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Dormitory thermal retrofitting to nZEB standard

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Abstract. The Recast of the Directive on the Energy Performance of Buildings (the EPB Directive) came into force on 9 June 2010. One of the main requirements of the directive is to set a definition of nearly zero energy building (nZEB). Most of the EU member states have already set a definition of nZEB for new buildings and some of the countries also done it for existing buildings. The measures of thermal retrofitting of a dormitory to nZEB standard are presented in this paper. As there is no definition of nZEB for existing buildings in Poland, the paper presents a considerations of such a standard. Next, a set of thermo-modernization solutions are presented on a basis of existing building of a collective residence. The aim of the paper is to present the barriers that occur in such projects and solutions that can be applied to achieve the set goals. Building chosen for analysis is under historic protection which makes the work even more difficult. It was proved that used solutions were chosen not only to reduce energy demand or increase energy production from renewable energy sources, but also to increase thermal comfort within building.

1. Introduction
The Recast of the Directive on the Energy Performance of Buildings (the EPB Directive) [1] came into force on 9 June 2010. EU member states should until 9 June 2012, publish the relevant laws and administrative regulations necessary to implement its provisions. European regulatory efforts towards increasing energy efficiency of buildings are focusing on building requirements. All new public building after 31.12.2018 must be nearly zero energy buildings. Such requirement can be very hard to implement in public buildings as the energy needs for heating, cooling and lighting to provide internal comfort are typically very high. It is even harder to retrofit existing public buildings to nearly zero energy standard.

In this paper a solutions that can be applied to achieve the set goals are presented. After definition of nZEB standard, thermomodernization measures are presented for a dormitory building. Both energy and comfort analysis are presented, as not only energy decrease but also a comfort increase are required.

2. nZEB definition
Directive 31/2010/EU [1] requires the introduction of nearly zero-energy buildings but does not specify a minimum or maximum harmonized requirements and detailed guidance framework procedure for calculating the energy performance of building. Member states have to define what that means exactly for them. Taking into account the local conditions in the definition does not preclude the adoption of a uniform methodology in all Member States.

The Directive defines a nearly zero-energy building as a high energy performance building and requires the determination of the ratio of primary energy. Very low or almost zero energy demand of the building should be covered from renewable energy sources or renewable sources produced on-site.
In Poland a nZEB standard has been defined by primary energy indicator (EP) and set in Ordinance on technical conditions to be met by buildings and their location [2]. This indicator does not include renewable primary energy for which the primary energy factor is equal to 0. For public buildings, like educational building maximal value of EP has been state as sum of three indicators:

- for heating and domestic hot water – 45 kWh/m$^2$a;
- for cooling – $25*(A_{c}/A_{f})$ kWh/m$^2$a (where $A_{c}$ is a cooled area and $A_{f}$ is a total regulated temperature area);
- for lighting – 25 kWh/m$^2$a for time of light operation <2500 h/year and 50 kWh/m$^2$a for time of light operation ≥2500 h/year.

In total maximum EP may vary from 70 to 120 kWh/m$^2$a.

From the other hand in a Directive 31/2010/EU a requirement of cost optimal parameters is given. Hence in the KOD$n$ZEB project [3] a study of the cost optimal EP value for educational building estimation has been done. The calculation has shown that cost optimal EP indicator, that include heating, cooling, hot water, lighting and auxiliary energy, should have value between 40 and 55 kWh/m$^2$a [4].

Despite existing requirements or analysis for the use of KOD$n$ZEB project a value of primary energy indicator equal to 20 kWh/m$^2$a has been set as nZEB standard for two chosen buildings. This target value include heating cooling, hot water, lighting and auxiliary energy. Such a stringent requirement was defined as a goal was to prove that educational building can be retrofitted with very high energy requirement reduction.

### 3. Case building description

The analysed building is Muszelka dormitory located in Warsaw, Poland. The building volume is 9,562 m$^3$ and usable area of 3,366 m$^2$. The building is a part of a dormitory complex of Warsaw University of Technology. The building offers 151 living places for students.

The building has 4 over-ground and one underground storey. There are technical rooms in the basement (warehouses, workshops, heating ducts). On each floor living rooms, a common kitchen and toilet are located. In addition on the ground floor administrative rooms are situated. Student rooms are designed in segments of 2-3 rooms in segment, and in each segment a bathroom with shower is placed. Communication in the building is provided by corridors and 2 staircases.

The shape of the building is similar to a rectangle with dimension 60m x 13m, the longer sides have the shape of arches, consistent with the curvature of the axis of Mochnacki Street. From the east, the building adjoins "Akademik" dormitory, and from the west "Bratniak" dormitory. The main entrance is on the south side. Figures 1 and 2 show current look of building facades.

The building was built in 1956 in the construction of a reinforced concrete frame filled with ceramic brick walls. Over the last storey of the building, the ventilated roof is designed.

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**Figure 1.** Photo of the south façade: west part (on the left) and east part (on the right)
In 1989, the roof was renovated and a insolation of ceiling over last floor was done. Then in 1996, all windows were replaced with airtight windows with an estimated U-value of 2.0 W/m²K. The external walls are made of bricks without an insulating layer, and the estimated heat transfer coefficient ranges from 0.90 to 2.02 W/m²K.

In the building only gravity ventilation system consisting of exhaust ventilation ducts is designed. The air inlet takes place through the gaps in the window joinery, and the outflow through gravity ventilation ducts extended above the roof of the building. The existing central heating installation is a water, two-pipe pump system. Heating installation is equipped with steel panel radiators. In 1993, thermostatic valves were installed. Currently, some of these valves are not working properly, some have been dismantled and replaced with ordinary shut-off valves, while others have been vandalized. The radiators are corroded.

In different types of rooms of the analysed building, different types of lighting fixtures are used. The largest variation in the types of lighting fixtures can be noticed in the living segments. In addition, students independently exchange light sources in luminaires in the segments, adapting them to their needs and preferences. Lighting of communication zones in the building, common kitchens and bathrooms is unified, and properly maintained by the administration of the facility.

The installed capacity of the lighting system in Muszelka dormitory (without individual table lamps in living rooms) is 27.152 kW, while nominal capacity for whole building is equal to 11.22 W/m².

The building is under constant operation for whole year, during students year as dormitory and during summer as hostel.

The climate in Warsaw is moderate with lowest temperature of -12.3°C and highest of 33.2°C. The mean yearly temperature is equal to 8.2°C and global horizontal irradiation about 980 kWh/m².

As part of the analysis of thermal retrofitting, simulations of energy consumption for heating in the building of the Muszelka dormitory were carried out. The results of numerical calculations were compared with measures values. The comparison showed that the difference is only 15.0%. Therefore, it can be concluded that the constructed dynamic model is correct and can be used for further energy analyses. Table 2 presents the energy performance of the building in the existing state.

### Table 1. The energy performance of the building in the existing state.

| Primary energy       | Unit          | Value |
|----------------------|---------------|-------|
| Heating              | kWh/m²/year   | 140.8 |
| Domestic hot water   | kWh/m²/year   | 69.1  |
| Lighting             | kWh/m²/year   | 85.3  |
| Auxiliary energy     | kWh/m²/year   | 3.3   |
| Photovoltaic         | kWh/m²/year   | 0     |
| Sum                  | kWh/m²/year   | 298.5 |

The total primary energy indicator for a building in the existing state is equal 298.5 kWh/m²/year and 255.0 kWh/m²/year if students' rooms are considered as independent living units. In the calculation a primary energy factors of 0.68 for district heating and 3.0 for electricity were used.
4. Modernizations

The following paragraphs present modernizations proposed for the Muszelka building introduced to meet the nZEB requirements set for the KODnZEB project. Proposed modifications include the thermal envelope of the building, technical systems, lighting as well as systems that influence behaviour of the occupants and the use of renewable energy sources.

4.1. Thermal envelope

The reduction of heat loss due to heat transfer and infiltration several modernisations were proposed:

- insulation of external walls,
- insulation of the ceiling between the top floor of the building and the unheated attic,
- replacement of windows.

4.1.1. External walls. It was proposed to insulate external walls with aerogel panels having the thermal conduction value of $\lambda = 0.015 \text{ W/mK}$ and the thickness of 4 cm. This modernization should result in a reduction of the heat transfer coefficient of walls from $U = 1.09 \text{ W/m}^2\text{K}$ down to $U = 0.279 \text{ W/m}^2\text{K}$. The type of the insulating material was dictated by the restrictions set by the monument conservator that allowed only a 4 cm increase of the external walls thickness. Due to the limited thickness of the insulating material the best possible material, in regards to the thermal conductivity coefficient, was chosen.

4.1.2. The top floor ceiling. To insulate the ceiling below the unheated attic and the roof over the staircase a mineral wool with a thermal conduction coefficient $\lambda = 0.035 \text{ W/mK}$ and a thickness of 16 cm was proposed. This modernization should result in a reduction of the heat transfer coefficient of the ceiling from $U = 2.02 \text{ W/m}^2\text{K}$ down to $U = 0.197 \text{ W/m}^2\text{K}$. This would be enough to meet the technical requirement for the year 2014. The analysis indicated that an increase of the insulation thickness up to 22 cm in order to meet the requirements set for the year 2021 would not result in a noticeable heat demand reduction.

4.1.3. Windows. It was proposed to replace the existing windows with a new set with a better heat transfer value. This would result in an improvement of the heat transfer coefficient of windows from $U = 1.87 \text{ W/m}^2\text{K}$ to $U = 0.70 \text{ W/m}^2\text{K}$. This would be enough to meet the technical requirement for the year 2021, moreover it would greatly reduce the heating demand. Simultaneously to the thermal insulation modernization works there would be conducted works leading to the improvement of the air tightness of the building. It is estimated that this modernization should allow to decrease the air tightness coefficient from $n_{50} = 3.0 \text{ 1/h}$ down to $n_{50} = 1.5 \text{ 1/h}$.

4.2. Ventilation

The concept of ventilation in modernized dormitory foresees several different types of systems:

- mechanical exhaust ventilation with air to water heat recovery from living spaces;
- balanced mechanical ventilation with air to air heat recovery in other zones (corridors and staircase, shared kitchens, shared bathrooms, service rooms);
- natural ventilation of unused rooms in the basement of the building.

4.2.1. Ventilation of living spaces. All living spaces are ventilated by decentralized mechanical exhaust ventilation system. Outdoor air will be supplied to the rooms via air vents that will be installed in window frames. In some cases small reduction of glazing will be required. Than used air will pass through small entrance corridor and will be exhausted from a shower recess. Exhaust fans installed in these spaces will work with several speeds according to demand. Collective vertical ducts will transport air the attics. Ducts serving rooms of the same purpose will be connected there and then before release air to the atmosphere heat will be recovered to the hot water tank.

Two concepts of ventilation rate control will be used. For single rooms the main assumptions are as follows:
• nominal supply ventilation rate 20 m³/h person (occasionally increased in case of using shower);
• nominal exhaust ventilation rate from shower recess 50 m³/h (higher fan speed), but ventilation rate can be reduced to 20 m³/h (lower fan speed);
• operation of the fan in a higher speed is activated by a light switch in the recess (with an additional delay of 15 minutes after switching off), when the light is switched off, the fan operates in a lower speed.

For units when one shower recess is dedicated for 1 double and 2 single rooms the main assumptions are as follows:

• nominal supply ventilation rate 20 m³/h person;
• exhaust fan can remove 80 m³/h (the highest fan speed), 50 m³/h (middle fan speed) or 20 m³/h; (the lowest fan speed);
• fan operation is controlled by a contactor system (central power switches for power sockets in the rooms); assumed fan operation scheme: 0 active contactors – ventilation rate 20 m³/h, 1 active contactor - ventilation rate 50 m³/h, 2 or 3 active contactors - ventilation rate 80 m³/h.

These schemes of control allow significant savings in energy demand for ventilation (both heat and electricity).

4.2.2. Ventilation of other rooms. All spaces in the dormitory with open access (common toilets and kitchens on the floors as well as corridors and staircases) will have balanced mechanical ventilation system with heat recovery of minimum efficiency 85%. The air flows have been designed to prevent the dispersal of undesirable odors. The assumed ventilation rates are:

• collective toilet rooms - 50 m³/h per 1 toilet bowl and 25 m³/h per 1 urinal;
• collective kitchen rooms - 70 m³/h for a gas stove;
• corridors and stairwells - 0.5 air changes per hour.

The modernization of ventilation in these rooms will solve existing problem of unbalanced air flows will lead to significant savings of heat demand for the preparation of ventilation air.

4.3. Space heating system
The heating system modernization includes replacement of the radiators and installation of regulating valves under the vertical piping and for the new radiators. The rest of the system, like piping, would remain unchanged.

4.4. Domestic hot water system
The domestic hot water system modernization includes installation of a water meter in each residential unit. This should allow occupants to monitor the use of water and therefore should result in hot water use savings. It is estimated that water meters installation should result in a 20% reduction of the hot water consumption. Additionally the old hot water tank is going to be replaced. The rest of the system, like piping, would remain unchanged.

4.5. The lighting system
The concept of the room lighting system in the Muszelka building includes a use of several different lighting fixtures, accordingly to the purpose of the rooms. The modernisation includes replacement of the existing lighting fixtures and light sources as well as installation of a lighting control system, regulated both by a time schedule and the presence of the occupants. Basing on the capacity of the installed lighting in the rooms, the total and nominal capacity of the lighting system on each floor and for the whole building was calculated.

The average nominal capacity of the lighting system in Muszelka building after the renovation is 3.34 W/m². Simultaneously it is proposed to install an automatic lighting control system that would allow further reduction of the energy consumption, it would include:

• residential rooms – no additional control system;
• technical rooms – no additional control system;
• corridors and staircases – installation of movement sensors (standby lighting reaching full capacity at a presence of movement)
• shared kitchens – installation of presence sensors (lighting active only if the occupants are present);
• shared bathrooms – installation of presence sensors (lighting active only if the occupants are present).

4.6. Heat source
The planned renovation does not include a replacement of the existing heat source. The heat would be still delivered by a heating unit supplied by the heat from the district heating network. The heating unit is planned to be equipped with a heat meter for the space heating system.

In case of the domestic hot water system, it is planned to install a heat pump system that would use the heat from the exhaust ventilation air from the residential rooms to pre-heat the water. Due to the varying ventilation air flow, the pump was selected for the average airflow value of 2 084 m$^3$/h. The remaining heat demand for the hot water preparation will be delivered from by the existing district heating unit.

4.7. Renewable energy sources
It is planned to install a PV system on the roof of the Muszelka building, that would produce energy for the internal needs when possible and for the rest of the buildings in the complex or sold to the external energy grid in case of over generation. The capacity of the system was selected taking into account the limitations set by the monument conservator in regard to the visibility of the system from the street level near the building. The figure 3 presents the results of the visibility analysis of the roof system.

![Figure 3. Analysis of the visibility of the photovoltaic installation on the roof of the building](image)

The photovoltaic system with a nominal capacity of 79,35 kWp and an area of the PV panels of 374,8 m$^2$ would produce annually 69 953 kWh of electricity. The production is limited due to the available area of the roof and the possible slope of the panels dictated by restrictions regarding visibility.

5. Results of energy calculation
As part of the modernization of the Muszelka dormitory, which is under historical protection, a measures interfering in the building envelope (insulation of partitions and replacement of windows), technical systems (exhaust ventilation with variable air stream, mechanical ventilation with heat recovery, thermostatic valves, water meters or energy-saving sources and lighting fixtures), alternative and renewable heat sources (heat pump on exhaust air or installation of solar panels on the roof) has
been proposed. Each of the applied solutions does not go beyond the limitations resulting from conservation protection restrictions.

For the proposed modernizations, simulations of dynamic energy demand of the building were carried out and the results of calculations are presented in Table 2.

### Table 2. The energy performance of the building after modernization

| Primary energy          | Unit          | Value |
|-------------------------|---------------|-------|
| **Heating**             | kWh/m²/year   | 19.7  |
| **Domestic hot water**  | kWh/m²/year   | 26.0  |
| **Lighting**            | kWh/m²/year   | 26.5  |
| **Auxiliary energy**    | kWh/m²/year   | 4.2   |
| **Photovoltaic**        | kWh/m²/year   | -58.6 |
| **Sum**                 | kWh/m²/year   | 17.9  |

The total primary energy indicator for a building after modernization would be equal 17.9 kWh/m²·year. It can be noticed that the total primary energy demand indicator is almost in line with the concept of nZEB definition for the purposes of the KODnZEB project, and as a result of modernization, its value has been reduced by more than 16 times.

### 6. Comfort analysis

The required temperature in the building during heating season was always maintained but due to lack of cooling system during late spring or summer an overheating could occur. Thus in addition to energy analysis a verification of summer comfort has been done.

For the assessment of the thermal comfort the number of hours with indoor temperature exceeding 24°C for I class, 25°C for II class, 26°C for III class has been calculated for six students rooms. Those values has been establish on a basis of PN-EN 15251 [5] adaptive comfort. For the purpose of this analysis two rooms on the ground floor, two on the 1st floor and 2 on the last floor has been chosen. On each storey one of the room was with the windows oriented to the south and other with windows oriented to the north. In the Table 3 and 4 the results of comfort analysis is presented.

### Table 3. Number of hours with indoor temperature exceeding required value for given comfort class – existing state

| Comfort class                          | I   | II  | III |
|----------------------------------------|-----|-----|-----|
| Ground floor – north oriented room     | 0   | 0   | 0   |
| Ground floor – south oriented room     | 0   | 0   | 0   |
| 1st floor – north oriented room        | 6   | 0   | 0   |
| 1st floor – south oriented room        | 49  | 10  | 0   |
| Last floor – north oriented room       | 60  | 19  | 0   |
| Last floor – south oriented room       | 158 | 52  | 12  |

### Table 4. Number of hours with indoor temperature exceeding required value for given comfort class – after modernization

| Comfort class                          | I   | II  | III |
|----------------------------------------|-----|-----|-----|
| Ground floor – north oriented room     | 0   | 0   | 0   |
| Ground floor – south oriented room     | 0   | 0   | 0   |
| 1st floor – north oriented room        | 1   | 0   | 0   |
| 1st floor – south oriented room        | 9   | 0   | 0   |
| Last floor – north oriented room       | 78  | 0   | 0   |
| Last floor – south oriented room       | 222 | 4   | 0   |

It can be noticed that the thermal comfort on in the rooms on the ground floor is always obtained and temperature do not exceed 24°C. For the 1st floor the number of hours with temperature that
exceeds required level for given comfort class has been decreased for the state after modernization. There is no hours with temperature over 25°C and the number of hours with temperature over 24°C is decreased by six times. In the case of last floor the total number of hours with temperature over assumed limit has not change but there was a shift form II and III class to I class limit. On the basis of presented analysis it can be concluded that due to applied modernization a thermal comfort has been increased and overheating phenomena has been limited.

7. Conclusions
In the paper a measures of modernization of existing building of a collective residence where presented. The aim was to obtain a nZEB standard after modernization. As the definition of nZEB standard in Poland is not very demanding the new, more sharp definition has been used. Next the applied measures has been presented.

It was shown that all the modernization allows to decrease the primary energy demand indicator by over 16 times, from 298.5 up to 17.9 kWh/m2year. The highest decrease in primary energy demand was for heating and lighting. Also a huge impact on final results has a photovoltaic system, that covers almost 20% of primary energy demand. It was also showed that due to building modernization thermal comfort of students room has been increased. The overheating risk has been limited almost to zero.

It was presented that due to integrated energy design, common work of architects and engineers the nZEB standard with increased thermal comfort can be achieved by modernization of building under historic protection.

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