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REFURBISHMENT OF THE PUBLIC BUILDING STOCK TOWARDS NZEB

ACRONYM OF THE PROJECT: REPUBLIC_ZEB

D4.4 REPORT ON THE SENSITIVITY ANALYSIS APPROACH AND ON THE MEDIUM/LONG TERMS TECHNOLOGIES

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RePublic_ZEB Project

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Project consortium

BME  WP3 Leader
BRE  WP6 Leader
BSERC  WP2 Leader
CRES  Partner
CTI  WP1-WP7 Leader
EIHP  Coordination
URBAN-INCERC  Partner
IREC  Partner
LNEG  WP5 Leader
MACEF  Partner
POLITO  WP 4 Leader
ZRMK  Partner
Project overview

The RePublic_ZEB project is focused on the energy and CO₂ emissions associated with existing public buildings and their refurbishment towards nZEB.

The **core objective** of the project is to:

- Define costs-benefit optimized "packages of measures" based on efficient and quality-guaranteed technologies for the refurbishment of the public building stock towards nZEB that are standardized and adopted by builders and building owners.

From this stems three **basic objectives**:

(i) State-of-the-art assessment of the public building stock through a country-specific evaluation of the energy consumption and CO₂ emissions;

(ii) Define reference buildings; and;

(iii) Develop a common framework and a harmonized methodology for the definition of a nZEB concept for public buildings.

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4.2.3 Office

4.3 ITALY

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5. CONCLUSIONS
## Acronyms

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<tr>
<td>EP</td>
<td>Energy Performance</td>
</tr>
<tr>
<td>GC</td>
<td>Global Cost</td>
</tr>
<tr>
<td>PBP</td>
<td>Pay-Back Period</td>
</tr>
<tr>
<td>RER</td>
<td>Renewable Energy Ratio</td>
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<td>ΔGC</td>
<td>Differential Global Cost</td>
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## Nomenclature

<table>
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<th>Symbol</th>
<th>Description</th>
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<tr>
<td>E</td>
<td>energy</td>
<td>[kWh]</td>
</tr>
<tr>
<td>PBP</td>
<td>pay-back period</td>
<td>[a]</td>
</tr>
</tbody>
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### Subscripts

- act: actualized
- gl: global
- nren: non-renewable
- ren: renewable
- tot: total
1. EXECUTIVE SUMMARY

This document has been developed within Task 4.3 “Sensitivity analysis” of RePublic_ZEB project.

According to RePublic_ZEB Description of the Action “In this task the main economic and technological parameters which can affect results of T.4.2 are analysed. The aim is to assess possible medium/long term effects of uncertainty factors on the development and widespread of technologies”.

This document reports on the sensitivity analysis performed on the nZEB solutions identified for each reference building considered in Task 4.2. The investment and the operating and maintenance costs, the energy costs and the real interest rate were considered as the key economic parameters affecting the results of T.4.2. These parameters are varied over a specific range of values and the results are used to investigate the boundary conditions that drive the refurbishment of the public building stock towards nZEB.
2. INTRODUCTION

According to WP4 actions, partners have defined for each reference building the most suitable energy efficiency measures in order to achieve the nZEB goal. The deliverable D4.3 reports on the nZEB solutions in terms of:

- energy performance;
- Renewable Energy Ratio, RER;
- global cost, subdivided in investment, operating and maintenance, energy;
- actualized pay-back period;
- CO₂ emission.

A sensitivity analysis is requested, in order to make the results robust. The main parameters affecting the choice of a package of measures are identified to be of economic nature. Also the technological parameters (e.g. the thermal conductivity of the insulating materials, the g-value of glass, the efficiency of the heating/cooling generators, and so on) can affect the choice of a package of measures, but their final impact is a cost reduction in terms of investment and energy costs. For these reasons, the sensitivity analysis is performed on the following economic parameters:

a) investment plus operating and maintenance costs;

b) energy costs;

c) real interest rate.

In Section 3, the procedure of the sensitivity analysis is explained.

In Section 4 the partners’ results are reported.

Section 5 is finalized to compare the results and to point out the economic barriers and drivers in the refurbishment process towards the nearly zero-energy target.
3. PROCEDURE

The sensitivity analysis is performed on the nearly-zero energy buildings (nZEBs) investigated in the project and reported in D4.3. For each package of measures defined as suitable to reach the nearly zero-energy target, the values of the following parameters have been changed one at a time, in between a specific range:

a) investment plus operating and maintenance costs, change of the values from -60% to +60%;

b) energy cost trend, from -6% to +6% applied together to all the energy sources in the years between 2015 to 2023;

c) real interest rate, change of the value from 1% to 6%.

In Section 4, results are presented in terms of $\Delta GC$ and actualised pay-back period for each nZEB investigated in D4.3. Three abscissa axes are shown, one for each economic parameter. The trends intersecting at the initial conditions, i.e.:

a) 0% change of the investment plus operating and maintenance costs;

b) 4% energy trend in the years between 2015 to 2023;

c) 3% real interest rate.

The aim is to determine the range of conditions that makes a package of measures cost-effective (i.e. $\Delta GC$ lower than zero) and sustainable in terms of return of the investments (i.e. $PBP_{act}$ around 5-10 years). Besides that, the analysis aims at investigating the economical boundary conditions that can drive refurbishments towards nZEB target. The sensitivity analysis results are useful at a country level; nevertheless in Section 5 some general consideration are made, as to draw a scenario of the actual economic barriers and drivers in the Southern EU countries.
4. RESULTS

4.1 BULGARIA

4.1.1 STUDENT HOSTEL

Figure 4.1. Bulgarian Student Hostel. Sensitivity analysis on the nZEB1.
Figure 4.2. Bulgarian Student Hostel. Sensitivity analysis on the nZEB2.
Figure 4.3. Bulgarian Student Hostel. Sensitivity analysis on the nZEB3.
Figure 4.4. Bulgarian Student Hostel. Sensitivity analysis on the nZEB4.
4.1.2 SCHOOL BUILDING

Figure 4.5. Bulgarian School Building. Sensitivity analysis on the nZEB1.
Figure 4.6. Bulgarian School Building. Sensitivity analysis on the nZEB2.
Figure 4.7. Bulgarian School Building. Sensitivity analysis on the nZEB3.
Figure 4.8. Bulgarian School Building. Sensitivity analysis on the nZEB4.
4.1.5 OFFICE BUILDING

Figure 4.9. Bulgarian Office Building. Sensitivity analysis on the nZEB1.
Figure 4.10. Bulgarian Office Building. Sensitivity analysis on the nZEB2.
Figure 4.11. Bulgarian Office Building. Sensitivity analysis on the nZEB3.
Figure 4.12. Bulgarian Office Building. Sensitivity analysis on the nZEB4.
4.1.9  HOSPITAL BUILDING

Figure 4.13. Bulgarian Hospital Building. Sensitivity analysis on the nZEB1.
Figure 4.14. Bulgarian Hospital Building. Sensitivity analysis on the nZEB2.
Figure 4.15. Bulgarian Hospital Building. Sensitivity analysis on the nZEB3.
Figure 4.16. Bulgarian Hospital Building. Sensitivity analysis on the nZEB4.
4.2 CROATIA

4.2.1 Office continent

Figures from Figure 4.17 to Figure 4.20 show that two solutions close to cost optimal have negative differential cost with payback period shorter than 15 years, and packages relying on larger investment on heating system are extremely sensitive to changes in all input parameters except interest rate, which proves to be of lesser significance in feasibility of nZEB refurbishment.

Figure 4.17. Croatia Office continent. Sensitivity analysis on the nZEB1.
Figure 4.18. Croatia Office continent. Sensitivity analysis on the nZEB2.
Figure 4.19. Croatia Office continent. Sensitivity analysis on the nZEB3.
Figure 4.20. Croatia Office continent. Sensitivity analysis on the nZEB4.
4.2.2 Office coast

Figures from Figure 4.21 to Figure 4.24 show that sensitivity of solutions which are exceeding costs of current building is very high, and that rise in operating or energy cost brings them out of the feasible range. Options 1 and 2, which rely on upgrade of current building heating and cooling system opposed to complete replacement, and addition of mechanical ventilation with heat recovery have in general payback periods within lifetime of the building, but cost of PV systems in last two proposals isn’t feasible.

![Graph showing sensitivity analysis](image)

**Figure 4.21. Croatia Office coast. Sensitivity analysis on the nZEB1.**
Figure 4.22. Croatia Office coast. Sensitivity analysis on the nZEB2.
Figure 4.23. Croatia Office coast. Sensitivity analysis on the nZEB3.
Figure 4.24. Croatia Office coast. Sensitivity analysis on the nZEB4.
4.2.3 Education continent

Differential global cost for all but the fourth nZEB package are negative, showing that only in extreme case of investment cost increase payback period rises above lifetime of the building.

Figure 4.25. Croatia Education continent. Sensitivity analysis on the nZEB1.
Figure 4.26. Croatia Education continent. Sensitivity analysis on the nZEB2.
Figure 4.27. Croatia Education continent. Sensitivity analysis on the nZEB3.
Figure 4.28. Croatia Education continent. Sensitivity analysis on the nZEB4.
4.2.4 Education coast

Figure 4.29. Croatia Education coast. Sensitivity analysis on the nZEB1.
Figure 4.30. Croatia Education coast. Sensitivity analysis on the nZEB2.
Figure 4.31. Croatia Education coast. Sensitivity analysis on the nZEB3.
Figure 4.32. Croatia Education coast. Sensitivity analysis on the nZEB4.
4.1 FORMER YUGOSLAV REPUBLIC OF MACEDONIA

4.1.1 Education building

From Figure 4.33 to Figure 4.34 point out that the differential global cost is mostly negative even changing the economical parameters considered in the sensitivity analysis. As well, the actualized pay-back periods are lower than the duration of the calculation (i.e. 30 years) in both cases (nZEB1 and nZEB 2). On the actualized payback period, it can be seen that the investment has the most impact.

Figure 4.33. Macedonian Education Building. Sensitivity analysis on the nZEB1.
Considering the above analysis, we can conclude that both of the proposed nZEB packages of measures are cost-effective.
4.1.2 Offices

Figure 4.35 through Figure 4.38 refers to the refurbishment of the reference office building towards nZEB. The sensitivity analysis shows that 2 of the nZEB solutions (nZEB1 and nZEB 3) are cost effective and economically reliable, even though the actualized payback period is higher than expected.

**Figure 4.35. Macedonian Offices. Sensitivity analysis on the nZEB1.**
The nZEB solutions 2 and 4 are not cost effective and economically reliable which can be seen in the graphs in Figure 4.36 and Figure 4.38. The differential global cost is above the “zero mark” and the energy cost and interest rate influence the payback period with negative impact (more than 30 years payback period).

Figure 4.36. Macedonian Offices. Sensitivity analysis on the nZEB2.
Figure 4.37. Macedonian Offices. Sensitivity analysis on the nZEB3.
Figure 4.38. Macedonian Offices. Sensitivity analysis on the nZEB4.
4.1 GREECE

4.1.1 Office

Figures from Figure 4.39 to Figure 4.42 show the differential global cost and the pay-back period for all nZEB solutions regarding the Greek office reference building. All the solutions have insulation on the walls and on the roof and more efficient windows. Except nZEB2, all the others have also external aluminum blinds (fixed or movable). The space heating and cooling consisting of geothermal heat pumps; with exception the nZEB3 which has air to water heat pumps. Finally, PV systems were installed.

The results of the first three nZEB solutions point out that there are cost effective and economically reliable. Moreover, the most cost effective solution (nZEB1), which has the higher reduce of the energy trend, the higher increase of Investment plus Operating & maintenance costs as well as interest rate, has also the highest pay-back period, which however, does not exceed the 20 years.

![Graph showing differential global cost and pay-back period for nZEB solutions.]

Figure 4.39. Greek Office. Sensitivity analysis on the nZEB1.
Figure 4.40. Greek Office. Sensitivity analysis on the nZEB2.
In the last Figure 4.42 the results show that the global cost is positive and only if the Investment plus Operating & maintenance costs decrease at least 20% and interest rate 2%, the solution will be cost effective.
Figure 4.42. Greek Office. Sensitivity analysis on the nZEB4.
4.1.2 School

The following Figures from Figure 4.43 to Figure 4.46 show the results which refer to the Greek School refurbishment towards nZEB.

The refurbishment consists of installing thermal insulation on the external walls and on the roof, replacing windows with more efficient (aluminum thermal break frame and double low-e glazing), replacing the heat boiler with solar geothermal heat pump and adding PV system.

The solutions differ in the specific technical characteristics of the above interventions, which are the thickness of the thermal insulation, the $U_w$ and the $m^2$ of the solar and PV panels.

The results point out that all the solutions are cost effective and the pay-back period is less than 10 years. However, the interest rate in the payback period does not change.

Figure 4.43. Greek School. Sensitivity analysis on the nZEB1.
Figure 4.44. Greek School. Sensitivity analysis on the nZEB2.
Figure 4.45. Greek School. Sensitivity analysis on the nZEB3.
Figure 4.46. Greek School. Sensitivity analysis on the nZEB4.
4.2 HUNGARY

4.2.1 Student hostel

In Figure 4.47 to Figure 4.50 are shown the global cost and payback period of the refurbishment of the Hungarian student hostel. Neither of the analyzed parameters have significant effect on the global cost, but all the parameters have high impact on the payback period. In case of only 20% higher costs, or 20% lower energy costs the refurbishment will not be cost effective.

Figure 4.47. Hungarian Student hostel. Sensitivity analysis on the nZEB1.
Figure 4.48. Hungarian Student hostel. Sensitivity analysis on the nZEB2.
Figure 4.49. Hungarian Student hostel. Sensitivity analysis on the nZEB3.
Figure 4.50. Hungarian Student hostel. Sensitivity analysis on the nZEB4.
4.2.2  Kindergarten

Figure 4.51 - Figure 4.54 show the global cost and payback period of the refurbishment of the Hungarian kindergarten. The energy trend and the interest rate has low effect on the global cost and the payback period. But in case of extremely high costs or extremely low energy prices, the refurbishment can be non-cost effective.

Figure 4.51. Hungarian Kindergarten. Sensitivity analysis on the nZEB1.
Figure 4.52. Hungarian Kindergarten. Sensitivity analysis on the nZEB2.
Figure 4.53. Hungarian Kindergarten. Sensitivity analysis on the nZEB3.
Figure 4.54. Hungarian Kindergarten. Sensitivity analysis on the nZEB4.
4.2.3 Office

Figure 4.55-4.58 show the global cost and payback period of the refurbishment of the Hungarian office building. All the parameters have low effect on the global cost. But in case of higher costs or lower energy prices, the refurbishment can be non-cost effective.

Figure 4.55. Hungarian Office. Sensitivity analysis on the nZEB1.
Figure 4.56. Hungarian Office. Sensitivity analysis on the nZEB2.
Figure 4.57. Hungarian Office. Sensitivity analysis on the nZEB3.
Figure 4.58. Hungarian Office. Sensitivity analysis on the nZEB4.
4.3 ITALY

4.3.1 Social Housing

Figure 4.59 to Figure 4.61 point out that the differential global cost is mostly positive even changing the economical parameters considered in the sensitivity analysis. As well, the actualized pay-back periods are higher than the duration of the calculation (i.e. 30 years). Only nZEB solution No. 3 is cost-effective if the Investment plus Operating and maintenance costs decrease for more than 20% or the interest rate decreases to 1%.

Figure 4.59. Italian Social Housing. Sensitivity analysis on the nZEB1.
Figure 4.60. Italian Social Housing. Sensitivity analysis on the nZEB2.
It is thus possible to conclude that for the present reference building, a refurbishment towards the nearly zero-energy target is not cost-effective, even if D4.3 showed the retrofit measures are still energy saving.

### 4.3.2 School

Figure 4.62 refers to the Italian school refurbishment towards nZEB through the use of the biomass generator associated to mechanical ventilation and thermal insulation of the envelope. Results point out that this solution may be considered cost effective and economically reliable only in case of a deep reduction of the investment costs.
In case of heat pump combined with the use of PV panels in place of the biomass generator, Figure 4.63 and Figure 4.64 point out that the reference solution is already cost effective and economically feasible; nevertheless, a reduction of the Investment plus Operating and maintenance costs allows a deep reduction of the time of the return of the investment.
Figure 4.63. Italian School. Sensitivity analysis on the nZEB2.
4.3.1 Office

The nZEB solutions for the office building are characterized by the use of the heat pump (either combined for H-C-W as in nZEB1 or for H-W in nZEB2 and 3, or for single uses in nZEB4) combined with PV panels, mechanical ventilation and building thermal insulation.

Figure 4.65 to Figure 4.68 show that the nZEB solutions become really competitive when a reduction of at least the 20% of the Investment plus Operating and maintenance costs occur. An increasing of the real interest rate as well as a negative energy trend can reduce the years of returning of the investment, but of no more than 2-3 years.
Figure 4.65. Italian Office. Sensitivity analysis on the nZEB1.
Figure 4.66. Italian Office. Sensitivity analysis on the nZEB2.
Figure 4.67. Italian Office. Sensitivity analysis on the nZEB3.
Figure 4.68. Italian Office. Sensitivity analysis on the nZEB4.
4.4 PORTUGAL

4.4.1 Social Housing

The differential global cost for the social housing are presented in Figure 4.69 and Figure 4.70. It is possible to observe that the differential global cost has good results only in the cases of lower Investment plus Operating&Maintenance Cost Change.

Concerning to the actualized pay-back periods it is shown that for almost all the economical parameters changes, these are superior to 30 years. The exceptions are for the decrease of the Investment plus Operating&Maintenance Costs; for these the actualized pay-back period can be inferior to 30 years, reaching a lower value of 5 years.

![Figure 4.69. Portugal Social Housing. Sensitivity analysis on the nZEB1.](image-url)
For Portuguese Social Housing the conclusions to take are that, taking in concern the study reference building, the refurbishments options presented to achieve the nearly zero-energy target only are cost-effective in the case of lower Investment plus Operating&Maintenance Cost Change and Interest Rate and higher Energy Trends.

4.4.2 Office

The study related to the Office buildings shows that the differential global costs provides good results for the economical parameters changes equal or inferior to 0% in the Investment plus Operating&Maintenance Cost Change, inferior to 3% in Interest rates and inferior to 4% in Energy Trends.

In Figure 4.71 and Figure 4.72 are presented the results obtained for the differential global cost and actualized pay-back period, which is inferior to 30 years in a small range of values, as can be seen in the graphs.
Figure 4.71. Portuguese Office. Sensitivity analysis on the nZEB1.
The conclusion obtained concerning to the Office buildings is that the nZEB solutions are more cost-effective for lower Interest Rates and Investment plus Operating & Maintenance Costs and higher Energy Trends.

Figure 4.72. Portuguese Office. Sensitivity analysis on the nZEB2.
4.5 ROMANIA

4.5.1 Office

The nZEB solutions for the office building are characterized by the use of high efficiency gas fired condensation boiler (nZEB1), connection to primary (transport) district heating network by a local substation (nZEB2), the use of heat pump (nZEB3) or high efficiency biomass boiler (nZEB4), in combination with PV panels, mechanical ventilation, LED lighting system and full building envelope thermal insulation.

From Figure 4.73 to Figure 4.76 show that the nZEB solutions are economically feasible for the duration of the calculation (i.e. 30 years), even if a 20% increase of the Investment plus Operating and maintenance costs occur. An increasing of the real interest rate as well as a negative energy trend can reduce the years of returning of the investment, but no more than 2-3 years.

![Graph showing sensitivity analysis on the nZEB1.](image-url)

Figure 4.73. Romanian Office. Sensitivity analysis on the nZEB1.
Figure 4.74. Romanian Office. Sensitivity analysis on the nZEB2.
Figure 4.75. Romanian Office. Sensitivity analysis on the nZEB3.
4.5.2 School

Figures from Figure 4.77 to Figure 4.80 refer to the Romanian school refurbishment towards nZEB through the use of high efficiency gas fired condensation boiler (nZEB1), connection to primary (transport) district heating network by a local substation (nZEB2), the use of heat pump (nZEB3) or high efficiency biomass boiler (nZEB4), associated to mechanical ventilation with heat recovery, use of PV system, LED lighting and thermal insulation of the building envelope. The packaged solutions are feasible from the point of view of global costs over the calculation period (30 years) and remain competitive even with the increase of the Investment plus Operating and maintenance costs (up to 20% increase).

An increasing of the real interest rate as well as a negative energy trend can reduce the years of returning of the investment, but no more than 2-3 years.
Figure 4.77. Romanian School. Sensitivity analysis on the nZEB1.
Figure 4.78. Romanian School. Sensitivity analysis on the nZEB2.
Figure 4.79. Romanian School. Sensitivity analysis on the nZEB3.
Figure 4.80. Romanian School. Sensitivity analysis on the nZEB4.
4.6 SLOVENIA

4.6.1 Office building

Figures below point out that the differential global cost is changing proportionally with changing the economical parameters considered in the sensitivity analysis. The actualized payback periods in most cases remain the same (10 – 11 years) and are well below 30 years, which is the calculation observation period and an indicator of a cost-effective measure. Only with de- or increased interest rate the differential global cost de- or increase substantially (up to 60 EUR/m² difference comparing to the reference case), comparing with other 2 parameters (less than 20 EUR/m² difference comparing to the reference case).

Figure 4.81. Office building - Sensitivity analysis on the nZEB1
Figure 4.82. Office building - Sensitivity analysis on the nZEB2
From the observed cases in the sensitivity analysis we can deduct for the following cases that we can expect in the future on the energy market:

- **Rise of energy prices**: analysis showed slight impact on payback period of the investment, but not critical; global costs are expected to increase.
- **High/low interest rate**: depending on the current national economy, the interest rate doesn’t have a big impact on payback period, but rather important one on total global cost, which significantly increase at low interest rate and vice versa.
4.6.2 School

Figures below point out that the differential global cost is changing proportionally with changing the economical parameters considered in the sensitivity analysis. The actualized payback periods in most cases remain the same (10 – 12 years for nZEB1 and nZEB2, and between 15 – 20 years for nZEB3) and are well below 30 years, which is the calculation observation period and an indicator of a cost-effective measure. Only with de- or increased interest rate the differential global cost de- or increase substantially (more than 100 EUR/m² difference comparing to the reference case), comparing with other 2 parameters (less than 20 EUR/m² difference comparing to the reference case).

Figure 4.84 School - Sensitivity analysis on the nZEB1
Figure 4.85 School - Sensitivity analysis on the nZEB2
From the observed cases in the sensitivity analysis we can deduct the following cases that we can expect in the future on the energy market:

- **Rise of energy prices**: analysis showed slight impact on payback period of the investment, but not critical; global costs are expected to increase.
- **High/low interest rate**: depending on the current national economy, the interest rate doesn’t have a big impact on payback period, but rather important one on total global cost, which significantly increase at low interest rate and vice versa.

**Figure 4.86 School - Sensitivity analysis on the nZEB3**
4.6.3 Kindergarten

Figures below point out that the differential global cost is changing proportionally with changing the economical parameters considered in the sensitivity analysis. The actualized payback periods in most cases remain the same (12 – 15 years) and are well below 30 years, which is the calculation observation period and an indicator of a cost-effective measure. Only with de- or increased interest rate the differential global cost de- or increase substantially (more than 100 EUR/m² difference comparing to the reference case), comparing with other 2 parameters (less than 20 EUR/m² difference comparing to the reference case).

Figure 4.87 Kindergarten - Sensitivity analysis on the nZEB1
Figure 4.88 Kindergarten - Sensitivity analysis on the nZEB2
From the observed cases in the sensitivity analysis we can deduct for the following cases that we can expect in the future on the energy market:

- **Rise of energy prices**: analysis showed slight impact on payback period of the investment, but not critical; global costs are expected to increase.
- **High/low interest rate**: depending on the current national economy, the interest rate doesn’t have a big impact on payback period, but rather important one on total global cost, which significantly increase at low interest rate and vice versa.

**Figure 4.89 Kindergarten - Sensitivity analysis on the nZEB3**
4.6.4 Health-care facility

Figures below point out that the differential global cost is changing proportionally with changing the economical parameters considered in the sensitivity analysis. The actualized payback periods in most cases remain the same (10 – 15 years) and are well below 30 years, which is the calculation observation period and an indicator of a cost-effective measure. Only with de- or increased interest rate the differential global cost de- or increase substantially (more than 100 EUR/m² difference comparing to the reference case), comparing with other 2 parameters (less than 20 EUR/m² difference comparing to the reference case).

![Graph showing differential global cost and payback period changes](image)

**Figure 4.90 Health-care facility - Sensitivity analysis on the nZEB1**
Figure 4.91 Health-care facility - Sensitivity analysis on the nZEB2
Figure 4.92 Health-care facility - Sensitivity analysis on the nZEB3

From the observed cases in the sensitivity analysis we can deduct for the following cases that we can expect in the future on the energy market:

- **Rise of energy prices**: analysis showed slight impact on payback period of the investment, but not critical; global costs are expected to increase.
- **High/low interest rate**: depending on the current national economy, the interest rate doesn't have a big impact on payback period, but rather important one on total global cost, which significantly increase at low interest rate and vice versa.
4.6.5 Home for elderly people

Figures below point out that the differential global cost is changing proportionally with changing the economical parameters considered in the sensitivity analysis. The actualized payback periods in most cases remain the same (12 – 16 years) and are well below 30 years, which is the calculation observation period and an indicator of a cost-effective measure. Only with de- or increased interest rate the differential global cost de- or increase substantially (up to 50 EUR/m² difference comparing to the reference case), comparing with other 2 parameters (less than 20 EUR/m² difference comparing to the reference case).

Figure 4.93 Home for elderly people - Sensitivity analysis on the nZEB1
Figure 4.94 Home for elderly people - Sensitivity analysis on the nZEB2
Figure 4.95 Home for elderly people - Sensitivity analysis on the nZEB3

From the observed cases in the sensitivity analysis we can deduct for the following cases that we can expect in the future on the energy market:

- **Rise of energy prices**: analysis showed slight impact on payback period of the investment, but not critical; global costs are expected to increase.
- **High/low interest rate**: depending on the current national economy, the interest rate doesn’t have a big impact on payback period, but rather important one on total global cost, which significantly increase at low interest rate and vice versa.
4.7 SPAIN

4.7.1 Office building

Figures from Figure 4.96 to Figure 4.99 show the sensitivity analysis results for the four nZEB office buildings. The nZEB1 is the only cost effective package in the reference scenario, and continues being cost effective for most of the tested scenarios. The other nZEBs are not cost effective in the reference scenario, and becomes cost effective in some scenarios: the nZEB2 is cost effective when the energy cost trend is negative and the operating and maintenance costs are lower; and the nZEB3 and nZEB4 when the operating and maintenance cost are lower. For all the cases, the pay-back is in most of the cases around 30 years.

Figure 4.96. Spanish Office building. Sensitivity analysis on the nZEB1.
Figure 4.97. Spanish Office building. Sensitivity analysis on the nZEB2.
Figure 4.98. Spanish Office building. Sensitivity analysis on the nZEB3.
Figure 4.99. Spanish Office building. Sensitivity analysis on the nZEB4.
4.7.2 Hospital

Figures from Figure 4.100 to Figure 4.103 refers to the Spanish hospital refurbishment towards nZEB. In all the cases the reference scenario is cost effective and continues being cost effective in most of the scenarios analyzed. Some of the scenarios analyzed achieves global cost savings higher than 200€/m$^2$, thanks to the operating and maintenance cost variability. Regarding the payback time, in some scenarios is lower than 5 years, however in some cases increase up to 30 years.

![Graph showing energy trends and cost effects for different scenarios.]

Figure 4.100. Spanish Hospital. Sensitivity analysis on the nZEB1.
Figure 4.101. Spanish Hospital. Sensitivity analysis on the nZEB2.
Figure 4.102. Spanish Hospital. Sensitivity analysis on the nZEB3.
Figure 4.103. Spanish Hospital. Sensitivity analysis on the nZEB4.
4.1 UNITED KINGDOM

4.1.1 Victorian Office

Figures from Figure 4.104 to Figure 4.107 show that the differential global cost remains negative for a fairly wide range of the economic parameters considered. All three parameters have a considerable impact on both differential global cost and actualised payback, although there are differences between the four nZEB packages.

The nZEB1 and nZEB2 packages have a negative differential global cost for a broad range of economic parameters. They only become positive when energy prices fall by 6% or capital investment costs increase by 40%. These trends are mirrored by the payback graphs where periods are typically 5-15 years but rapidly exceed 30 years at the extremes.

The nZEB3 package is more sensitive to variations in these parameters, i.e. the differential global cost becomes positive when energy prices fall by just 2%, capital investment costs increase by 20% and discount rates increase by 4%. Conversely, the differential global cost of the nZEB4 package remains negative for the whole range of economic parameters considered, and payback periods are well below 15 years.
Figure 4.104. UK Victorian Office; Sensitivity analysis for nZEB1.
Figure 4.105. UK Victorian Office; Sensitivity analysis for nZEB 2.
Figure 4.106. UK Victorian Office; Sensitivity analysis for nZEB 3.
The packages of measures for the Victorian Office are cost effective for a broad range of economic parameters and, generally, only become cost ineffective when investment costs increase by much more than 20% and energy prices fall by at least 2%.
5. CONCLUSIONS

The following table summarizes the results of the sensitivity analysis for each country. Each parameter is categorized as:

- **++ very effective**, when a change in it produces a very significant variation in the actualized pay-back period and/or global cost;
- **+ effective**, when a change in it produces a significant variation in the actualized pay-back period and/or global cost;
- **− ineffective**, when a change in it produces little variation in the results.

<table>
<thead>
<tr>
<th>Reference building</th>
<th>Use</th>
<th>ΔGC</th>
<th>PBP_{act}</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>Investment operating maintenance costs</td>
<td>Energy trend</td>
</tr>
<tr>
<td><strong>BULGARIA</strong></td>
<td>Student hostel</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Hospital</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><strong>CROATIA</strong></td>
<td>Office continent</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Office coast</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Educational continent</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Educational coast</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td><strong>FORMER YUGOSLAV REPUBLIC OF MACEDONIA</strong></td>
<td>Office</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>School</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GREECE</strong></td>
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<td>++</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td><strong>HUNGARY</strong></td>
<td>Office</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>Kindergarten</td>
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<td>+</td>
</tr>
<tr>
<td></td>
<td>Student hostel</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>ITALY</strong></td>
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<td>−</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>++</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>+</td>
<td>+</td>
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<tr>
<td><strong>PORTUGAL</strong></td>
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<td>−</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>School</td>
<td>+</td>
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</tbody>
</table>
The cross-country comparison shows that the economic variables that have the greatest impact on the variation in the global cost are the investment and the operating/maintenance cost. These are the costs for the use, application and management of the technologies needed to transform the building into a nearly zero-energy one.

Generally speaking, a decrease in the energy cost reduces the differential global cost; in many cases this reduction allows a retrofit solution to become cost-effective.

In addition, a decrease in the interest rate generally yields a reduction in the differential global cost. The exception to this is when the retrofit running costs for the building are higher than those for the building in its current state: in this instance the differential global cost decreases when the interest rate increases. This situation is almost unique amongst the cases analysed.

In conclusion, in order to effectively promote the refurbishment of the building stock into very energy efficient buildings, it is extremely important to have financial support from municipalities in conjunction with central governments to provide grants, low interest loans, tax breaks and other subsidies. Moreover, smart management contracts for nZEBs are recommended to reduce the impact of the operating and maintenance costs on the global cost.