2 emission and other gases responsible for global warming can be significantly improved by upgrading the building's envelope, using a more energy efficient HVAC system and by generating energy from renewable energy sources as well as applying occupancy-dependent smart controls. In this aspect the Posejdon building is an example of best practices in the area of energy efficient renovation of non-residential buildings for the full decarbonisation of the European building stock by 2050. The list of elements being included in the renovation strategy, as set out in this article, provides an example that can be used as a guideline to fulfil this target.

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Summary

The way to limit emission – energy efficient buildings. The example of the largest facility in Poland in nearly Zero Energy Building standard. In Szczecin a mixed-use complex Posejdon is being constructed. It will be the first nearly zero-energy building (NZEB) in Poland that meets the strict ecological standards that all buildings will have to meet after January 2021. The project was presented at the COP24 United Nations Climate Change Conference in Katowice. The calculated building CO_2 emission is very low. Based on the example of the Posejdon complex's office-service section before and after renovation modern technical solutions for meeting the buildings energy demand and the resulting reduction of CO_2 emission have been presented. The emissions were obtained after the calculation of energy use in accordance with Polish and European regulations concerning the energy performance of buildings using climatic conditions taken from a Polish meteorological database. The described renewable energy technologies implemented in the Posejdon building, serve as a reference to export management and design strategies to other NZEB with similar characteristics in the same region.

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