Abstract: - Implementation of energy efficiency measures and technologies for renewable energy production in the building sector has become a key strategy in reducing the depletion of global resources and environmental pollution. Therefore, the current preoccupation of most engineers and architects concerns low energy buildings and moreover the use of renewable energy technologies. Yet, the costs for procuring and installing renewable energy technologies are quite high in the Romanian market, making it harder for the building owners to decide whether to invest in such systems of energy. This paper presents the life cycle cost analysis of two energy efficient houses located in Timisoara, Romania. The purpose is to assess how cost-effective is to invest a system of photovoltaic panels in a house that already has a very low energy demand. Therefore, a study on the life cycle costs will be performed, comparing the results for the house equipped with the system of photovoltaic panels with the results for the same house without the system. This study is relevant taking into consideration the high costs of such an investment but also the uncertainty regarding the future energy prices.

Key-Words: - life cycle cost, nearly zero energy building, passive house, monitoring, renewable energy.

1 Introduction
Energy consumption in the building sector represents a major source of environmental impact and the awareness of the need to reduce this impact has significantly increased lately. In the European Union buildings are held responsible for 40% of the total energy consumption [1]. In the current situation of natural resources depletion and also high level of pollution due to the use of fossil fuels, the reduction of energy consumption became a requirement at a global level. According to Sartori [2], in the operating phase, conventional buildings account for about 90-95% of the total energy consumption throughout their entire lifecycle, the rest represents the embodied energy in the materials and production. The energy demand of buildings can be limited by reducing its operating energy significantly through use of passive and active technologies even if this conducts to a slight increase of the embodied energy. In Romania, the national regulations for minimum building performance standards are relatively weak comparatively with the restrictions in other parts of Europe. The European Union published the Energy Performance of Buildings Directive (EPBD) as a common legislation related to the energy performance of buildings for the European member states and aims to promote improvements in the energy efficiency of a building. The recast on the EPBD introduced in Article 9 the concept of nearly zero energy building as a future requirement to be applied to all new buildings [1]. The EPBD defines the nearly zero energy building as “a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” [1]. Nevertheless, the recast on EPBD does not establish a uniform methodology in order to implement this type of buildings causing each individual Member State to develop its own definitions complying with their national particularities. However, throughout Europe there are many other concepts of energy efficient buildings such as passive house, active house or zero energy building. Broadly, all these concepts imply a certain level of energy efficient measures for the building envelope combined with renewable energy technologies. Thus, the challenge is to find the balance between energy efficiency measures and implementation of renewable energy. In the case study by Marszal and Heiselberg [3], on a multi-story residential net zero energy building, the authors concluded that it is crucial to reduce first the energy use to a minimum, and afterwards implement renewable energy technologies to compensate the remaining energy demand.
However, regardless of the level of energy efficient measures or renewable energy technologies, the design and construction of such a house implies a higher initial investment. Generally, building owners take in consideration only the initial costs of a new building without thinking of the future costs for operation and maintenance. Thus, the investors lack the overall approach leading to the choice of an unprofitable solution throughout the life cycle of a building. Buildings are long term investments, which assume that the initial decision on the quality of the investment has long term consequences [4]. The purpose of this study is to examine whether the investment in a system of photovoltaic panels applied to an already built energy efficient house, is cost effective in the Romanian economic context. The study compares the life cycle cost (LCC) of a passive house (PH) with the life cycle cost of a nearly zero energy building (NZEB) as an upgrade from passive house. A life cycle cost analysis for the passive house was already performed and compared with the life cycle cost of a conventional house [2]. Stoian et.al. concluded that on the long run, a passive house is cost effective compared to a conventional house, due to the low energy consumption of the passive house.

2 Characteristics of the studied houses

The studied house is part of a duplex which is located near the city of Timisoara, Romania. The duplex was designed to achieve the passive house limitation for energy requirement. The investment in a system of photovoltaic panels was determined by the idea of an upgrade from passive house to nearly zero energy building. The house has a monitoring system that measures and collects data regarding the energy consumption, comfort and ambient parameters, solar radiation. The passive house is inhabited for more than two years, all the time being continuously monitored. The measured data was used to determine its real energy performance. After the installation of the photovoltaic panels the monitoring of the nearly zero energy building started.

2.1 Description of the envelope

The envelope of the duplex is designed to reduce thermal losses: the U values for the walls (0.093 W/(m²K)), the roof (0.066 W/(m²K)), the ground floor (0.086 W/(m²K)) and the windows (Low E, triple glazed windows) were designed accordingly to the values recommended for a passive house and are much lower than the minimum values required by the actual Romanian legislation. The building has prismatic volume and the maximum dimensions are 14.15x13.65 m and 6.67 m height [5].

2.2 HVAC and renewable energy

The building is equipped with a system providing ventilation, heating, cooling and domestic hot water. The system consists of a heat recovery ventilation unit that features an underground heat exchanger for fresh air input, a 2 kW air-water heat pump, a 2.5 square meter solar collector. The system uses a hot water boiler and a heating buffer as energy storage, both equipped with an electric heater which starts when heating is required and none of the above mentioned sources are available. For heat distribution the convectors mounted in the ceiling are used. All equipment installed in the building uses electricity thus facilitating an accurate and clear evaluation of the building’s total energy consumption.

The photovoltaic system is an upgrade to the existing system of the building. The system was designed to cover the total energy consumption of the building. The producer estimated a yearly energy production of around 6900 kWh, taking in consideration the climatic conditions in Timisoara. The photovoltaic system is connected to the national energy grid through a bidirectional energy meter that technically makes grid level energy storage possible. Currently, the energy delivered in the grid is not repaid due to the lack of an appropriate methodology, although proper legislation act exists [6].

2.3 Monitoring

The evaluation of the actual performance of the building was made by analysing the amount of energy consumption during 1 year of monitoring campaign on the Passive House. The monitoring of energy consumption was performed continuously with a custom built monitoring system. The collected data are automatically uploaded to a webserver in order to make it instantly available anytime.

2.3.1 Monitoring system

The core monitoring system consists of a Web Energy Logger name. The data collection unit consists of a low power embedded computer featuring a TCP/IP stack and an interface board that...
manages actual data collection via following channels: a 1wire bus, 6 counter inputs, 8 state inputs, 2 analog inputs and the possibility to interface with IP power meters. The WEL collects the measurements from the sensors every minute and posts the data to a webservice provided by the manufacturer of the unit. The service offers the possibility to display trend graphs for collected data and to download all data in spreadsheet software friendly form [7].

2.3.2 Monitoring results
The energy consumption of the building was measured for a period of 1 year. The monitored period was between 05.2013 and 04.2014. The results are presented in the graph in Fig. 1, where it is possible to observe that energy consumption increases greatly during the cold season. The total energy consumption for the monitored year is 4715 kWh.

During this period, temperature inside the building was monitored as well, in order to assure that the building provides a comfortable environment. Analysis of the graph in Fig. 2 shows that the installation system was able to maintain a constant and comfortable temperature inside the building, even when the external environmental conditions changed significantly.

3 Methodology
The method used in this study is the life cycle cost analysis. The analysis serves as a tool to determine the cost-effectiveness and break-even point of a renewable energy system applied in an energy efficient house. The real energy performance of the house is known due to the monitoring system making this economical calculation more reliable. Thus, a life cycle cost analysis will be made for the passive house and for the nearly zero energy building considering the costs for the actual energy consumption obtained through monitoring.

Life cycle cost analysis is a valuable technique for assessing and comparing different building designs in terms of initial cost increase against operational cost benefits with a long-term perspective [8]. Life cycle cost is described as a “technique that is used for predicting and assessing the cost performance of constructed assets” [9]. Life cycle cost can be used for comparative evaluations over a specified period of time, considering initial costs and future operational costs. In the guideline developed by the Stanford University [10], life cycle cost analysis is defined as “a process of evaluating the economic performance of a building over its entire life”. Although the life cycle cost analysis is a commonly used technique for the economic evaluation of projects, in Romania the background for life cycle cost analysis applied in the building sector is not very comprehensive, and has only few explanations. The life cycle cost applied in this paper addresses all the potential and relevant costs that occur over the analysis period.

3.1 Process description
The mathematical expression of the life cycle cost applied in this paper is presented in Equation (1) and is based on the calculation formula defined in [12].

\[
LCC = I + \sum_{i=0}^{n} \left( FC_{it} \cdot \frac{1}{(1 + d)^t} \right)
\]

The life cycle cost components presented in Equation (1) are: \(I\) is the initial investment, \(FC_{it}\) is the future cost of category \(i\) at time \(t\), \(d\) is the real discount rate and \(n\) is the period of analysis. For the study presented in this paper, the future costs considered are: energy costs and maintenance costs. In order to sum up the costs that occur at different times, it is necessary to convert all cash flows to a reference date using the discount rate. For this study, the reference date is year 0 and represents...
the beginning of the buildings use phase. The value of the discount rate influences the present value of the future costs. For Romania, according to “Guide to Cost-Benefit Analysis of investment projects” [13], a rate of 5% in real terms, excluding inflation, is recommended. The decision on the period of analysis takes into account the technical lifetime of the building elements. The period of analysis can be determined by the renovation cycle of the building, which represents the time after the building is subjected to a series of major renovations and improvement overall. Renewal cycles vary from one building to another, but almost never below 20 years [14]. In this case, the life cycle cost analysis will be performed for a period of 20 years.

Another important factor in the life cycle cost calculation is the price escalation rates (e%). Bear in mind that this study includes cost of energy, which frequently changes over time, it is important to take into consideration these possible changes by estimating the energy price escalation rates in the future. Future energy price escalation rates can be estimated considering past rates of energy price escalation. In the last years, the electricity prices for household consumers in Romania were different from one year to another. Although there have been increases and decreases in the price of electricity, the average of the annual price escalation rates for the last ten years was approximately 4.2%, calculated using the data provided by the statistical office of the European Union [15]. Due to the lack of data regarding the evolution of maintenance services prices, the same escalation rate as for the energy price will be used.

Both the discount rate and the price escalation rate show a high degree of uncertainty. In order to assess the uncertainty of the life cycle cost analysis, a sensitivity analysis is performed by applying different discount rates and escalation rates. The sensitivity analysis helps determining which input values, if different, would make a crucial difference to the result of the life cycle cost analysis. This technique can be used to test various scenarios by applying a set of more pessimistic or more optimistic values than the expected ones [11]. Multiple life cycle cost analysis were performed. One uses recommended discount and price escalation rates. The other analyses are based on different scenarios considering different values for discount rate and price escalation rate.

3.1.1 Initial investment

The initial investment cost is the sum of the cost of the foundation, the materials for constructing and finishing the building, the windows, the technical work connected to the building construction, the installations and the taxes for the connections to the utilities (electricity grid and water supply). Extra, for the upgrade to nearly zero energy building, additional costs related to the system of photovoltaic panels will be included. The costs of the initial investment for the studied cases are presented in Table 1. All costs will be expressed in EURO. Taking in consideration that the house is already built, the cost data represents the real spent money on constructing and equipping the building.

<table>
<thead>
<tr>
<th>Type</th>
<th>Initial investment €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive house</td>
<td>92,640</td>
</tr>
<tr>
<td>Nearly Zero Energy Building</td>
<td>101,176</td>
</tr>
</tbody>
</table>

3.1.2 Future costs (\(FC_{it}\))

As mentioned earlier, the future costs considered relevant for the period of analysis in this study are the maintenance costs and the energy costs.

The maintenance cost is costs of measures for preserving and restoring the desired quality of the installation [16]. This includes annual costs for inspection, cleaning, adjustments, repair under preventive maintenance, consumable items [16]. These maintenance services are needed to enhance long term uptime, performance and economic efficiency.

Some data about life span and annual maintenance cost for the building equipment are presented in Table 2, according to EN 15459 [16].

<table>
<thead>
<tr>
<th>Component</th>
<th>Life span (years)</th>
<th>Annual cost in % of the initial investment</th>
<th>Annual cost (euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump</td>
<td>20</td>
<td>2%</td>
<td>PH: 50</td>
</tr>
<tr>
<td>Heat recovery unit</td>
<td>20</td>
<td>4%</td>
<td>NZEB: 3</td>
</tr>
<tr>
<td>Boiler</td>
<td>20</td>
<td>1%</td>
<td>21</td>
</tr>
<tr>
<td>Convectors</td>
<td>20</td>
<td>1%</td>
<td>4</td>
</tr>
<tr>
<td>Meters</td>
<td>10</td>
<td>1%</td>
<td>4</td>
</tr>
<tr>
<td>Solar collector</td>
<td>15-20</td>
<td>0.5%</td>
<td>4</td>
</tr>
<tr>
<td>Photovoltaic panels</td>
<td>20-25</td>
<td>0.5%</td>
<td>0</td>
</tr>
<tr>
<td>Piping system</td>
<td>30</td>
<td>0.5%</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>96</td>
</tr>
</tbody>
</table>

The calculation of the energy cost for the passive house is based on the measured energy consumption through monitoring. As the building has only electrical energy consumption, the energy cost is calculated by using a price of 0.132 €/kWh for electrical energy. For the nearly zero energy
building the energy consumption will be considered zero. As presented in the previous chapter, the energy consumption of the building is 4715 kWh/year and the estimated energy production of the photovoltaic panels is 6900 kWh/year. Although the energy delivered in the power grid is not yet repaid, this study considers that the excess renewable electricity production from photovoltaic panels is fed back to the grid to offset the electricity purchased from the grid. The calculation are made assuming that the annual balance between purchased and delivered electricity is zero and therefore the energy consumption of the building is zero.

3.2 Life cycle cost calculation

3.2.1 Constant annual costs analysis

Outcomes of constant future costs scenario (e=0%, d=0%) analysis are presented in Fig. 3, for both options passive house and nearly zero energy building. In this scenario the break-even time for the NZEB compared to PH is after 14.7 years. The result of a sensitivity study investigating the influence of a higher discount rate in case of constant costs analysis is presented in Table 3.

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>0%</th>
<th>2%</th>
<th>3%</th>
<th>5%</th>
<th>7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive house</td>
<td>107008</td>
<td>104386</td>
<td>103328</td>
<td>101592</td>
<td>100250</td>
</tr>
<tr>
<td>Nearly zero energy</td>
<td>103996</td>
<td>103482</td>
<td>103274</td>
<td>102933</td>
<td>102670</td>
</tr>
</tbody>
</table>

As we can see in Table 3, the life cycle cost of the two studied houses decreases along with the growth of discount rate. By increasing the discount rate, the equivalent present value of the future costs decreases, and thus they comprise a smaller part of the life cycle cost. From Table 3 results that for constant future costs and discount rates higher than 3% the break-even time of the investment in photovoltaic panels is higher than 20 years because the LCC for the NZEB overcomes the LCC for PH. We can deduct that with low or even zero discount rate, the benefits of the photovoltaic panels are more noticeable.

3.2.2 Growing annual costs analysis

Although estimating future cost involves a high degree of risk and uncertainty, past experiences prove that on the long run, in Romania, the electrical energy prices strive to grow. Fig. 4 shows the life cycle cost for an expected price escalation rate of 4.2% and the discount rate of 5%. In this case the break-even time is after 14.5 years which is very close to the result in Fig. 3.

To consider the influence of growing future costs, other scenarios are simulated, namely an annual growth of 2%, 6%, 8% and 10%. For the purpose of this analysis, real discount rate of 5% is applied. As we can see in Fig. 5, the present value of the life cycle costs increases under the high price scenario.

At a low price escalation rate (2%), we can observe that the difference between the two life cycle costs is small, meaning that the break-even time will be
reached near the end of the period of analysis. Along with the growth of the escalation rate, the payback time goes down. By applying lower discount rates to the previous analyses, the present value of the future costs increases and thus the payback time decreases (Fig. 6).

**Fig. 6. Break-even time sensitivity analysis**

4 Conclusion

The main goal of the life cycle cost analysis was to assess the cost-effectiveness of investing in renewable energy technologies for a house with very low energy demand. By investing in a system of photovoltaic panels on a passive house, the initial investment increases by approximately 9.1%. The results of the life cycle cost analyses are strongly dependent on the used financial data. The analysis has shown that with growing future costs of maintaining and operating the building, the investment in a system of photovoltaic panels for producing electricity is cost-effective leading to a payback period of around 8-11 years. The break-even time sensitivity analysis presented in Fig. 6 shows that even a slight increase in prices (2%) and a high discount rate of 5% leads to reaching the payback before the life span of the system is over. Nevertheless, in case of constant future costs and a high discount rate, the life cycle cost of the NZEB exceeds the life cycle cost of the passive house meaning that the break-even time for NZEB is higher than 20 years. However, past experiences prove that on a long term, prices have the tendency to increase rather than decrease, especially energy costs which are the most relevant for this analysis.

With the current high price level of photovoltaic panels in Romania and the prospects of future energy prices escalation, investing in this technology for a residential building shows some risk but also chance of profit. Due to the great environmental impact of the energy consumption in the building sector, national authorities should persuade energy distributors and carriers to direct their efforts in developing as soon as possible the methodology to make possible the reimbursement of the excess energy that is delivered in the grid by photovoltaic panels system, in order to make the investments in renewable energy technologies more attractive and safe.

Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI–UEFISCDI; project number PN-II-PT-PCCA-2011-3.2-1214-Contract 74/2012.

This work was partially supported by a collaborative project between “Politehnica” University of Timisoara and ArchEnerg Cluster (SolarTech Nonprofit PLC.), project number HURO/1001/221/2.2.3.

References:


[8] Miro Ristimäki et.al., Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy...


