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To cite this article: D N Isopescu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **586** 012010

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Analysis of contemporary solar house in terms of sustainability criteria

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Abstract. When discussing the importance of sustainability principles for both architecture and construction fields, the selection and analysis of design directions (from concept to implementation phase) represent a major topic of the whole integrated process. The constructions sector has already established itself worldwide as an important consumer of both energy and resources. Therefore, the long life of the edifices implies that initial design decisions (conceptual phase) have a significant, amplified effect over time. This paper presents a proposal for a contemporary solar house, with a design in accordance to sustainability criteria. The research highlights the methods applied in the conceptual phase, as well as a comparative study in terms of embodied energy, with two scenarios for the structure: wooden frame versus masonry. Life cycle assessment methods (LCA) have played an important role in optimizing the proposed model in order to deliver a product that is both environmentally and economically efficient.

1. Introduction

When discussing the future of sustainable development, the overall consensus is that finding new solutions to energy production and consumption issues should be of fundamental importance. Currently, the maintenance and further progress of living standards, in the economic, technical and social sectors depend mainly on improving the energy efficiency of buildings, the technological systems and especially ensuring the use of sustainable energy sources and materials with minimal impact on the environment [1]. The future of housing design will definitely take into account environmental issues, which are already at the core of the policy for governments, industry and non-profit organisations worldwide. The most important aspects to be considered are: life-cycles assessments, production technologies analysis, energy efficiency and regional impact studies [2].

1.1. Sustainability principles incorporated in the design stage

Integrated design is essential in respect to sustainability criteria and involves several aspects that need to be taken into account from the conception phase (house orientation, materials, energy efficiency strategies, etc.) and the collaboration of different fields (architecture, construction, sociology, etc.). An important component is represented by passive solar design, a cumulative method of organizing the premises of a building that exploits and controls radiation input. The goal is to maximize positive inputs in the cold season while reducing the effects of overheating during the warm season [3].

The house presented in this paper incorporates integrated passive design strategies, analyzed in the conceptual phase. Life cycle assessment (LCA) and energy efficiency evaluations have been performed in order to support the premises and to optimize the model.

The semi-detached house (cumulating a total living area of 160m²), figure 1, has been designed as part of a research study focused on developing ecological and affordable dwellings for a residential



development comprising approximately 100 housing units, on the outskirts of Iasi, Romania. The task was to establish a balance between ecological design principles and economical solutions, specific to regional technical building practice. In this respect, the following strategies have been implemented:

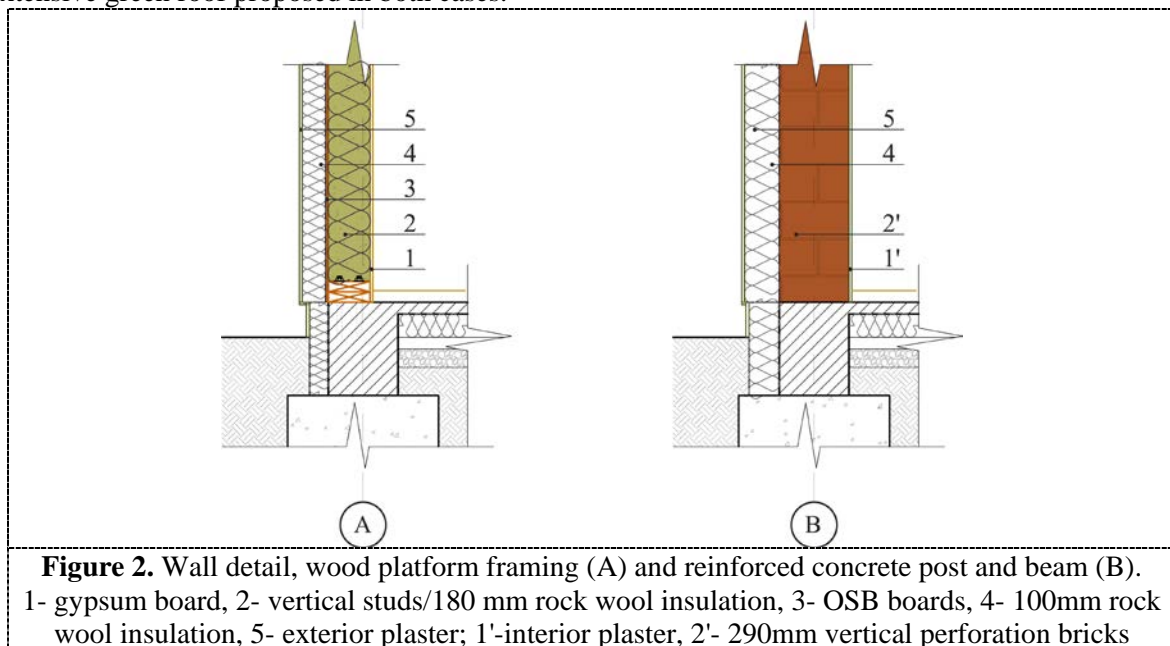
- *optimal orientation.* The houses overall geometry coupled with the opportunity of double access/entrance (from the front and the back) determined an unconventional approach in order to maximise solar exposure for both houses that compose the semi-detached unit. Instead of the traditional linear distribution that would have provided southern exposure only to one house, thus leaving the other exposed mainly to the North, a different juxtaposition solution was adopted (back-wall adjacency). Thus, both houses can benefit from southern exposure, even if not in equal terms, exploiting south-east and south-west directions.
- *passive solar design strategies.* The functional distribution of rooms and the subsequent glazing ratio of the facades follow the passive design strategies, with southern orientation of living area and north orientation for technical spaces. The generous south-facing windows are shaded during summer by either volumes or roof eaves, while allowing for passive solar gains in winter, when the sun's trajectory is lower. The indoor open space permits north to south cross-ventilation.
- *materials.* The environmental benefits of wood are universally acknowledged, as listed forward: renewability, good strength-to-weight ratio, low- embedded energy, low carbon impact. Also, it is an aesthetically pleasing material, thus being a desirable choice for the housing program [4]. The wooden platform framing system has been analysed in a LCA comparison with a reinforced concrete and brick structure, the latter representing a commonly used solution in Romanian building practice.
- *energy efficiency of envelope elements.* The optimal solution selection strategy for energy efficiency in residential buildings synthetically consists of: listing of above mentioned technical solutions, designed to increase energy efficiency; optimal solutions selection in accordance with restrictions arising from specific analysis and impact assessment.
- *active solar design strategies.* The implementation of solar systems for housing units technologies remains a priority, Iasi being located in an area with annual solar energy fluxes ranging from 1120-1490 kWh/m² per year, applying the Photovoltaic Geographical Informational system (PVGIS) [5].



Figure 1. Renderings of the semi-detached houses

1.2. Investigation of structural and envelope scenarios

For the same architectural solution, two scenarios for the structure and enclosures have been considered, both well suited in terms of spans and loads: *wood platform framing* and *reinforced concrete post and beam* with vertical perforation bricks masonry framed walls, figure 1. The wooden structure consists of 200 mm wide studs, spaced at 400 mm, stiffened at the exterior with OSB boards and protected by an outer layer, 100 mm thick, of rock wool insulation. In between studs insulation is placed, with vapour barrier and gypsum boarding to the interior. The slabs consist of 240 mm thick beams, strengthened with OSB boards and the same median layout and to the interior as the walls. The concrete system consists of 300x300 mm columns and 300x450 mm beams, with 290 mm thick masonry, plaster to the interior and 100 mm thick rock wool insulation to the exterior, figure 2. The reinforced concrete slabs are 150 mm thick, with a 100 mm thick ground slab that was implemented in both solutions. The pre-dimensioning of elements had to take into account the extra loads given by the extensive green roof proposed in both cases.



2. Life Cycle Assessment comparison in the design stage

Life Cycle Assessment (LCA) methodology evaluates inputs and outputs of a system, in particular a construction, over a life cycle, in terms of system interaction with the natural environment. Systemic modelling takes into account all inputs, including raw material extraction, energy and water consumption, among the most important and all outputs, including mainly air emissions, water and soil pollution values [6].

2.1. Methodology of the environmental assessment

Based on analysis of available software and study of scientific literature, ATHENA Impact Estimator was chosen, a program that allows complex modelling and is also suitable for comparative evaluations in early design stages. The software can be used for LEED global assessments and is based on the life cycle standard: *ISO 14040, Environmental Management, Life Cycle Assessment, Principles and Framework*. ATHENA Impact Estimator [7] is a useful tool in making decisions about the impact of materials on the environment, in cradle to grave assessments, incorporating input data related to production, energy and transport processes [8]. Jrade and Jalaei, 2013, have developed an integrated building evaluation model using ATHENA Impact Estimator, which they consider to be an international tool for LCA evaluation, which allows users to implement various project modifications,

replace materials, and make comparisons to optimize any model [9]. For the model evaluation, the information related to the proposed dwelling and a detailed extract of materials, in both scenarios, were used. The estimated life expectancy is of 60 years, from material extraction phase up to demolition and recycling. Since the software uses the energy balance specific only to cities and states in North America (not from Europe), a comparison was made between Romania's energy balance and all states in the program database, opting for Portland, Oregon, with the closest values to those of our country. The data for each building element was entered separately, based on predefined program elements, modelled to match the proposed stratifications. Since the program has certain limitations, which do not allow for the introduction of more complex elements, each building component (floor, walls, roof) was added, using the *Extra Materials* option, with additional materials not included in the predefined configurations, resulting in a model matching the proposed design. For the windows, project-specific data was introduced, modelling the opaque – glazed ratio for each wall, opting for triple glazed aluminium frame. Two simulations have been performed for each of the scenarios for the structure and enclosures, wood platform framing (WPF) and reinforced concrete post and beam (CPM).

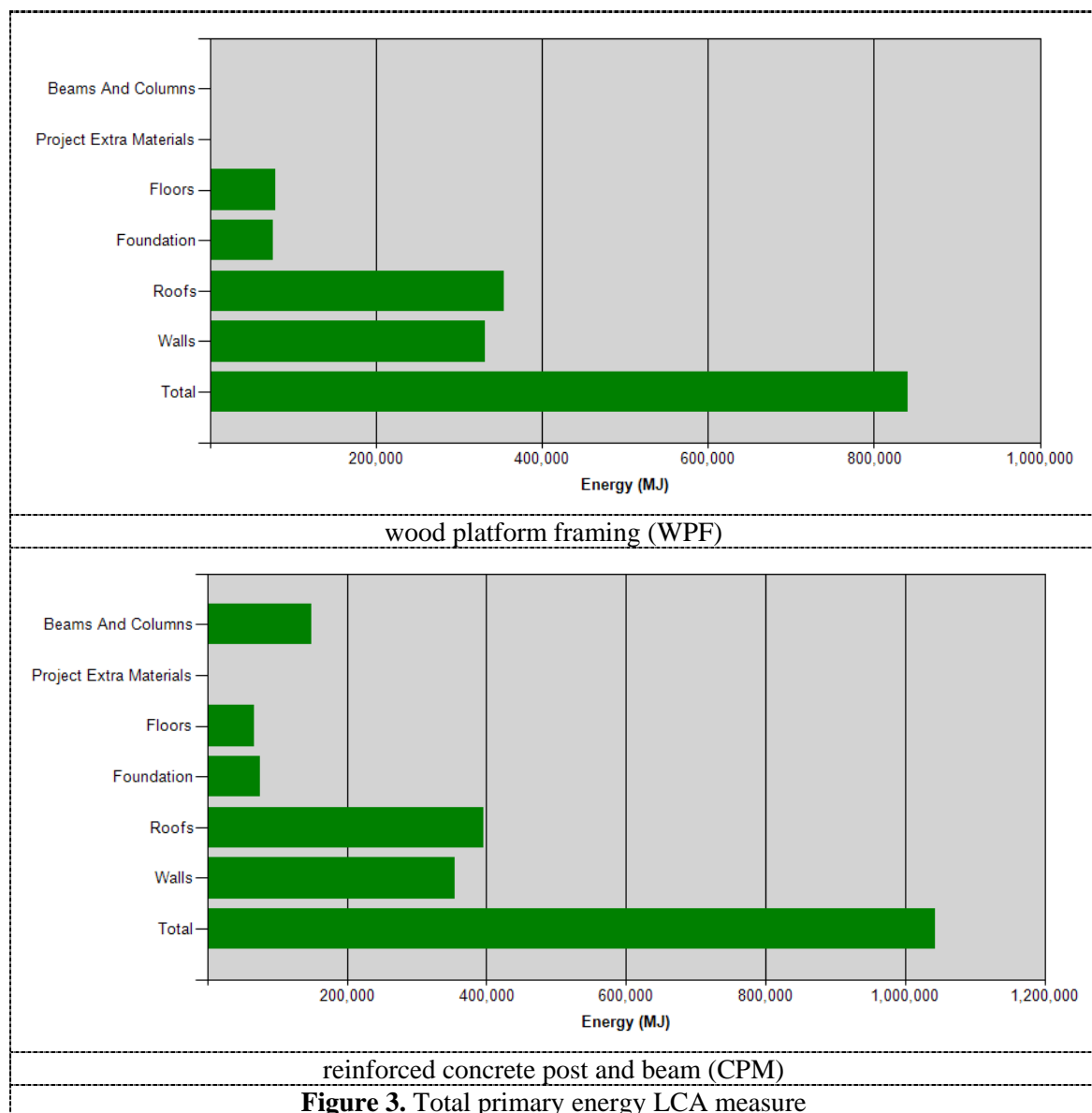
2.2. Results and discussions

After entering all the necessary information, ATHENA Impact Estimator provides a series of reports on:

- Primary Energy Consumption;
- Acidification Potential;
- Global Warming Potential;
- Human Health (HH) Respiratory Effects Potential;
- Ozone Depletion Potential;
- Photo- chemical Smog Potential;
- Eutrophication Potential, table1.

LCA Measures	Unit	Product		Process		End Of Life		Total	
		WPF	CPM	WPF	CPM	WPF	CPM	WPF	CPM
Global Warming Potential	kg CO ₂ eq	3.24E+04	5.47E+04	5.67E+03	6.40E+03	1.80E+03	2.95E+03	5.44E+04	7.86E+04
Acidification Potential	kg SO ₂ eq	2.23E+02	2.97E+02	6.01E+01	6.44E+01	1.64E+01	3.02E+01	4.01E+02	4.95E+02
HH Particulate	kg PM _{2.5} eq	5.83E+01	8.23E+01	4.83E+00	4.87E+00	8.06E-01	1.62E+00	1.06E+02	1.30E+02
Eutrophication Potential	kg N eq	1.71E+01	3.74E+01	3.93E+00	4.69E+00	8.97E-01	1.75E+00	2.45E+01	4.65E+01
Ozone Depletion Potential	kg CFC-11 eq	7.94E-04	1.03E-03	4.85E-05	5.05E-05	1.10E-07	1.55E-07	9.29E-04	1.17E-03
Smog Potential	kg O ₃ eq	2.57E+03	3.57E+03	1.68E+03	1.87E+03	4.61E+02	9.05E+02	5.48E+03	7.21E+03
Total Primary Energy	MJ	5.43E+05	7.21E+05	8.35E+04	8.95E+04	2.52E+04	4.25E+04	9.65E+05	1.17E+06
Non-Renewable Energy	MJ	4.54E+05	6.58E+05	7.76E+04	8.69E+04	2.51E+04	4.20E+04	7.91E+05	1.02E+06
Fossil Fuel Consumption	MJ	4.25E+05	5.84E+05	7.68E+04	8.55E+04	2.46E+04	4.15E+04	7.46E+05	9.33E+05

From the comparative results presented in the table above, we can conclude that the post and beam solution has a greater impact on the environment, aspect attributed in part to the higher embodied energy in the reinforced concrete elements and the difficulties related to the recycling of these materials. The overall difference is about 45% higher in the case of post and beam structure in terms of global warming potential, 21% for the total primary energy. These differences in the calculated values for the global warming potential can be largely attributed to the use of wood, which stores CO₂ through the photosynthesis process, during the tree's life, which afterwards becomes "captive" in the products, elements or structures that use this material. As shown in figure 3, the main differences occur within the elements employing the most reinforced steel and concrete (post and beam, floors, where the total energy difference is almost 2.0E+5MJ) and less in respect to elements utilising masonry (for walls the difference is negligible). The estimated design life of only 60 years is a simplified approach that does not give enough credit to the main sustainability quality of concrete and masonry, and that is their durability.



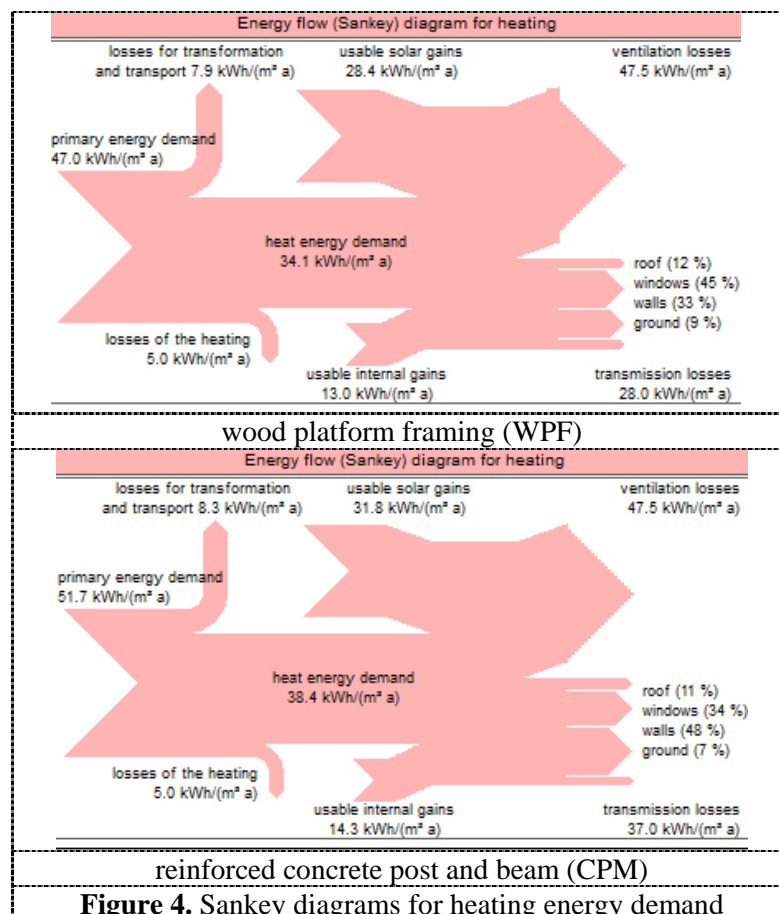
3. Energy efficiency assessment

In order to determine the best scenario in terms of thermal efficiency, the house has been evaluated through numerical simulations using specialized programs, in particular CASAnova software [10]. The inputs are based on the computed values of the adjusted thermal resistances for each specific element for the wooden platform framing (WPF) and concrete post and beam (CPM) solutions, table 2. Adjusted thermal resistances (R'), expressed in $m^2 K/W$, represents the corrected value of thermal resistance by the influence of the thermal bridges and tends to equal the value of the real characteristic of the constructive element [11].

Table 2. Adjusted thermal resistances (R') for constructive elements specific to the wooden platform framing (WPF) and concrete post and beam (CPM) scenarios.

Element	R' value WPF [$m^2 K/W$]	R' value CPM [$m^2 K/W$]
Ground slab	6,083	6,083
Exterior wall	7,416	3,910
Roof	7,495	6,188

The results of the comparative study indicate a high level of energy efficiency, characterised by low specific annual energy consumption for heating (q_i) in both scenarios, aspect largely due to solar gains, as presented in the Sankey diagrams, figure 4.



4. Conclusions

Implementation of passive design strategies in the conceptual phase of a project is as important as design optimization through numerical simulations, in terms of embedded energy and thermal efficiency. With respect to sustainability criteria, the comparative study presented in this paper underlines that wooden structure is a better solution than reinforced concrete and masonry. Both life cycle assessment and energy efficiency simulations prove that wooden platform framing can be a more appropriate sustainable option. Thus, in terms of life cycle assessment, the comparative study all sustainable parameters indicate a less impact on the environment in the case of the wood structure. The most relevant is the Total Global Warming Potential that is $7.86 \text{ E}+04 \text{ Kg CO}_2\text{eq}$ in the case of reinforced concrete, compared to $5.44 \text{ E}+04 \text{ Kg CO}_2\text{eq}$ in the case of wood platform framing (a 70% difference). In terms of heating and cooling energy demand, primary energy for heating is smaller in the case of wood platform framing ($47.0 \text{ kWh/m}^2\text{a}$ compared to $51.7 \text{ kWh/m}^2\text{a}$ for concrete post and beam).

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Acknowledgments

This paper was elaborated with the support of the “Ecoinnovative Products and Technologies for Energy Efficiency in Constructions – EFECON” re-search grant, project ID P_40_295/105524, Program co-financed by the European Regional Development Fund through Operational Program Competitiveness 2014-2020.