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Партизански одреди 24, П. Фах 560, 1000 Скопје Северна Македонија

MASE
MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS
Partizanski odredi 24, P. Box 560, 1000 Skopje North Macedonia

MMT-10
mase@gf.ukim.edu.mk
http://mase.gf.ukim.edu.mk

ENVIRONMENT AS AN ASPECT OF LIFE CYCLE ASSESSMENT ANALYSIS TOWARDS SUSTAINABLE BUILDINGS

Mihail NAUMOVSKI[1], Marijana LAZAREVSKA[2]

ABSTRACT

There is no doubt that climate change is the biggest threat to humanity; and vice versa - humanity is the biggest threat to the planet. The concentration of greenhouse gasses in the atmosphere is on the rise and there is enough scientific evidence that highlights the threat and the potential of climate change.

The building sector accounts for up to 25% of globally available resources. Furthermore, it has been estimated that the building sector is responsible for up to 33% of the global greenhouse gas emissions. These are mainly the reasons why environment is chosen as one of the three main parameters in the Active House Design. The Environmental category is then divided into three subcategories: LCA Evaluation (Environmental Impact), Freshwater Consumption and Sustainable Sourcing.

An Active House aims to have a positive impact on the environment through several different strategies that are presented in this paper. Life Cycle Analysis (LCA) is a method that is being increasingly used to evaluate the potential environmental impacts of products and services and their resource consumption. LCA is also being used in the building sector as a crucial part of the assessment of buildings environmental sustainability.

The aim of this paper is to develop an example of a Life Cycle Assessment on a case study building in order to define the environmental impact of the designed building.

Life Cycle Assessment is being performed through surveying of all inputs and outputs linked to the building's life cycle. Potential environmental impacts are being analyzed and calculated on the basis of different key factors, such as consumption of resources, emissions etc. All the impacts are being analyzed for each stage of the building's life cycle., while the LCA is performed according to EN 15804. The results presented in this paper are being calculated through a selected range of measurable indicators.

Keywords: Life Cycle Analysis; Active house design; assessment; sustainability; building; construction; environment; resources.

[1] Gymnasium Josip Broz Tito, Bitola, Republic of North Macedonia
[2] Faculty of Civil Engineering, University "Ss. Cyril and Methodius", Skopje, Republic of North Macedonia

Corresponding author: Marijana LAZAREVSKA, e-mail: marijana@gf.ukim.edu.mk

1. INTRODUCTION

The building sector accounts for up to 25% of the globally available resources; this is mainly the reason why Environment is chosen as one of the three main parameters in the Active House Design. The environmental category is then divided into three subcategories: Evaluation (Environmental Impact), Freshwater Consumption and Sustainable Sourcing. The emissions are divided into five categories (equivalents): Global Warming Potential [kg CO_2–eq.], Ozone Depletion Potential [kg R_{11}–eq.], Photochemical Ozone Creation Potential [kg C_2H_4–eq.], Acidification Potential [kg SO_2–eq.], and Eutrophication Potential [kg PO_4–eq.].

Life Cycle Analysis (LCA) is one of the most frequently used tools for environmental assessment of materials and buildings; this is because of the possibility to include every stage in the Life Cycle of a particular system.

An Active House aims to have a positive impact on the environment through the following strategies:

- Limitation of the environmental loads during the whole life cycle of the building: The construction process of a new building leads to different emissions to air, soil and water.
- Minimization of freshwater consumption: The demand gets higher each year which leads to depletion and scarcity of freshwater resources.
- Taking sustainable constructions and sourcing into consideration: Sourcing and use of recyclable materials is key for minimizing the carbon footprint.

The aim of LCA is to calculate the overall environmental impact the building has throughout its life cycle. The environmental impact starts with the product stage, then construction process, use stage and end of life. Concerning materials, the LCA must be performed according to EN15804. Environmental Product Declarations (EPDs) are used in the building-level calculation. At the building level the LCA must be performed according to EN15978. The following is needed to carry out an LCA calculation:

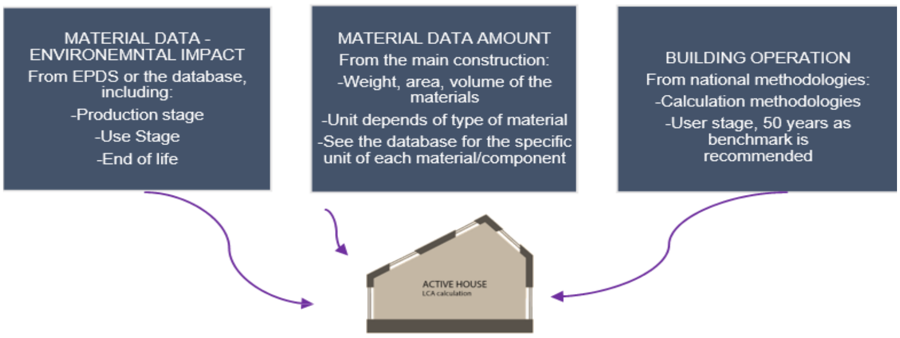

Fig 1: Input parameters needed to carry out an LCA.

1.1 LCA as a method in construction

Life Cycle Assessment (LCA) is a method which is being increasingly used to evaluate the potential environmental impacts of products and services, and their resource consumption. LCA is also being used in the building sector, where it is a crucial part of the assessment of building's environmental sustainability. For the different players working in the assessment of the environmentally related parts of sustainable building, LCA provides a basic knowledge of the parameters that contribute to resource use and the potential environmental impacts during a building's life cycle. Incorporating LCA as a tool in the building design stage, makes it possible to evaluate the environmental significance of building elements or of the different life cycle stages of the building. LCA can thus be used as part of the environmentally friendly design of buildings and in documenting the results.

More sustainable solutions will be achieved by shifting the focus from optimizing the buildings parts and products; lifetime, to considering their life cycles. Materials and building parts should be recyclable, either as whole components or as part of the production of new products.

An LCA of a building normally involves evaluating its whole life cycle. This means including all of the stages in the assessment – raw material supply, manufacture of construction products, the construction process stage, use stage, demolition and when the materials are disposed or recycled. The building's life cycle is therefore divided into five stages: The product stage, construction process stage, use stage, the end-of-life stage and benefits and loads beyond the system boundaries.

Fig 2: Various stages of LCA of a product.

Most often, the first two stages are best known, even though in practice acquiring sufficient data for the calculation can be problematic. The next three stages are scenario-based, which means that assumptions have to be made about how the building will be used, maintained, and finally demolished. According to the European standard EN 15878:2011, the final stage, which concerns the recycling of building waste, must be reported as separate part of the calculation.

1.2 Environmental loads

LCA involves surveying all of the inputs and outputs linked to the examined system's life cycle. The potential environmental impacts are calculated on the basis of all of the inputs and outputs, i.e., consumption of resources and emissions which can be associated with the different processes.

The results of an LCA can be calculated using a selected range of measurable indicators. The most used indicators for assessing environmental impact and resource use are shown below (Fig 3.).

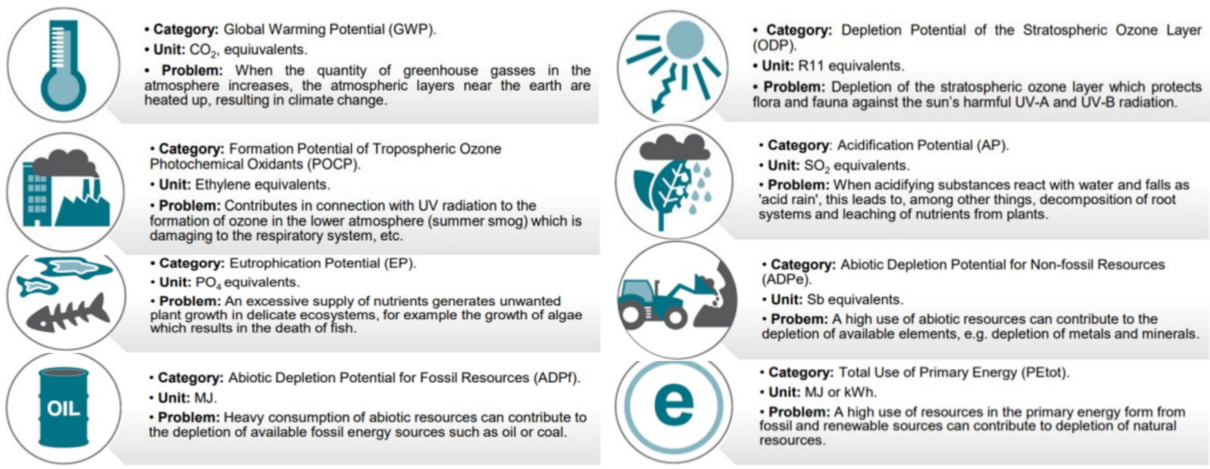

Fig 3: Most used indicators for the purpose of assessing environmental impact.

2. THE MAIN GOAL

The aim of this paper is to develop LCA on a case study in order to define the environmental impact of a designed building. Calculations of the quantities of each material used is needed in order to assess the emissions of each single component of the functional unit. The results obtained in terms of production can be used in the Active House Protocol in order to fulfil the third category which is the "Environment", and is composed of necessary parameters for "Environmental Loads", "Freshwater consumption" and "Sustainable construction" of the previously mentioned protocol.

In order to perform the LCA analysis, certain codes have been used as reference:

- BS EN ISO 14040:2006: Environmental management – Life Cycle Assessment – Principles and framework.
- BS EN ISO 14044:2006: Environmental management – Life Cycle Assessment – Requirements and guidelines.

- BS EN 15804:2012: Sustainability of construction works – Environmental product declaration – Core rules for the product category of construction product.
- BS EN 15978:2011: Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method.

3. DESIGN OF THE BUILDING

3.1. Architectural design

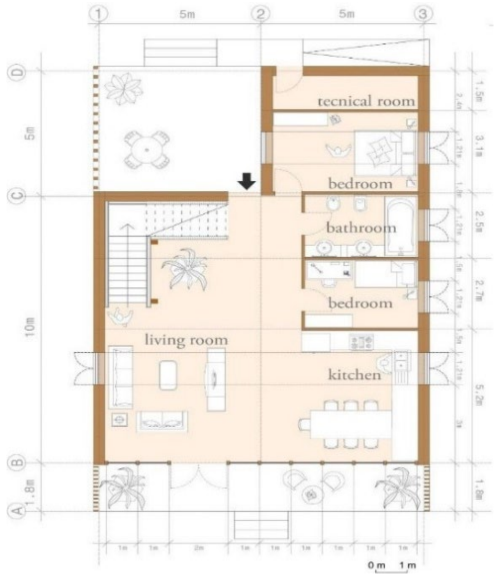

Fig 4: Architectural plan of the ground floor.

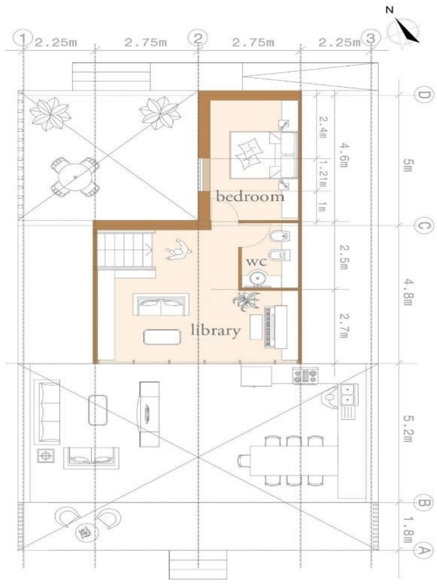

Fig 5: Architectural plan of the mezzanine floor.

As it can be seen above from the ground floor plan (Fig 4.), there are two entrances, the main entrance from the porch facing north, and the south entrance. The main part of the ground floor is the opened living room area with the kitchen composing a total of 90 [m^2], one master bedroom with 18 [m^2], one smaller bedroom with 12 [m^2], one main bathroom with 10 [m^2], which altogether are defining the usable space for the ground floor, which is 130 [m^2]. The south porch has a total of 20 [m^2], and the north porch 25 [m^2]. On the mezzanine floor plan (Fig 5), there is the living room staircase leading up to the opened library with total area of 28 [m^2], one small toilet with 4.5 [m^2]. Altogether they compose total usable area of 45 [m^2]. The ground floor and the mezzanine level together compose a total area of 175 [m^2].

Fig 6 and **Fig 7**: 3D model of the building.

3.2. Structural design

The structural skeleton is made entirely from wood. The roofing structure is composed of the main ridge mean (30x50cm), seven primary beams (25x40cm), and fourteen secondary beams (10x20cm). The walls are made from cross laminated timber (CLT technology) and they amount to 160.3 [m^2]. CLT offers high strength and the structural simplicity needed for cost-effective buildings, as well as a lighter environmental footprint than concrete or steel. It also provides numerous other benefits, including quicker installation, reduced waste, thermal performance and design versatility.

Fig 8: Structural design of the building.

4. GOAL AND SCOPE DEFINITION

The most important step according to the codes is to define a goal and scope of the analysis in the LCA framework. Basically, it is of great importance to define what is going to be analyzed and why this content is going to be processed in the LCA. The results of this step are to define the functional unit, by answering five main questions of the case study (the residential building):

What? How much? How long? Where? How well?

In this case study, the functional unit had the purpose of permanent housing for a family of three members, providing proper comfort (in terms of daylight and energy) in 175 [m^2], during the entirety of a year. The intended life cycle of the house is 50 years. The house is designed as a wooden structure with CLT technology. It has two bedrooms, bathroom, living room with a kitchen, technical room, and two porches located on the ground floor, and on the second level with is the mezzanine it has a small library, bedroom and a small toilet. Referring the functional unit, it is important to define the reference flow. According to the Active House Protocol, the reference flow is generally the unit of area [m^2].

5. ENERGY DEMAND AND SUPPLY

In order to highlight the real environmental impact of the building, one must deal with installations and operations of the same and conduct a proper analysis as well. Energy supply to an Active House should, to the utmost extent, be supplied from renewable energy sources, which by definition cannot be exhausted, such as electricity from wind turbines or photovoltaic cells, solar thermal energy, hydropower, biogas, energy supplied by heat pumps (using energy that originates from renewable sources, and that the primary energy reservoir is unlimited). The renewable energy can be installed on the building, on the plot, nearby systems or in the grid. When renewable energy equipment is not installed in/on the building of an Active House or within the vicinity, it must be proven that the energy used from remote collective sources (like district heating/cooling and electric grid comes from renewable energy resources.

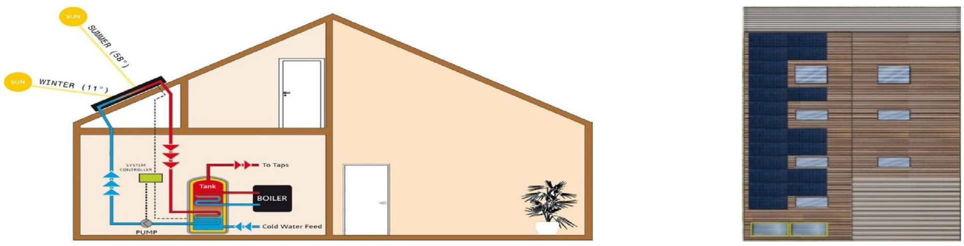

Fig 9: Implementation of renewable energy sources (Solar Thermal System and PV system).

The building (Fig 9) has a big glass surface facing South in order to maximize the solar gains and use them to create natural daylight and heat up the building reducing the energy demand for artificial lightning and heating. Skylights positioned in strategic areas are used in order to maximize the daylight in the mezzanine and to exploit the stack effect promoting natural ventilation minimizing the energy demand for cooling and for the mechanical ventilation. The envelope is designed in such a way that the building is highly insulated. Indoor temperature is higher than outdoors during winter, and very close to outdoors during summer, reducing costs. The envelope has been studied in a way that the losses through the external ambient are the smallest possible.

The designed building – the case study of this paper, follows the suggestions of the Active House and has the following systems exploiting renewable energy implemented:

- **Solar Thermal System:** Two flat plate collectors are integrated in the roof and exposed to East with 31° of inclination so that the total area of the absorber is equal to 4.68 [m^2]. According to the UNI 9182 appendix E the water volume demand has been determined to be 210 [1/day] for the 3 occupants, and the heat generated to warm up domestic water is equal to 2228 [kWh/y] which means that 12.73 [kWh/m^2] need to be produced annually. Consequentially, the volume of the tank has been dimensioned and it is equal to 500 [l].
- **Photovoltaic System:** A decision has been made to integrate PV panels on the pitched roof as another source of renewable energy. For this reason, on the east side of the 31° pitched roof at total of 20 PV panels are installed in order to cover about 30% of the electricity needed for the household. A PV panel type with a panel power rating of 315 [W] has been implemented. A total of 20 panels have been installed with a panel area of 38.85 [m^2]. According to the calculation the total energy production is around 6444 [kWh/y].
- **Water Source Heat Pump:** Since the energy needed for heating represents the majority of the energy required, it was necessary to implement another renewable energy source. Thanks to the fact that the building is located near a river (not populated by animals), a water-to-water electric heat pump is the best choice for obtaining the highest performance. The water source heat pump can be driven by the electricity produced by the photovoltaic system which is another benefit. Furthermore, the cycle can be inverted and the heat pump can also be used for cooling when it is needed. A heat pump power assessment based on the heating degree days has been conducted, and a power or P=10.53 [kW] is needed in order to cover 100% of the demand. Since the peak of the demand of 14.06 [kW] is reached on the 13th of February (according to the weather data analysis for Copenhagen) a heat pump with a power of 15 [kW] has been implemented.

6. METHODOLOGY AND INPUT DATA

6.1 Environmental loads

All the defined parameters and the data which is necessary in order to achieve a result for the environmental loads category have been inserted in the official LCA tool. The LCA tool is divided into multiple different sections that are filled with the necessary data and they are: General data (general settings), Outside walls, Internal walls, Windows and doors, Slabs, Foundations, Installations and Environment, as an aspect of the LCA analysis towards sustainable building operations. In the following pages the most important data or characteristic building parts will be presented.

Table 1: Attributes of the building and the total energy demand.

LCA Attributes of the building	**Quantity**		**Comments**
Usable space	175	[m^2]	/
Estimated service life of the building	50	[years]	Default: 50 years
Energy Demand (final energy)	**Quantity**		**Comments**
Heating	11043	[kWh/a]	From energy calculation
PV current	-6440	[kWh/a]	Produced current from PV (negative value)

Table 2: Summary for internal and external walls.

Outside walls			Internal walls		
East Wall	38	[m²]	Internal partitions for ground flood	58.5	[m²]
West Wall	59		Internal partitions for mezzanine rooms	12.2	
North Wall	47		Internal partitions for mezzanine separation from unused space	20.4	
South Wall	16.3				
Total	**160.3**	[m²]	**Total**	**91.1**	[m²]

Table 3: Summary for windows and doors. Summary for slabs.

Windows and Doors			Slabs			
N0.	Name	**Quantity**	**N0.**	Name	**Area**	
1	Façade window 1.21x1.37 [m]	10	**1**	Ground Slab	130	[m²]
2	Skylights 0.78x1.4 [m]	5	**2**	Mezzanine slab	45	
3	Skylights 1.34x1.4 [m]	2	**3**	Unused part of the mezzanine slab	30	
4	Curtain Wall at south façade	1	**4**	Finishing of the south and west porch	45	
5	Wooden doors	7	Total		**250**	[m²]

Table 4: Summary for roof. Summary for foundations.

Roof				Foundations			
N0.	Name	**Area**		**N0.**	Name	**Area**	
1	Pitched Roof	156.4	[m²]	**1**	Concrete foundations – slab + side strips	201	[m²]
Total		**156.4**	[m²]	**Total**		**201**	[m²]

The environmental impact of each building component has been considered concerning the quantity needed for the construction stage. The first step has been to calculate the amount in [m²] for each building component, and then all of these values have been inserted into the LCA evaluation tool. The share percentage of each element has also been considered depending on whether they cover the whole area being analyzed or just some parts of it. Each building component (material) has its Environmental Product Declaration (EPD), which can be seen in the Ökobau database. The final values of GWP, ODP, POCP, AP, EP, PE (ren), and PE (non-ren) are needed to understand to which environmental class of the Active House protocol does the building belong to, so the final results obtained in terms of environmental impact per [m²/year] (GWP, ODP, AP, EP, POCP, PE (ren) and PE (non-ren)) are:

Building element	Environmental impact per [m^2/year]						
	GWP	ODP	AP	EP	POCP	PE (non-renewable)	PE (renewable)
	[kg CO_2-eq.]	[kg R11-eq.]	[kg SO_2-eq.]	[kg PO_4-eq.]	[kg C_2H_4-eq.]	[MJ]	[MJ]
Outside walls	0.1	9.0E-08	0.007	0.001	0.001	15	39
Internal walls	0.2	3.8E-08	0.004	0.000	0.001	8	11
Windows and doors	0.3	1.6E-08	0.002	0.000	0.000	5	0
Slabs	-1.4	8.7E-08	0.009	0.001	0.001	23	53
Roofs	-0.7	5.1E-08	0.002	0.000	0.000	-3	38
Foundations	7.1	2.5E-07	0.012	0.001	0.002	60	1
Installations	-0.1	7.4E-08	-0.001	0.000	0.000	1	-2
Constructions	5.4	6.1E-07	0.035	0.004	0.006	108	141
Operation	6.7	1.3E-06	0.013	0.001	0.001	82	-605
Total	**12.1**	**1.9E-06**	**0.048**	**0.005**	**0.007**	**190**	**-464**

Fig 10: Output results: Environmental impact per [m^2/year].

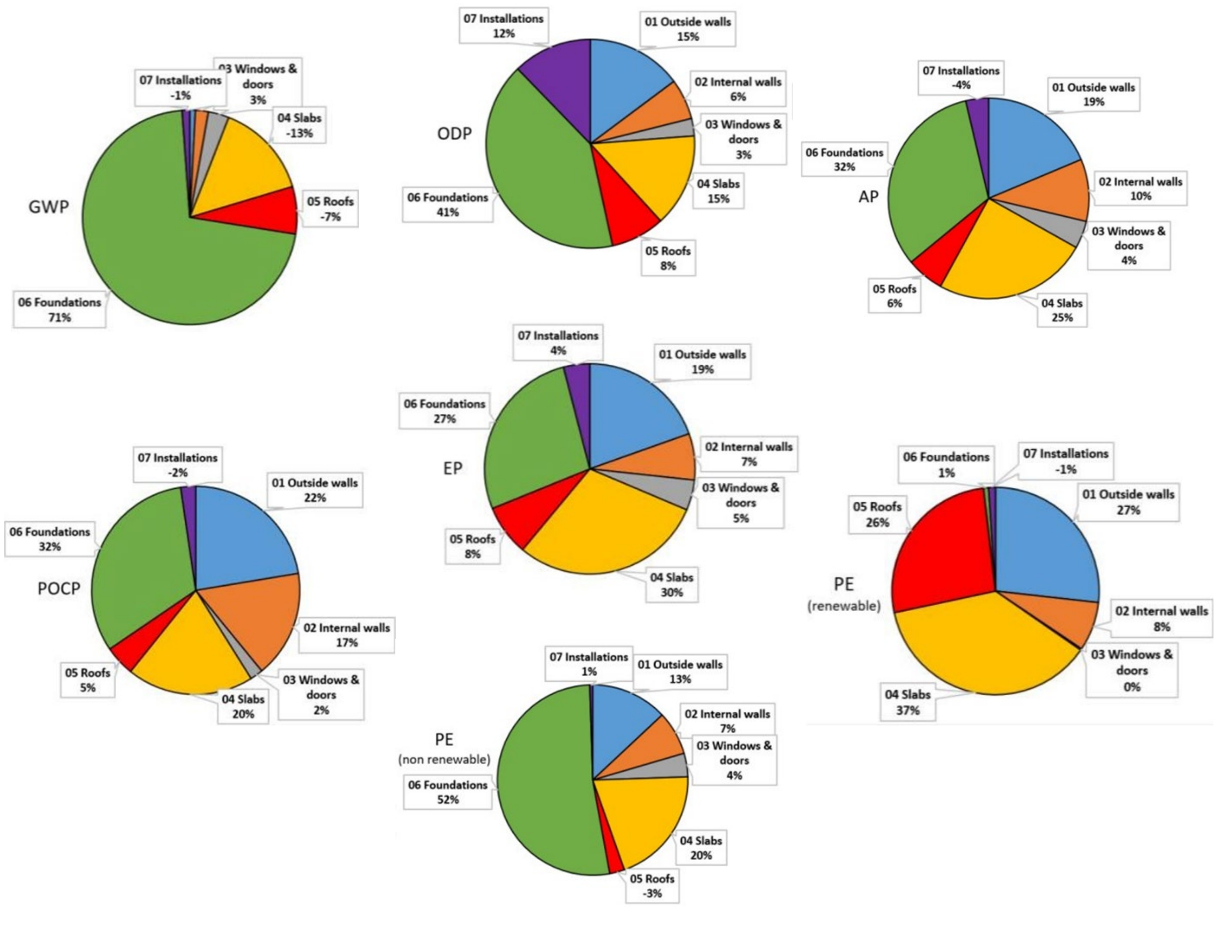

Fig 11: Output results for GWP, ODP, AP, POCP, EP, PE (non renewable), PE (renewable).

Regarding GWP, the highest impact comes from the concrete foundations, while it's significantly lower for all the other categories in which both massive wood-larch and cross-laminated timber CLT has been used. We see negative results because wood does not produce CO_2, but consumes it (it acts as a carbon sink). Regarding ODP, AP and POCP, the most significant impact comes also from the concrete foundations, and for what the other construction components concern, the % vary throughout the table.

	GWP	ODP	AP	EP	POCP	PE (n.r.)	PE (r.)
Constructions	45%	32%	73%	85%	85%	57%	19%
Operations	55%	68%	27%	15%	15%	43%	-81%

Fig 12: Comparison between output results: Construction vs. Operations.

When it comes to the comparison between construction and operations, we can see that the most significant impact comes from the operations in the categories of GWP, ODP, and PE (renewable). When it comes to the categories of AP, EP, POCP, and PE (non-renewable), the most significant impact comes from the construction stage.

6.2 Freshwater Consumption

Installation	Flow	Tap – length	Number of taps	Consumption
	[l/s]	[s]	[person/day]	[person/day]
Bath (shower)	/	300	0.8	0
Bath tube	0.25	600	0.1	15
Hand wash (Toilet)	0.15	20	3	9
Hand wash (Kitchen)	0.2	20	6	24
Dish Washer	25	/	0.25	6.25
Washing machine	40	/	0.25	10
WC	30	1 small + 2 large flush	1	30
Total				**94.25**

Fig 13: Total freshwater consumption is based on the national average.

Only the water from the kitchen sink is potable (24 [l/person/day]) while the rest of it is not potable (70.25 [l/person/day]), which means it can be substituted by rainwater appropriately filters, for total water consumption of (94.25 [l/person/day]). Considering the national average of water consumption in Denmark (104 [l/person/day]), 9% of freshwater is saved without any systems applied. After assessing the water demand, the amount of rain collected by the roof and stored into the underground tank has been calculated to be 63508.725 [l/year], which equals an average of 174 [l/day]. A water tank of 4000 [l] has been chosen as the best volume for our purposes. There are three people in the residential unit, which means that 174 [l/day] becomes 58 [l/person/day] of rainwater that can averagely be stored during the year, which decreases the freshwater consumption from 94.25 [l/person/day] to 36.25 [l/person/day] leading to a saving of 65% concerning the national average.

6.2 Sustainable Construction

The recycled content is assessed by weight and accounts for 80% of the building, including pre-consumer, internal and post-consumer recycling. Responsible sourcing instead includes the use of certified materials.

6.3 Output results from the LCA tool (Active House – Version 1.09).

Fig 15: Output results from LCA tool.

ENVIRONMENT	VALUE	CATEGORY
Environmental loads	Good level	**2.5**
Freshwater	65% savings	**1.0**
Sustainable construction	Best level	**1.0**

Fig 16: Achieved categories according to the Active House Guidelines for the Environmental category.

7. CONCLUSIONS

The goal of realization for this LCA study is conducted to perform an assessment of a particular case study and, if the assessment is applicable and relevant, to compare it to other similar case studies/projects sharing the same scope. Some of the most critical compulsory properties of the house are: to protect people from exterior atmospheric conditions, offer suitable needs for comfort and try to have minimum impact on the environment. CLT technology has been chosen for the main structural skeleton of the residential unit. Wood acts as a carbon sink - during its growth receives as much CO2 by turning it into biomass. Since the environmental product declaration (EPD) for the CLT panels used is taken directly from the database called "Ökobau," we are assuming that the wood used is sourced either from Forest Stewardship Council (FSC) or by the Programmed for the Endorsement of Forest Certification (PEFC). For what concerns the accounting of environmental products declarations (EPD), it has been decided to use materials that are already certified and present in the LCA tool database ("Ökobau"), and an implementation of a new EPD has been done from a certified producer of PV panels. The construction process and the use of a new building causes different emissions in the air, soil, and water, which all have a different impact on the environment. During the Life Cycle Impact Assessment conducted with the LCA tool, we have considered the main impact categories: the GWP, ODP, POCP, AP, EP, and PE. At the end of the Active House process, it is obtained a final score with a unit of measurement for each potential and for the residential house as a whole unit, which allows to evaluate the impact on the environment from the building and compare it to other case studies. As it can be seen from the results for the GWP, ODP, and POCP, they are in class 3.0, PE, AP, and EP are in class 2.0. The overall score for the environmental load is 2.5. With the five impact categories studied and the part of primary energy embodied in each of the building components a satisfactory life cycle assessment has been conducted and an initial life cycle assessment has been done that can give an overall look at the impact of the designed residential unit. A conclusion can be deducted that the Active House Tool is a sufficient tool for conducting a properly good LCA, but it has its own limitations and can be ill-adapted or not precise enough to consider some aspects like waste-water treatment, on-site or some other operations. Sometimes, a lack of data can be a problem which leads to not every aspect of the building being accounted for the impact assessment, as no usable or reliable data can be found for some peculiar building materials or even composite materials.

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