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ENERGY AND ENVIRONMENTAL EVALUATION OF RETROFITTING FACADES FOR ZERO ENERGY BUILDINGS: THE CASE OF AN OFFICE BUILDING IN GREECE

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Abstract. Energy and environmental targets are expressed clearly by the EU policies setting ambitious goals for 2030 and 2050 considering energy intensive sectors such as buildings. Pursuing high energy performance with the least environmental impact of a building, along with ensuring the well-being of the occupants, is the ultimate goal of an institutional framework that addresses energy efficiency and environmental sustainability. Part of this effort is the improvement of the building envelope's thermal performance, along with the respective one of HVAC systems, as those determine thee energy performance of buildings in their use phase. Main scope of the paper is to evaluate and analyse different scenarios considering the retrofitting of facades as part of the refurbishment towards Zero and Positive Energy Buildings, but also in connection with the strive for Net Zero Energy, Net Zero Cost Energy and Net Zero Emissions goals. The paper also discusses energy and environmental evaluation of refurbishing an office building in Greece, examining the performance of different envelope construction typologies and alternative insulation scenarios. These scenarios include state of the art insulation techniques, but also innovative design elements such as the use of different final coating materials for ventilated façades like the use of phase-changing materials (PCMs). The results of the assessment undertaken are used to rate the construction solutions by means of energy and environmental parameters proving the environmental impact of concrete and insulation materials in construction phase but also the reduced primary energy consumption and thus the CO_2 emissions in the life cycle of the building. Considering the environmental evaluation, the carbon footprint analysis was used according to Greenhouse Gas Protocol focusing mainly on CO_2 emissions, which is the main emission target of EU policies. The impact assessment followed demonstrated that the most significant impact categories are global warming, acidification and eutrophication.

1. Introduction

The EU energy and environmental policy sets defined goals for energy efficiency upgrade, reduction of energy consumed, introduction of renewable energy sources and carbon neutrality. Within this direction the short term goal of 20-20-20 has been almost accomplished nevertheless there is a fruitful vision for the upcoming years of 2030 and 2050 [1]. The digitalization and smart technologies implementation (such as buildings' automations, control systems and devices, smart metering, etc), e-mobility and carbon neutrality seem to be the challenges of the future actions towards nZEB buildings. The existing building stock is undoubtedly the biggest challenge comparing to the new constructions because of the poor energy efficiency along with the social parameter and the users difficulty to support financial the buildings' upgrade [2]. The EU Renewable Energy Sources (RES) share in energy consumption for residential buildings in different countries shows significant difference. Main goal of the European Union (EU) is to be the leader of transition to clean energy main aspects in this direction are the continuous improvement of energy efficiency and CO_2 reduction.

Towards this direction and in compliance to policies and national legislation framework a lot of studies have been focused on the materials' use and systems in terms of reducing environmental impacts as well as reducing the final energy used, the CO_2 emissions and the operational cost. The use of thermal insulation helps buildings to ensure thermal comfort in the building in correspondence to the efficient operation of HVAC systems achieving the vision of energy efficient buildings.

Main scope of the paper is to evaluate and analyse different constructive scenarios considering the retrofitting of facades as part of the refurbishment towards Zero and Positive Energy Buildings, but also in connection with the strive for Net Zero Energy, Net Zero Cost Energy and Net Zero Emissions goals. The effective thermal protection of the envelope is a key issue in order to reduce heat flow controlling with this way the indoor temperature and succeeding along with the efficient operation of HVAC efficient energy performance of buildings in the use phase.

Moreover and keeping in mind the materials' use in the construction phase in accordance to circularity and resilience it is more than evident that apart form the energy analysis the environmental impact analysis focusing on CO_2 emissions is essential. In order to quantify and evaluate the building efficiently Life Cycle Assessment (LCA) is implemented. Terms like Life Cycle Energy Assessment (LCEA) and Life Cycle Carbon Emissions Assessment (LCCO2) actually go along with the classic LCA approach emphasizing on each case either to energy used, primary or final or to CO_2 in a more carbon neutrality base. Nevertheless the approach and the goal of the analysis still remain the same quantifying in each case the energy and material in the inventory analysis and evaluating the environmental impacts in the building's life cycle. [3,4]

2. Methodology

Life cycle assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal based ISO 14040 - ISO 14044 : 2006 the life cycle methodology contains the following basic steps: goal and scope definition, inventory analysis (input data analysis), impact assessment (output emissions and impacts) and interpretation. In order to evaluate and quantify the different scenarios studied the OpenLCA software is used using emission factors from CML2012 methodology. for advanced long term environmental impact analysis as required by the European EN 15978 (EN 15978 : 2011) and EN 15804 (EN 15804 : 2013) standards [5,6] .

2.1. The Office Building case in Greece: Scenarios analysis

A typical office building is used for the scenarios analysis, as depicted on Figure 1, located in Thessaloniki, the second-largest city of Greece. According to Köppen-Geiger's climate classification, Thessaloniki has humid subtropical climate (Cfa) and semi-arid climate (BSk) showing similarities with the coastal city of Limassol in Cyprus and the Croatian coastal area of Split [7]. Significant research has been performed on the optimal insulation thickness for different building elements based on different climatic conditions.

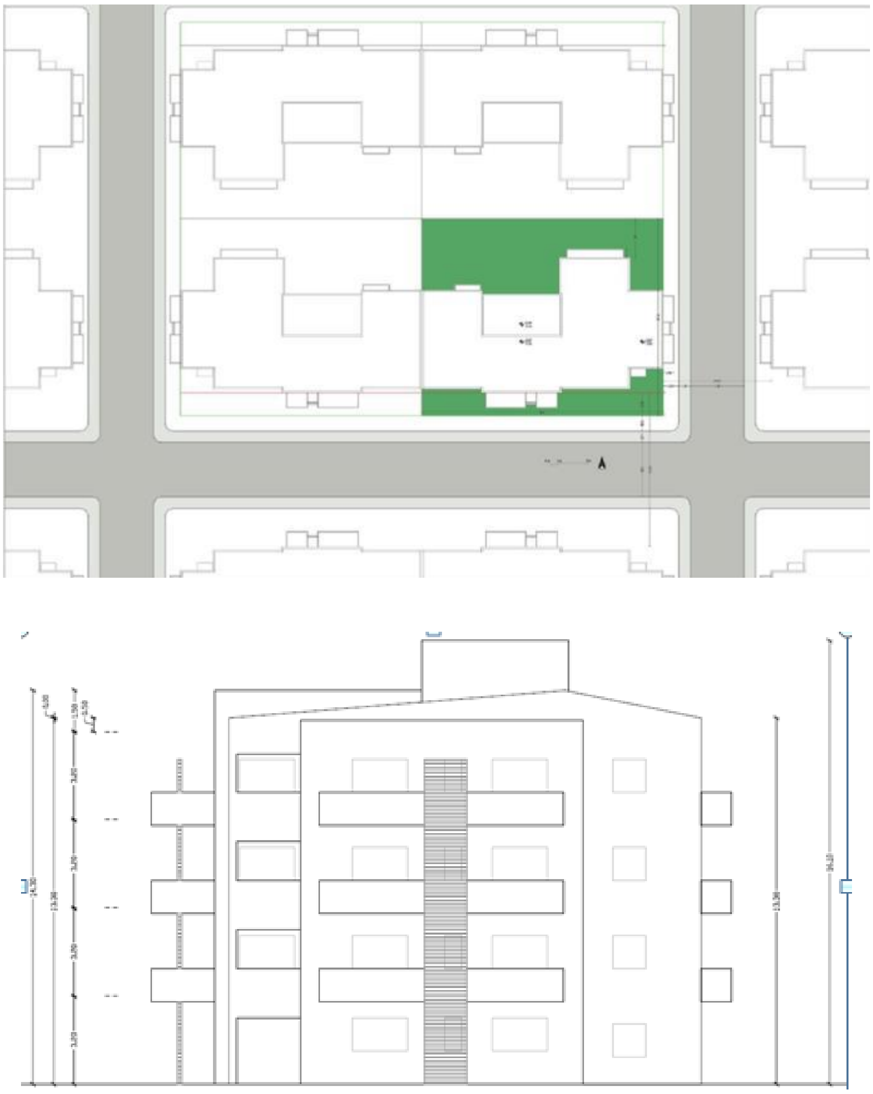

Figure 1: Office building's plan

The evaluation construction sections of the building envelope consist of brickwork and a variety of insulation materials based on their type and dimensions (Figure. 2). The eight developed construction scenarios are presented in table 1 focusing on using classic base insulation materials like stonewool, graphite expanded and extruded polystyrene as well as more innovative like PCMs [8]. The scenarios also used different width 5cm and 10cm in order to check the impact on the primary energy consumed and the environmental impacts.

The thermal conductivity (λ) of stonewool, graphite expanded polystyrene and extruded polystyrene, is 0.035, 0.031 and 0.033 (when width≤60mm) or 0.034 (when width>60mm), respectively. Moreover, the thermal resistance (R) is noted for 5cm and 10cm width of materials. In detail, the graphite expanded polystyrene has a 1.60m^{2}K/W and 3.20m^{2}K/W; the extruded polystyrene has a 1.50m^{2}K/W and 2.90m^{2}K/W and finally the stonewool has a 1.40m^{2}K/W and 2.85m^{2}K/W, respectively.

Table1. Scenarios simulated in terms of primary energy consumption and CO_2 emissions

Scenarios	Description
SC1	Non insulated
SC2	Extruded polysterene (5cm)
SC3	Extruded polysterene (10cm)
SC4	Expanded polysterene (5cm)
SC5	Expanded polysterene (10cm)
SC6	Stonewool (5cm)
SC7	Stonewool (10cm)
SC8	PCM

2.2. *Building Envelope*

The requirements of the Energy Performance of Buildings Directive, in conjunction with the progress towards new Nearly Zero-Energy Buildings (NZEB) by 2019 in non-residential, and therefore including office buildings, form the boundary conditions regarding the reference model construction characteristics for this study [9].

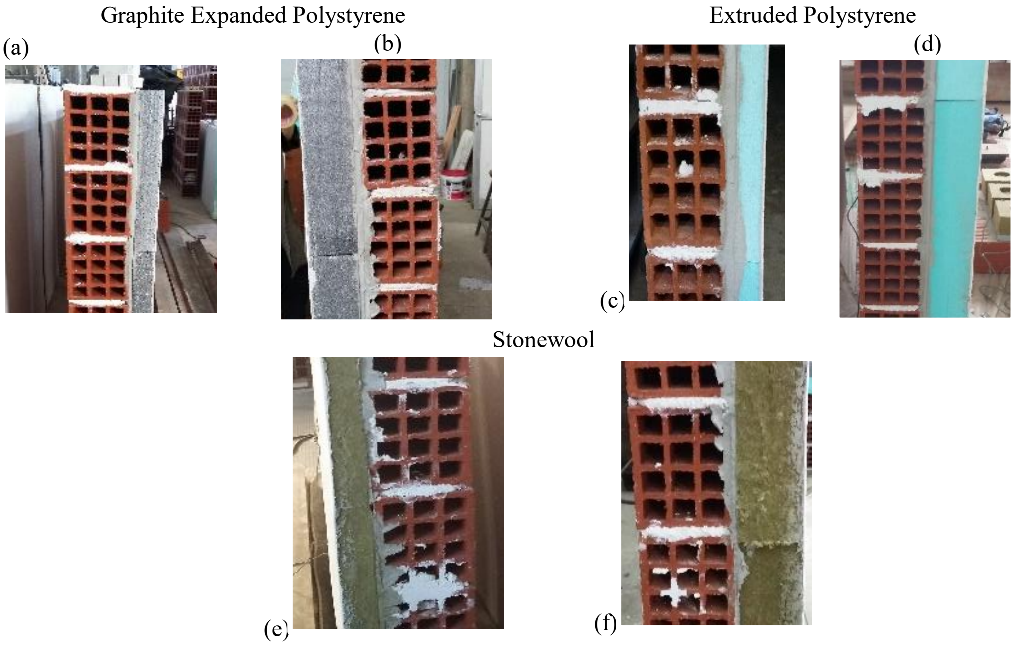

Figure 2. Presentation of under evaluation construction section of a typical building envelop, (a) 5cm of graphite expanded polystyrene; (b) 10cm of graphite expanded polystyrene; (c) 5cm of extruded polystyrene; (d) 10cm of extruded polystyrene; (e) 5cm of stonewool; (f) 10cm of stonewool.

The external wall consists of a typical medium-weight brick wall, insulated with extruded polystyrene (XPS), while also including a single-layer gypsum board with 12.5mm thickness on the interior side and a layer of gypsum plaster on the exterior. All the internal walls consist of two double-layer gypsum boards at about 25mm thickness. The floor and ceiling consist of a 150mm concrete slab with no additional coating.

3. Results analysis

The eight different construction typologies are evaluated in terms of primary energy consumption along with the carbon footprint related to the buildings life cycle. In the evaluation process the transportation of the construction products are also included in the inventory analysis. The SC1 which is the scenario with the non insulated external wall has increased primary energy use because of the increased energy consumed in the use phase while the carbon footprint indicator was reduced comparing to the other scenarios SC2, SC3,SC4,SC5,SC6,SC7,SC8 in which the CO_2 emissions are increased due to the production process of the insulation materials (table 3).

Table 2: Primary energy consumption and carbon footprint for the different insulation scenarios

SC	Primary Energy (kwh/m^2)	Carbon Footprint (kgCO$_2$/m^2)
SC1	53.56	392.56
SC2	35.38	401.86
SC3	33.71	412.86
SC4	35.81	391.54
SC5	33.95	393.33
SC6	35.53	393.79
SC7	33.76	397.80
SC8	33.31	383.08

Based on the LCA results, thermal insulation appears to be the element with the strongest impact after the concrete use. The impact assessment followed (table 3 and figure 3), demonstrated that the most significant impact categories are global warming, acidification and eutrophication. The ozone layer depletion, respiratory organics, aquatic ecotoxicity and aquatic eutrophication less significant contribution to the impact assessment. The impact of the global warming category, which is a quantified target in EU, accounts form from 128 kgCO$_2$eq/kg at the SC1 up to 182.3 kgCO$_2$eq/kg for the SC4 because of the significant emissions at the production phase of the extruded polystyrene (table 3 and figure 3).

Table 3: Environmental impacts for the insulation scenarios

SC	Global Warming (kgCO2eq/kg)	Acidification (kgSO2eq/kg)	Eutrophication (kgPO4eq/kg)
SC1	128	114	9.89
SC2	171.7	136	11.82
SC3	182.3	139.5	12.93
SC4	169.5	126	10.5
SC5	158.7	129.8	11
SC6	139	122	10.6
SC7	142.8	128.8	11.1
SC8	145	109	10.7

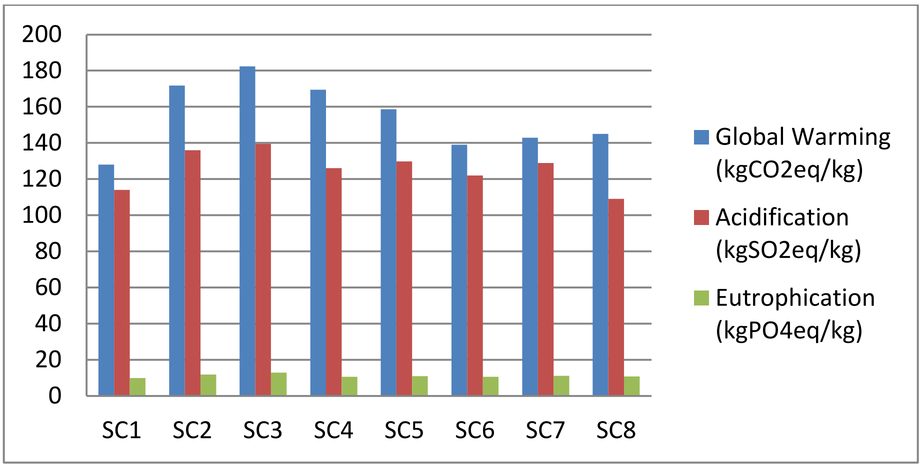

Figure 3: Environmental impacts for the insulation scenarios

The materials' contribution to the impact assessment analysis as depicted in figure 4 show a significant effect of concrete production process with almost 80% while the percentage of insulation material counts from 9% for the PCM (SC8), 13% for stonewool (SC6, SC7), up to 15% for the extruded polystyrene (SC2, SC3).

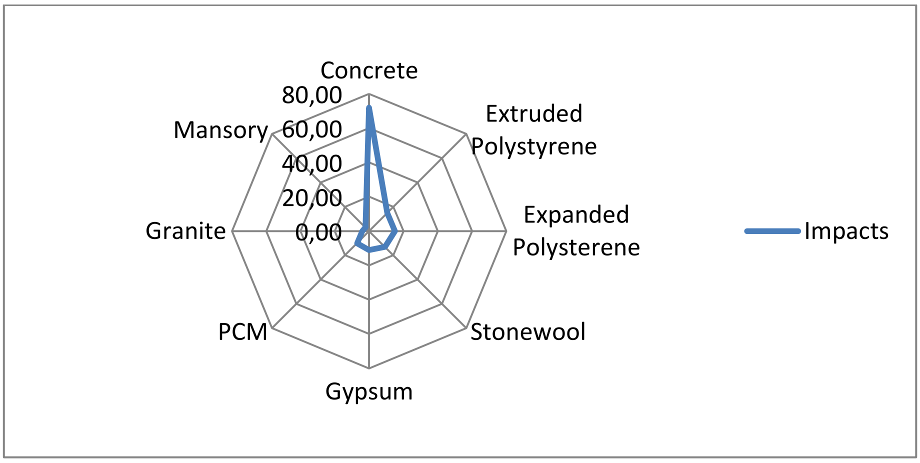

Figure 4: Material base impact analysis

4. Conclusions

The energy performance along with the reduced environmental impact of the life cycle of buildings still remains a key issue target for the EU energy and environment policy. The main challenge is to optimize the economic and environmental factors reducing the impacts at the materials' production phase in order to balance the benefits from the use phase without sacrificing the health and wellbeing of the users. Future work will focus on the introduction of renewable energy sources as a key parameter of achieving increased energy efficient and carbon neutrality.

Moreover, the requirements of the Energy Performance of Buildings Directive, in conjunction with the progress towards new Nearly Zero-Energy Buildings (NZEB) in non-residential, and therefore including office buildings, form the boundary conditions regarding the reference model construction characteristics for this study. Based on the scenarios analysis the impact of the global warming category, which is a quantified target in EU, counts form 128 $kgCO_2eq/kg$ at the SC1 up to 182.3

$kgCO_2eq/kg$ for the SC4 because of the significant emissions at the production phase of the extruded polystyrene. The primary energy consumption counts from 33.31 kwh/m^2 for the SC8 with the PCM contribution to the insulation up to 53.56 kwh/m^2 for the non insulated scenario. The monitoring stage reviled the role of insulation in the use phase of the building life cycle and the indicators could be even more improved if the circular parameter is introduced in the insulation materials' production process.

Nevertheless, significant progress has been made in the construction sector especially if we take into consideration that apart from the severe economic recession the construction sector has to confront unexpected circumstances like covid-19 which affect the real economy and increase the already unstable economic framework.

Acknowledgement
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