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ENERGY EFFICIENT REFURBISHMENT TOWARDS NEARLY ZERO ENERGY HOUSES, FOR THE MEDITERRANEAN REGION

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Abstract

The building sector in Europe is responsible for an estimated 40% of the total energy consumption and 10% of the total CO2 emissions. Given that new buildings represent only about 1% of the housing stock annually, it is estimated that more than 80% of the existing buildings will still exist in 2020. Therefore, the energy efficient renovation of the existing housing stock is imperative in order to reduce the building energy consumption. It is for this reason that the European Union ranked the improvement of the energy performance of the old building stock, as a high priority in its research agenda. Following Europe's 20:20:20 objective, this case study investigates refurbishment scenarios in order to achieve Nearly Zero Energy houses, in Cyprus.

The research focuses on the Single Family House typology, as classified in previous studies for Cyprus, in the framework of the IEE, EU project EPISCOPE and specifically on retrofitting an old house that was built before 1980. The aim is to upgrade it into a Nearly Zero Energy Building (nZEB) with the implementation of the national energy performance requirements, as drafted by the Ministry of Energy, Commerce, Industry and Tourism (MECIT). Following the EPISCOPE project methodology, a representative Single Family House from the corresponding residential building typology in Cyprus was chosen and modeled using the iSBEMcy tool. This is the official governmental software in Cyprus used for issuing Energy Performance Certificates (EPC), for the categorization of the energy class of the building and the calculation of the CO2 emissions according to the European Directives 2002/91/EC and 2010/31/EC.

The study investigates whether it is possible for an old Single Family House to reach the nZEB standards and identifies the lurking obstacles and challenges, through building simulations. To this end, various refurbishment scenarios were developed, with the implementation of strategies aiming at fulfilling the MECIT requirements. Through analysis of the results, the efficiency of each strategy and technique employed towards minimising the energy consumption and the greenhouse gas emissions was

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evaluated, in terms also of its cost effectiveness. Furthermore, the results of the research were investigated in order to assess whether the nZEB requirements, as developed by the MECIT, are appropriate for the existing single-family houses in Cyprus and whether alternative strategies may be employed in order to meet the target of nZEB and to reduce effectively the energy consumption.

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Keywords: Energy performance; Existing Single Housing Typology; Old houses; Nearly Zero Energy Buildings;

1. Introduction

Residential buildings are of great importance endeavoring to reduce energy consumption and CO_2 emissions, since they account for the 63% of the total energy consumption of the building stock [1]. The existing residential building stock exceeds the number of newly built dwellings in most developed countries. While new constructions add at most 1% per year to the existing stock, the other 99% of the buildings are already built and produce about 26% of the energy-use and the induced carbon emissions [2]. Thus, greater potential of energy savings can be achieved in the existing residential buildings than the newly built structures.

The improvement of the energy performance of the existing residential stock in every country is essential, since the operational cost, the energy consumption and the carbon dioxide emissions are a major issue worldwide. The EU has set targets for 2020, which aim at a 20% reduction in greenhouse gas emissions from 1990 levels. The intent is to raise the share of the European energy consumption produced from renewable resources by 20% and to improve energy efficiency by 20%. In order to meet these targets the EU stresses the need of national definitions for the nearly Zero Energy Building "nZEB building". Complying with the E.U. targets [3], Cyprus has published the Directive 366/2014 referring to the minimum national requirements concerning the nZEB building [4].

Many surveys have been carried out in search of the nZEB standards, concerning the optimization of the buildings envelope, the upgrade of the electromechanical systems and the introduction of Renewable Energy Sources (RES). Regarding the optimization of the buildings envelope, in a recent study Serghides and Georgakis investigated the energy performance of the building envelope in order to identify the optimum relationship of cost effectiveness and energy efficiency in the thermal performance of the buildings in the Mediterranean region. From this study it was concluded that the most effective solution for an improved building envelope thermal performance is provided by the combination of external insulation on the building envelope and with the increase of the internal mass, which in turn increase the thermal capacity of the structure [5].

The RES contribution towards nZEB is proven to be vital for the improvement of the energy performance of a building [6] and can even result to a positive energy building [7]. A combination of upgrading the electromechanical systems, refurbishing the external envelope and introducing RES is the most effective approach. Furthermore, an individualised approach for each building is necessary in order to reach an optimal solution [8].

Previous studies on the Cyprus housing stock investigated the impact of different refurbishment scenarios on the energy consumption of the dwellings and the resulting savings [9,10,11]. The studies demonstrated the effectiveness of the insulation on the buildings envelope and the high contribution of the PV systems in the reduction of the greenhouse gases.

This study focuses on the conversion of an existing Single Family House, representing one of the main residential typologies in Cyprus [12] (50% of prevalence among the residential building stock), into a nZEB house and it highlights the arising challenges.

2. Methodology

According to the IEE Project TABULA and the ongoing IEE Project EPISCOPE [13], twelve residential building typologies were established as typical and representative of the national residential building stock in Cyprus [14]. These are classified according to their chronological period of construction and their architectural and constructional characteristics. The three building typologies consist of; the Multi Family Houses, the Terrace Family Houses and the Single Family Houses. These are divided into four different chronological periods, supported by the data collected from the Cyprus Statistical Service [12]. Each chronological division was defined based on the different constructional regulations and techniques that were applicable throughout the years, formulating the four distinctive chronological categories, before 1980, between 1981 and 2006, between 2007 and 2013 and after 2014. These divisions were also guided by the rapid growth of the construction industry in Cyprus, which occurred after 1980, by the adoption of the European Directive in 2007 and the amendment of the Directive, which was enforced in beginning of 2014. It is worth mentioning that before the entrance of Cyprus in the European Union there was no energy related legislation for the building sector.

The building under study was selected according to its space-related characteristics (floor area, number of bedrooms etc.), which approach those of the typical Single Family House of that period. In order to perform the study, the total building area, the heated living volume and the constructional characteristics of the building envelope, as well as the type of the electromechanical systems for heating, hot water and cooling were collected. The constructional characteristics of the roof, the wall, the floor slab, the structure and the openings were recorded and their U-Values as well as their thermal capacity were calculated. The installed electromechanical systems were documented and their energy efficiency was estimated. When this study was contacted, due to the lack of available data, mainly concerning the installed electromechanical systems, certain assumptions were made (length and type of pipes, condition of systems) [15].

The modeling tool used throughout this paper for the energy performance calculation is the iSBEM-Cy, which is the governmental software for the issuance of Energy Performance Certificates, [16]. This is the official governmental software in Cyprus used for the categorization of energy efficiency in buildings and the calculation of CO_2 emissions according to the European Directive 2002/91/EC [17].

Initially, the energy performance of the house was found for its existing state and the corresponding energy savings were calculated. Subsequently a standard nZEB refurbishment scenario was applied, based on the Directive 366/2014 [4] and the energy efficiency and the cost viability for each refurbishment measure related to the building envelope elements thermal performance was assessed separately. Based on the findings an optimized nZEB scenario was developed oriented to improve the energy efficiency and cost effectiveness of the refurbishment. The cost for the nZEB refurbishment scenarios as well as the payback period, were based on the current market values. These were calculated with the official tool published by the Ministry of Energy, Commerce, Industry and Tourism of Cyprus for the cost optimal energy conservation measures [18], in order to include the purchase, installation and construction costs for all the systems used for these retrofitting scenarios.

3. Case Study

The case study is a Single Family House representative of its typology for the period prior to 1980. It was constructed in 1963 and it is situated in Strovolos, in the Capital City of Nicosia, inland area. This building type amounts to a 20% of the total national housing stock square meters [13] and has the poorest energy performance among all the typologies and chronological periods [15]. Therefore, the impact of an effective deep energy refurbishment in this house may be applied to all the old single-family houses and result to high-energy savings at a national level.

3.1. The existing condition of the building

The house under study is a single-storey dwelling with a usable heated living area of $134{,}5m^2$ and a corresponding heated living volume of $396{,}9m^3$.

It has a North-East to South-West orientation, with 15% of the total wall surface corresponding to glazing, of which 44% is North-East and 35% South- West oriented. The house has 3 bedrooms, 3 bathrooms, one of which was added during a recent refurbishment, and an open plan kitchen, dining and living room (Figure 1).

The dwelling has a non-insulated flat concrete slab roof, rendered brick walls and a floor concrete slab in contact with the ground. Initially the glazing consisted of aluminium frame single glazed windows, which were recently replaced by the owners with double glazed ones for better indoor comfort and energy efficiency. It is worth to be mentioned that windows upgrade it was a common practice in Cyprus during the recent years due to governmental subsidies that support the marker and the building owners [19].

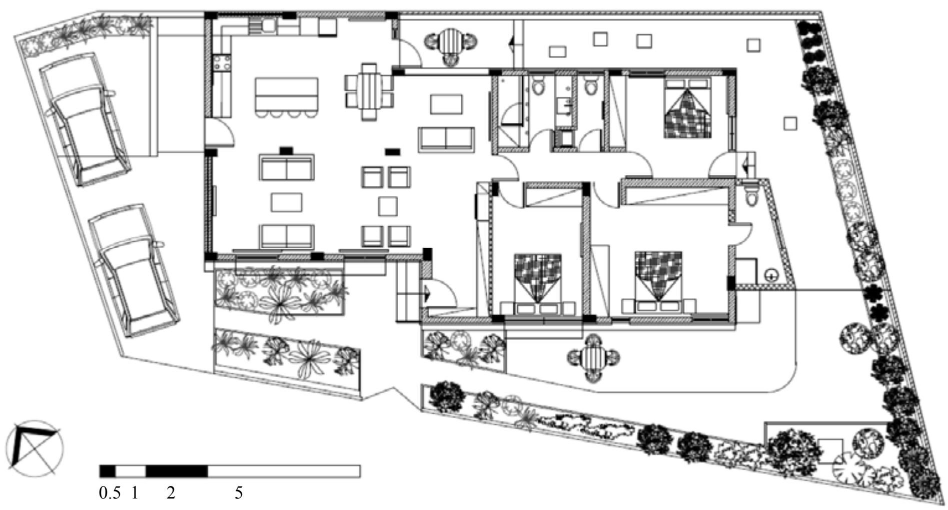


Fig. 1. Plan of the house

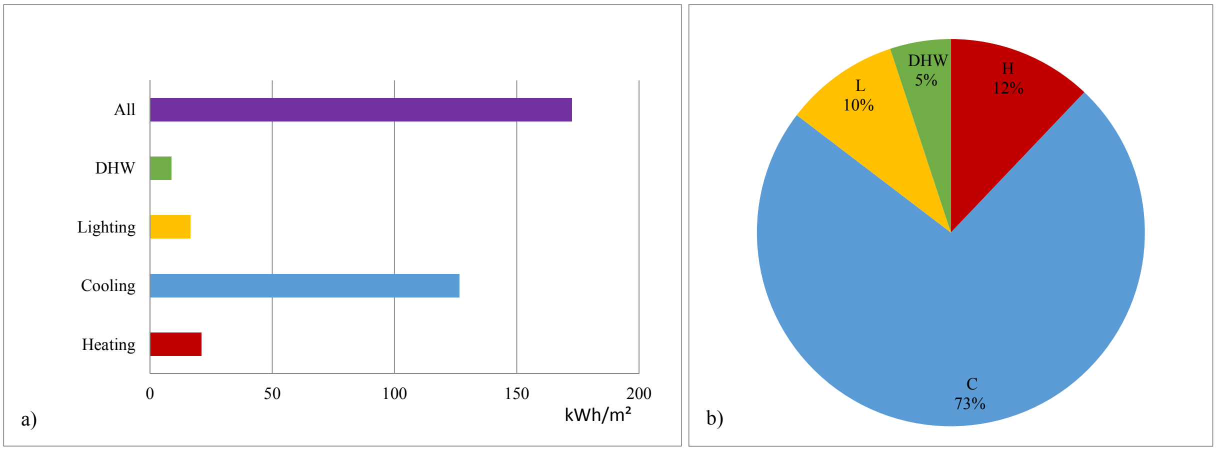
Regarding the cooling and the heating of the space 5, standard air-conditioning split units are installed, 2 of them in the open plan living room - kitchen and the remaining 3 in the bedrooms of the house. For Domestic Hot Water (DHW), the house is equipped with solar thermal panels on the roof and a back-up electric element, which connects to the water storage tank. The thermal characteristics of the building envelope are calculated as shown on Table 1.

Table 1: Thermal characteristics of the building envelope of the Single Family House

Construction Element	U-Value W/(m^{2}k)
Flat roof	3.08
External walls	1.39
Floor in contact with the ground	3.58
Double glazed windows	3.20

After simulating the building's energy performance using the iSBEM-cy tool, the calculated Total Primary Energy Consumption is 471 kWh/ (m^{2}a), the 5 kWh/ (m^{2}a) of which are produced from Renewable Energy Sources (RES), attributed to the solar thermal panels on the roof for DHW consumption. Therefore, the renewable energy reaches a 1.06% of the total energy consumption of the dwelling.

The total energy consumption for the house reaches the 193.55 kWh/(m^{2}a). The major energy consumption is attributed to the high need for cooling. (Graph1) The energy consumption for heating is 20.85 kWh/(m^{2}a), for cooling is 126.48 kWh/(m^{2}a), for DHW 8.74 kWh/(m2a) and for lighting is 16.49 kWh/(m^{2}a). The Energy Performance Certificate (EPC) Categorization reaches the class F.



Graph 1 a) Existing State: Yearly energy consumption for heating, cooling, lighting, DHW and Equipment b) Existing State: Percentage over the total energy consumption for heating, cooling, lighting, DHW and Equipment.

3.2. The Standard nZEB Refurbishment Scenario

Based on the existing Directive 366/2014, specific U-values must be obtained and certain requirements to be fulfilled, to define a building nearly zero energy one. The minimum energy performance requirements concern the buildings' envelope elements, U-values and the energy demand for heating, as well as the total primary energy consumption and the share of the renewable energy sources in the total primary energy consumption. These requirements are shown on Table 2.

Table 2: NZEB requirements for houses in Cyprus according to Directive366/2014

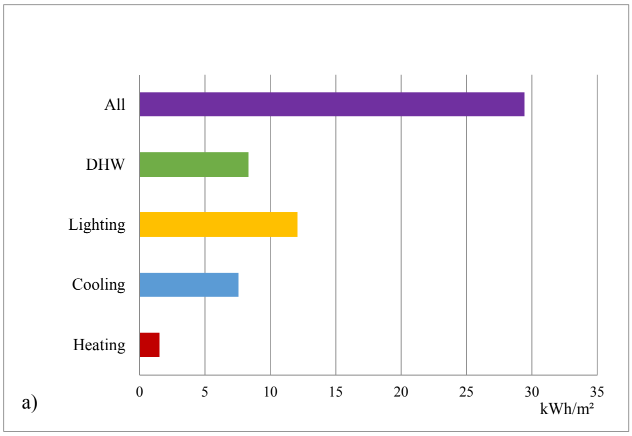
NZEB REQUIREMENTS FOR HOUSES	
Technical specifications - Construction Element	U-Value W/(m^{2}K)
Flat roof	0.40
External walls	0.40
Double glazed windows	2.25
Energy Performance specifications	Minimum requirements
Energy Performance Certificate	A
Total Primary Energy consumption	100 kWh/(m^{2}a)
Energy Demand for heating	15 kWh/(m^{2}a)
Renewable energy percentage of the total primary energy consumption	25%

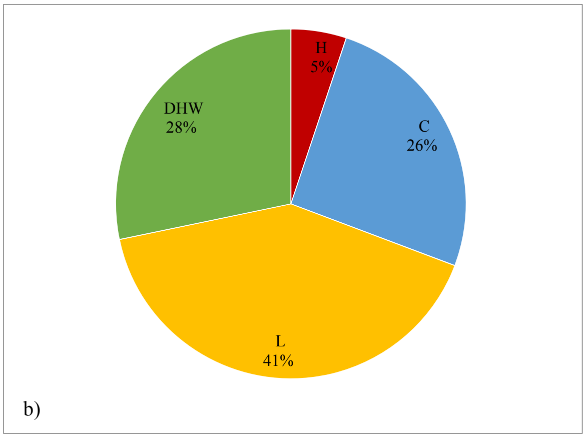
In order to meet the minimum set requirements for the building envelope for a nZEB house; 80mm of thermal insulation (expanded polystyrene) was added externally on the walls and 90mm was also installed externally on the roof. The windows were replaced with new, thermally improved ones and additionally horizontal overhang shades (aluminium frame and fabric) were placed above the south-facing windows [20]. The thermal characteristics of the building envelope after the energy conservation measures were calculated in order to reach the minimum technical specifications of the nZEB Directive. The roof and the walls reached 0.38 W/(m^{2}K) U-value, whereas the windows selected have a U-value of 2.20 W/(m^{2}K). Furthermore, 3 photovoltaic panels of total area of 4.8m2 were placed on the roof with an inclination of 30o and the existing AC units were substituted with ones of A+++ class.

Using the above energy conservation measures the house was raised by five EPC categories, from F to A and met all the requirements of the nZEB definition for residential buildings under deep renovation [21].

The calculated total primary energy consumption for the nZEB refurbishment scenario is reduced to 86 kWh/(m^2a). The contribution of Renewable Energy Sources (RES), including solar thermal panels for DHW and PV panels on the roof, was 29 kWh/(m^2a), covering a 33.72% of the total primary energy consumption.

The total final energy consumption is 29.41 kWh/(m^2a) from which the energy consumption for heating is 1.51 kWh/(m^2a) and for cooling is 7.54 kWh/(m^2a). The lighting and DHW consumptions are 12.06kWh/(m^2a) and 8.32kWh/(m^2a) respectively. (Graph 2).





Graph 2 a) Standard nZEB refurbishment: Yearly energy consumption for heating, cooling, lighting, DHW and Equipment b) Standard nZEB refurbishment: Percentage over the total energy consumption for heating, cooling, lighting, DHW and Equipment.

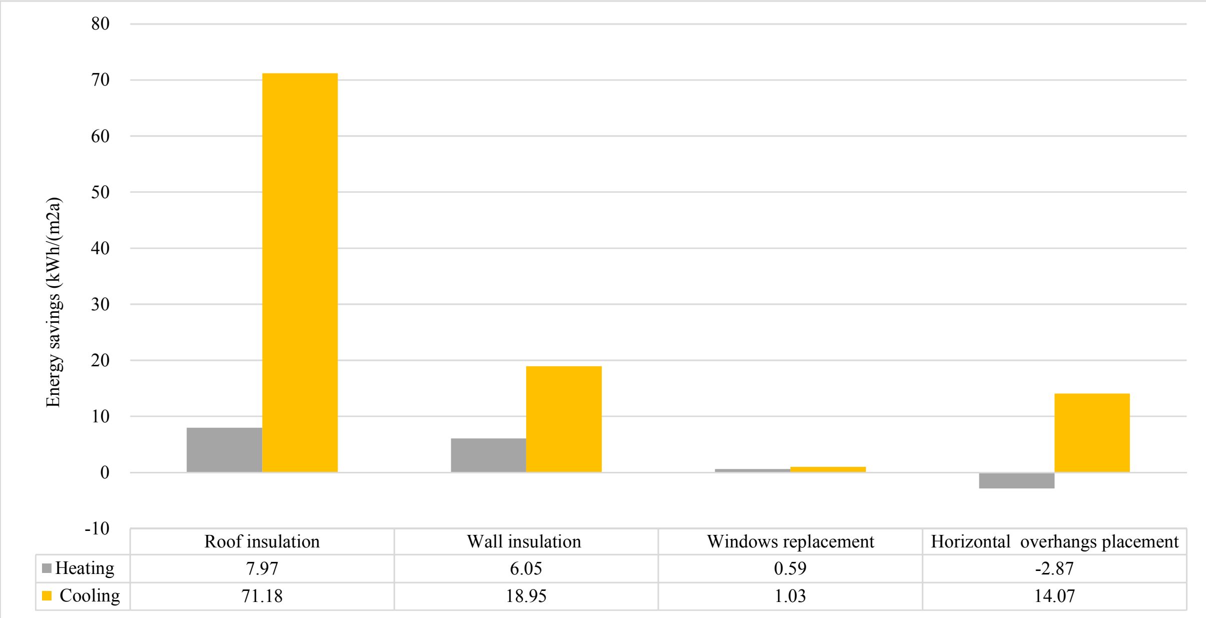
3.3. Impact of the Energy Conservation Measures and their Cost-Effectiveness

The impact of each measure addressing the building envelope energy performance upgrade was separately investigated in order to detect the most energy efficient and cost optimal measures. The measures investigated were the placement of insulation on the roof and the walls, the replacement of windows and the installation of horizontal overhangs above the south facing windows. Each measure was studied separately and its energy savings for space heating and cooling were calculated.

It was concluded that the most effective measure is the placement of thermal insulation [22]. (Graph 3) The thermal insulation of the roof has the highest percentage of energy savings among the investigated measures. The thermal insulation when placed on the roof results to a 79.23 kWh/(m^2a) energy savings and the corresponding savings for the walls insulation placement is 25.08 kWh/(m^2a). The energy savings obtained for heating are 7.97 kWh/(m^2a) and 6.03 kWh / (m^2a) for the roof and the walls insulation respectively; whereas the cooling savings after insulating the roof are more than 3 times higher than the ones incurring from the placement of insulation on the walls. This indicates the high effectiveness of the roof insulation in the reduction of the cooling energy need.

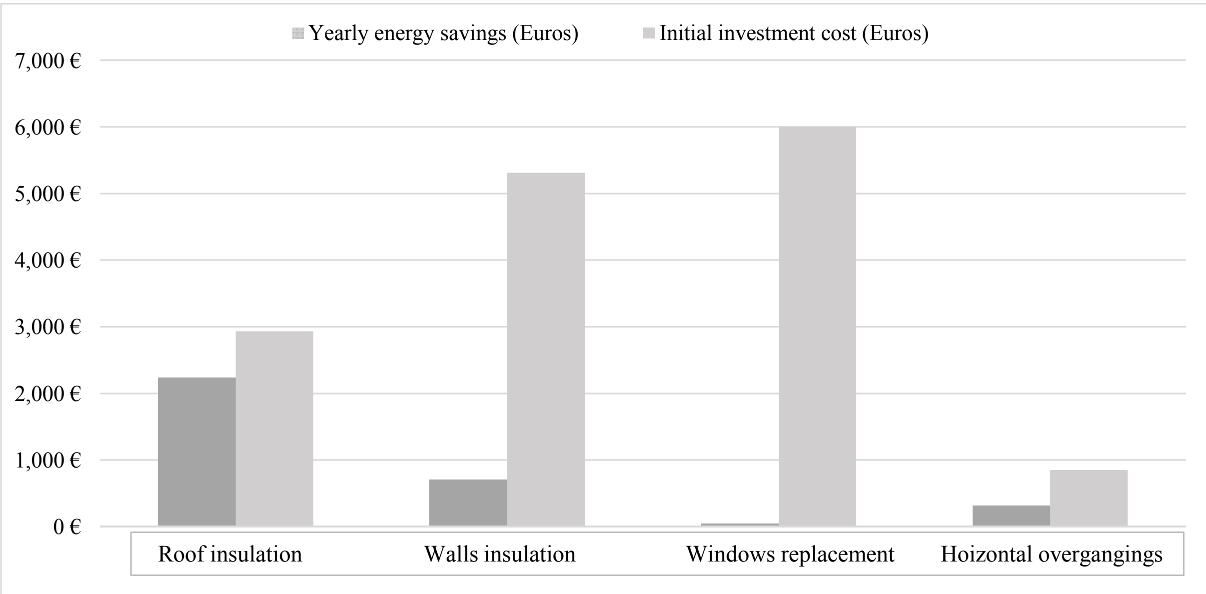
The replacement of the existing double glazed windows with new ones, of lower U-value, results to minimal, almost negligible, savings with 0.58k kWh/(m^2a) decrease in the heating consumption and 1.03 kWh/(m^2a) in the cooling consumption. The replacement therefore is not considered as an effective measure.

The placement of the 1m length overhangs above the windows with southern orientation, complying with the existing building regulations [20], reduces the total final energy consumption by 2.15 kWh/(m^2a), which corresponds to a saving percentage of 6.54%. The energy consumption for cooling decreases from 8.85 kWh/(m^2a), to 5.87 kWh/(m^2a). Whereas, the energy consumption for heating increases from 2.22 kWh/(m^2a),to 3.03 kWh/(m^2a). In order to prevent this and further increase the positive effect of, the shading devices these must not be fixed but manually or automatically operated, so as to benefit from the solar radiation during winter.



Graph 4. Energy savings corresponding to the envelope energy conservation measures.

From Graph 4 it is obvious that the most cost - effective measure is the addition of insulation on the roof, with a payback period of less than 2 years, followed by the placement of horizontal overhangs, with 3 years of payback time and the insulation of the walls. The replacement of the single-glazed windows with double-glazed is proven to be the least effective measure needing more than a century to amortize its initial investment cost.



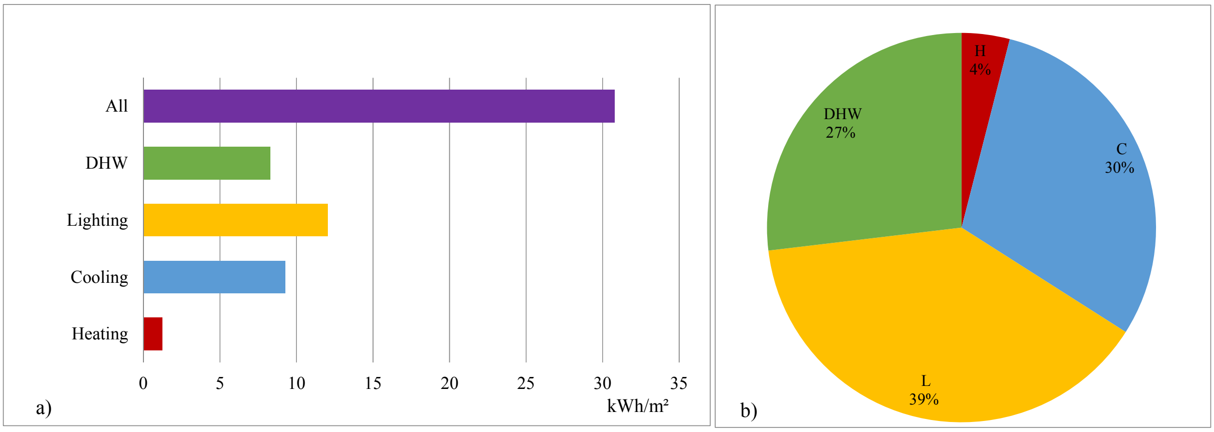
Graph 4. Yearly energy savings in operational costs and initial investment for the envelope refurbishment measures.

3.4. Optimized nZEB refurbishment Scenario

From the evaluation of the energy and cost effectiveness results of the different energy conservation measures of the building envelope, it was considered necessary to develop an alternative nZEB Scenario for the house, which aims in maximizing the effectiveness of the refurbishment both in terms of energy savings and payback period. The Scenario included placement of insulation on the roof and the walls, achieving the same U-values as the standard nZEB Scenario and installing horizontal overhangs in the south facing windows. The split units were substituted with ones of higher energy efficiency (A+++) and the number of PV panels was increased from the initial standard nZEB Scenario from 3 to 12, amounting to 19,2 m^2, which correspond to the maximum permissible potential of 3kW per dwelling [23].

Using the above energy conservation measures the house was raised by five EPC categories, from F to A. The calculated total primary energy consumption for the nZEB refurbishment scenario is lowered to 89 kWh/(m^{2}a). The contribution of Renewable Energy Sources (RES), including solar thermal panels for DHW and PV panels on the roof, was 98 kWh/(m^{2}a), covering 110% of the total primary energy consumption and resulting to a positive energy building.

The total final energy consumption is reduced to 30.79 kWh/(m^{2}a) from which the energy consumption for heating is 1.23 kWh/(m^{2}a) and for cooling is 9.24 kWh/(m^{2}a). The lighting and DHW consumptions are 12.04kWh/(m^{2}a) and 8.28 kWh/(m^{2}a) respectively (Graph 5).

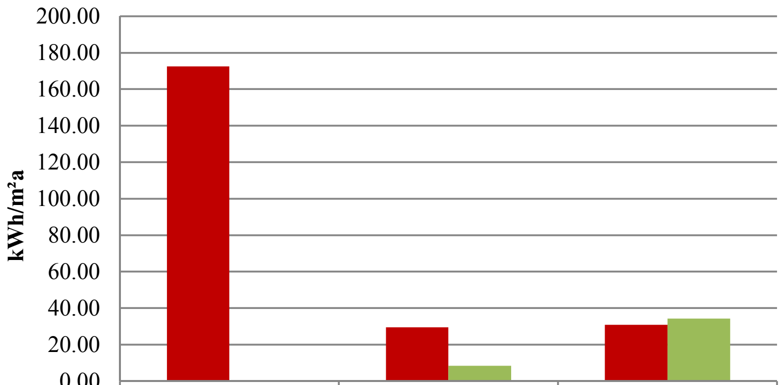


Graph 5 a) Optimized nZEB refurbishment: Yearly energy consumption for heating, cooling, lighting, DHW and Equipment b) Optimized nZEB refurbishment: Percentage over the total energy consumption for heating, cooling, lighting, DHW and Equipment.

3.5. Comparison of nZEB Scenarios with the existing condition of the building

The building at its existing state consumes yearly 172.56kWh/(m^{2}a) and emits 137.07kg/(m^{2}a) of Carbon Dioxide. After the standard nZEB refurbishment the house's yearly consumption is reduced by 82.29%, whereas the corresponding reduction after the realization of the optimized nZEB Scenario is 82.15%. (Graph 6) The CO_2 emission reductions after the simulations calculated at 87.81% for the standard nZEB refurbishment and 102.00% for the optimized nZEB refurbishment, achieving with the second refurbishment scenario an energy positive house.

The operational annual cost of the house at its existing state is 3469€. After the standard nZEB refurbishment is reduced to 422€, whereas in the optimized nZEB scenario, due to the surplus production of electricity from the PVs, the dwelling has yearly gains of 69€, from supplying electricity to the grid. Therefore, although the initial investment cost for the standard nZEB scenario is 9250€, 450€ lower than the corresponding for the optimized nZEB scenario, the payback period of the latter is 7 years, being shorter by 1 year than the payback period for the standard Scenario.



	Existing	Standard nZEB	Optimised nZEB
Total Energy Consumption	172.56	29.42	30.79
Energy produced by the PV system	0.00	8.38	34.24

Graph 6 Comparison of total energy consumption and energy produced by the PV between the existing state, the standard nZEB scenario and the optimized nZEB scenario.

4. Conclusions

The study was carried out in order to determine the overall economic viability of the refurbishment on an old Single Family House towards a nearly Zero Energy Building, and to evaluate the effectiveness of the energy conservation measures related to the upgrading of the energy performance of the envelope, in terms of energy savings and cost effectiveness. The results indicate that the refurbishment of an old Single Family House (a representative, existing dwelling of this typology in Cyprus) into a nearly Zero Energy Building, as it is defined by the Directive 366/2014, is financially viable, with a payback period of 8 years, when the money for the investment is paid with the current prices.

However, the payback period will be greater when taking into consideration the necessity for a loan, since the cost to refurbish a Single Family House into a nearly Zero Energy Building exceeds the annual income of the average household [24]. It is also noted that the actual amount of money spent on the air conditioning of the house is significantly less [25] than the expenses calculated by the iSBEM-cy tool. This has as a consequence an even larger payback period and smaller savings, making this refurbishment scenario a less attractive option.

From the study it is concluded that the most effective refurbishment measure is the thermal insulation of the roof, followed by the placement of horizontal movable shading devices and the walls insulation. Furthermore, it is found that when a house has already double glazed windows, their replacement with ones of improved thermal characteristics does not render it cost effective, resulting to negligible energy savings.

Whereas, an alternative refurbishment scenario incorporating an increased contribution of RES with larger PV panel area, results to shorter by 1 year payback period and reduced by 102% the CO2 emissions. The results indicate the drawbacks of the minimum requirements towards nearly zero energy houses, as drafted by the Cyprus government, especially the replacement of the windows, which is obligatory by the Directive. This is attributed to the low U-values (2,25W/m^{2}K) proposed by the Directive, which are the same for all typologies and chronological periods of houses and do not take into consideration the high cost associated with their replacement. This has a share of 24% of the total investment, and incurs a saving of only 2kWh/m^{2}year on the total energy consumption. On the contrary, the placement of shading devices presents both an energy effective and economically viable choice, although not included in the requirements according to the Directive 366/2014.

Therefore, the cost effectiveness of the different refurbishment measures on the building envelope and the high amounts of energy produced from PV systems must be taken into consideration for the definition of the nearly zero energy buildings in Cyprus and redirect it into a more flexible and cost effective choice, in order to constitute a feasible choice of refurbishment for old houses.

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