ENVIRONMENTAL FOOTPRINT ASSESSMENT OF INNOVATIVE CONSTRUCTION MATERIALS

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ABSTRACT

Conventional construction materials have been implicated, on a global level, in the excessive consumption of natural resources; what is more, the building industry comes second in consuming the biggest amount of raw materials after the industry of food production. Furthermore, based on the Life cycle Analysis of both construction materials and buildings in general, it was found that the use of conventional materials increases the environmental and energy footprint and, as a result, it is necessary to seek innovative solutions. These solutions consist in making the most of existing materials though the circular economy and sustainability. The construction and demolition waste can act as a resource which gets recycled and reused instead of contaminating and polluting the environment. The reduction, reuse and recycling of construction waste can be the input for producing innovative materials. In the present paper three types of innovative construction materials (ecological, reused and recycled) are compared with the convectional construction materials in terms of Life cycle Analysis (LCA) of a rock building subject of renovation and repair interventions. The operational energy of the building is calculated using the quasi-steady-state monthly method described in ISO13790, the embodied energy is calculated using the data base of Inventory of Carbon&Energy (ICE), of the University of Bath UK while for the LCA the Athena Impact Estimator. For each examined case the following impact indicators are calculated: Global warming potential, fossil fuel consumption, acidification potential, HH particulate, ozone depleting potential, smog potential, total eutrophication potential primary energy and non- renewable energy. The LCA showed the benefits that the reuse and recycling of materials has for the environment and the society. By using a combination of ecological, recyclable and reusable materials, the desired results can be achieved so that the environmental footprint decreases with the minimum cost possible.

KEYWORDS

Carbonate emissions, Construction waste, Environmentally friendly materials, Life Cycle Analysis

1. INTRODUCTION

The construction sector, in global level, depletes the 40% of natural resources, consumes the 40% of total primary energy and the 15% of fresh water resources and produces the 25% of total waste while emitting 40-50% of gaseous pollutants that cause the greenhouse effect [1]. These data indicate the depletion of energy resources, the need to reduce greenhouse gas emissions and the need to control the environmental impact of construction in conjunction with their social and economic impact.

During last years a great research effort has been devoted in finding new environmentally friendly building materials but also the environmental upgrade of the existing ones, in order to prevent the above mentioned reverberations. To achieve this goal, the principles of circular economy and sustainability are applied, emphasizing ‘reduce, reuse, recycle’ and waste elimination, imitating the strategies and patterns of nature.

This paper whether the use of environmentally friendly ecological materials as well as the recovery of waste and construction waste through reuse, processing and recycling, instead of conventional building materials can lead to lower energy consumption and lower environmental - energy footprint. The present research focus on rock wall buildings that represent the 7% of existing building stock in Greece [2]. Those building also present historical, cultural, architectural, aesthetic and tourist value in the context of the preservation of cultural heritage, awareness raising as well as the economic and social benefits of cultural tourism.

For this reason a typical stone house was examined with the Life Cycle Analysis software Athena Impact Estimator. Conclusions are drawn regarding the environmental - energy footprint of the building after the use of environmentally friendly materials for invasive reinforcement and repair work.

2. METHODOLOGY

2.1 Models used

For the life cycle analysis the software Athena Impact Estimator for Buildings software inversion 5.4.01 (version 5.43 Build 0101) [3] is used for the calculation of the following impact indicators: Global warming potential, fossil fuel consumption, acidification potential, HH particulate, ozone depleting potential, smog potential, total eutrophication potential primary energy and non- renewable energy. The above indices concerns five phase of the building/materials combinations: a) Production of materials, b) construction phase, c) use of building, d) End of life, e) Beyond building life.

The Athena software is developed to guide designers-engineers in a more accurate initial design by exploring the environmental footprint of different material for the shell building construction. Through the inventory of the life cycle from the foundation to the demolition of the building, the flows of energy and raw materials from and to nature, the emissions in the air, the water and the earth are recorded. The software has been developed for Canadian energy mix of electricity generation. For the needs of the present research the energy mix of Municipality of Halifax is used since it coincides with the Greek Energy mix of electricity generation and of energy resources consumption. Finally, it is designed for the calculation of buildings of rectangular cross-section

The Athena Impact Estimator software requires data regarding the operational energy of the building and the embodied energy of materials

The operational energy was calculated with the quasi-steady-state method described in ISO:13790 [4] with the monthly step using the TEE-KENAK Greek calculation tool with the following assumptions: a) use as family house, b) design temperature during heating period 20 oC and during cooling period 26 oC, c) calculation of energy needs for heating, cooling and domestic hot water. The used results are the primary energy consumption as well as the production of CO2.

The embodied energy of materials was calculated using the data base of Inventory of Carbon&Energy (ICE), of the University of Bath UK, v.2 January of 2011 [5]. This European data base is close to Greek materials, the followed methodology is considered valid and transparent while it contains a big number of materials. The used results are the embodied energy and the greenhouse gases emission for each material.

2.2 Study case

The present research concerns the invasive actions of strengthening and repairing the 1st floor of a stone-built typical historical house sited in Central Mountain Peloponnese. The floor plan of which is shown in figure 1. It is a 8.3 m x 12 m building, with height 4 m and pitched roof. All the masonry is made of stone 0.70 m thick, while the floor and the roof are wooden. The roof is covered with tiles. The openings' frames are metallic without thermal break with single glazing and have wooden shutters.

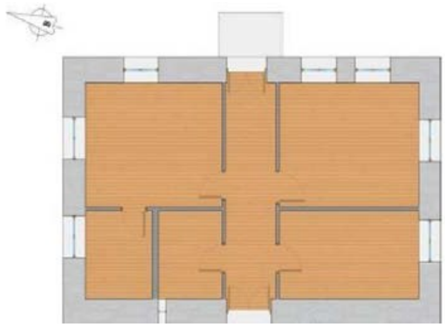

Figure 1. Floor plan of examined building.

For heating, a 6 kW oil boiler with an efficiency of 80% is used, with an insufficiently insulated distribution system and radiators on the external walls. For cooling, a split type heat pump with annual EER = 1.7 is used, without distribution network which covers 50% of the cooling loads. An electric water heater with boiler is used to produce domestic hot water.

2.3 Parametric study

Four renovation scenarios was examined. The scenario 0 corresponds to the usage of convectional construction materials and solutions. The scenario 1 is based in the usage of ecological construction materials [6]. The scenario 2 focuses in the reuse of materials and the use of materials from small-scale processing of construction or municipal waste such as glass and plastic. And finally the scenario 3 is based on recycling while retaining materials where it is preferred and a more realistic choice. The four examined scenarios are summarized in the following table 1.

Table 1. Examined cases

Intervention Type	***Intervention materials***			
	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Floor replacement	Concrete slab	three-ply timber of local origin	reuse of timber of local origin	Recycled timber
demolition and local restoration of the north side due to an extensive crack in the load-bearing masonry	addition of new stone walls and cement mortar	addition of new local stone and mortar from mud and sawdust	reusable stone and inert glass mortar	reusable stone and cement mortar with recycled glass replacement rate
Roof replacement	conventional wood (pine wood) and clay tiles	logs of the area (spruce timber), stone for coating and insulation from mineral wool	logs of the area (spruce timber), stone for coating and insulation from mineral wool	recycled wood and recycled tiles
grout injections in local cracks	cement mortar	ecological mud and sawdust mortar	cement mortar with a percentage of aggregates from lightly processed recycled glass	cement mortar with a percentage of cement replacement from recycled glass

mass homogenization on the east side of the building	cement mortar	ecological mud and sawdust mortar	cement mortar with a percentage of aggregates from lightly processed recycled glass	cement mortar with a percentage of cement replacement from recycled glass
Replacement of windows	aluminum frame and double glazing	Frame of new local timber (spruce timber) and double glazing	Frame of reusable spruce timber and double glazing	Frame of recycled timber and double glazing
Energy performance upgrade	internal thermal insulation from expanded graphite polystyrene 8 cm of exterior masonry	Internal insulation of exterior masonry and roof from 8 cm mineral wool	Internal insulation of exterior masonry and roof from 8 cm mineral wool	Internal insulation of exterior masonry from 8 cm mineral wool

3. RESULTS AND DISCUSSION

In Figures 2-10 the impact indicators are presented comparatively for the 5 examined phases of building life. In Figure 2 the Global Warming potential is presented in Kg of equivalent CO_2. The energy consumed during the use of the building seems to have the bigger contribution in warming potential. The second important contributor is the materials' production phase followed by the building construction phase. From the examined scenarios the best behavior is achieved with the scenario 2 which corresponds to the reuse of construction materials and the worst scenario is the one concerning the conventional construction materials.

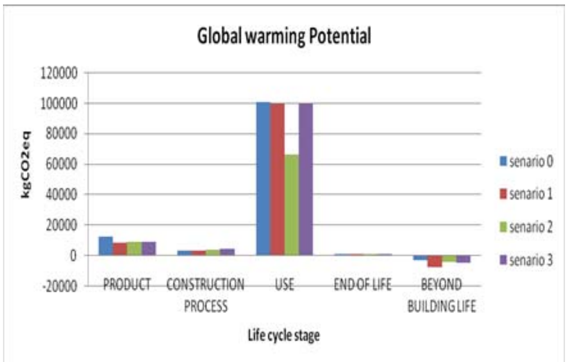

Figure 2. Global Warming Potential

In figure 3 the acidification potential is given in Kg of equivalent CO2. The comments are the same as for the Global Warming Potential with enhanced contribution from the construction phase.

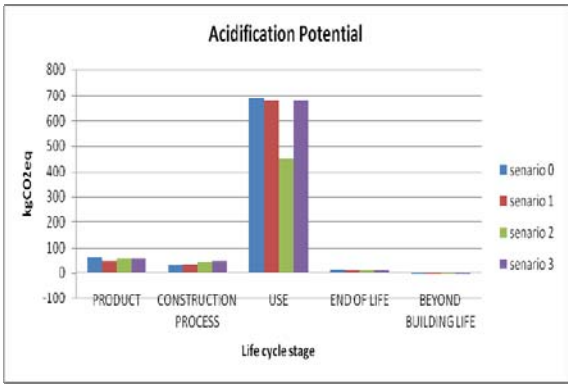

Figure 3. Acidification Potential

In figure 4 particulates matter of various sizes (PM10 and PM2.5) that have a considerable impact on human health are presented in kg of equivalent PM2.5. Except from the phase of building operation important are the HH particulate that appears in the phase of production of the construction materials. Again the lower amounts of PMs are emitted in the case of reused materials in the materials production phase and during the building operation. The smallest amount of particles is emitted by reusable materials followed by recyclable and environmentally friendly materials. Conventional construction materials are responsible for the largest particle emissions

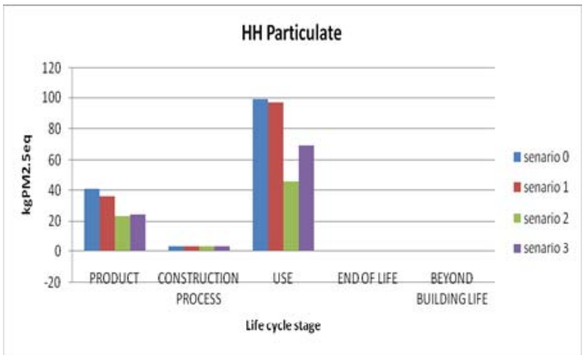

Figure 4. HH Particulate

Figure 5 shows the eutrophication potential during the life cycle stages of the building in kg of equivalent N2. Conventional materials present high eutrophication potential in the phase of their production as well as in the phase of building operation. The lower eutrophication potential belongs to reused materials while the recycled and the environmental friendly behaves in the same way.

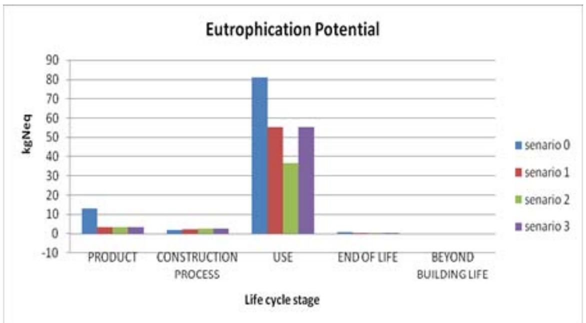

Figure 5. Eutrophication Potential

Figure 6 gives the Ozone Depletion Potential of the examined cases in kg of equivalent O3. Again the higher ozone depletion arises from the building operation with the reused materials presenting the better behavior and the other three scenarios having almost the same behavior. The rest building life cycle phases can be ignored in this impact indicator.

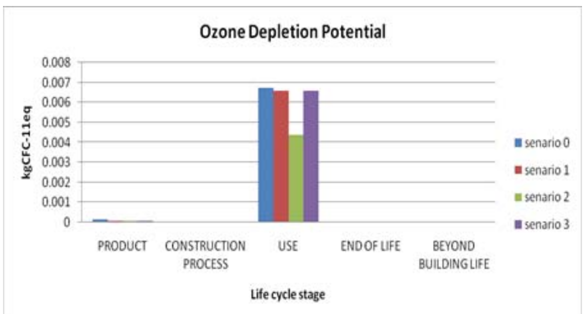

Figure 6. Ozone Depletion Potential

In figure 7 the smog potential of the examined cases is presented in kg of equivalent CFC. In this case important smog potential appears in the phases of materials' production and of building construction. During the materials production the differences between the examined scenarios are small with the conventional materials behave with the worst way. On the contrary during the building construction phase the conventional construction materials have the best behavior followed by the ecological materials, reused materials and finally recycled materials. Important can be also characterized the contribution of the end of building life phase. Nevertheless during the operation phase of the building, and therefore overall, the reusable materials have the best performance

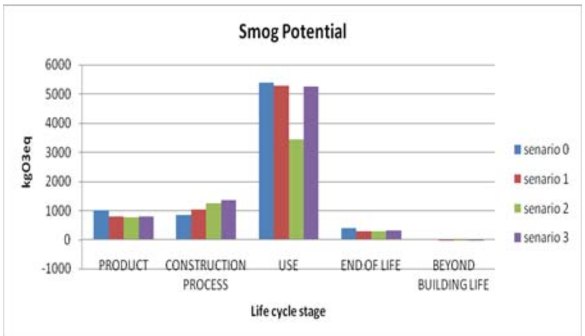

Figure 7. Smog Potential

In figure 8 the fossil fuel consumption is given in MJ. During the materials production and building construction phases all examined scenarios have almost the same behavior with the ecological materials excelling during the production phase and the conventional construction materials during the building construction phase respectively. Again during building operation best results are achieved with the reused materials.

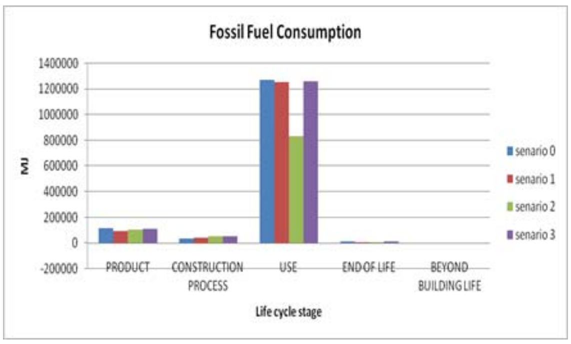

Figure 8. Fossil Fuel Consumption

In figure 9 the consumption of primary energy in MJ for the examined scenarios in life cycle phases of the building are compared. Again the most important part of consumed primary energy is related with the building operation and with the materials production with the reused materials presenting the best results. In the rest phases the patterns are the same with one described in fossil fuel consumption.

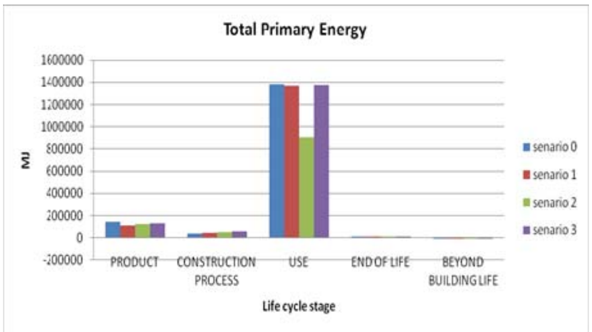

Figure 9. Total Primary Energy

Finally in Figure 10 the non-renewable energy consumed for the examined cases is presented in MJ. The observed patterns are the same as the one described in fossil fuel consumption and in primary energy consumption with an overall excelling of the reused materials.

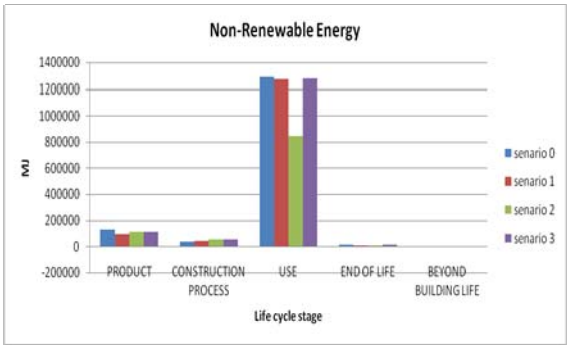

Figure 10. *Non Renewable Energy*

4. CONCLUSIONS

From the presented materials it comes out that the most important source of environmental impact is the building operation, followed by the phase of materials construction and the phase of building construction. The phases of end of use of the building and beyond building life contribute little in the building environmental footprint. During the materials production phase and during the building construction phase all the scenarios give comparable results. But during the building operation phase the reused materials present the lower environmental impact as they are described in scenario 2. Overall, the greatest burden on the environment and society comes from the use of conventional materials, scenario 0. Ecological construction materials do not seem to fulfill the expectations for low environmental foot print since they lead to depletion of natural resources.

REFERENCES

[1] Grace K. C. Ding., 2016 ‘Life cycle assessments (LCA) sustainable building materials: an overview’ University of Technology Sydney, Australia

[2] Hellenic Statistical Authority, 2011, 'Building census 2011' http://www.statistics.gr/el/census-buildings-2011,retrived 30/12/2018

[3] Athena Sustainable Materials Institute, 2015, 'Athena Impact Estimator for Buildings'

[4] Energy performance of buildings - Calculation of energy use for space heating and cooling (ISO 13790:2008)

[5] Hammond, G& Jones, Cr 2011,’Inventory of Carbon & Energy (ICE) Version 2.0’, University of Bath, Bath

[6] Berge, Bj 2009, The ecology of Buildings Materials, Architectural Press, Burlington