Chapter 11
Life Cycle Cost Analysis of Energy Efficient Buildings: Theory and Study Case

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Abstract Implementation of energy efficiency and renewable energy in the construction industry has become a main strategy towards a sustainable built environment. One of the pillars of sustainable development, besides the environmental and social aspects, is the economic efficiency. Therefore, economic efficiency throughout the life cycle should be addressed as well when designing highly energy efficient buildings. Buildings are long term investments, which assume that the initial decision on the quality of the investment has long term consequences. The purpose of this chapter is to present the method of life cycle cost (LCC) analysis from the various perspectives existing in the literature and standards. LCC of evaluation is extremely important towards the promotion of energy efficiency measures in front of investors, building owners and authorities. Therefore, it is necessary for architects and engineers to have the basics for applying the LCC analysis and to include it in the design phase of a building.

11.1 Introduction

The attention towards energy efficiency is becoming increasingly present in all fields of activity, as it is an essential action in the climate change mitigation process. Reducing the energy consumption from fossil fuels and use of a higher share of energy from renewable sources are necessary steps in order to cope with the global energy challenge and climate change consequences. According to the International Energy Outlook 2016 (U.S. Energy Information Administration (EIA), between 2012 and 2040 there will be a 48% increase in the worldwide energy need [22]. A major part of this growth is assigned to the Asian non-OECD countries (outside the Organization for Economic Cooperation and Development) where the strong economic

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development and increase of population is assumed to lead to a 45% increase of the energy need by 2040 compared to 2012 [22]. With this prevision ahead, solutions of decoupling the economic growth and development from the energy requirements should be implemented. The high worldwide energy consumption from fossil fuels and also the previsions of future growth of energy need implies the increase of environmental pollution through the greenhouse gas emissions. The climate change phenomena is a consequence of human activities that generate greenhouse gas emissions (burning fossil fuels, emissions from the transport sector etc.), which due to their high concentration lead to heat-trapping in the atmosphere and increase of the global temperature. According to the Intergovernmental Panel on Climate Change's Third Assessment Report [9], over the course of the twentieth century the global average surface temperature increased by nearly 0.6 °C and the concentration of CO_2 in the atmosphere increased by about 80% between 1970 and 2004. During the 21st Conference of Parties in Paris, on 12 December 2015, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) established a new agreement to avoid and combat climate change and also to improve the steps required for a safe and clean natural environment. Under the Paris Agreement, UNFCCC Parties seek to reduce the rise in global average temperature well below 2 °C above pre-industrial rates with a view to reducing the adverse effects of climate change. The Paris Agreement entered into force on 4 November 2016 and requires to all Parties to enhance their efforts in achieving the goals of the agreement. Governments have agreed to submit their contributions every five years in order to establish future objectives. The European Union agreed to continue providing funding for climate change to support developing countries to reduce emissions and strengthen their resilience to climate change. In addition to the well-known targets set through the Climate and Energy Package 2020 adopted in 2007, the European Commission presented a long-term policy plan as a climate action for the European Union. The goals for 2050 are to reduce GHG emissions by 80–95% relative to 1990 rates [2]. In 2014, an intermediate climate and energy policy framework for the period from 2020 to 2030 was released [4]. This brings new perspectives as to reduce greenhouse gas emissions by 40%, to increase the share of renewable energy production by more than 27% and to increase energy efficiency by 27%. According to the data from Eurostat, the evolution of the final energy consumption by sector in the European Union between 1990 and 2015 shows an increase of the consumption in the residential-tertiary sector and transport and a decrease in the industry and agriculture sectors [20]. The continuous development of transport infrastructure and transport in recent years led to a significant increase of energy consumption in this sector (from 26.24% in 1990 to 33.14% in 2015). Significant as well is the decrease of energy consumption in the industry sector. In 2015, the energy consumption in the building sector represented 39% of the total energy consumption in the European Union, registering an increase of almost 4% compared to 1990. The significant share of energy consumption of the building sector from the total energy consumption makes it responsible for 36% of CO_2 emission in the European Union. Thus, a high potential of reducing the energy consumption from fossil fuels lies in the building sector and therefore is a key player in achieving the long-term objectives of the European Union to reduce the greenhouse gas emissions up to 80–95% by 2050, compared to 1990 levels [5].

Buildings are long term investments, considering that the majority of buildings are designed to have a lifetime of 50 years. Moreover, the majority of the existing buildings are inefficient from energetic perspectives and they will most certainly be standing by 2050. Therefore, it is essential to improve the energy efficiency of the existing buildings through renovations but also to construct new buildings that are highly energy efficient. Throughout time, standards that set minimum energy efficiency requirements for buildings were developed at national level of countries in the European Union. Also, there are various international standards of energy efficient buildings such as the passive house standard, which provides energy efficiency criteria in terms of heating energy demand and primary energy consumption but also detailed guidelines on how to achieve the criteria. Regardless of the type of energy efficient building, there are several aspects that must be considered when designing such a type of building. These aspects are related to both building envelope and building systems and include: thermal insulation, advantageous orientation, thermal bridges reduction, envelope airtightness, mechanical ventilation with heat recovery, efficient windows glazing and frames, use of ground-sourced heat exchanger. An energy efficient building can be provided as well with equipment that uses renewable energy or technologies to produce energy on site such as photovoltaic panels. All these energy efficiency measures must be assessed from an economic point of view in order to balance the initial investment with the annual costs on the life cycle of the building. There are situations when a good thermal insulation can assure a maximum efficiency of an investment but if exceeded it can also lead to economic inefficiency. Therefore, it is important to corelate the energy efficiency measures in order to obtain a cost-optimal investment. Marszal and Heiselberg [12] concluded in their study that it is cost-effective to first reduce the energy need to a minimum, and afterwards implement renewable energy technologies to compensate the remaining energy demand. In order to support and increase the energy performance of buildings, the EU has provided a legislative framework, including the recast on the Energy Performance of Buildings Directive EPBD [6], through which Member States are mandated to establish specific plans to implement nearly zero-energy buildings and improve the energy efficiency by using cost-optimal solutions. According to Article 2 of the EPBD recast [6], a nearly zero-energy building is a very high-performance building, where the nearly zero or very low energy requirements should be met to a very significant extent by renewable energy sources, including on-site or local renewable energy sources. At the time when the EPBD recast was launched, each Member State was required to detail a nearly zero-energy building definition by considering their specific conditions and national context. In Romania, a more specific definition was provided in the past years, stating the energy need of a nearly zero energy building must be covered with at least 10% renewable energy produced on site or nearby, while the maximum admissible primary energy consumption depends on the building category and climate zones in Romania. The energy performance of nearly zero-energy buildings must be linked to the economic aspects in order to identify the solutions that have the lowest global cost on the economic life cycle. Thus, the “cost optimal" or "cost-effective" notions have to be considered when developing nearly zero-energy buildings. The cost-optimal level is defined as the level of energy efficiency that leads to the lowest cost during the projected economic lifecycle, where the lowest cost is calculated taking into account energy-related investment costs, maintenance and operating costs, disposal costs and energy-generated earnings [6].

The general approach when it comes to the energy need and consumption of a building is divided in two main aspects:

- building thermal envelope characteristics, which is ultimately translated into energy demand for heating and cooling
- building heating, cooling, ventilation and domestic hot water systems features.

The above-mentioned elements, which ultimately define the energy efficiency of the building, must be balanced so that the initial investment cost is minimum. As it is required through EPBD, the energy performance of buildings must be connected to the economic aspects with the purpose of identifying cost optimal solutions. Nowadays there are a multitude of possible solutions in terms of energy efficiency, for both building envelope and building systems. Therefore, it is important to investigate various scenarios of energy performance and costs, in order to choose the solutions that brings the best benefits in terms of energy savings but is also cost-effective.

This chapter presents the life cycle cost analysis of an existing residential building in three variants of energy efficiency. The case study house was designed and constructed following the passive house design guidelines. This study introduces an upgrade of the existing building by proposing the implementation of photovoltaic panels to cover the electricity demand of the building, thus achieving the nearly zero energy building standard. The two scenarios will be compared with the reference building in Romania, composed according to the minimum energy efficiency criteria that are currently mandatory in Romania and are regulated through the Methodology for Calculating the Energy Performance of Buildings Mc 001/2006, updated in 2017 [17].

11.2 Background

The construction of a building is a long-term investment and therefore the quality and efficiency of the chosen solution has long term consequences. Unfortunately, most of the times, the clients and investors are looking only at the initial costs of a building and not consider the future costs for energy and maintenance. Therefore, very often investors lack the overall approach which leads to the selection of an economically inefficient solution throughout a building's life cycle. Life cycle cost analysis (LCCA) is a good method for evaluating and comparing several building designs options from the perspective of initial cost and future costs [15]. This type of economic assessment can generally be used for predicting and evaluating the cost performance of constructed assets [10] and is extremely useful for comparative cost assessments over a specified period of time. In other words, LCCA provides information about the economic performance of a building throughout its life span. This analysis can be performed for new building in the design phase but also for existing buildings when renovation solutions are needed. The concept of life cycle cost started being used in the construction sector back in 1970s for public investments. Throughout time, there has been a great interest in researching and developing the field of life cycle cost analyses in all parts of the world and the methods include calculating and analysing the present value of all costs that occurs throughout the life cycle of a building. There are a variety of works that use the LCCA of buildings, being frequently used in combination with energy analysis of a building. Furthermore, LCCA is considered a decision-making factor in the building sector projects [7]. Moreover, recent research shows a growing interest towards the integration of economic and environmental analysis by joining the LCCA with life cycle assessment [8]. Badea et al. [1] created a mathematical model to analyse the life-cycle cost of a passive house in 14 different energy efficiency configurations and concluded that it is easier to make a decision for a possible investment by using LCCA classifications. Moran et al. [13] applied the life cycle cost and environmental analysis to assess a number of case study buildings that use various heat sources. Another study applied the life cycle analysis to promote the implementation of maintenance plans as a way of reducing global costs and increasing the life of materials [16]. LCCA was applied to investigate the implementation of a hybrid energy system for a typical residential building [14].

11.3 Life Cycle Cost Analysis Methodology

According to the literature review, a general mathematical model of life-cycle is based on the fact that every category of cost is updated at the present value, considering the discount rates. The life-cycle cost calculations were performed following the mathematical model for global cost calculation presented in EN 15459:2006 [21], which is a standard for economic evaluation procedure for energy systems in buildings. This procedure is based on calculating the global cost, considering the initial investment, the present value of annual costs on the period of analysis and the final value the building and all its components at the end of the analysis period. Following the Delegated Regulation No.244/2012 [3], the global cost calculation must include following cost categories:

- Initial investment cost CI;
- Yearly costs Ca (energy costs, operational costs, maintenance costs, replacement costs);
- Disposal costs (if applicable);
- Costs related to the greenhouse gas emissions (only for macroeconomic calculations).

In other words, the global cost is the sum of all the above-mentioned categories of costs, all updated to present value. The net present value of the future costs depends on the discount rate, price growth rate and period of analysis, which are extremely important factors in the equation. Based on EN 15459:2006 [21], the mathematical model for global cost calculation is presented in Eq. 11.1:

$$\boldsymbol{CC} = \boldsymbol{C_g(\tau)} = \boldsymbol{C_I} + \sum_{j}[\sum_{t=1}^{T}(\boldsymbol{C_{a,i}(j)} \times \boldsymbol{R_d(i)}) - \boldsymbol{V_{f,\tau}(j)}] \quad (1)$$

τ—calculation period.

$C_g(\tau)$—global cost on the considered calculation period (referred to starting year τ_0).

CI—initial investment cost.

$C_{a,i}(j)$—annual cost during year i for measure or set of measures j.

$R_d(i)$—discount factor for year i based on discount rate r.

$V_{f,\tau}(j)$—residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0).

Using the discount factor, calculated based on the discount rate, the present value of future costs is determined. The discount rate does not only weigh money time value, but also potential cash flows ‘ risk and unpredictability. The discount rate depends on several factors including: interest rate, profit rate, the rate of increase of the national income and can be assimilated to them [20]. In global cost calculations, a real discount rate must be used, which means that the inflation is not considered. The discount factor is calculated using the Eq. 11.2.

$$R_d(p) = \left(\frac{1}{1 + \frac{r}{100}}\right)^p \quad (2)$$

where:

r—real discount rate [%].

p—number of years passed from the starting year of the analysis.

The calculation period is defined as the time period in years for which the global cost calculation is performed. The decision on the period of analysis takes into account the technical lifetime of the building and building components. The calculation period can be the lifetime of the building defined in the design phase, which is usually 50 years for most of the buildings. The calculation period may also be defined as the period of time after a series of major renovations and overall improvements have been made to the building. Major renewal cycles vary from one building to another, but almost never below 20 years. When calculating global costs, future price growth must also be considered in real terms (excluding inflation) by using price growth rates when calculating the annual costs. The future price growth rate is very important, especially in studies that include costs of energy, which frequently changes over time. At the end of the analysis period, the residual value of the building components must be calculated considering the remaining lifetime. Based on EN 15459:2006 [21], the residual value of building components is calculated following the mathematical formula in Eq. 11.3:

$$V_{f,\tau}(j) = V_0(j) \times \left(1 + R_p\right)^{n \times \tau_n(j)} \times \left(\frac{(n+1)\tau_n(j) - \tau}{\tau_n(j)}\right) \times \frac{1}{(1 + {}^{r}/_{100})^{\tau}} \quad (3)$$

where:

$V_{f,\tau}(j)$	final value of component j
$V_0(j) \bullet \left(1 + R_p\right)^{n \bullet \tau_n(j)}$	price of component j considering the evolution of products costs;
$\left(\frac{(n+1) \bullet \tau_n(j) - \tau}{\tau_n(j)}\right)$	straight-line depreciation;
$(1 + \frac{r}{100})^{\tau}$	discount factor value at the end of the calculation period.
n	number of replacements during the calculation period
$\tau_n(j)$	lifespan for building component j.

11.4 Case Study: Comparative Life Cycle Cost Analysis of a Residential Building

11.4.1 Description of the Energy Efficiency Scenarios

The case study building was built in 2011 near Timisoara, being part of a research project developed by Politehnica University Timisoara, entitled “Passive house and Nearly Zero Energy Buildings—sustainable solutions for residential buildings”. The first phase of the mentioned project aimed to build a house based on design principles specific to passive houses and using traditional materials and technologies that are specific to residential constructions in Romania. The investigated building has two floors with a rectangular horizontal plan and prismatic volume. The structural system consists in concrete foundation blocks connected by foundation beams, structural masonry walls with reinforced concrete columns and belts and wooden beams floor. Table 11.1 summarizes the geometric parameters of the building which is characterised by compactness and south orientation of large windowed façade, as it is specific to passive houses.

For this study, three configurations of the case study building were investigated, namely:

- As built house and technical systems—PH
- As built house and technical systems with a 4.8 kW power grid connected photovoltaic panels system—NZEB
- Reference building—RB

Table 11.1 Geometry data for the case study building

Indicator	Value	Indicator	Value
Treated floor area [m^2]	141.8	Exterior walls [m^2]	158.6
Envelope area [m^2]	393.9	Ground floor [m^2]	86.7
South windows area [m^2]	16.5	Roof terrace [m^2]	96.6
East windows [m^2]	12.7	Cantilevered floor [m^2]	6.8
West windows [m^2]	9.7	Interior volume [m^3]	354

Table 11.2 Energy related characteristics of the investigated configurations of the case study building

		PH and NZEB[a]	RB
Thermal insulation	Exterior walls	30 cm polystyrene	8 cm polystyrene
	Ground floor	40 cm polystyrene	20 cm polystyrene
	Roof	42 cm polystyrene	20 cm polystyrene
	Cantilevered floor	50 cm polystyrene and mineral wool	20 cm polystyrene
	Windows	triple glazing windows	double glazing windows
	Technical systems	Air—water heat pump—rated heating capacity 5.2 kW Fan coils installed in the ceiling Air—water heat pump with reversible cycle solar panel 4.92 m^2 Domestic hot water boiler—0.15 m^3 Mechanical ventilation with heat recovery Soil-air heat exchanger for preheating/precooling the fresh air	Condensing gas boiler for space heating and radiators for heat distribution Gas boiler for domestic hot water Multi split cooling

[a]NZEB also has 20 polycrystalline PV panels with a 14.74% module efficiency and 240 W power inverter 5 kW nominal power

The reference building has the same geometrical characteristics, volume and envelope elements areas as the real building, but complies with the minimum requirements required by Romanian legislation in terms of energy efficiency. NZEB is a package that intends to be an upgrade of PH through the implementation of on-site renewable energy production technologies. A more detailed description of the energy efficiency packages is presented in previous papers and reports (Tanasa, [20]. The characteristics of each scenario are presented in Table 11.2, where thermal insulation thickness, technical systems and renewable energy technologies are listed.

11.5 Energy Consumption Evaluation

11.5.1 Energy Models

The energy consumption evaluations of the energy efficiency packages earlier presented was performed using the dynamic building simulation software EnergyPlus. The construction of the models started from the already existing building energy model of the real building by modifying the features to match each of the energy efficiency packages. The simulations were conducted using the typical year weather data file for Timisoara from International Weather for Energy Calculations (IWEC), available on EnergyPlus software web page in section Weather. The heating systems were scheduled to be available from the 15th of October until the 15th of April and the cooling system availability was set between 15th May and 15th September. The heating temperature setpoint was set to 20 °C while the cooling set point to 26 °C. The building was considered to be occupied by a family of three persons. The occupancy schedule was defined for weekdays and weekends, as fraction from the total number of occupants. Thus, a typical occupancy schedule was defined for weekday and weekend. During weekdays, between 23:00 and 07:00, the bedrooms are considered fully occupied, while the living room and kitchen were occupied by two persons between 09:00 and 18:00 and fully occupied between 18:00 and 22:00. The outdoor air flow rate for the mechanical ventilation was set to 0.4 air changes per hour for NZEB and PH, while natural ventilation was considered for RB with fresh air rate of 0.6 h^{-1} [20]. Besides heat gains related to occupancy, a part of the energy consumed by the interior electrical equipment and interior lighting in the building also becomes a heat gain and influences the building energy balance. The internal loads associated to interior lighting and electrical equipment were considered through hourly electricity consumption schedules defined as fraction of lighting and interior equipment power [20].

11.5.2 Simulation Results

Table 11.3 presents the end use energy for each building scenarios and the amount of energy produced. In order to better compare the end use energy of the proposed energy efficiency packages with the energy use of the reference building, the total energy consumption was also converted to primary energy from non-renewable sources.

As it can be seen in Table 11.3, the energy consumption for lighting and interior equipment is constant for all scenarios because no energy efficiency measures were considered for these two ends uses. Differences can be seen with respect to energy consumption for heating, cooling and domestic hot water, which are much lower for PH and NZEB compared to RB.

The conversion to primary energy was made considering the Romanian conversion factors for each type of energy: 1.17 for natural gas and 2.62 for electricity [17]. For

Table 11.3 Energy consumption and primary energy from non-renewable sources

		PH	NZEB	RB
Heating	Electricity [kWh/m^2]	13	13	0
	Natural gas [kWh/m^2]	0	0	95.7
Cooling electricity [kWh/m^2]		2.9	2.9	5.6
Lighting electricity [kWh/m^2]		1.1	1.1	1.1
Household appliances [kWh/m^2]		9.5	9.5	9.5
Pumps electricity [kWh/m^2]		5.7	5.7	6.6
Fans electricity [kWh/m^2]		5.8	5.8	None
Domestic hot water electricity	Electricity [kWh/m^2]	4.5	4.5	0
	Natural gas [kWh/m^2]	0	0	19.6
On site electricity—PV production [kWh/m^2]	None	None	43.2	None
Total energy consumption	Electricity [kWh/m^2]	42.5	42.5	22.8
	Natural gas [kWh/m^2]	0	0	115.3
Primary energy from non-renewable sources [kWh/m^2]		111	– 2	194.5

NZEB, the primary energy from non-renewable sources is calculated as the difference between the primary energy corresponding to the energy imported from the grid and the primary energy corresponding to the energy exported to the grid [11]. According with the current Romanian requirements for residential nearly zero-energy buildings, the primary energy consumption is 111 kWh/m^2 for the climate zone II, where the building is located [18]. Thus, both PH and NZEB are in line with this prescription. Moreover, NZEB configuration leads to a negative value for primary energy, because the electricity production from PV panels is higher than the energy consumption.

11.6 Life-Cycle Cost Calculation

11.6.1 Initial Investment Assessment

The PH building's initial investment was calculated using the specific costs of building construction and equipment, given by the building owner. All taxes and VAT are included in the value. The costs were split into: structural system construction, thermal insulation, windows, technical systems (heating and cooling equipment, ventilation, hot water, heating terminals etc.). These costs have then been adjusted to suit each of the other two scenarios, NZEB and RB. For NZEB, the initial investment is the same as for PH, having only the PV system extra. The costs of building construction and structural system are the same for all three configurations. The initial investment costs are presented in the graph in Fig. 11.1. The highest invest-

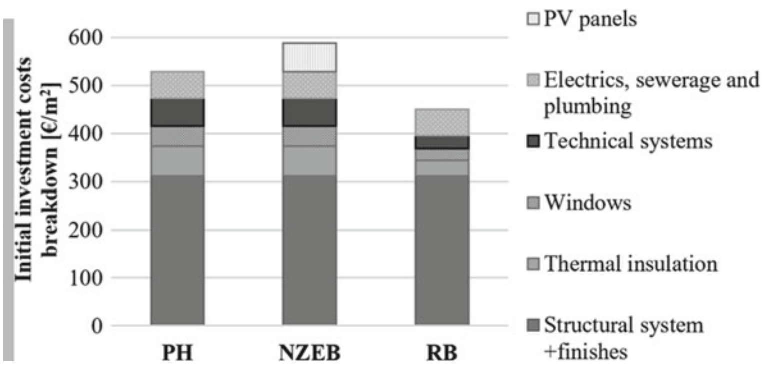

Fig. 11.1 Initial investment costs breakdown

ment costs are for NZEB, which corresponds to real building envelope and technical systems with extra investment for 20 photovoltaic panels. The initial investment of NZEB is approximately 11% higher than the initial investment of PH, due to the implementation of PV panels. Obviously, the lowest investment cost is the one of the reference building, which is 15% lower than PH and 23% lower than NZEB. We can see how the initial investment for structural system and finishes remains constant among the building packages. The costs of technical system of the reference building is the lowest and also the costs of thermal insulation and windows.

11.6.2 Periods of Analysis, Discount Rate and Price Growth Rate

The calculation period was selected following estimated service life of the house, which is 50 years. The discount rate is used in the calculation of the global cost to determine the present value of the amounts of money paid (earned) in the future. The discount rate does not only consider the value of money over time, but also the risk or unpredictability of future cash flows. A discount rate of 3% was used, as it is the same rate used by the Romanian authorities in global cost and cost optimal calculations [19]. The future growth of energy prices has a significant influence on the balance of the costs, especially in case of energy efficiency buildings. In this study, an average price growth rate of 5% was used for the electricity and natural gas prices [20].

11.6.3 Annual Costs, Replacement Costs and Residual Value

Annual costs include the following categories: maintenance costs, replacement costs and energy costs. The replacement costs depend on the lifespans of the different building systems components, which were established using Annex A of EN 15459:2006 [21]. For each component that has a lifespan shorter than the calculation period, a replacement cost is considered in the year of the replacement. The replacement cost is actualized at present value using the discount rates.

The maintenance costs include those cost necessary for the quality conservation of the building systems in time. The costs refer to inspection costs, adjustments, repairs and preventive maintenance. Thus, the global cost is calculated considering that the equipment and building systems are properly maintained and periodically inspected. The maintenance costs were established in compliance to EN 15459:2006 [21], which offers data related to maintenance costs for different types of building components, expressed as percentage of the initial investment of each component. Table 11.4 lists the annual maintenance cost and number of replacements for different building components of the investigated building scenarios. The residual value for each building component was calculated at the end of the analysis period, using

Table 11.4 Lifespan and data for maintenance costs and replacement costs calculation

Component	Life span [years]	Annual maintenance cost in % of the initial investment	Number of replacements
Thermal insulations	50	–	0
Structural system	50	–	0
Windows	30	–	1
Condensing boiler	20	1–2	2
Fan coils	15	4	3
Expansion vessels	30	1	1
Ventilation fans	15	6	4
Heat pumps	20	2–4	2
Heat recovery units	20	4	2
Circulation pumps	20	2	2
Radiators, water	30	1–2	1
Tank storage for hot water	20	1	2
Wiring	30	1	1
Solar collector	25	0.5	1
Piping system	30	0.5	1
Photovoltaics	25	1	1
Split air conditioning	20	4	2

Table 11.5 Annual costs used for life cycle cost calculation

		PH	NZEB	RB
Annual costs	maintenance costs [€]	164	201	150
	energy costs [€]	717	301	1360

Eq. 11.3, and was subtracted from the global cost. The energy costs were calculated using the prices for natural gas and electricity in Romania. In this paper are considered prices of fossil fuels (natural gas) of 0.06 Euro/kWh and also the price for electricity from the National Grid of 0.13 Euro/kWh. In the energy costs calculation, the benefits from electricity exported to the grid were accounted. It was assumed that the electricity exported in the grid is sold with a price of 0.048 €/kWh. In Table 11.5 are listed the annual maintenance and energy costs for the three situations.

11.6.4 Life-Cycle Cost Results

In Fig. 11.2 are presented the results of the global cost calculations on costs categories. As expected, the highest global is the one of the reference building due to the high energy. Maintenance costs have the lowest values from the considered cost categories, followed by cost of replacement and cost of energy. The energy costs decrease proportionally with the energy consumption. Therefore, the lowest energy costs throughout the life cycle correspond to NZEB followed by PH. The global cost of RB is approximately 26% higher than the one corresponding to PH and 47% higher than NZEB. By comparing PH with NZEB, it can be observed that PH has a higher global cost with approximately 16%. Residual values are insignificant for all three configurations as the calculation was performed for a period of 50 years which is also the service life of the house. In Fig. 11.3 is presented the life-cycle cost variation throughout the calculation period. In this graph is noticeable how the high

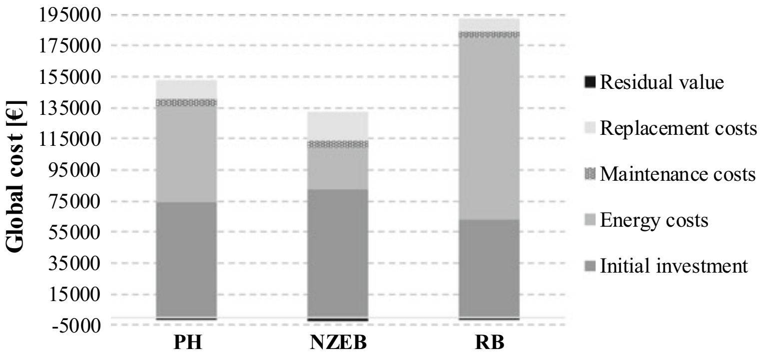

Fig. 11.2 Life-cycle costs breakdown

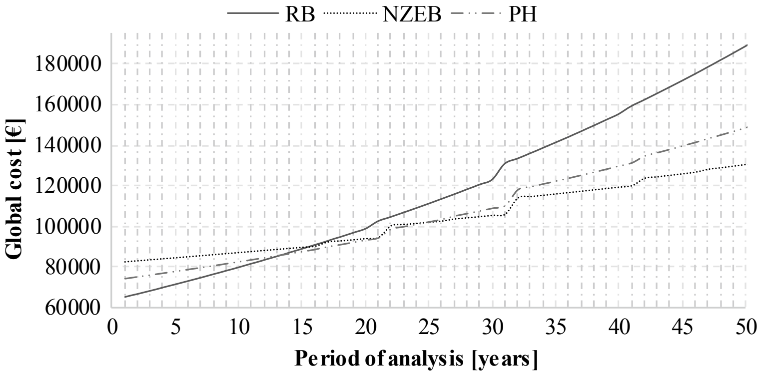

Fig. 11.3 Life-cycle cost variation

annual costs of the RB lead to overcome the global cost of NZEB and PH, despite the lower initial investment. It can be observed that after approximately 14 years, the global cost of RB overcomes the global cost of PH. The global cost of NZEB is exceeded by that of RB after about 16 years. If PH and NZEB life cycle cost variations are compared, it is noticeable that they maintain close values for most of the analysis period. The global cost of PH house slightly increases over NZEB after 23 years.

11.7 Sensitivity Analyses

A sensitivity analysis was performed order to determine the influence that the variables used in the calculation have on the final result. The purpose of this analysis is to assess the output data that are obtained after varying precise input variables such as discount rate and period of analysis. The sensitivity analyses improve the decision-making process because it allows the evaluation of the robustness of the results. The first step in the sensitivity analysis is to define the input variables that could most affect the final result of the evaluation. In this study, the variables considered for sensitivity analyses are the discount rate and the period of analysis. The following variations are proposed:

a. Discount rate:

   – Base case scenario: 3%
   – Scenario 1: 0.5%
   – Scenario 2: 1%
   – Scenario 3: 2%
   – Scenario 4: 4%
   – Scenario 5: 4%

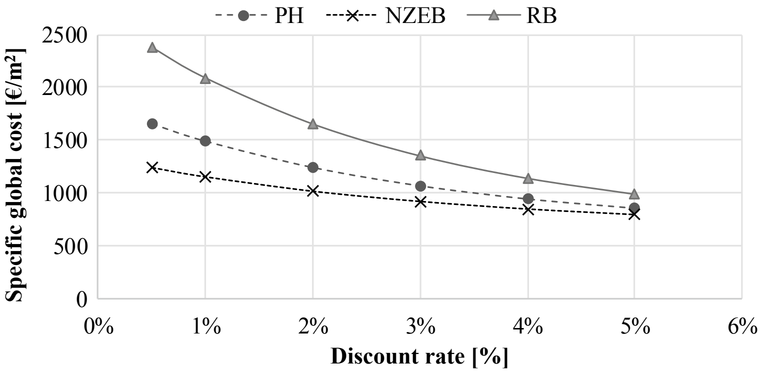

Fig. 11.4 Life-cycle cost change with respect to discount rate variation

b. Period of analysis

- Base case scenario: 50 years
- Scenario 1: 10 years
- Scenario 2: 20 years
- Scenario 3: 30 years
- Scenario 4: 40 years.

In Fig. 11.4 it can be observed how the global cost changes with the variation of the discount rate. By increasing the discount rate, the net present value of the future costs decreases, and thus they comprise a smaller part of the life cycle cost. Applying a 5% discount rate the global cost decreases for all three building scenarios. By still analyzing the results obtained, it is easily intuitive how the variation of the discount rate influences the global costs. The global costs are higher with a lower discount rate and vice versa, global costs are lower by using a higher discount rate. This can be simply deducted from the formula for calculating the global cost (Eq. 11.1), where it is noticeable that the two values are inversely proportional. Therefore, as the discount rate increases, the global cost values will tend to decrease and vice versa. Nevertheless, it can be affirmed that the results of the global cost calculations are robust with respect to the variation of the discount rate. The NZEB scenario remains the option with the lowest global cost over a wide range of discount rates. However, as the discount rate increases, NZEB global cost is almost approaching PH and RB global costs. In other words, a lower discount rate reflects better the benefits that energy efficiency investments bring over the life-cycle. Reversely, a higher discount rate minimizes the benefits of lower annual costs associated to energy efficient buildings, encouraging a purely commercial approach to the valuation of investment.

The second sensitivity analysis has been made by changing the calculation period in order to evaluate how a shorter or a longer investment time perspective influences the final results. Figure 11.5 shows the changes in global costs with respect to the variation of the period of analysis.

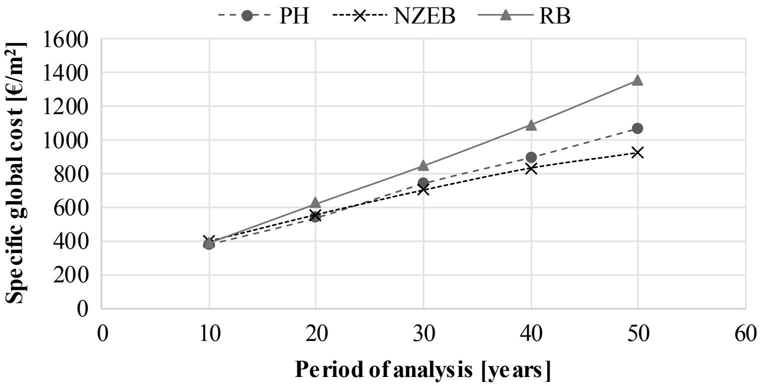

Fig. 11.5 Life-cycle cost change with respect to period of analysis variation

As expected, a shorter calculation period results in lower global costs, while a longer period of analysis of results in higher global costs due to the annual costs required for the operation and maintenance of the building. It is underlined that the gap between the global costs positions among the investigated scenarios increases along with the increase of the analysis period. For the 10 years period of analysis, the difference between the three scenarios is very small and the lowest global cost corresponds to PH, while the highest corresponds to NZEB. In case of 20 years global cost, PH still remain the most cost-effective, while RB global cost is the highest. The highest gap between RB and the energy efficient building packages is noticeable for the analysis performed on a period of 50 years. Intuitively, the longer the period of analysis, the more obvious the disadvantage of RB.

11.8 Conclusion

This chapter presents the life cycle cost analysis in terms of global cost for a residential building in three configurations: passive house (PH), nearly zero-energy building (NZEB) and reference building (RB). The main goal of this study was to assess the long-term advantages of highly energy efficient measures in buildings (PH and NZEB) in comparison to minimum energy efficiency requirements for residential buildings in Romania (RB). The study concluded that the higher initial investment of PH and NZEB can be recovered in approximately 14 years, respectively 16 years when compared to RB, for a discount rate of 3% and energy price growth rate of 5%. The extra investment in photovoltaic panels for NZEB becomes cost-effective after approximately 23 years. It can be concluded that with the current high prices of PV technology and low price of the electricity delivered to the grid, investing in PV panels, besides the other efficiency measures of PH, might not seem such an economically attractive solution due to the high break-even time. The design and construction of buildings with high energy performance, in addition to the energy renovation of existing ones, represents an important step towards decarbonizing the built environment and achieving the EU targets for reducing greenhouse gas emissions. As this study has shown, energy efficient buildings proved to be cost-effective on the long-term perspective. Also, the sensitivity analysis has shown that for buildings that have a lower energy consumption, the discount rate variation does not result in as great changes in global cost as for the reference building (RB). It can be concluded that buildings with high energy performance are not so vulnerable to the changes that financial market might encounter throughout the life-cycle.

11.9 Future Research Directions

This research follows a topic that is of great interest at an international level, among researchers, national authorities but also for the construction market and building owners. Therefore, research activities have still a long run to go in order to ensure an energy efficient built environment, which is cost-effective at the same time. The analyses are based on a series of specific parameters and assumptions such as the location of the building and corresponding outdoor weather conditions, economic indicators, user behavior and energy efficiency measures. The climatic parameters represent essential values in order to evaluate the energy performance of a building. Therefore, it is relevant to extend this study for the other climate zones in Romania. User behavior is as well an important factor in the equation of energy consumption of a building and the associated energy costs. Thus, a future research direction is to perform energy consumption analyses for different user behavior scenarios, to see just how much the way the building is operated can modify the yearly costs on energy. Moreover, life cycle cost analyses for different user behavior scenarios can show how user comportment can influence the energy and economic performance of a building throughout its life span.

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