Refurbishment Solutions for Public Buildings Towards Nearly Zero Energy Performance

Laura Aelenei(✉) and Helder Gonçalves

Laboratório Nacional de Energia e Geologia, Lisbon, Portugal
laura.aelenei@lneg.pt

Abstract. This study presents some results of an recent closed European Project, RePublic_ZEB [1], where an extensive analysis was conducted for identifying cost-optimal refurbishment solution an sets of solutions applied to exiting public buildings, towards nearly Zero Energy Buildings (nZEB) performance. The analysis was applied to 12 reference buildings identified in 8 countries participants in the project and for different building typologies. A cost-optimal solution sets matrix of the 12 buildings is presented together with the results of nZEB energy performance.

Keywords: nZEB · Refurbishment · Public buildings · Cost-optimal

1 Introduction

Nearly Zero Energy Buildings have gained more attention since the publication in 2010 of the EPBD recast [2]. EPBD recast requests all new buildings to meet higher levels of performance than before, by exploring more the alternative energy supply systems available locally on a cost-efficiency basis and without jeopardizing the comfort. To this end, beginning in 2020, all new buildings should become "nearly zero-energy". A "nearly zero-energy building" refers to a high energy performance building of which annual primary energy consumption is covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The directive requires nearly zero energy buildings, but it does not give minimum or maximum harmonized requirements as well as details of energy performance calculation framework. Furthermore, the EPBD recast states that MS must ensure that minimum energy performance requirements for buildings are set with a view to achieving cost-optimal levels according to the Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 on the cost optimal methodology framework. In this context, MS implementation of the Regulation emphasized the cost-optimal analysis for the residential buildings, at the expense of all the other categories.

The nZEB concept still does not seem to be easily applied in the member countries: the IEE programs past and current efforts clearly show that required investments and optimal integration of the technologies suitable for the buildings construction and/or renovation into nZEB are among the major barriers. Furthermore, the confidence both of the buildings industry and of the building owners in the real energy performance of

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the nZEBs and in the real risks associated to new technologies, seems one of the most strategic point. The resolution of which could possibly solve the problem related to the high investments required in the process.

2 RePublic_ZEB Project

2.1 About the Project

In this context and trying to respond as well to the European building legislation, RePublic_ZEB project started in 2014 focuses in the refurbishment of the public building stock towards nZEB in the countries of the South-East of Europe in line with the EU's Energy Performance of Building Directive and its energy targets for 2019 and 2021. The project's main objective is to support the participant countries to develop and promote on the market a set of concrete technical solutions for the refurbishment of the public building stock towards nZEB. To achieve this goal, RePublic_ZEB's includes an assessment of the current public sector building stock and the determination of reference buildings. The expected output is the definition of cost optimal packages of measures for the refurbishment of the public buildings towards nZEB, which will be included in guidelines and the promotion activities addressed to national and regional authorities as well as construction industry, housing organizations, owners of large building stock and developers.

The project plan was structured in 6 Working Packages (WP), from which two of them were related with project management activities (WP1) and project dissemination activities (WP6).

Taking into account that two methodologies, the main streams of the project, were: one the cost-optimal methodology for calculating cost-effective packages of measures for refurbishment of public buildings and the other one the nZEB calculation approach, three of the WPs were dedicated to this development: WP2 was related with analysis of the public building stock in each country, definition and identification of reference buildings in each country and for each typology, WP3 was related with the identification of existing nZEB definitions and approach and proposing a common approach to be used in the project and for all participants and WP4 was related with the calculation of the cost-effective packages of measures for the identified reference buildings and nZEB common approach. WP5 was related with communication activities between the main actors and project guidelines development, including all the results from WP2, WP3 and WP4. In this paper, the refurbishment cost-effective solutions will be present, together with the matrix of these solution and set of solutions for 12 reference buildings and the energy performance of these buildings before the refurbishment and after applying the refurbishment solutions.

2.2 Methodologies

One of the main objectives of the RePublic_ZEB project was to propose a common framework and a harmonization methodology for the nZEB concept for existing public building". To this aim, and considering the legislative context of each country, the consortium has formulated the following definition: "*Transformation of an existing public building to nZEB means to apply renovation technologies that reach a target share of RES and enables energy performances or CO_2 emissions better than the optimal case but still cost effective*." As commonly defined in the framework of the project, a building is considered as nearly Zero Energy when the following requirements are met:

- The EP is lower than the cost-optimal level (a nZEB has higher energy performance than the cost-optimal building);
- The differential Global Cost (ΔGC) is negative (nZEB renovation is cost effective);
- When available, the national minimum energy performance requirements for nZEBs are fulfilled.

The proposed definition is coherent with the indicators proposed by the European Directive. The selected parameters to characterize the refurbishment toward nZEB are the followings:

- Non-renewable primary energy consumption
- Renewable energy ratio
- Global costs.

Based on these indicators, the cost-optimal methodology [3, 4] is used. Figure 1 represents an example of the effect of several retrofit measures (every dot) in terms of energy performance and differential global cost, in comparison with the existing building. The figure shows how the nZEB range is located between the cost-optimal package of measures and the measures with an equal or lower global cost than the existing building.

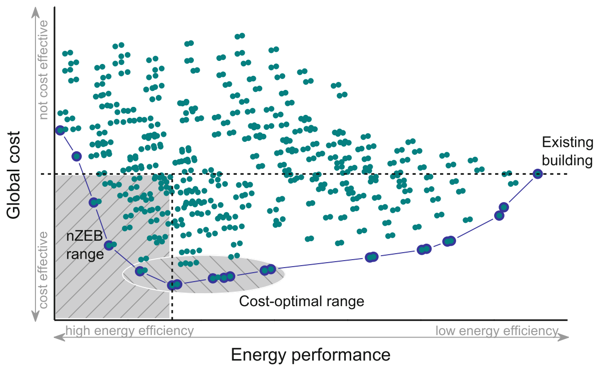

Fig. 1. Energy performance and differential global an example [5]

The economic indicator, global cost, is calculated following the European standard EN 15459:2008 Energy performance of buildings. Economic evaluation procedure for energy systems in buildings. The global cost method is the calculation of a present value of all the costs during a long period, taking into account the residual values of components with longer lifetimes. Basically, the costs can be divided in three main groups: energy costs, investment costs and running costs. Each of these costs is calculated for the established period in the study, in this case 30 years.

The energy costs are composed of two terms: costs related to the consumed energy by the building (purchased energy) and the costs related to the produced energy in the building (sold energy). In both terms, the included costs can be: energy cost (€/kWh), additional values for purchase/sale (€/yr, as for example power fix term of the electrical contract), and environmental costs (€/CO_2 emission). In this study, the environmental cost is not included because the perspective of the evaluation is microeconomic (financial). The investment cost of each retrofit option includes three terms: the initial investment cost, the replacement cost and the final value of the component.

The total replacement cost and the final value of the component are related to the lifespan of the retrofit measures. Finally, the running cost includes the annual cost for the maintenance of the building and their systems, which is considered every year of the calculation period. The proposed nZEB definition wants to be useful for the countries in which nZEB has not been defined yet, and also for the countries that have already defined nZEB in detail, in order to help to better orientate the discussion on the matter and facilitate better future regulations.

3 Case Studies

As mentioned previously, a methodology of defining the reference buildings based on the public building stock in each participant country has been developed. The reference building categories analyzed in the framework of the project were: residential buildings, office buildings, school buildings and hospitals, as these categories represent the highest fraction of primary energy consumption in all the countries.

Furthermore, every building category has been analyzed in different countries and climates in order to compare which strategies are the most appropriate in each situation. Twelve examples of reference building for different categories were selected for the application of the refurbishment measures and solutions of public buildings towards nZEB: 4 buildings offices, 3 educational (schools), 3 hospitals and 2 residential (multifamily) buildings. It worth mentioned also regarding the location of these building that 5 large buildings (3 offices, 1 school and 1 hospital) are located in South Europe, 5 large buildings (1 office, 2 schools and 2 hopsitals) are located in Central-East Europe and 2 residential are located in Central-East Europe.

The buildings are presented in the Fig. 2 together with the information about location, type of building, area and year of construction.

A number of efficient cost-optimal solutions and set of solution were applied and tested according with the types of building, climate location, energy savings and costs.

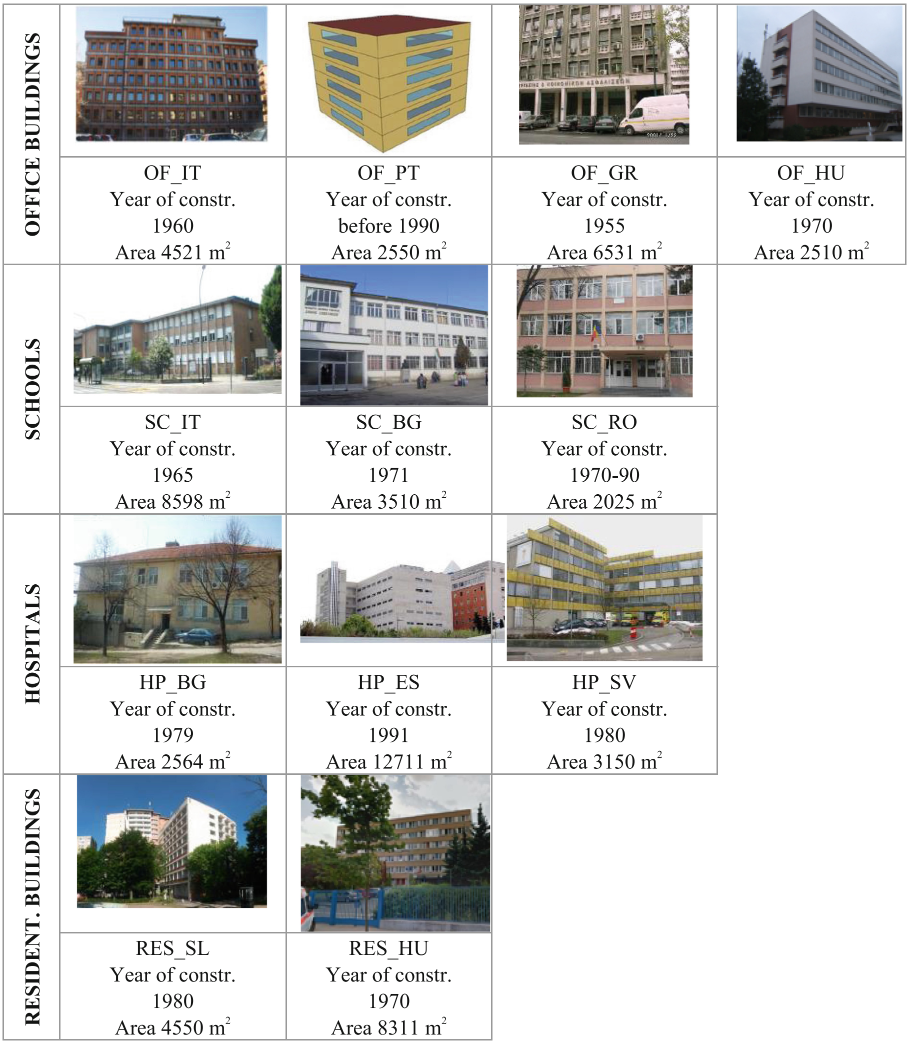

Fig. 2. Case studies

3.1 Refurbishment Measures

For each kind of reference building a set of solutions have been simulated in order to identify those more cost-effective.

The description of the final refurbishment solutions adopted for the 12 case studies are present in the Table 1. The solutions with the larger variety were those regarding building opaque envelope, representing 7 solutions of different external insulation for walls and roofs, 4 solutions for windows, 2 solutions for shadings device, 6 for efficient systems, 2 for lightening, 3 for renewable energy systems and one of district heating.

Table 1. Refurbishment solutions

M1 wall insulation	M1-1	Roof – External insulation (25–34 cm EPS)
	M1-2	Roof – External insulation (15–22 cm XPS)
	M1-3	Roof – External insulation (6–10 cm XPS)
	M1-4	Wall – External insulation (20–22 cm EPS)
	M1-5	Wall – External insulation (12–15 cm EPS)
	M1-6	Wall – External insulation (3–9 cm EPS)
	M1-7	Wall – External insulation (30 cm EPS)
M2 windows	M2-1	Window – Triple glass low-e filled with gas
	M2-2	Window in PVC – Triple glass low-e
	M2-3	Window in PVC – Double glass
	M2-4	Window in aluminum – Double glass, low-e
M3 shading	M3-1	External movable shadings
	M3-2	External fixed shadings
M4 energy efficient systems	M4-1	Air source heat pump
	M4-2	Ground or water source heat pump
	M4-3	High efficient chiller
	M4-4	Mechanical ventilation
	M4-5	Heat recovery system
	M4-6	Load management
M5 lighting	M5-1	LED
	M5-2	Linear fluorescent lamp T5, T8
M6 RES	M6-1	Solar thermal systems
	M6-2	Photovoltaic system (monocrystalline, polycrystalline)
	M6-3	Biomass boiler
M7	M7	District heating

The thermal transmittance of the building (external walls, roof, attic floor, ground or cellar floor slab) has a great influence on the heating and cooling demand. The thermal insulation of the building is one of the most expensive measures, but probably it has the biggest impact on heating energy saving. The best insulation is placed on the exterior of solid walls, so it enables the building to continue to benefit from the thermal mass of the walls and can easier reduce the effect of thermal bridges; however there are limitations for historic or protected buildings. The most common types of insulation are expanded polystyrene (EPS), extruded polystyrene (XPS), fiberglass and mineral wool. The air space of cavity walls can be filled with insulation materials such as cellulose insulation, glass wool and foam that can be blown into the cavity through suitably drilled holes. In all case studies the insulation was placed on the exterior of the walls and roofs.

Windows have very high impact on the heating and the cooling demand, therefore the energy saving potential of changing or modernizing windows is significant. The required investment can be variable from moderate to high levels, depending on the type of refurbishment. The effect depends on the frame and the glazing of the windows:

the frame can be made of wood, PVC or aluminum. The aluminum frame must be designed with thermal breaks to avoid high thermal losses due to the high thermal transmittance of the material. There are three main characteristics to consider with glazing: the number of panes (double or triple), the filled gas (air, argon etc.) and its emissivity. Special coatings can reduce the infrared radiation transmission without compromising the amount of visible light that is transmitted.

Solar shading is the term used to identify the systems to control the amount of heat and light from the sun admitted to a building. Solar shading devices can offer energy savings in different areas: they can reduce the amount of energy required for heating or cooling, can reduce the energy required for lighting, by optimizing the admittance of daylight, and enhance indoor comfort and stimulate productivity. Installation of solar shading devices is highly recommended in buildings exposed to the sun in summertime. Well-designed solar shading devices help to keep the building cool and comfortable, reducing the air-conditioning needs and, at the same time, taking benefits from solar gains in winter. The most efficient shading devices are placed outside the windows. In this way, the solar radiation is reflected to outside before reaching the window. When the protection is placed inside, only a fraction of the incoming solar radiation is reflected outside. The shading devices can be fixed or movable. For rooms exposed to the East or to the West, movable solar shading devices are better for an optimal operation in the different seasons.

Regarding the energy efficient systems, the ground source heat pump transfers thermal energy stored within the soil to the building by means of an electric heat pump. The thermal energy is collected with closed horizontal or vertical loop coils. Horizontal collectors may be more economical but require a sufficient area near the building. The first 1.5 m layer of the ground is moderately influenced by the sun and the season variations. Deeper, the ground temperature is almost constant and warmer than the air temperature in winter and colder in summer. Horizontal ground collectors (coils or spirals) are buried below freezing depth over a certain surface area, depending on the heating/cooling demand. Vertical ground collectors (pipes or loops) are placed in bored wells that can reach 120 m or more in depth. The water source heat pumps use the heat energy available in water as a heat source. Water source heat pumps can operate with “open” or “closed” loop.

Air source heat pumps use the outside air as a heat source. Air temperatures vary seasonally and moisture content fluctuates: an air source heat pump will always depend on the climate conditions. The colder the air temperature, the harder the heat pump must work to lift the temperature up to what is required for heating. Air source heat pumps use electricity to move heat from a cool space to a warm one, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the outdoors into the building and during the cooling season, from the buildings to the outdoors.

Chillers are part of centralized systems and are adopted for the cooling of the buildings. A vapour compression chiller produces chilled water by transferring heat from the chilled water circuit to the re-cooling circuit. The vapour compression cycle is driven by electrical energy supplied to the compressor. The main components of these machines are: electric compressor, condenser, thermal expansion valve and the evaporator.

The objective of the ventilation is to guarantee a good air quality for the occupants. Adequate ventilation is needed for both the comfort and the safety of occupants, as it removes pollutants produced in the building. The air renovation depends on the number of occupants and the relevant activity. Mechanical ventilation is used where natural ventilation is not appropriate, like in cold climates. Air extraction produces a constant depression and the inlet air should be pre-conditioned to ensure an appropriate air quality (filters) and temperature. Mechanical ventilation must be combined with a control system to optimize its operation and reduce the energy consumption. The control can regulate the air flow according with the air temperature and quality inside the building (CO_2 concentration, humidity etc.).

Energy recovery takes energy from exhaust air and transfers it either to the supply air or to the domestic hot water. The heat recovered from exhaust air reduces the quantity of energy required for heating or humidifying the outdoor air in air ventilation systems.

Several types of energy efficiency lighting technologies exist, such as T5 fluorescent lamps, compact fluorescent lamps (CFL) and light-emitting diodes (LED). All this types of lamps are suitable to replace old T8 fluorescent lamps and incandescent lamps. When continuous lighting is required, the application of energy efficient T5 fluorescent lamps is suggested. With intermittent lighting, the application of energy efficient LED lamps is suggested. LED lamps have long life spans even with frequent switching and generate much lesser heat compared to other lighting systems. To reduce the energy consumption of the lighting system, control strategies (M18) are required, like: occupant sensors, daylighting control, dimmer controllers.

A Building Management System (BMS) is a computer-based controller network that controls and monitors the building's mechanical and electrical equipment such as heating, cooling, ventilation, lighting, power supply, fire and security plants. Current generation BMS systems are based on open communication protocols and are WEB enabled allowing integration of systems and access from everywhere in the world. These systems incorporate sensors to monitor the use of the building and to control and regulate, through the actuators, the level and time of operation according with the set-point established. These systems make possible to collect information, guaranteeing an adequate operation and giving the possibility to detect and predict possible problems.

District heating/cooling means the distribution of thermal energy from a central source to multiple buildings or sites through a network. Where water is used as heat transfer medium, heat exchangers and water flow meters are the only equipment needed to provide heating and cooling to the buildings. The advantage of these systems is the higher performance of the generation plants in comparison with individual systems.

The production of domestic hot water can be achieved using a solar thermal panels. In some climate regions, the system is useful for heating as well. In summer, there is a possibility to feed absorption machines for cooling. The most common solar panels are of the following types: flat-plate collectors and evacuated tube collectors.

PV panels convert solar energy to electricity. Even in cloudy, northern latitudes, PV panels can generate power to meet totally or partially the building's electricity demand. PV is a flexible and versatile technology. Panels can be used on roofs, curtain walls and decorative screens. With Building-Integrated PV (BIPV) the photovoltaic components are used to replace part of the conventional building materials such as the roof covering and the external layers of facades.

3.2 Results Refurbishment Solutions Set Matrix

In order to understand common strategies and solutions adopted regarding building categories and also locations (different climates) a matrix of solution sets was developed in the following (Fig. 3). The methodology focused by the project Republic_ZEB is suitable for defining the packages of measures needed to refurbish the existing buildings towards optimal nZEBs.

Envelope solutions
Energy Efficient systems solutions
Renewable energy Systems solutions

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Fig. 3. Matrix of solution set for public building refurbishment toward nZEB

Despite all differences between the 12 analyzed case studies the type of construction and climate conditions, the strategies to achieve the nZEB criteria are nearly common. In fact, the measures that have been selected in most of the buildings are the following:

(a) Envelope solutions (M1, M2, M3)

(M1) Thermal insulation has been adopted in most of the buildings to: facade, walls and slabs separating conditioned and unconditioned rooms, roof and ground.

Despite their high investment costs, this measure is the most effective in terms of energy demand reduction. The thermal insulation permits to reduce the heating, the cooling demand and the thermal bridges of the building. Its sizing is dependent on the climate (more insulation in colder climates).

(M2) Efficient windows. This measure is one of the most effective measures. The investment cost is high but the benefits are significantly important. There are many types of efficient windows and the appropriate selection depends on the climate and the overall design of the building (heat gains, solar shading devices, daylighting control have to be considered).

(M3) Shading devices as fixed or movable were used in some case studies.

(b) Energy efficient systems (M4)

(M4-6) Load management. To ensure a proper operation of the systems it is very important to manage the building with advanced tools, as building management systems and optimal control strategies. There are different levels of implementation, depending on the needs and features of the building.

(M4-1) Air source heat pump. The air source electric heat pump has been chosen in several building categories and climates, in which more services have to be provided (only heating; heating and cooling; heating, cooling and hot water). The technical and economic feasibility and the reliability of the heat pumps are increasing and this makes the technology very flexible today. It is also an ideal technology to be combined with electric renewable generators. The use of geothermal (ground source) and water heat pumps (M4-2) depends on the location of the building and is less generalizable.

(M4-4) Mechanical ventilation. The system permits to control the rate of air renovation guaranteeing the indoor air quality. However, the more interesting achievements in terms of energy savings require combining it with additional measures: advanced control systems (M18) and heat recovery systems (M13).

(c) Efficient lighting (M5)

The artificial lighting has a significant impact on the energy balance and the adoption of efficient lamps provides positive impact also from an economic point of view. The most common solutions are the LED technologies and fluorescent lamps T5, combined with control strategies.

(d) Renewable energy systems (M6)

(M6-1) Solar Thermal Systems were proposed as solution for the case studies school in Romania and hospital in Bulgaria.

(M6-2) Photovoltaic system. The PV system is the most adopted renewable energy system due to the simplicity of the installation and the benefits in terms of reduction of electric consumptions. Almost all case studies integrate the PV systems for generating electricity.

(M6-3) Biomass boiler. This technology has been adopted in large buildings, where the heating and the sanitary hot water production must be covered by the boiler. This system is more adequate in cool climates or in buildings with high energy demand (for example, the hospital).

3.3 Results Energy Performance

The 12 case studies were simulated taking into account the real characteristics or the characteristic of the reference buildings considered for each category. Taking into account the considered solutions and set of solution identified for refurbishment towards nZEB, all case studies were simulated with the implemented solutions. The results of the energy performance of all case studies before and after refurbishment, can be observed in the Fig. 4 for residential and office buildings and Fig. 5 for schools and hospitals. It can be observed that generally, after the application of the refurbishment solutions, the primary energy consumption (non-renewable) is reduced after applying the refurbishment measures. In the same time, the use of renewable energy is also higher, as in some cases even before refurbishment the buildings were equipped with renewable energy systems (Hungary, Italy, Portugal).

In which regards the general aspect and nZEB approach, there are some differences in the context of each country that could make difficult the comparison between the featured buildings. In particular:

- In some countries there is no official definition of nZEB and the retrofit solutions have been selected just according to the project definition: a refurbished building is more energy efficient than the cost-optimal solution, but at the same time is cost effective.
- The share of renewable energy regulated in each country is different.
- The energy needs and the number of services considered in the final energy consumption are not the same for all the countries and for all the building categories.
- Some countries have no official values for the primary energy factors, specifically regarding the renewable fraction of primary energy.
- The chosen buildings are different as typologies, constructive characteristics and volume.
- The climate and the occupation of the buildings are also different; these factors highly influence the energy consumption of the buildings.

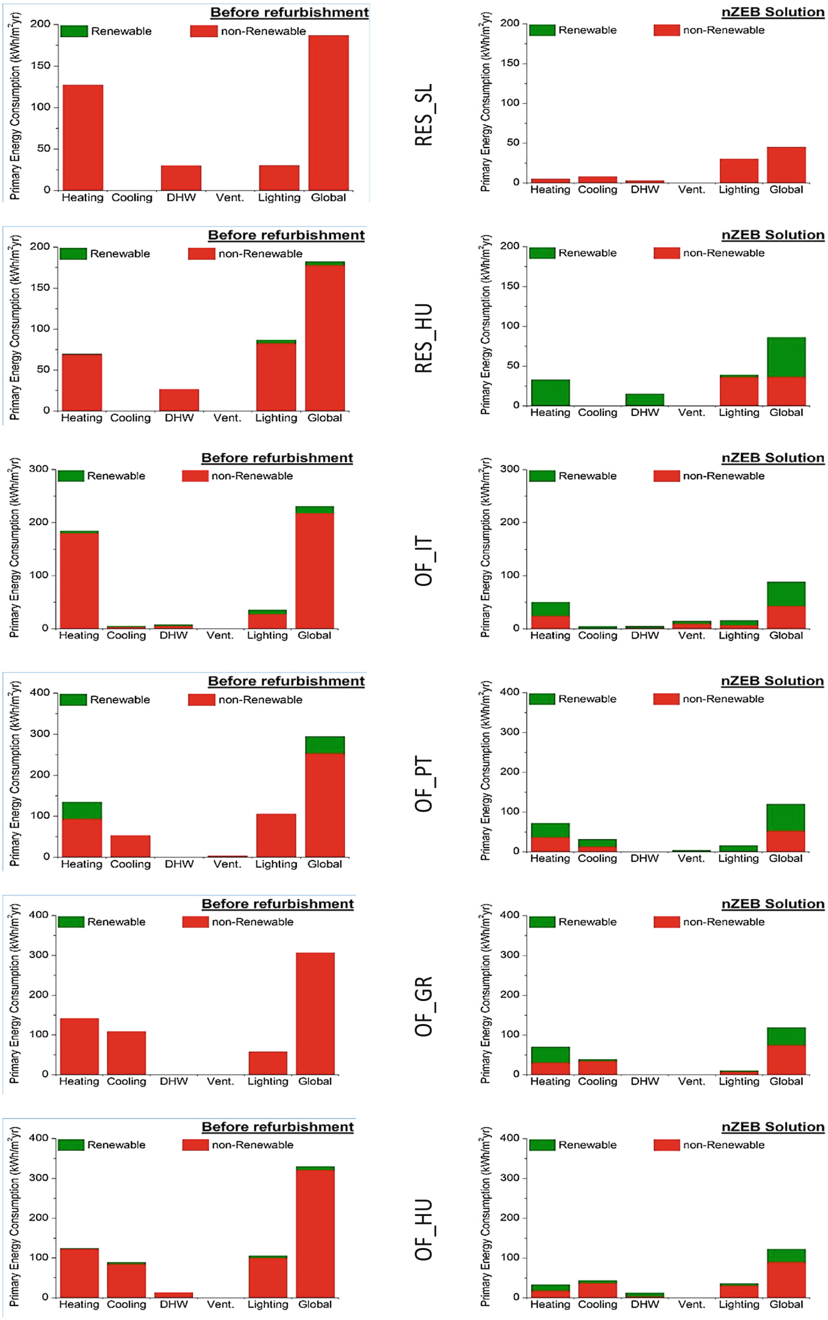

Fig. 4. Energy performance before and after refurbishment for residential and office buildings

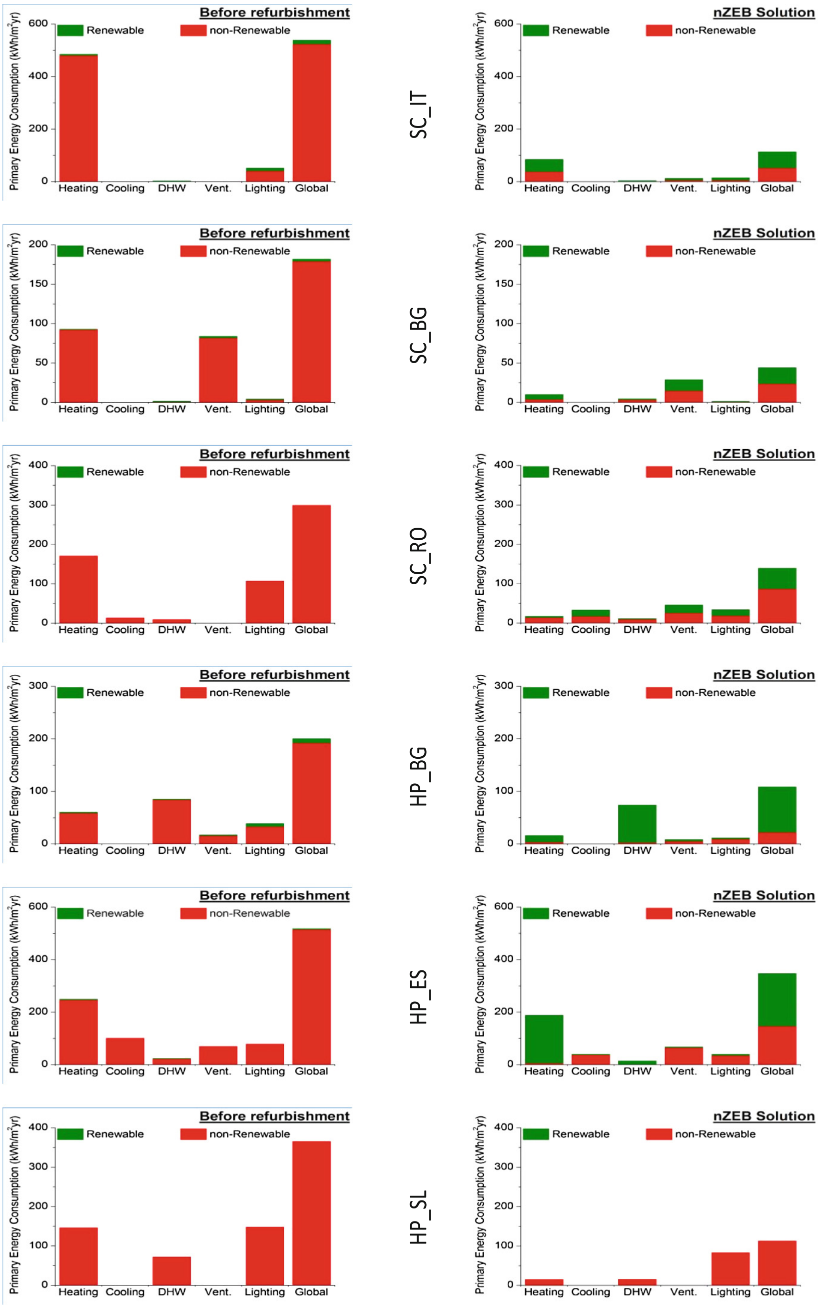

Fig. 5. Energy performance before and after refurbishment for schools and hospitals

4 Conclusions

This study presents some results of an recent closed European Project, where an extensive analysis was conducted for identifying cost-optimal refurbishment solution an sets of solutions applied to exiting public buildings, towards nearly Zero Energy Buildings (nZEB) performance. The analysis was applied to 12 reference buildings identified in 8 countries participants in the project and for different building typologies. A cost-optimal solution sets matrix of the 12 buildings is presented together with the results of nZEB energy performance. As a final remark, it important to underline that the energy diagnosis and an overall assessment of the existing building are a very substantial step in the design of the retrofit measures. In fact, the transformation towards nZEB is, at the end, an energy and an economic issue based on the energy balance of the building. This means: reducing energy needs, improving efficiencies in general and increasing the use of renewables taking into considerations the characteristics of the building and the local climate. However, other aspects must be considered in refurbishments, like: the comfort, the rationalization of the use of the building, eventual artistic demands (often required in public buildings by the local regulation) and the eventual preservation of historic value (this is a very big issue in ancient cities and town) etc. Then, the consultation of these results should not make us forget the need to also analyse all these aspects.

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