nZEB into the existing building fund as an affordable solution

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Abstract. A holistic approach with high level of replicability and financial feasibility for the public existing fund of buildings is undertaken, in order to transform existent public buildings, that are serving communities, into nearly Zero Energy Buildings. Finding large scale solutions from both technical and financial point of view, to reduce energy consumptions and CO₂ emissions for the existent building fund represents at this point a major challenge for all stakeholders. Several existent educational units (kindergartens, schools, high schools) from a city in Romania were analysed, in order to improve their energy efficiency and to transform the typical existent educational unit into nZEB. A framework package of technical solutions is proposed and the effect of its implementation is analysed, in terms of energy consumptions and CO₂ emissions reductions. Economic analysis is undertaken, to identify the feasibility of the nZEB concept implementation. An alternative approach is analysed for public authorities, in order to transform groups of existent buildings, which are serving communities, into nZEB.

1. Introduction
Considering that the reduction of energy consumption into buildings has an increasing importance across the world, it has to be taken in consideration that, actually, this consumer is represented by the existing buildings fund. Several measures have been undertaken, but it can be seen that the reduction of final energy consumption in buildings is still modest, with 6.6% in 2018 related to 2009 for European Union’s countries, respectively with 3% for the same considered period for Romania, according to the Eurostat database [1].

Although European directives related to energy efficiency of buildings [2] are already implemented in the European countries legislation, both public and private sectors encounter difficulties to implement measures leading to the energy reduction of the buildings, due to several reasons as: lack of informations related to the topic, lack of specific technical knowledge, lack of financial incentives etc.

According to Energy Performance of Buildings Directive 2010/31/EU, amended by (EU) 2018/844 [2], nZEB is the building with a very high energy performance, whose reduced energy requirement should be covered with RES in a very significant percent, produced on-site or nearby. In the Romanian legislation, the percent of renewable sources was introduced in 2016 and imposed to a minimum 10% of the total energy consumption of the building. The percent was modified starting with July 2020 and increased to minimum 30%.
nearly Zero Energy Building concept is a reasonable approach in technical terms, both for new buildings [3] and for existent buildings [4], [5], but related to the financial assessment and conditions, there are many discussions and very different approaches [6], [7], [8].

Different, but feasible technical approaches related to the nZEB implementation are undertaken, such as macro-scale perspective (the whole site analysis, including annex buildings, car parks etc.) and micro-scale assessment (the main building analysis) [4]. To achieve the nZEB target, the building’s envelope deep retrofit is considered, including using volumetric add-ons [5], which also provide other benefits as the increase of the acoustic and visual comfort, the increment of the living space, the increase of the real estate value of existing edifices etc.

Related to the financial assessment, cost-optimal analysis integrated in nZEB retrofit reveals a gap between the required costs and the primary energy consumption level to be achieved, for a certain non-residential building type, although nZEB concept is technically feasible too [7]. A first approach of integrated embodied impact into the cost-optimal level of nZEBs was undertaken and reveals the necessity of further analysis related to the design aspect of nZEBs, considering the variable definitions among the EU countries [8].

An approach related to groups of existent public buildings of which energy efficiency implementation is managed by a sole authority can be a solution to accelerate the process of mass renovation, which is prefigured, in order to achieve relevant energy consumption reduction, to reduce the CO$_2$ emissions and to controle the longterm greenhouse gases effects in the temperatures rising, as is intended [9].

Given the large diversity of parameters required for the implementation of the concept, is raised the question if the concept is reasonable in order to apply it in the non-residential built fund as a large scale solution, considering the existing technical limitations or the specific conditions of use, such as: fixed orientation towards the cardinal points, location or other surrounding buildings, occupancy hours or degree of occupancy etc.? This is a question that this paper aims to contribute to an answer from the perspective of the typical educational unit, by studying 15 educational units, with very different parameters related to: year of construction, conditioned area, constructive solutions and equipment, but having in common the same destination.

The objectives of this paper are:
- to create a nZEB retrofit model for the typical educational unit in Romania, through a framework package of solutions with high level of replicability;
- to evaluate the economical feasibility of the implementation of the framework package of solutions, considering that the selection of technical solutions is from common materials and equipment existent on the market.

| Abbreviations                          | Description                                                                 |
|----------------------------------------|-----------------------------------------------------------------------------|
| e                                      | luminous efficiency of the light source (lm/W)                              |
| e                                      | cost of energy saving unit (euro/kWh)                                       |
| g                                      | penetration degree of solar energy (°)                                      |
| NPV                                    | Net Present Value (euro)                                                   |
| p$_{sp}$                               | specific power of the fans (W/m$^3$/h)                                     |
| U$_w$                                  | thermal transmittance of the window (W/m$^2$-K)                            |
| DHW                                    | Domestic Hot Water                                                         |
| ESEER                                  | European Seasonal Energy Efficiency Ratio                                  |
| EPS                                    | Expanded Polystyrene                                                       |
| MW                                     | Mineral wool                                                               |
| nZEB                                   | nearly Zero Energy Building                                                 |
| PV                                     | Photovoltaic panel                                                         |
| RES                                    | Renewable Energy Sources                                                   |
| XPS                                    | Extruded Polystyrene                                                       |
2. Brief description of chosen buildings for educational units case study

The studied buildings are located in Arad, a city in the western part of Romania. The buildings are managed by the Municipality and have the destination of kindergartens, schools and high schools. In the figures below (figure 1, figure 2, figure 3) various parameters of them are described, such as areas, period of construction and the heating source type, which offer an image on their variety.

![Figure 1. Conditioned areas](image1.png)

![Figure 2. Period of construction](image2.png)

![Figure 3. Heating source type](image3.png)

Figure 2 shows the period of construction for each building and it can be noticed that construction range for considered buildings is more than 100 years. Related to the heating source type (figure 3), 33% of the studied buildings are connected to the district heating network, but because district heating is no longer a common solution in Romania, most of them have their own source, even if they are public buildings.

3. Brief description of nZEB framework package by considered type of destination

A framework package of solutions was applied on each of the studied buildings, with the main purpose to achieve nZEB target-values fixed for Romania, which are specific primary energy consumption and specific CO\textsubscript{2} emissions, depending on the type of the building and on the climatic area in which the building is located. The framework package of solutions, considered from an energetic point of view, is a holistic one and is comprising solutions for: the building’s envelope, installations and RES (Renewable Energy Sources). The technical solutions were chosen in order to obtain an affordable package, in financial terms. In table 1 the analyzed technical solutions are centralized by type.
Table 1. Framework package of solutions applied for each educational unit

| Brief description of solution (material or equipment) | Educational unit number |
|------------------------------------------------------|-------------------------|
| 15 cm of MW for walls                                 | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| 10 cm of XPS for base walls                           | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| windows and doors replacement                         | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| door closing automation system                        | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| 30 cm fireproof EPS for terrace roof / garret floor   | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| 10 cm of EPS for slab over unheated basement          | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| 10 cm XPS for slab on ground                          | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| new condensing boiler                                 | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| thermal energy meter                                  | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| insulation of heating pipes with mineral wool shells  | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| cleaning of heating elements                          | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| equipping static bodies with thermostatic valves      | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| introduction of electric boilers                      | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| AC equipment, ESEER = 4 or 5                          | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| mechanical ventilation, heat recovery efficiency = min.73% | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| LED lighting fixtures, e = min. 100 lm/W              | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| photovoltaic panels, yield = 16%                      | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |
| solar collectors with vacuum tubes and storage        | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 |

Building envelope. Thermal insulation of the opaque part of the facades with 15 cm of basaltic mineral wool insulation system, 10 cm of XPS for the outer walls of the base, with extension of 50 cm below the ground level. The replacement of the existing windows and doors, with airtight insulating joinery, with max. \( U_w = 1.45 \text{ W/m}^2\text{K} \) and \( g = 0.6 \% \), but only for the buildings in which replacement wasn’t undertaken in the recent years. In case of replacing the glazed elements, their installation is done on the outer face of the wall and not in the central section, as is common. For the garret floor or exterior terrace floors was applied a range of 20-25 cm XPS or 30 cm of EPS as insulation layer within the framework solution, with the provision of other common constructive layers specific to the roof type. Where the useful height allowed, a thickness of 10 cm of XPS thermal insulation for the slab on ground was proposed too, but only in four cases from the 15 studied (table 1). In the case of existence of unheated basement, a layer of 10 cm EPS was proposed, protected with fiberglass mesh. Automation of the closing system of the outdoor access doors by hydraulic shock absorbers was also considered.

Heating. In four cases the heating source was proposed for changing with condensation boilers, but because for all buildings the source was replaced over time and in the recent years, the heating source was commonly kept. A common measure, given the reduced net area for a range of the buildings, is the introduction of thermostatic valves for static bodies.

Sanitary installations. For one school introduction of DHW was required. In this case, the measure has a double purpose, to be energy efficient and to increase the level of comfort for the students.

Air conditioning. None of the buildings are equipped with centralized air conditioning. In a very few cases, local air conditioning is available, but only in administrative spaces. The framework package
propose the introduction of air conditioning equipment, with ESEER = 4, for reduced dimensions buildings and ESEER = 5, for larger educational buildings. The introduction of equipment with higher efficiency and price as well, is not justified, given the fact that from 15th of June to 15th of September educational units are not used, with the exception of kindergartens with extended program, which have a month of vacation during summer.

Mechanical ventilation. The framework package considers as mandatory the introduction of mechanical ventilation with heat recovery, both from comfort requirements and energetic efficiency, in all spaces, with the recovery efficiency of min. 73%. Technical parameters, such as supply and exhaust flows, were calculated for each building, and requirements for the motor of inlet and outlet fans were provided, also imposing maximum specific fan power $p_{sp} = 0.20 \text{ W/m}^3/\text{h}$.

Lighting. It is proposed to replace the current luminaires (usually fluorescent tubes) with LED luminaires, bringing to the current design standards in terms of visual comfort by properly dimensioning the lighting system, both qualitatively and quantitatively, with required $e = \text{min. 100 lm/W}$.

RES. In order to ensure the electric consumption in operation for DHW equipment, mechanical ventilation, air conditioning and lighting, it is proposed to install photovoltaic panels, with imposed parameters for: type, surface, orientation, minimum efficiency, tilt angle.

For the kindergartens with extended program and high requirement of DHW, solar collectors were proposed too, along with PVs.

4. Results and discussion

The initial results vary between 917.84 kWh/m²-year and 153.24 kWh/m²-year for specific final energy consumption, respectively and 196.43 kgCO$_2$/m²-year and 34.58 kgCO$_2$/m²-year (figure 4). The lower limit is a kindergarten with a very dilapidated building envelope, in terms of thermal resistances and air tightness and provided with medium energy performant equipment. The upper limit is considered a high school which had in the last years a range of improvements, including partial thermal insulation, respectively it has a good maintenance.

![Figure 4](image_url)

**Figure 4.** Actual specific final energy consumption, by type, and related CO$_2$ emissions

The results obtained after the implementation of the package in each studied building vary between 147.66 kWh/m²-year and 23.03 kWh/m²-year for the specific primary energy consumption, respectively between 34.18 kgCO$_2$/m²-year and 13.15 kgCO$_2$/m²-year for the specific CO$_2$ emissions (figure 6).
Figure 5. Proposed specific primary energy consumption, RES* and CO₂ emissions

Comparing figure 6 with figure 5 it is noticed that the occupancy hours of the building influences directly the target-values, especially because of the direct dependence of solar renewables sources to the radiation intensity, correlated with the use schedule of the building, which can be quite reduced (some of the kindergartens are used 5 h / per day, from Monday to Friday and considering the summer vacation as well, from 15th of June to 15th of September). For figure 5 it is specified that RES* notation represents the hourly energy production provided by PVs during the occupation of the building (number of hours per day, working days), while RES in figure 6 is the total energy production provided by PVs.

Figure 6. Proposed specific primary energy consumption, RES and CO₂ emissions

If the energy produced with PVs and introduced in the national power system is considered and it should be, because although it is not used directly by the building it is compensated with energy from the national power system and used indirectly by the group of public buildings managed by the same sole authority, then 13 of the 15 studied educational units have values of specific primary consumption and specific CO₂ emissions, below the national values required for Romania. This observation permits the conclusion that the implementation of nZEB concept to non-residential buildings from the existing fund is feasible from the technical point of view, in specified conditions.
However, the financial analysis becomes really important, especially when is considered the public sector, so it was undertaken to see if the implementation of a framework package of solutions it is realistic from the financial perspective and if the concept can be a real option in terms of large scale renovation for an existing typical unit. The results are centralized in figure 7.

![Figure 7. Financial results](image)

As regarding financial results, dynamic analyzes were undertaken for the calculation of payback period, considering the projected costs over the average life of the solution package, depending on the depreciation rate of the currency and the projection of the energy price growth. Imposing the condition for NPV = 0, the payback period was obtained with a range between 10 and 34.7 years and an average value of 20 years. For the upper limit, the studied building has a protocol home inside, so this value is not considered. The next value is 24.8 years, which represent the upper limit of the payback period range.

The specific investment cost to transform a common existent educational unit into nZEB has an average value of 244 euro/m², with reference to the gross area of each analyzed building. Is noticed that from financial perspective results are good and prove the feasibility of the concept.

5. Conclusions
An approach related to groups of existent public buildings of which energy efficiency implementation is managed by a sole authority is provided.

It is demonstrated that a single framework package of solutions applied to the type of building could lead to nZEB for existent public buildings, in general, and for the typical educational unit, in particular. The package is applicable to a range of current technical conditions, from buildings in very poor condition to buildings that have introduced partial measures over time.

Such an approach could lead to helpful guides for energy auditors and for designers, architects and engineers, because they will have clear technical specifications related to the solutions and specific parameters to introduce in deep renovation technical projects within a holistic approach from an energy point of view. Is identified, as well, a good opportunity for existent educational buildings to be raised to current standards considering comfort requirements, even if currently they comply a low level of comfort.

The paper demonstrates the economical feasibilty of the implementation of the concept to the typical educational unit and offers an affordable approach for this type of existent public building, whose local operation and decisions related to energy efficiency targets depend on a group of stakeholders.
By preparing the design process and the specialists to reach the level of performance to be achieved through a specific guidance, from a holistic energy point of view, will help the market to accelerate the deep renovation process of the existing built fund, as is already prefigured.

References
[1] Eurostat [Online] Available: https://ec.europa.eu/eurostat/data/database
[2] EC 2018 Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency Off. J. Eur. Un. 61 L156
[3] Măgurean A M 2019 Case study of NZEB implementation into an early stage of the design phase for a new residential building Procedia Manuf. 32 450-57
[4] Alajmi A, Short A, Ferguson J, Poel K V and Griffin C 2020 Detailed energy efficiency strategies for converting an existing office building to NZEB: a case study in the Pacific Northwest Energy Effic. 13 1089–1104
[5] Assimakopoulos M –N, De Masi R F, Fotopoulou A, Papadaki D, Ruggiero S, Semprini G and Vanoli G P 2020 Holistic approach for energy retrofit with volumetric add-ons toward nZEB target: Case study of a dormitory in Athens Energy Build. 207 109630
[6] Dimitriou S, Kyprianou I, Papanicolas C N and Serghides D 2020 A new approach in the refurbishment of the office buildings - from standard to alternative nearly zero energy buildings Int. J. Sustain. Energy 39 761–78
[7] Salem R, Bahadori-Jahromi A, Mylona A, Godfrey P and Cook D 2020 Energy performance and cost analysis for the nZEB retrofit of a typical UK hotel J. Build. Eng. 31 101403
[8] Chastas P, Theodosiou T, Bikas D and Tsikaloudaki K 2020 Integrating embodied impact into the context of EPBD recast: An assessment on the cost-optimal levels of nZEBs Energy Build. 215 109863
[9] United Nations 2015 Paris Agreement [Online] Available: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf