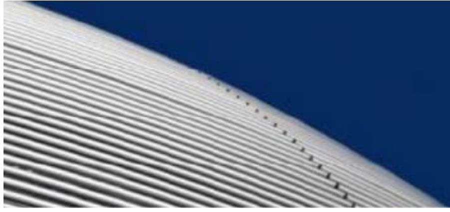

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SUSTAINABLE DESIGN OF A STEEL INTENSIVE DWELLING. ADAPTATION TO THREE EUROPEAN CLIMATIC REGIONS.

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ABSTRACT

This thesis study deals with the design of a Sustainable 2-storey steel intensive residential building, located in three different European climatic regions: Timisoara (Romania), Coimbra (Portugal) and Lulea (Sweden). The building ‘Affordable houses’ was originally designed in Timisoara, it presents an innovative structural/envelope solution, enabling flexible floors plans and modular construction and faster fabrication and erection times and a high solution diversity for floors and envelop. The use of steel as several benefits; steel is one of the most sustainable of major structural materials; assures the lightness of the house and the proper response to climatic and seismic loading . It is a cost effective solution and delivers long-term value through flexibility, adaptability and lasting appeal. The thermal mass of a building can be used to reduce the requirement for active heating and cooling. Steel structures are inherently reusable in full or part as well as recycling rate of 98%.

In order to check the sustainable performance of the buildings in the different locations, a Life cycle assessment is made considering potential environmental impacts, in all life cycle stages (materials production, use, end-of-life and reuse/recovery/recycling potential), in a modular system. Where the operational energy use, i.e., the building energy consumption consist the consumption of energy need for space cooling, space heating and domestic hot water (DHW) production. A LCA analysis is performed with three different LCA tools, SBsteel, AMECO and Sima Pro.This thesis also presents a comparative life cycle analysis for the above house for the different climatic zones, designed with various solutions. For this purpose, the building was designed with three different LCA tools, each having its own structural system, as follows: (1) SBsteel – conceptual stage of design (2) AMECO - Preliminary stage design; (3) Sima Pro- developed stage of design. They focus on the structure and the materials of the buildings and permits the evaluation of the Embodied energy, Embodied carbon and yearly energy consumption.

For that purpose, a different set of original data is taken into account depending on the location, in which the monthly temperatures, energy mix, heating and cooling systems are defined. Input Data taken into account for each house varies, which is affected by the climatic zone, and information available on the LCA tool used. The energy consumption, being for heating space or water, for cooling or for lighting is transformed into CO_2 emissions to deduce the Operational carbon as well. This study allows us to compare the influence of several parameters on the LCA of residential buildings: the climate related to the temperatures and the buildings insulation thicknesses, the materials, the energy mix and the heating/cooling systems. A basic comparison of the average values showed by the three building would reflect different climate features of the buildings performance. The combination of results obtained from values was used to produce Sustainable house standards for the three different locations.

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1 INTRODUCTION

1.1 Background.

For developing sustainable building, it is important to take the process of buildings into account. The most emphasis in green and sustainable buildings, according to Kubba (2010), is on the buildings that are in compatible with the environment in which they has been built as well as on the buildings that are energy efficient and use natural or domestic materials. The criteria of rating systems for sustainable buildings also show that sustainable construction focuses more on the buildings and how the sustainability requirements are achieved by improving the building systems and details. These codes consider the buildings' specifications more than their design and construction process especially management practices (Wu & Low, 2010).

1.1.1 European directive on energy performance of buildings

In 2007, the European Union made a commitment to, by the year 2020, reduce its own GHG emissions by 20% (in relation to 1990 levels), increase the share of renewable energy to 20% and reduce the total primary energy use by 20% (Europa 2012). Since buildings account for approximately 40% of the total energy consumption within the Union, the building sector plays a key role in achieving the climate policy. The reduction of energy consumption and the use of energy from renewable sources in the building sector are important measures needed to reduce the Union's energy dependency and GHG emissions. Thus, the European Parliament and the Council of the European Union promoted the Directive on Energy Performance of Buildings (EPBD) in 2002, with a recast formally adopted in 2010, as a legal framework for all member states in order improve the energy performance in buildings (European Parliament 2010).

The EPBD requires that all member states shall:

- Apply a methodology for calculating the energy performance in buildings in accordance with the general framework.
- Take the necessary measurement to ensure that both new and renovated buildings meet the minimum energy performance requirements.
- Ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings. Establish a system of certification of the energy performance of buildings.
- Establish a regular inspection of heating and air-conditioning systems in buildings.

- Ensure that independent control systems for energy performance certificates and building inspections are established.

It is each member states responsibility to set national minimum standards on energy performance in buildings. This makes it possible to take into account differences in outdoor climatic and local conditions as well as indoor climate requirements and cost-effectiveness. To comply with the EPBD, member states need to implement the directive in national building codes by 2013 at the latest (European Parliament 2010).

1.1.2 Zero-energy buildings

According to the European Directive on Energy Performance of Buildings (EPBD), "*a nearly zero energy building is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*" (European Parliament 2010).The nearly zero-energy building standard still has to be defined in detail on both European and national level. However, this is not an easy task since many parameters must be regarded. The concept has been described in literature with a wide range of terms and definitions, according to a review and overview carried out by Marszal, Heiselberg et al. (2011). First, the main issue must be to agree on the unit that is measured (and must be "zero") in the balance. The unit can for instance be primary energy, end-use energy, energy, CO2 emissions or energy cost. The most frequent unit so far is primary energy. The next thing to discuss is if the period of time for the energy balance is the entire life cycle, a year, a season or a month. Furthermore, the options for renewable on-site and off-site energy supply, as well as the connection options to the energy grid must be discussed. The authors also discuss whether all energy types should be included in the balance or not. A building's energy performance is often judged by the consumption of auxiliary energy only. The user related energy is mostly neglected since it is difficult to predict and since there is a lack of reasonable data. This approach ought to be changed though the authors consider. There is a great potential for reducing overall energy by motivating energy efficient behavior. Furthermore, the user related energy becomes a more and more important part of the total energy use as the auxiliary energy constantly improves (Marszal, Heiselberg et al. 2011). Since the overall objective of the EPBD is to reduce the CO2 emissions and the primary energy use in European buildings, the most logical approach should be to include the user related energy. User related energy is electricity and most electricity has high primary energy use and emits a large amount of greenhouse gases in production.

1.2 Guidelines for a sustainable design within the residential buildings

From the above case study analysis the following is a summary of guidelines that would help achieve sustainable architecture, in terms of energy and water use, within the residential sector:

- Follow the principles of climate-responsive design, as well as vernacular architecture, when designing new houses in order to improve the energy performance of residential buildings.
- Use sufficient insulation in the building's walls and roofs. An emphasis should be placed upon selecting materials with good thermal insulation properties, which lead to having both low U-values and high thermal inertia of the construction.
- Use appropriate external shading systems in order to shade residential buildings and their gardens from excessive solar radiation. It should be recognized that effective design and positioning of solar shading devices are not only important to reduce undesirable solar gain, but also to utilize natural light for indoor illumination.
- Place windows in such a way as to maximize the utilization of natural light and thereby lessens the need for electric light during the day. Windows should also be opened during winter in order to allow for natural ventilation and reduce the demand for mechanical air conditioning.
- Integrate zero-carbon energy technologies such as solar PV and/or wind turbines if feasible. This indeed should not underplay the possibility of other, and perhaps low-cost, energy saving options such as the fitting of solar-based domestic water heaters, the utilization of wasted heat from air conditioning for domestic heating (or preheating the mains water supply), as well as the use of free cooling (if compatible with the type of air conditioning system employed).
- Use energy-efficient appliances and lighting equipment (e.g. use of fluorescent lights instead of incandescent lamps).Based on this study's findings, it is recommended that at least 70% of the building's lighting should be of the fluorescent type. Make use of water-saving means, such as low-consumption sanitary fittings and controls, as well as incorporating grey water recycling equipment in design of residential buildings. In this regard, this study reveals that the potential daily savings per capita that could result from fitting low flow tap aerators, a grey water system and efficient washing machines are estimated to be 21.2%, 7.7% and 7%respectively.

In addition to the above design-related recommendations, the following are general, yet relevant, guidelines which could also contribute towards achieving sustainability within the residential section of Saudi Arabia: Allocate secure and suitable storage spaces for bikes, and encourage tenants to use them for short journeys instead of the utter reliance on private cars.

- Promote household waste recycling schemes.
- At the building design stage, only recycled and responsibly sourced construction materials should be selected.
- Launch intensive electric and water rationing schemes.
- Initiate public awareness programmes on the need for conserving natural resources and the importance of recycling. Implement building regulations, compulsory codes and standards that promote energy efficiency in buildings.
- Impose strict plumbing codes and penalties for wasting household water, as well as removing the consumer price subsidies on conventional fossil-based electricity.
- Encourage the use of energy- and water-efficient household appliances, whose prices could be subsidized by the government.
- Introduce and enforce sustainability assessment systems, which are tailor-made to assess homes in a two stage process (i.e. design stage and post-construction).
- Allocate the necessary resources to enhance awareness with regard to sustainable architecture among architects, engineers and the general public.

1.3 Objective

The objective of the case study refers to the sustainable design and adaptation of a 2-storey steel residential building to 3 European climatic zones. This give a measure of the effectiveness of the increase of buildings energy performance, taking in to account at the climatic conditions, interior comfort of the occupants and economic viability the locations considered are Timisoara-Romania, Lulea-Sweden and Coimbra-Portugal, with a Köppen-Geiger climate classification of Csb, Dfc and Cfb respectively, is briefly described in **1.6**.

1.4 Presentation of building

The original building was designed in Timisoara , thought at CEMSIG Laboratory (within Affordable Houses Project – sustained by ARCELOR – MITTAL) is represented by a modular steel framed house, innovative by the application of industrial building technologies to a house.

In this context, an innovative structure/envelope solution is proposed by:

– The application of industrial building technologies in dwelling building systems (residential applications) achieving fast erection and fabrication times. The basic assumption is that an affordable house should rely on the standard details and common technologies available to most builders instead of experimenting with new materials with no record of accomplishment.

–the development of a modular system in such a way that at any time the owner can add a new module, both vertically and/or horizontally, with a high solution diversity for floors and envelope.

– The design – in terms of structural performance – of both the walls and the floors based on stressed skin technology. It is well known that using oriented strand board (OSB) panels for walls and profiled steel sheeting as the floor decking results in very effective shear diaphragms. Provided they are positively attached to the secondary members and main frames by mechanical fasteners or welding, they are extremely reliable and predictable, and may be confidently used as structural components.

– the use of structural systems made from lightweight steel frames, hot rolled sections or timber framing, which assures the lightness of the house and the proper response to climatic and seismic loading. All these improvements should be judged in comparison with the classic building system of masonry or concrete, which represents the traditional house in Romania. In a modern design approach the environmental impact should also be integrated into the development process. Only in this way can new systems comply with the approach of the sustainable development of construction works. The main architectural and technical features of the proposed solution are demonstrated and structural performance and sustainability scoring are presented below.

1.5 General Characteristics of building.

The architectural concept relies on the development of a rectangular footprint of 5.60 × 13.40 m, that gives a first module of 75 m^2 for a one-level unit. The dwelling is a two-storey building, with rooftop terrace, having a gross built area of 150 m^2 and a usable area of 124.41 m^2. Fig.1.1 shows a 3D view of the house, Fig.1.2 the ground and upper floor plans.

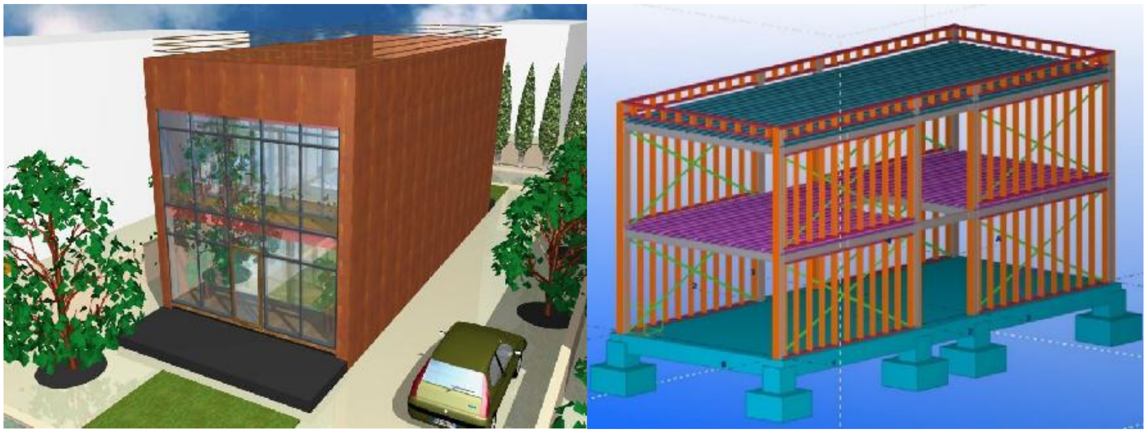


Fig 1.1. 3D view of the house: (a) architectural layout; (b) structural layout

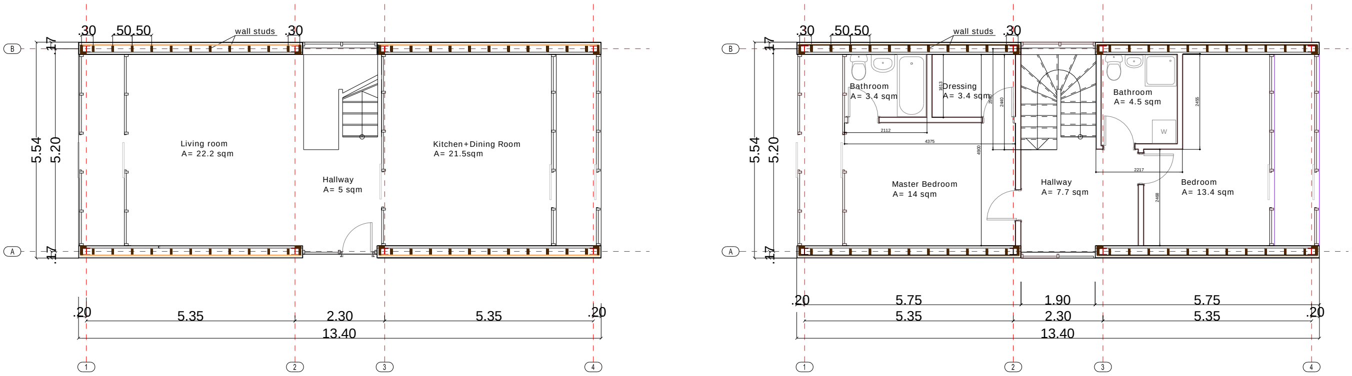


Fig 1.2.The ground floor and (b) the upper floor

Further development of the house is possible by adding a new module by horizontal addition, thus extending the living area. The proposed construction system, as shown in Fig.1.1, consists of:

1.5.1 Hot-rolled framed steel structure

The elements of the frame are made of standard hot rolled steel sections. The columns of the frames are HEB sections, the main and secondary beams of the frames are IPE Sections, steel ,the world`s most recycled products, not only allow to design sustainable buildings but also suit aesthetic criteria and provide speed of implementation, flexibility, lightness as well as safety. Before recycling, buildings with steel structures can be readily designed to facilitate reuse or dismantling and reconstruction at the end of their useful life.

1.5.2 Floor structure – lightweight concrete topping on trapezoidal steel deck

Lightweight concrete is commonly used because the obvious advantage of (typically) 25% weight saving can provide economic benefit for the overall design of the structure and its foundations with a yield strength of 350 N/mm2. Trapezoidal profile steel decking dimensions are in range of 45 to 80 mm height and 150 to 300mm trough spacing, (rib spacing). This type of decking typically spans until 3 m or 4.5m. Decking is generally rolled from 0.9 to 1.5 mm thick strip steel. Steel grades used for this application are S350 (steel yield strengths of 350N/mm2). The steel is galvanized before forming, in the same way as light steel sections. Decking is generally rolled from 0.9 to 1.5 mm thick strip steel.

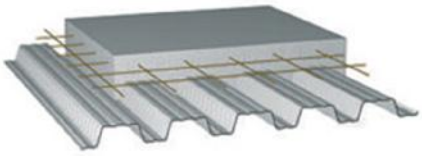


Fig.1.3. A typical steel-concrete composite slab with trapezoidal decking.

The steel is galvanized before forming, in the same way as light steel sections. The decking may also be used to stabilize the beams against lateral torsional buckling during construction, and to stabilize the building as a whole by acting as a diaphragm to transfer wind loads to the walls and columns. The decking, together with the fabric mesh reinforcement placed in the top of the slab, also helps to control cracking of the concrete caused by shrinkage effects

1.5.3 Rooftop terrace

The main role of the roof is to close the building and to create an interior environment protected from the outside. This building has an accessible flat roof, which consist – lightweight concrete topping on trapezoidal steel deck, covered with insulation and topped with a waterproofing membrane. A protected membrane roof can employ the same elements, but the membrane is positioned under the insulation, offering exceptional long-term performance and durability.

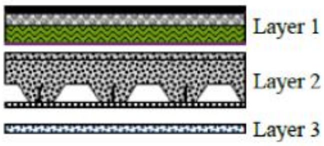
1.5.4 Infrastructure

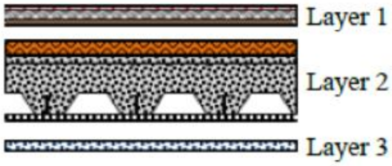
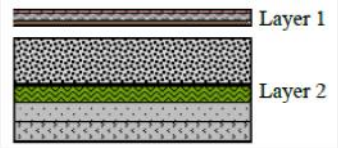
Concrete foundations or masonry/block foundation walls are the standard solution for nearly all types of buildings. Through the mechanism of its heat storage capacity (thermal mass), concrete slab-on ground construction helps make a house cool in summer and warm in winter. Since the slab is constructed directly on the ground and the earth temperature is almost constant, thermal stability is achieved. Concrete slab-on-ground is critical to delivering a sustainable home, by reducing the energy required for heating and cooling. This saves money and improves the thermal comfort of homes, delivering a truly sustainable housing solution across environmental, social and economic dimensions.

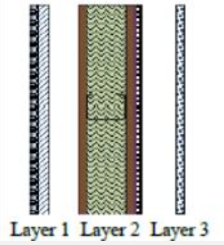
1.5.5 Material list of macro component

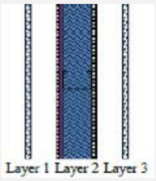
The building fabric, external and internal, plays a major role in the behavior of the building in terms of the energy consumption and environmental burdens. This led the way for the creation of pre-assembled solutions for the main components of the building, i.e., the macro-components. Therefore, macro-components are pre-defined assemblages of different materials that fully compose the same component of a building. To enable the life cycle assessment of the building, macro-components are selected for the main components of the building, namely, the superstructure, the exterior vertical enclosure and the interiors, which are indicated in *Table 1.1*. The building envelope assumptions are constant regardless of the building location's climate with the exception of the insulation varying by climate zone, and will be described in Section 1.6.

Table 1.1. Specifications of the building materials and their thermal properties per m^2

		Coimbra	**Timisoara**	**Lulea**
Roof Floor	**Layer 1 materials**	mm	mm	mm
	Bitumen waterproofing membrane	5	5	5
	Concrete screed	50	50	50
	XPS	180	250	250
	Vapour barrier	0.5	0.5	0.5
	Layer 2 materials			
	Composite slab h total	50	50	50
	Gypsum Plasterboard	13	13	13
	Steel structure kg/m^2	40	40	40

	Layer 3 materials			
	Paint	0.125	0.125	0.125
	U-Value (W/m².K)	*0.18*	*0.13*	*0.07*
Interior Floor	**Layer 1 materials**			
	Ceramic tile	5.5	5.5	5.5
	Concrete screed	13	13	13
	**Layer 2 materials**			
	Polyethylene foam	50	50	60
	Composite slab h total	100	100	100
	Gypsum Plasterboard	12.5	12.5	12.5
	Steel structure kg/m²	40	40	40
	Layer 3 materials			
	Paint	0.125	0.125	0.125
	U-Value (W/m².K)	*0.78*	*0.78*	*0.67*
Ground Floor	**Layer 1 materials**			
	Ceramic tile	5.5	5.5	5.5
	Concrete screed	13	13	13
	Layer 2 materials			
	Concrete slab	50	50	50
	Waterproof film	1.63	1.63	1.63
	XPS	60	80	100
	Sand	30	30	30
	Gravel	350	350	350
	U-Value (W/m².K)	*0.48*	*0.38*	*0.31*
External Wall	**Layer 1 materials**			
	Paint	0.125	0.125	0.125
	Rendering (reinforced)	1.16	1.16	1.16
	EPS	70	100	220
	Layer 2 materials			

	OSB	10	10	10
	Cold rolled steel	11	11	11
	Rock wool	60	100	150
	OSB	10	10	10
	Vapour barrier	0.5	0.5	0.5
	Gypsum Plasterboard	12.5	12.5	12.5
	Layer 3 materials			
	Paint	0.125	0.125	0.125
	U-Value (W/m².K)	*0.30*	*0.21*	*0.12*

Interior Wall	**Layer 1 materials**			
	Paint	0.125	0.125	0.125
	Layer 2 materials			
	Gypsum Plasterboard	15	15	15
	Vapour barrier	0.5	0.5	0.5
	Cold rolled steel	10	10	10
	Mineral wool	60	60	90
	Gypsum Plasterboard	15	15	15
	Layer 3 materials			
	Paint	0.125	0.125	0.125
	U-Value (W/m².K)	*0.78*	*0.78*	*0.71*

1.6 Description of Climatic Region Köppen-Geiger Climate Classification

The Köppen-Geiger climate classification has been the basis for different systems of building energy efficiency regulations setting up different requirements for different climatic zones.

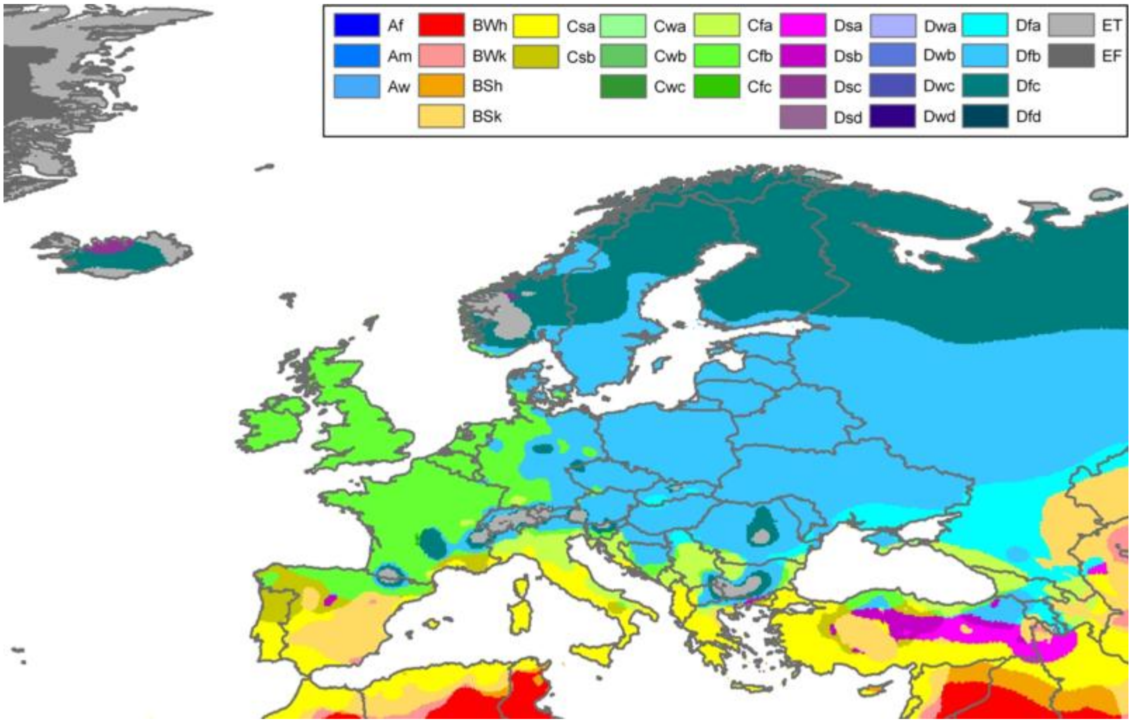
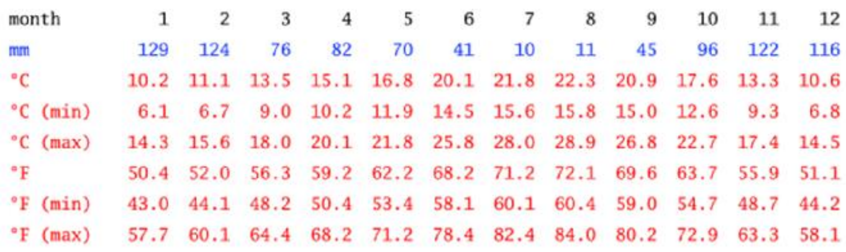


Fig 1.3. Europe ***Köppen-Geiger*** *Map*

1.6.1 Coimbra

Dry-summer subtropical or Mediterranean climates (Csb)-These climates usually occur on the western sides of continents between the latitudes of 30° and 45°. These climates are in the polar front region in winter, and thus have moderate temperatures and changeable, rainy weather. Summers are hot and dry, due to the domination of the subtropical high pressure systems, except in the immediate coastal areas, where summers are milder due to the nearby presence of cold ocean currents that may bring fog but prevent rain. The least amount of rainfall occurs in July. The average in this month is 10 mm. Most precipitation falls in January, with an average of 129-mm. Coimbra's climate is classified as warm and temperate. In winter, there is much more rainfall in Coimbra than in summer. The climate here is classified as Csb by the Köppen-Geiger system. The average annual temperature is 16.1 °C in Coimbra. In a year, the average rainfall is 922 mm. The temperatures are highest on average in August, at around 22.3 °C. In January, the average temperature is 10.2 °C. It is the lowest average temperature of the whole year.

Climate table



month	1	2	3	4	5	6	7	8	9	10	11	12
mm	129	124	76	82	70	41	10	11	45	96	122	116
°C	10.2	11.1	13.5	15.1	16.8	20.1	21.8	22.3	20.9	17.6	13.3	10.6
°C (min)	6.1	6.7	9.0	10.2	11.9	14.5	15.6	15.8	15.0	12.6	9.3	6.8
°C (max)	14.3	15.6	18.0	20.1	21.8	25.8	28.0	28.9	26.8	22.7	17.4	14.5
°F	50.4	52.0	56.3	59.2	62.2	68.2	71.2	72.1	69.6	63.7	55.9	51.1
°F (min)	43.0	44.1	48.2	50.4	53.4	58.1	60.1	60.4	59.0	54.7	48.7	44.2
°F (max)	57.7	60.1	64.4	68.2	71.2	78.4	82.4	84.0	80.2	72.9	63.3	58.1

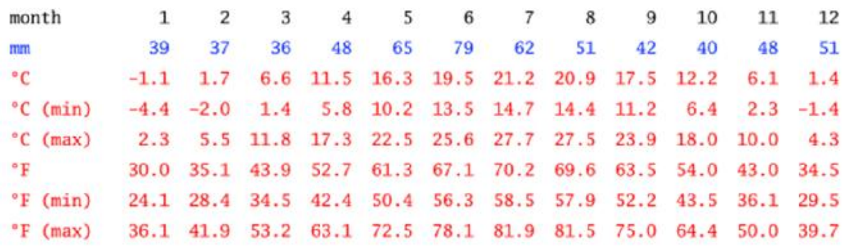
The variation in the precipitation between the driest and wettest months is 119 mm. The average temperatures vary during the year by 12.1 °C.

1.6.2 Timisoara

Maritime Temperate climates or Oceanic climates (Cfb) - climates usually occur on the western sides of continents between the latitudes of 45° and 55°; they are typically situated immediately poleward of the Mediterranean climates. These climates are dominated all year round by the polar front, leading to changeable, often overcast weather. Summers are cool due to cool ocean currents, but winters are milder than other climates in similar latitudes but usually very cloudy

The climate is warm and temperate in Timisoara. There is a great deal of rainfall in Timisoara, even in the driest month. The average annual temperature is 11.2 °C in Timisoara. The rainfall here averages 598 mm. The driest month is March, with 36 mm of rainfall. The greatest amount of precipitation occurs in June, with an average of 79 mm. The warmest month of the year is July, with an average temperature of 21.2 °C. The lowest average temperatures in the year occur in January, when it is around -1.1 °C.

Climate table



month	1	2	3	4	5	6	7	8	9	10	11	12
mm	39	37	36	48	65	79	62	51	42	40	48	51
°C	-1.1	1.7	6.6	11.5	16.3	19.5	21.2	20.9	17.5	12.2	6.1	1.4
°C (min)	-4.4	-2.0	1.4	5.8	10.2	13.5	14.7	14.4	11.2	6.4	2.3	-1.4
°C (max)	2.3	5.5	11.8	17.3	22.5	25.6	27.7	27.5	23.9	18.0	10.0	4.3
°F	30.0	35.1	43.9	52.7	61.3	67.1	70.2	69.6	63.5	54.0	43.0	34.5
°F (min)	24.1	28.4	34.5	42.4	50.4	56.3	58.5	57.9	52.2	43.5	36.1	29.5
°F (max)	36.1	41.9	53.2	63.1	72.5	78.1	81.9	81.5	75.0	64.4	50.0	39.7

The difference in precipitation between the driest month and the wettest month is 43 mm. The variation in temperatures throughout the year is 22.3 °C.

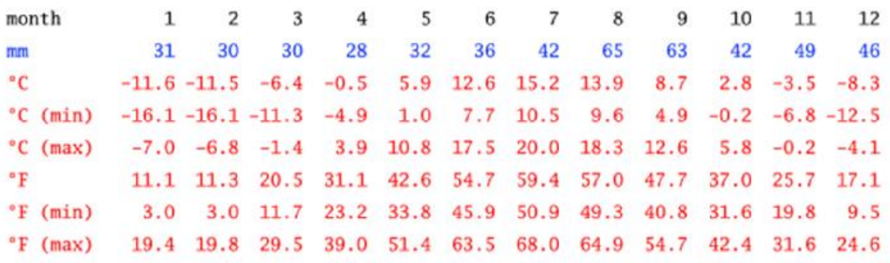
1.6.3 Lulea

The **subarctic climate** (also called **boreal climate**) (Dfc) - is a climate characterized by long, usually very cold winters, and short, cool to mild summers. It is found on large landmasses, away from the moderating effects of an ocean, generally at latitudes from 50° to 70°N poleward of the humid continental climates .Generally, it is cold and temperate in Lulea. Lulea has a significant amount of rainfall during the year. This is true even for the driest month.

The average annual temperature in Lulea is 1.4 °C. About 494 mm of precipitation falls annually.

The least amount of rainfall occurs in April. The average in this month is 28 mm. With an average of 65 mm, the most precipitation falls in August. The temperatures are highest on average in July, at around 15.2 °C. January has the lowest average temperature of the year. It is -11.6 °C.

Climate table



month	1	2	3	4	5	6	7	8	9	10	11	12
mm	31	30	30	28	32	36	42	65	63	42	49	46
°C	-11.6	-11.5	-6.4	-0.5	5.9	12.6	15.2	13.9	8.7	2.8	-3.5	-8.3
°C (min)	-16.1	-16.1	-11.3	-4.9	1.0	7.7	10.5	9.6	4.9	-0.2	-6.8	-12.5
°C (max)	-7.0	-6.8	-1.4	3.9	10.8	17.5	20.0	18.3	12.6	5.8	-0.2	-4.1
°F	11.1	11.3	20.5	31.1	42.6	54.7	59.4	57.0	47.7	37.0	25.7	17.1
°F (min)	3.0	3.0	11.7	23.2	33.8	45.9	50.9	49.3	40.8	31.6	19.8	9.5
°F (max)	19.4	19.8	29.5	39.0	51.4	63.5	68.0	64.9	54.7	42.4	31.6	24.6

The variation in the precipitation between the driest and wettest months is 37 mm. During the year, the average temperatures vary by 26.8 °C.

1.7 Life cycle assessment methodology

It is observed that the aim of Life Cycle Assessment is to assess the potential environmental impacts associated with identified inputs and releases. The environmental assessment follows the ISO standards 14040 and 14044 [17–20]. The functional unit of the life cycle assessment (LCA) is the use of 1 m^2 of the building's living area over the period of one year. The environmental life cycle based impacts are presented in impact categories. These environmental impact categories were selected, based on scientific robustness, relevance and practicability. Find below the list of environmental impacts:

1.7.1 Global warming potential (GWP)

GWP is a relative measure of the amount of CO_2, which would need to be released to have the same radiative forcing effect as a release of 1 kg of the GHG over a particular time period. GWP is therefore a way of quantifying the potential impact on global warming of a particular gas. This indicator is expressed in kg of CO_2 equivalents.

1.7.2 Ozone Depletion Potential (ODP)

Ozone depletion potential is expressed as the global loss of ozone due to a substance compared to the global loss of ozone due to the reference substance CFC-11. This gives ODP a reference unit of kg chlorofluorocarbon-11 (CFC-11) equivalent.

1.7.3 Acidification Potential (AP)

Acidification potential is measured using the ability of a substance to release H+ ions, which is the cause of acidification, or it can be measured relative to an equivalent release of SO_2.

1.7.4 Eutrophication Potential (EP)

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial.
This leads to a decrease in photosynthesis and less oxygen production
This indicator is expressed in kg $PO^3$4 - equivalents.

1.7.5 Photochemical Ozone Creation Potential (POCP)

The POCP impact category is a measure of the relative ability of a substance to produce ozone in the presence of NO_x and sunlight. POCP is expressed using the reference substance ethylene. This indicator is expressed in kg of ethylene (C_2H_4) equivalents.

1.7.6 Abiotic Depletion Potential of Minerals and fossil resources (ADP-e) (ADP-ff)

Abiotic Depletion Potential (Elements) of resource (ADP) is given by the ratio between the quantity of scarce minerals and fossil fuels extracted and the recoverable reserves of that resource, expressed in kg of the reference resource. This indicator is expressed in kg of antimony while the indicator Abiotic Depletion Fossil is expressed in MJ.

Table.1.2. Summary of environmental impact and their units

Impact category	**Characterization factor**	**Unit**
Global Warming	Global warming potential (GWP)	kg CO_2 eq.
Ozone Depletion	Depletion potential of the stratospheric ozone layer (ODP)	kg CFC11 Eq.
Acidification for soil and water	Acidification potential of soil and water (AP)	Kg SO_2 eq.
Eutrophication	Eutrophication potential (EP)	kg $(PO_4)^{-3}$ eq.
Photochemical ozone creation	Formation potential of tropospheric ozone (POPC)	kg C_2H_4 eq.
Depletion of abiotic resource - elements	Abiotic depletion potential (ADP – E) for non-fossil resources	kg Sb eq.
Depletion of abiotic resources – fossil fuels	Abiotic depletion potential (ADP – F) for fossil resources	MJ

2 CONCEPTUAL DESIGN OF LIFE ENVIRONMENTAL IMPACT USING SBSTEEL

2.1 Introduction

The conceptual LCA study presented in this section uses the SBsteel methodology (Sustainable Building Tool adapted to European countries). The SBsteel is a building sustainable assessment method that results from the collaborative work of several countries. It has since 1996 been was promoted by the International Initiative for a Sustainable Built Environment This international involvement supported its distinction among the others methodologies, since SBsteel was designed to allow users to reflect different priorities and to adapt it to the regional's environmental, socio-cultural, economy and technological contexts.

In this methodology all, the three dimensions of the sustainable development are considered and the final rate of a building depends on the comparison of its performance with two benchmarks: conventional practice and best practice. The aim of this tool is to provide a quick evaluation, in the early stages of design, of the sustainability of steel-framed buildings, taking into account the life cycle environmental performance of the building, including the use stage (use of operational energy). In the early stages of design, a building designer often faces different questions in relation to the building location (which is usually not really a decision of the building designer but of the owner of the building); the building orientation; the building shape; the structural system to be adopted; the building envelope and the interior finishes. The methodology used was steel framed residential buildings.

Regarding the time boundary, it includes the whole life cycle, from cradle to grave of 50 years. Table .1.2 in chapter one shows the list of the categories (global indicators) and indicators that are used in the In addition, from the point of view of the environmental assessment, the problem is more complex as one constructional solution may be beneficial in some environmental categories and simultaneously be very harmful in others. The developed approach aims to provide the building designer guidance to the above questions. Therefore, the general flowchart of the methodology is illustrated in Fig. 2.1 and a detailed description of the main steps is provided in the following sub-sections.

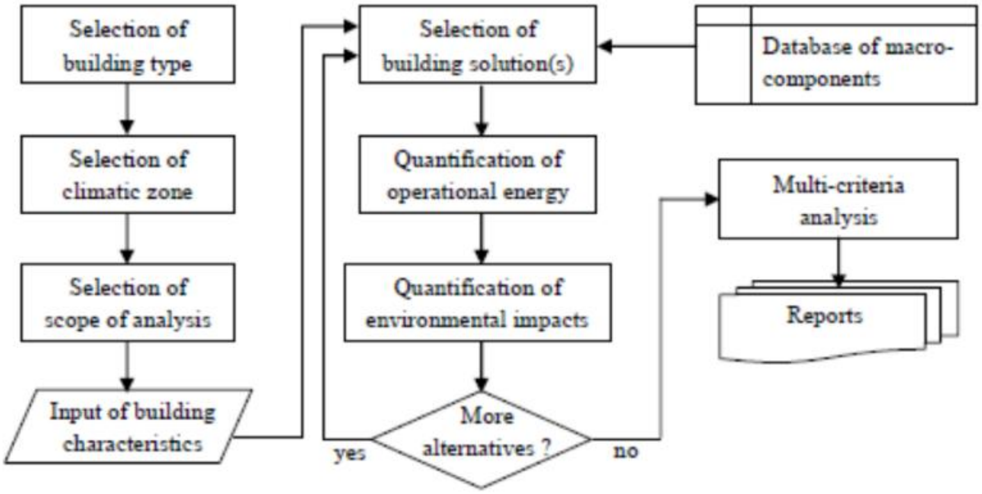


Fig. 2.1 General flowchart of the software tool

1. Scope of the analysis

The sustainability assessment is undertaken in accordance with recent European standards EN 15804 (2012) and EN 15978 (2011).The modular concept of the aforementioned standards, which is represented in Table 1.2, is adopted in the methodology. In the tool, the life cycle environmental analysis of the building comprehends the product stage (modules A1 to A3), the construction stage (module A4), the use stage (modules B2 to B6), and the end-of-life stage (modules (C1 to C4) and the benefits and loads due to recycling processes (module D). However, the designer is able to select between a cradle-to-gate analysis (modules A1 to A3), a cradle-to-gate analysis plus recycling (modules A1 to A3 and module D) or a cradle-to-grave analysis plus recycling (modules A to D).

Fig. 2.2 Steps of the life cycle analysis- cradle-to-grave analysis

2.2 Energy need calculation method

The adopted approach enables to calculate energy needs on a monthly basis for space heating, space cooling and DHW production. In order to determine the contribution of each term involved in the thermal calculations it is necessary to rely on several standards, for the space cooling and space heating.

Table.2.1. Summary of case scenarios considered for each location.

Climate	Cfb	Csb	Dfc
Site	Timisoara	Coimbra	Lulea
Orientation	South		
Floor area m^2	150		
Glazing type	Double glazing low-Emissivity		Triple glazing low-Emissivity
U-value glazing [W/m^{2}K]	1.2	1.4	0.8
Heating	Gas Fuel Heater		
Glazing Frame type	Wood		
Cooling	Split		
DHW System	Electric Boiler		
Ventilation type	Mechanic		
Heat recovery efficiency		0.5	
Winter room temperature [°C]	20		
Summer room temperature [°C]	26		
Air Flow rate, cooling ac/h	0.6	1.0	0.3
Air Flow rate, heating ac/h	0.6	0.6	0.3
Shading device	Interior transparent curtains Light		
Color of opaque envelope	Light		dark
Ground floor type	Slab-on ground floor		
Soil type	Clay or Silt		

2.3 Impact assessment and interpretation of result

The impact assessment is divided into two parts: the impacts due to the system infrastructure, i.e., embodied energy associated with the 50-year study period, and the impacts for the operational energy use over the 50-year study period.

2.3.1 Environmental impacts per unit floor area m2

Overall environmental impact of the building in terms of used building materials of selected according to structures (external walls, interior walls, ground floor, roof and ground floor, glazing) per m^2.

The results of impact assessment of the 3 residential buildings are represented in *Figures* below, shows the building stage with the highest environmental impact (e.g. for GWP interior floor in the production stage had the highest impact among all the stages) .

The most significant element category is interior Floors, which contributes to highest environmental impact in all the categories occurring in end of life stage for ADP-ff, ADP-e and AP and production stage for GWP, ODP and POCP followed by the roof. Floors and Roof include large quantities of reinforced steel and concrete, which is known as one of the most impact-intensive construction materials, and may be assumed the main source of these elements’ importance. The external wall has the highest contributing element in the environmental impact EP and depends on the quantity of insulation material used.

It shows that the environmental performance of all load bearing construction systems considered are very similar in all the location.

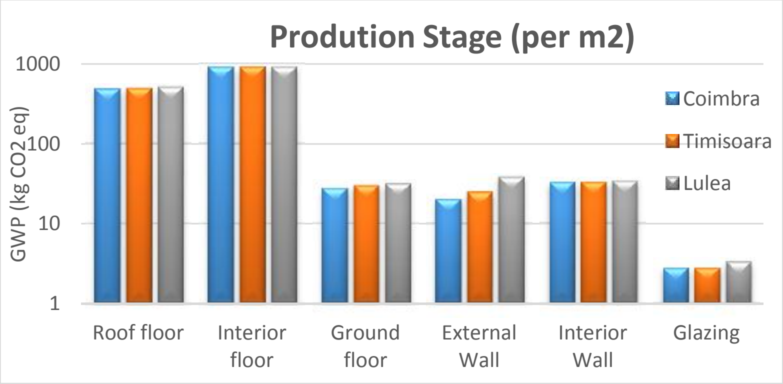


Figure.2.3. Highest Global warming impact occurred in the production stage in of building elements per m^2

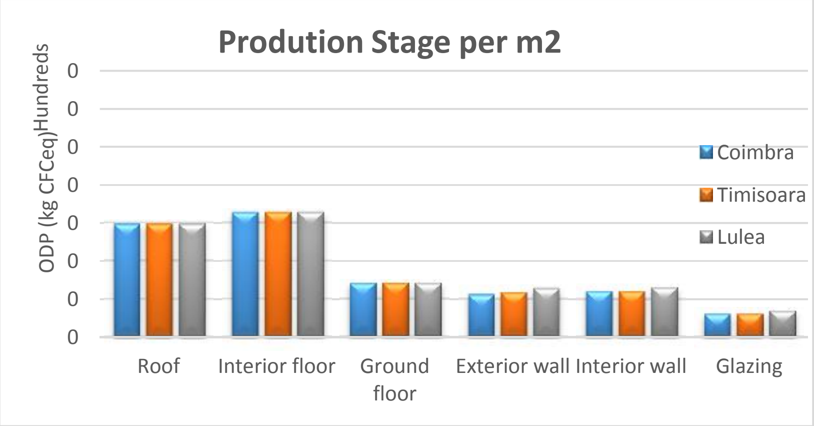


Figure 2.4 Highest Ozone depletion impact occurred in the production stage in of building elements per m^2

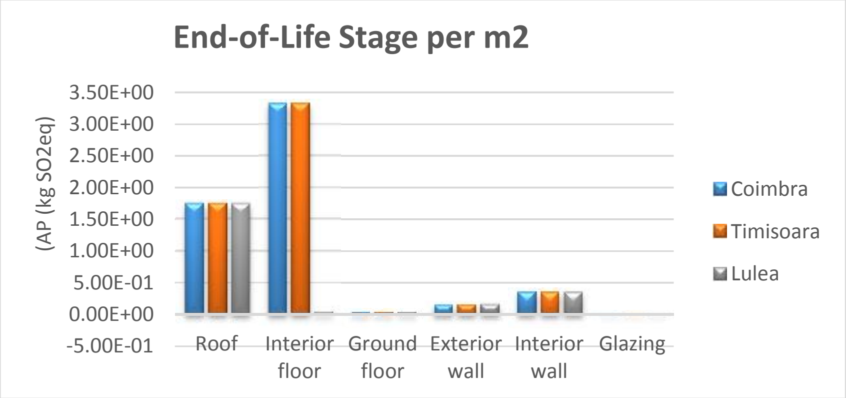


Figure 2.5. Highest Acidification impact occurred in the end of-life stage in of building elements per m^2

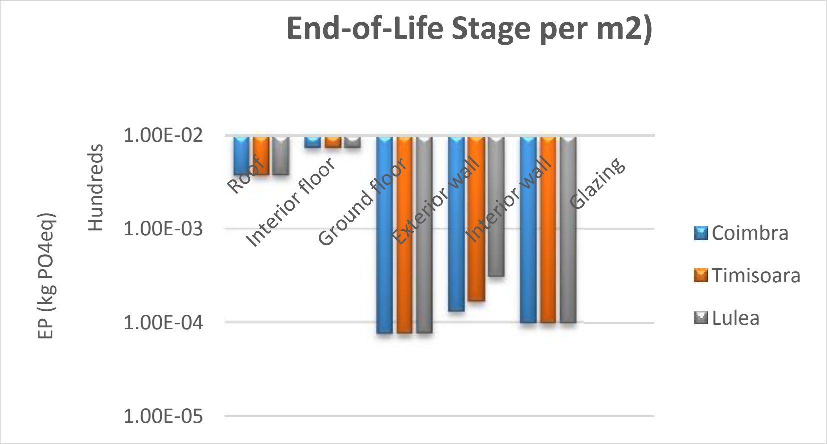


Figure.2.6 Highest Eutrophication impact occurred in the end of-life stage in of building elements per m^2

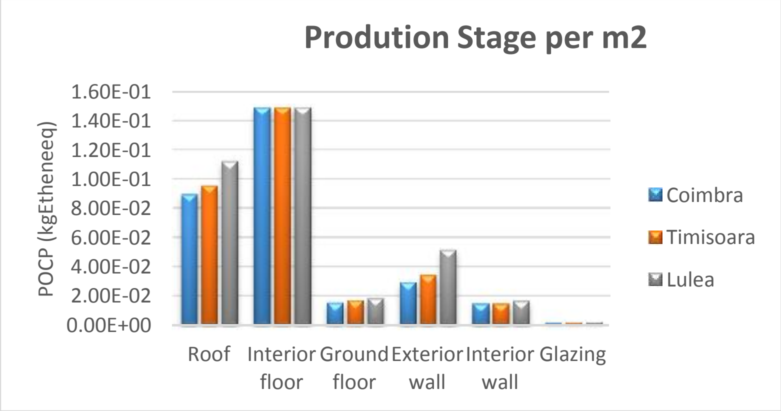


Figure 2.8. Highest Photochemical creation impact occurred in the construction stage in of building elements per m^2

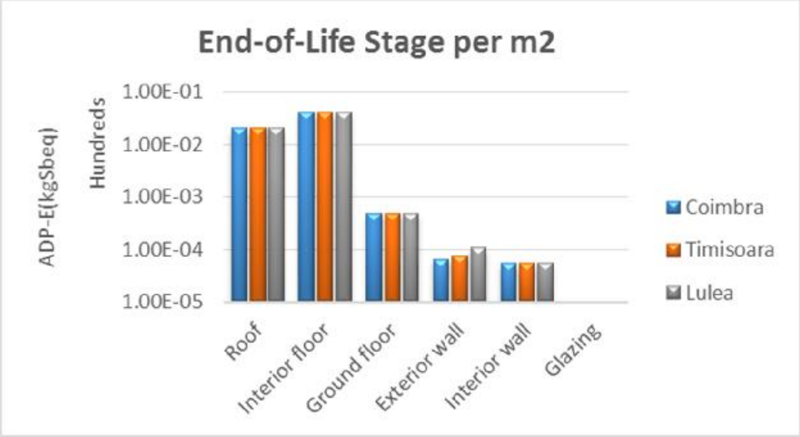


Figure 2.9. Highest Abiotic depletion of mineral resources impact occurred in the end of life stage of building elements per m^2

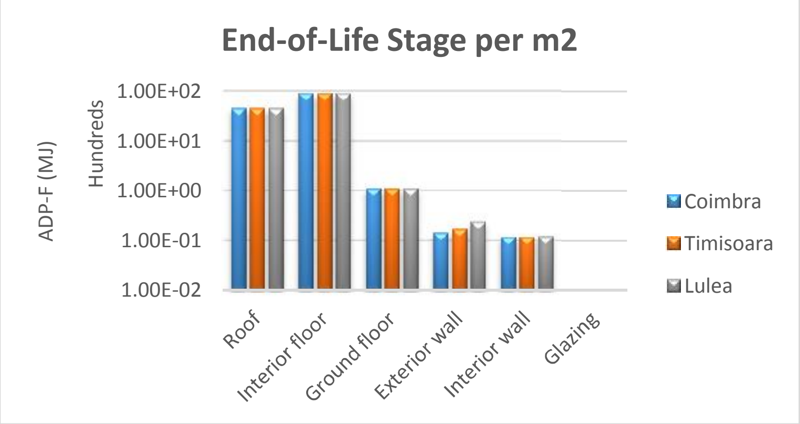


Figure.2.10. Highest Abiotic depletion of fossil fuel impact occurred in the end life stage per house in of building elements

2.3.2 Total impact per house for the construction stage

The total results of the environmental impact in the construction stage only, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators varies between 2 and 4% between the houses. Lulea had the largest impact due to it cold climatic zone, more insulation is necessary for comfort, while Coimbra has least impact because of it low quantities in insulation.

Table.2.2. Total environmental impact analysis results constructions stage

Impact category	Coimbra	Timisoara	Lulea
Abiotic depletion-f	11778.7	12116.42	13028.36
Photochemical oxidation	0.3179598	0.3302574	0.3679503
Global warming	1591.312	1604.549	1639.568
Abiotic depletion-e	6.3912	6.43952	6.59094
Acidification	5.28832	5.33757	5.45555
Eutrophication	0.619728	0.624741	0.634877
Ozone layer depletion	0.000302681	0.000302868	0.000303891

Fig 2.11. Total GWP per house – Construction stage

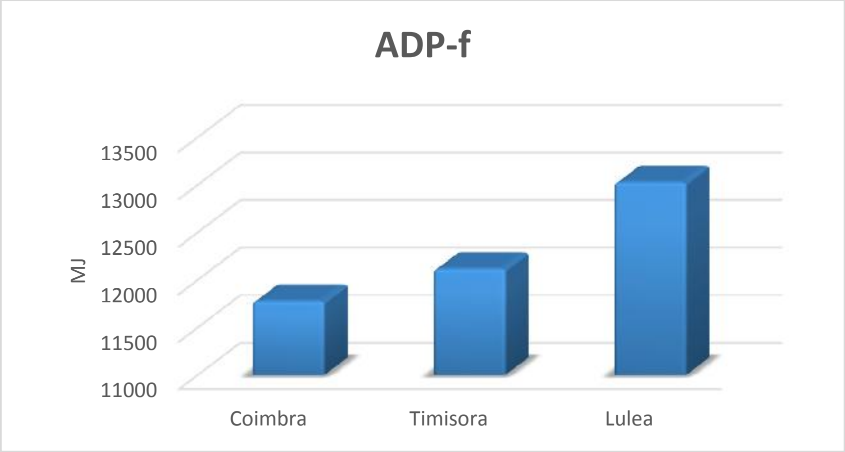


Fig 2.12. Total ADP-f per house – Construction stage

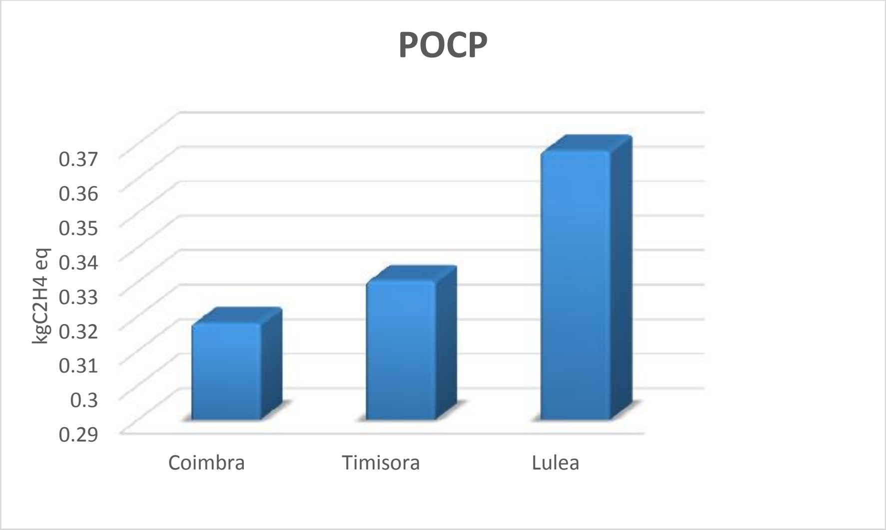


Fig 2.13. Total POCP per house – Construction stage

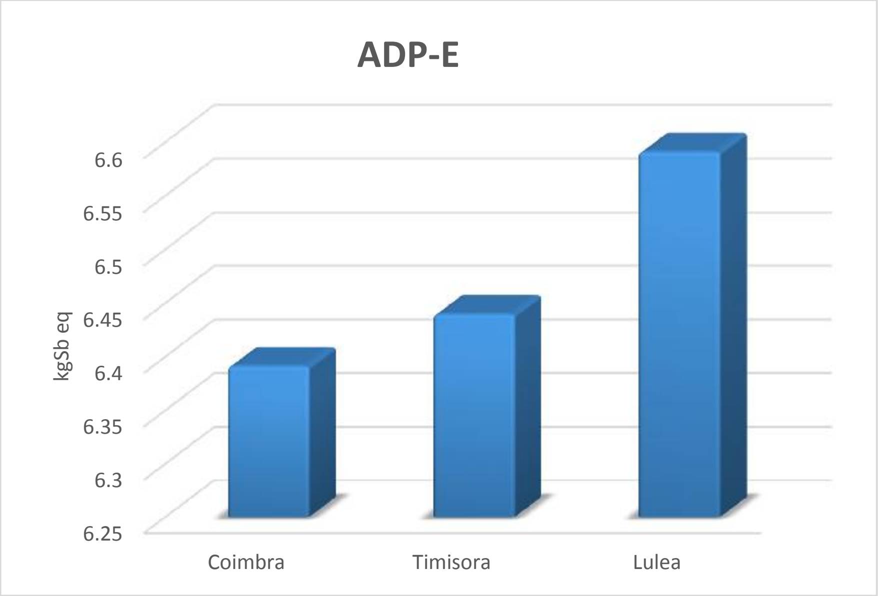


Fig 2.14 Total ADP-e per house – Construction stage

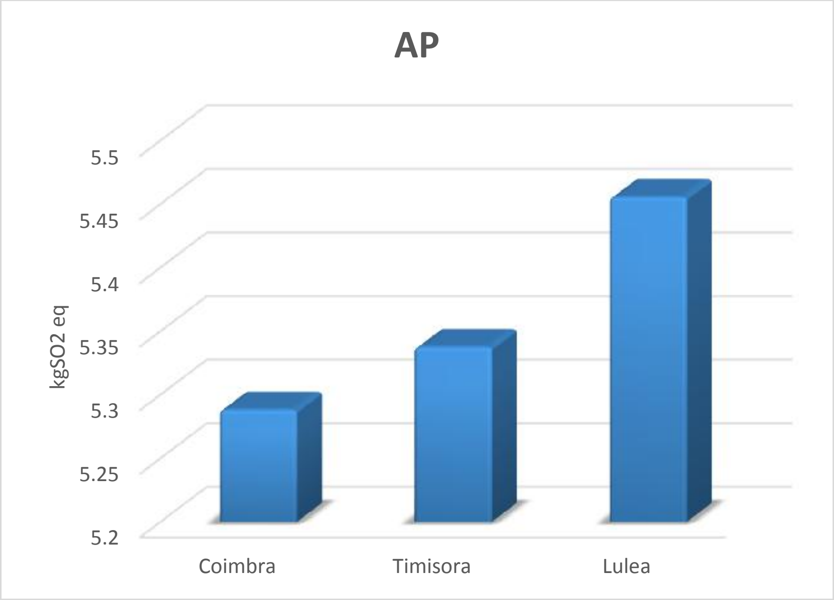


Fig 2.15 Total AP per house – Construction stage

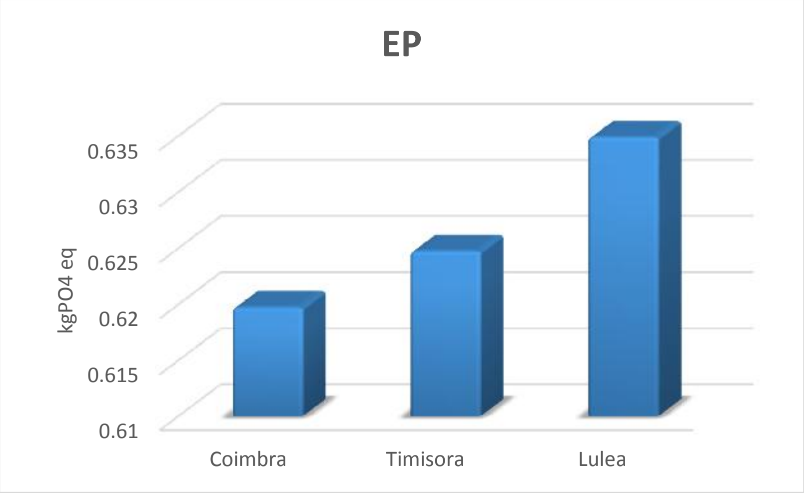


Fig.2.16 Total EP per house – Construction stage

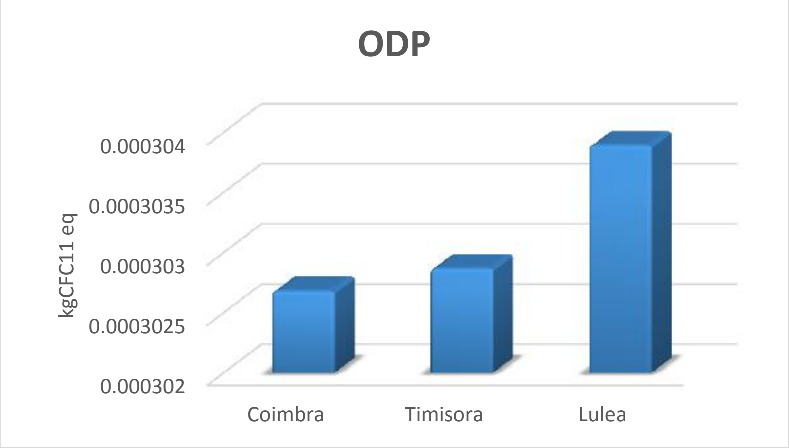


Fig.2.17. Total ODP per house – Construction stage

2.3.3 Total impact per house for the LCA analysis

Complete LCA analysis was performed taking into account the building life cycles stages according to EN 15804: Construction stage, End of life scenario, Embodied energy and Operational energy.

The total results of the environmental impact obtained in the complete LCA analysis, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators vary between 2 and 4% between the houses, the impacts are differ slightly between the houses Lulea had the largest impact due to it cold climatic zone, more insulation is necessary for comfort, while Coimbra has least impact because of it low quantities in insulation.

Table.2.3 Total impact per house for the LCA analysis

Impact category	Coimbra	Timisoara	Lulea
Photochemical oxidation	31.9	33.1	37.6
Abiotic depletion-e	884	892	919
Acidification	818	822	833
Eutrophication	133	134	138
Ozone layer depletion	0.0328	0.0328	0.033
Global warming	159000	161000	165000
Abiotic depletion-f	1840000	1870000	1950000

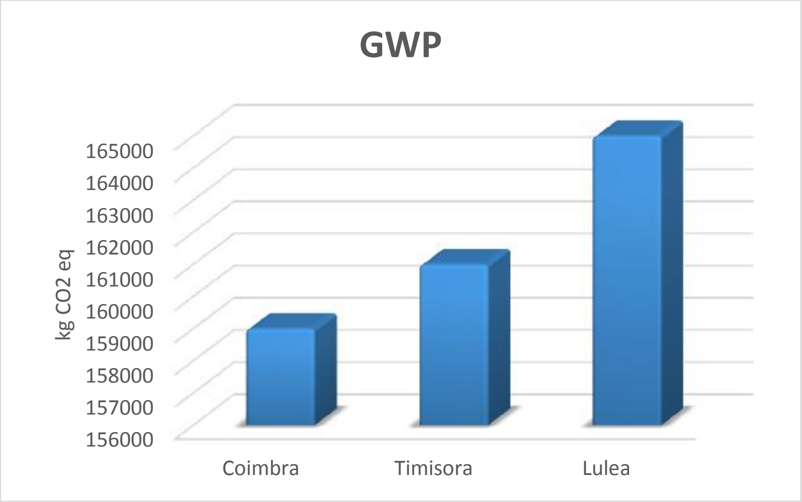


Fig. 2.18. Total GWP per house – LCA analysis

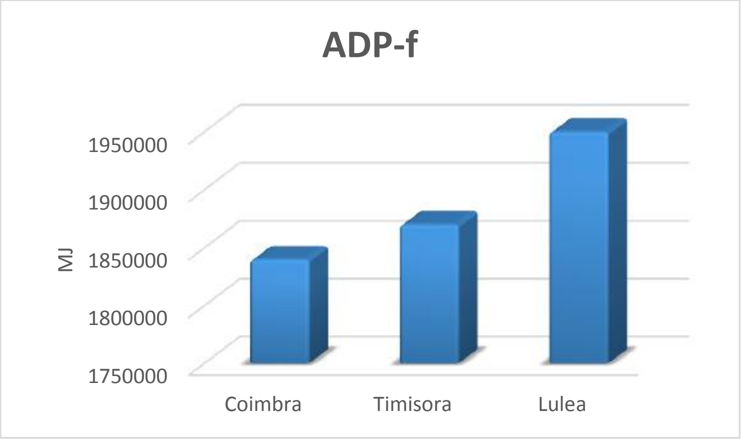


Fig. 2.19. Total ADP-f per house – LCA analysis

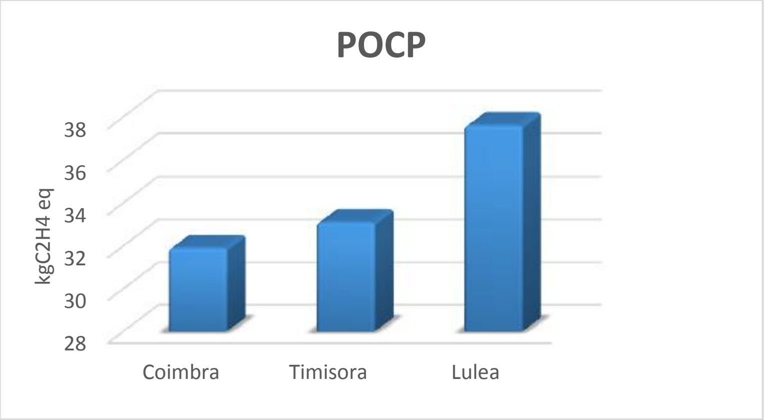


Fig.2.20.Total POCP per house – LCA analysis

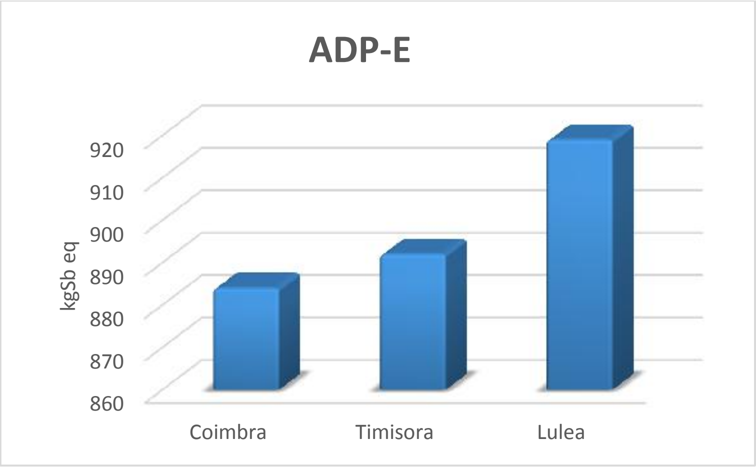


Fig 2.21.Total ADP-e per house – LCA analysis

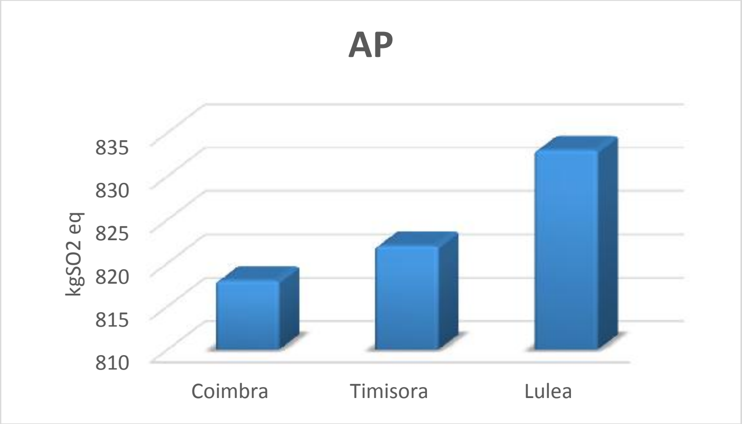


Fig.2.22. Total AP per house – LCA analysis

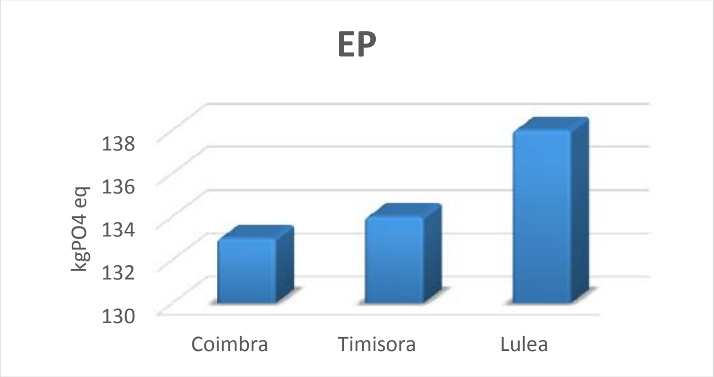


Fig.2.23 Total EP per house – LCA analysis

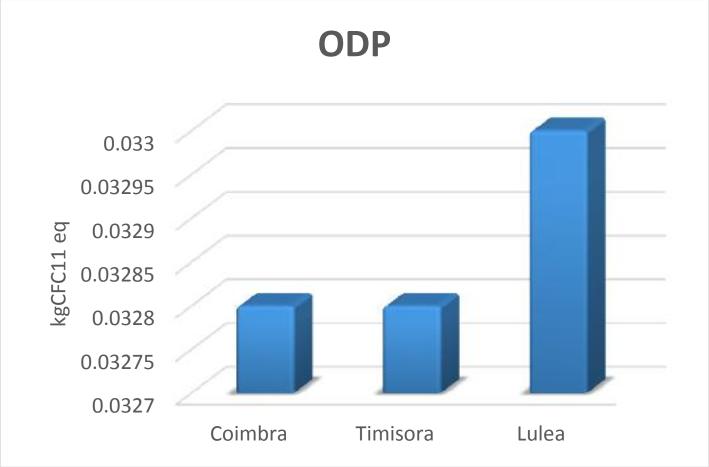


Fig.2.24.Total ODP per house – LCA analysis

2.3.4 Operational energy

Fig 2.16. and fig 2.17 below illustrates the output for the space heating energy, which includes the heat transfer from the various elements.

2.3.4.1 The energy for space heating

From the breakdown of the heat transfer contributions, it is easy to identify the most critical processes. In this case, Fig 2.16 shows that the glazing areas are the main contributor to the heat loss of the building, followed by the ventilation. The heat transfer by walls also contributes significantly to the losses. This type of information helps to decide on the most effective changes to improve the performance of the building. For instance, it is easier to intervene in the envelope (by reducing the U-value of its elements, for example), reducing the heat transfer by ventilation, as the airflow in the winter is already low i.e. 0.30 ac/h for Lulea, 0.6 ac/h Timisoara and 0.6 ac/h Coimbra including an introduction of mechanical ventilation with heat recovery.

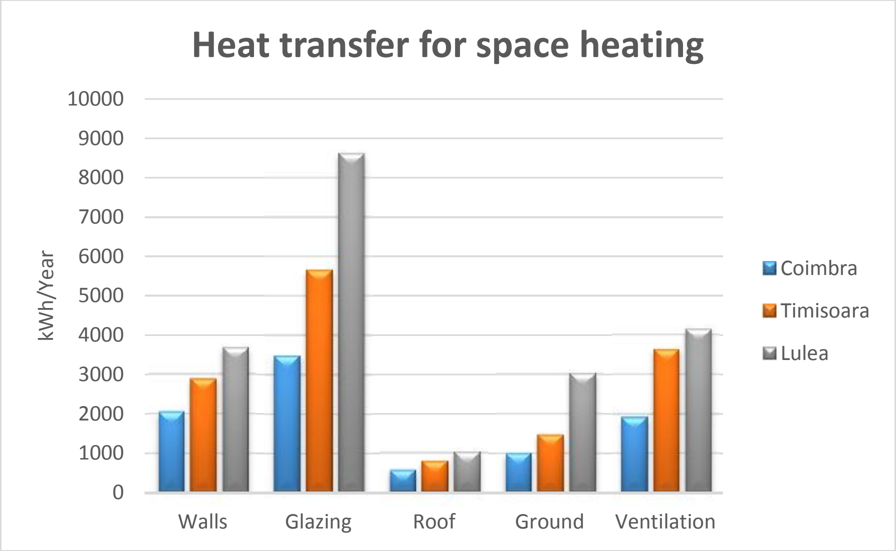


Fig 2.25. The energy for space heating

2.3.4.2 The energy for space cooling

From Figure 8c, it is observed that the heat transfer is higher in the cooling mode due to a higher ventilation rate in the summer season (1.20 ac/h). The effect of changing, a higher ventilation rate in the summer season, from 1.2ac/h to 0.6 ac/h for Timisoara, 1 ac/h Coimbra, and a value of 0.30 ac/h maintained for Lulea. The shading devices was order to reduce the energy need for space cooling. Lulea had the highest heating demand and Coimbra –the highest cooling demand by ventilation due to their climate zones.

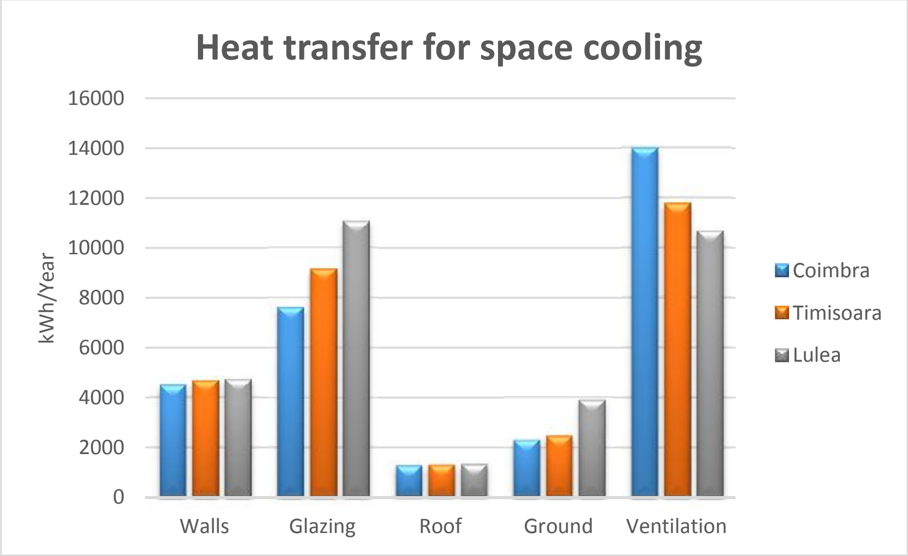


Figure 2.26. The energy for space cooling

The energy needs for space heating and cooling are presented in the table 2.4 below

Table 2.4.Energy Need

		Heating kWh	Cooling kWh	DHW kWh	Total kWh	kWh/m^2
Timisoara	SBsteel	1971.41	7710.34	2877.57	12559.32	84
Coimbra	SBsteel	149.56	7217.65	2877.57	10244.78	68
Lulea	SBsteel	6521.8	2615.02	2877.57	12014.39	80

2.4 Chapter Conclusion

This chapter compares the impacts of the three houses over their service life per unit floor area m^2 in the conceptual stage using SBsteel. As can be observed from Figure 4.13, Lulea, Coimbra, Timisoara house had similar impacts per unit of floor area m^2, where the interior floor acted as the highest contributor in following environmental indicators occurring in end of life stage for ADP-ff, ADP-e and AP and production stage for GWP, ODP and POCP. Material list and quantities for the interior floor for the various climate zones remained constant for the 3 locations. Main materials of the interior floor are steel and concrete, which are the main contributors to emissions.
The external wall had the highest impact in the EP category, varied for the different locations depending on the quantity of insulation used.

In the construction stage and Lulea had the largest impact due to it cold climatic zone, since more insulation is necessary for comfort, while Coimbra has least impact because of it low quantities in insulation. Observed in the results of operational energy demands for the different climatic zones , as expected, the energy for space heating in Lulea is considerably more than Coimbra and Timisoara, which is due to the fact that the heat loss in Lulea, is more than heat gain with compared to the Coimbra especially in cold seasons. On the other hand, the space cooling energy demand in Timisoara, Lulea and Coimbra. However, the Lulea space cooling energy for cooling is not important because no cooling or less is required in case of using natural ventilation due to the low outdoor temperature in Lulea. The heat transfer for cooling obtained is 3 times that of heat transfer for cooling the values obtained could not be justified.

3 STRUCTURAL ANALYSIS AND DESIGN

3.1 Overview and Scope

The design was conducted in accordance to Eurocode. The design will be performed in the ultimate limit state and the serviceability limit state. The design of structural elements was dependent on the seismicity and soil conditions and climatic conditions. All load combinations were entered into the model, and the combined load effects were compared to the reduced nominal strengths of the members. A computer model was constructed in **SAP2000** to conduct three-dimensional frame analysis of the structure. The model included only the main beams, floor beams and the columns; and decking was designed by hand. Lateral loads were applied to diaphragms at each floor; diaphragms were assumed rigid as justified by a diaphragm flexibility study the structural analysis software used is **SAP2000** as shown in fig.3.1.

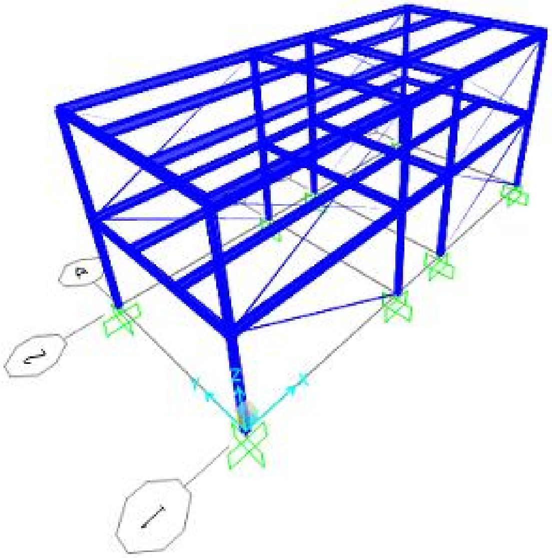


Fig 3.1. Model in SAP2000

3.2 Materials: Structural Steel

Prepared for specific purposes steel can be manipulated for many different roles. Structural steel is rated and prepared for creating a framework for the building. Solid bars can be used for reinforcement and in certain shapes make a building’s foundation or slab more effective. The framework of a building is composed of columns, girders, beams and joists, essentially composing the skeleton. The material properties of the structural steel members are as listed below.

- Young’s modulus, E - 310,000N/mm2
- Shear Modulus, G - 80,000 N/mm2
- Density - 7850 kg/m3
- Poisson’s ratio - 0.3
- Coefficient of Thermal Expansion- 11.7 x 10-6/^{0}C

For plastic design, all sections containing plastic hinges must be Class 1.

3.3 Design Codes

Table3.1 Minimum design loads for buildings other than seismic loads

Eurocode	***Description***
EN 1991-1-1	*Densities, self-weight –Dead load*
EN 1991-1-1	*Imposed loads*
EN 1991-1-3	*Snow loads*
EN 1991-1-4	*Wind loads*
EN 1990	*Load combination*

Table3.2 Seismic Provision for buildings

Eurocode	***Description***
EN 1998 – Eurocode 8	*Design of structures for earthquake*

Table3.3 Building code for design of steel structures

Eurocode	***Description***
EN 1993 – Eurocode 3	*Design of Steel Structures*

3.4 Loading Calculations

The following section will describe the loading calculations for the 2-storey case study building.

3.4.1 Dead load

Accurate estimate of dead load is an important factor in the structural safety and economy of the design. Dead loads were calculated, including the weight of all structural components (columns, beams, and floor system, including claddings, finishes, and fixed equipment. finishes, and fixed equipment. The dead load was considered depending on the specific materials considered for the building.

Table .3.4 Dead loads applied to the floors listed in kN/m²

Element	Timisoara	Coimbra	Lulea
Roof	2.36	2.33	2.41
First floor	2.52	2.52	2.52
External wall	0.43	0.41	0.46
Parapet	0.3	0.3	0.3

3.4.2 Live loads

The live loads on floors in buildings are caused by the weight of furniture, equipment, stored objects and persons. A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads, such as wind load, snow load, rain load, earthquake load, flood load, or dead load. When imposed loads act simultaneously with other variable actions (e.g. wind, snow, cranes or machinery) the total of those imposed loads may be considered as a single action. However, for roofs of buildings, imposed loads should not be considered to act simultaneously with snow loads or wind actions, there fore in Timisoara and Lulea only snow load was considered as live load on roof. The imposed load on the roof is given according to EN 1991-1-1.

Considering that the roof is accessible, the characteristic value of the uniformly distributed imposed load q_k, is shown in *Table 3.3.*

Table 3.5 Live loads applied to the floors in kN/m²

	Timisoara	**Coimbra**	**Lulea**
Roof	0	1.8	0
First floor	2	2	2

3.4.3 Seismic loads

For ordinary buildings, an equivalent static load is calculated using a response spectrum method and is to be used for static stress analysis (this series of procedure may be referred to as the equivalent static analysis). The response spectrum method is applicable only for elastic structures, but can be used to approximately estimate elasto-plastic structures with uniform plasticity within the structures.

Most often, the horizontal components of seismic loads are significant for ordinary buildings, the vertical components may be neglected is, under the ordinary conditions mentioned above.

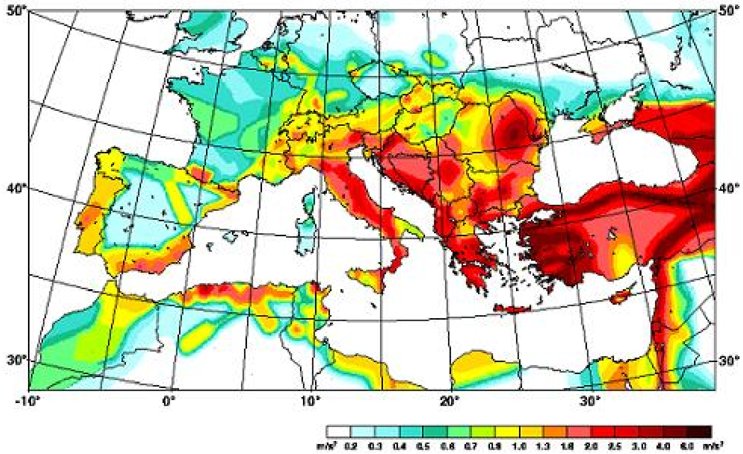


Fig 3.2. Seismicity in Europe, based on Peak Ground Acceleration

Table 3.4. Seismic load

	Timisoara	***Coimbra***	***Lulea***
Seismic intensity	Moderate	Severe	-
Ground acceleration a_g	0.16	0.24	-
Soil class	C	C	-
Behavior factor q	1	1	-

3.4.4 Snow load

Snow loading for The Eurocode for wind loads on building structures. Snow loads should be classified as variable, fixed actions. The load should be assumed to act vertically and refer to a horizontal projection of the roof. When artificial removal or redistribution of snow on a roof is anticipated the roof should be designed for suitable load arrangements The Eurocode prEN 1991-1-3 is provided with maps which give the characteristic values of the snow loads on sea level for the relevant European countries. Several snow load maps are available for different climatic regions. The maps for the several climatic regions are sub-divided into snow load zones *Z*. In addition to the values of the altitude the numbers *Z* of these zones are the basic input parameters for the determination of the characteristic value of the ground snow load *s*k. Snow load on roofs should be designed as followed:

According to prEN 1991-1-3 the snow load on the roof is described by the following equation:

$s = \mu i \cdot Ce \cdot Ct \cdot s_k$

Where: μi roof shape coefficient
*C*e exposure coefficient
*C*t thermal coefficient
s_k characteristic value of the ground snow load for the relevant altitude

The characteristic value of snow loads is been given in national annexes.

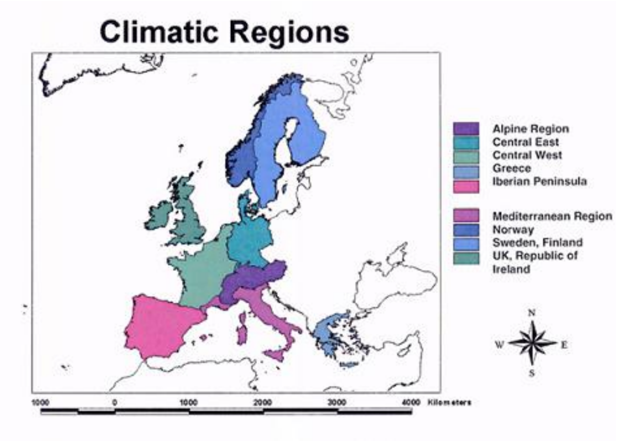


Fig 3.3. European Ground Snow Load Map

Table 3.5. Ground Snow loads

	Timisoara	*Coimbra*	*Lulea*
s_k (kN/m^2)	1.5	0.1	3

3.4.5 Wind loads

The wind pressure on a structure depends on the location of the structure, height of structure above the ground level and also on the shape of the structure. The Eurocode gives the basic wind pressure for the structures in various parts of the country .A simplification of the wind load has been made in regards of the wind pressure on the roof and the internal pressure. The calculations show both a suction on some parts of the roof and pressure on other parts. The different parts are depended on the width of the structure. The calculations of characteristic wind load shows a positive windward pressure and a negative leeward pressure this is also illustrated in table 3.6.

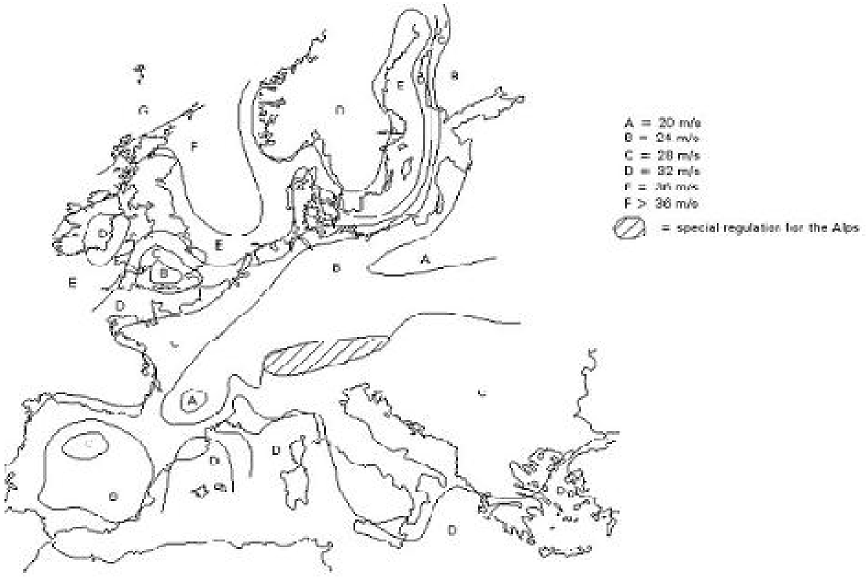


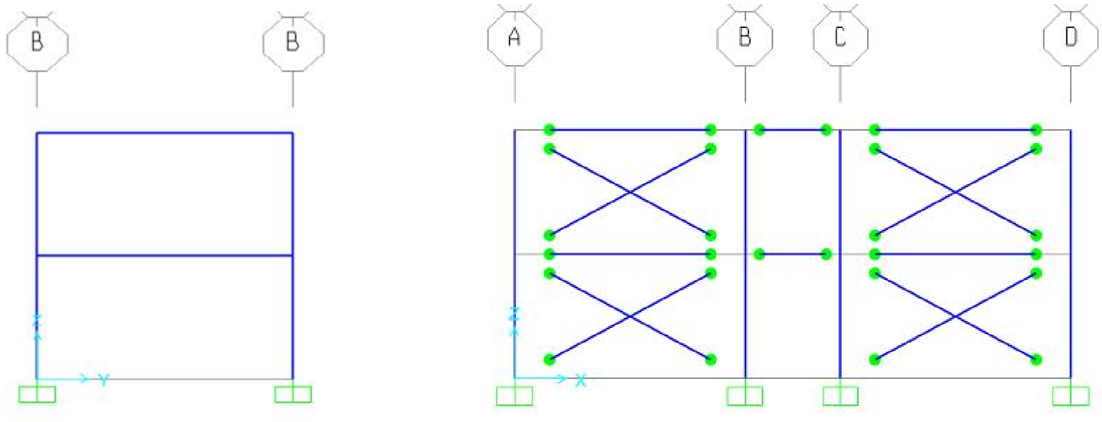
Fig 3.4. Wind map of Europe

Table 3.6. Wind loads applied to the building.

External Wind load	**Timisoara**	**Coimbra**	**Lulea**
Windward zone D	0.917	0.675	0.253
Leeward, zone E	0.573	0.422	0.158

3.4.6 Force-resisting system

The lateral force-resisting system is comprised of Concentric braced frame steel along the long dimension and moment resisting frames along the short dimension**.** Concentric braced frame steel will provide resistance against lateral loads whilst moment resisting frames will resist gravity loads. Moment resisting frames can be seen below in Figure 8. The moment frame deforms in order to resist the applied forces. The Concentric braced frame steel resist the lateral load as shown in figure.3.5 . It is a graphic obtained from the structural analysis program, SAP 2000 (Computers and Structures, 2004).



(a) *(b)*

Fig.3.5 (a) Moment resisting frame steel (b) Concentric braced frame steel

3.5 STRUCTURAL ELEMENTS

3.5.1 Main Steel beam

Verification check;

1. Resistance of cross-section
- Bending moment
- Shear resistance
- Bending and shear Interaction
2. Buckling resistance

In order to evaluate the sensitivity of the frame to 2nd order effects, a buckling analysis is performed to calculate the buckling amplification factor α_{cr} for the load combination giving the highest vertical load:

- Flexural buckling - Uniform members in compression

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$$, where $$N_{b,Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

- Lateral-Torsional Buckling Check - Uniform members in bending

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1.0$$

where the design buckling resistance moment, $M_{b,Rd}$ is taken as::

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\lambda_{MI}}$$

- Bending moment and axial compression

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy} \frac{M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz} \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

Table 3.7. Bending moment and axial compression

Timisoara	***Coimbra***	***Lulea***
0.389	0.236	0.41

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy} \frac{M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

Table 3.8. Bending moment and axial compression

Timisoara	***Coimbra***	***Lulea***
0.245	0.158	0.25

- Verification of the serviceability limit state of deformation

$$\delta_{max} \leq L/250$$

Table 3.9.deflection of the main beams

	Timisoara	***Coimbra***	***Lulea***
¢ (mm)	19.7	18.7	21.5

Where the deflection limit is

$$\frac{L}{250} = 22.4mm$$

3.5.2 Secondary Steel beam

To design the beam, the maximum moment and forces was determined and the member checked for the following;

1. Resistance of cross-section

- Bending moment
- Shear resistance
- Bending and shear Interaction

2. Buckling resistance

In order to evaluate the sensitivity of the frame to 2nd order effects, a buckling analysis is performed to calculate the buckling amplification factor α_{cr} for the load combination giving the highest vertical load:

- Lateral torsional buckling

Secondary beam is not susceptible to lateral-torsional buckling as long as it is laterally restrained with reinforced concrete slabs on the floor and roof. The slab prevents lateral displacements of the compress parts of the cross section.

- Flexural buckling - Uniform members in compression

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0 \quad \text{, where} \quad N_{b,Rd} = \chi \frac{A f_y}{\gamma_{M1}}$$

- Verification of the serviceability limit state of deformation

The verification of the maximum vertical deflection is performed using deformations δ from SAP2000 for serviceability limit state $\delta \leq L/250$

Table 3.10.The Wind loads applied to the building.

	Timisoara	*Coimbra*	*Lulea*
¢ ***(mm)***	18.4	18.3	19.5

$$\frac{L}{250} = 22n$$

3.5.3 Steel column

Verification check;

1. Resistance of cross-section
- Bending moment
- Axial
- Shear resistance
- Bending and axial Interaction
- Bending and shear Interaction
2. Limitation of inter-Storey drift
   $d_r\nu \le 0{,}005h$
3. Buckling resistance

In order to evaluate the sensitivity of the frame to 2^{nd} order effects, a buckling analysis is performed to calculate the buckling amplification factor α_{cr} for the load combination giving the highest vertical load:

- Flexural buckling - Uniform members in compression

$$\frac{N_{Ed}}{N_{b,Rd}} \le 1.0 \quad \text{, where} \quad N_{b,Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

- Lateral-Torsional Buckling Check - Uniform members in bending

$$\frac{M_{Ed}}{M_{b,Rd}} \le 1.0$$

where the design buckling resistance moment, $M_{b,Rd}$ is taken as::

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\lambda_{MI}}$$

- Bending moment and axial compression

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz}\frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \le 1$$

Table 3.11.Ratio of the bending moment and axial compression above

	Timisoara	Coimbra	Lulea
eqn.1	0.784	0.9	0.84

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz}\frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \le 1$$

Table 3.12. Ratio of the bending moment and axial compression above

	Timisoara	Coimbra	Lulea
eqn.2	0.511	0.63	0.69

- Verification of the serviceability limit state of deformation

$$\delta \le L/250$$

Table 3.13.deflection of the main beams .

	Timisoara	*Coimbra*	*Lulea*
¢ *(mm)*	18.4	18.3	19.5

3.5.4 Braces

Although the force in the diagonal X-braces can be either tension or compression, only the tensile value is considered because it is assumed that the diagonal braces are capable of resisting only tensile forces the bracing selected is a diameter 20 mm steel rod.

Verification check;

- Design resistance to tension

$$\frac{N_{Ed}}{N_{t,Rd}} \leq 1.0$$

3.5.5 Floor system

The floor system consists of composite metal decking; lightweight concrete is used to mitigate gravity and seismic loads by reducing weight. The decking is supported on floor beams that are designed and analyzed compositely. One very important element in a building is the floor diaphragm. Most of the time, the floor is concrete on metal deck in steel buildings and acts to resist gravity loads, both dead and live. Another function that the floor diaphragm serves is to transfer forces to the perimeter moment frames. For the majority of steel buildings, with metal corrugated decking filled with structural concrete, the floor diaphragm can be considered rigid, meaning that the mid-span deflection of the diaphragm is relatively insignificant to the deflection of the seismic load resisting system.

3.6 Steel connections

Connections are an important aspect of steel design and construction. Connections also play a large role in the speed and cost of construction. Welding performed in the field is much slower and more expensive than bolting. Therefore, most connection plates are welded to one member in the fabrication shop and bolted to the other member in the field. For the scope of this project the group chose to design the bolted connections which would be performed in the field, and assume the welded connections would be designed by the fabricator. Autodesk Robot structural analysis was used in the design of the connection.

3.6.1 Bolted End Plate beam-column connection

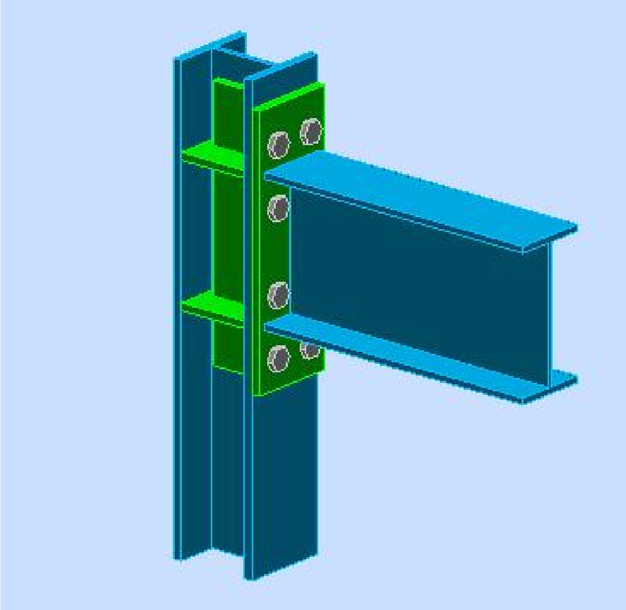


Fig.10 Bolted End Plate Connection

The connection between the Main beams and the column is fully restrained, which means that the connections have sufficient stiffness to maintain the angles between intersecting members. The beams frame into the columns and are connected in such a way that moment, as well. The joint at the intermediate beam consists of an extended end plate with a specified thickness with transverse stiffeners and panel in the column web. The bolts are

M16, class 10.9.The Moment resistance of a joint $M_{j,Rd}$ should be determined from the bolted connections. The Rotational stiffness of a joint Sj should be determined from the flexibilities of its basic components, each represented by its elastic stiffness coefficient k_i.

- Connection stiffness

$$Sj,ini = E\,zeq2\sum i\left(\frac{1}{k1}+\frac{1}{k2}+1\frac{1}{keq}\right)$$

Table 3.13. Connection stiffness

	Timisoara	*Coimbra*	*Lulea*
Sj (kN.m)	19295.61	13831.89	11674.89

- Moment resistance to bending $M_{j,Rd}$

$$Mj,Rd = \sum h_j F_{tj,Rd}$$

Table 3.14.The Wind loads applied to the building.

	Timisoara	Coimbra	Lulea
M(b,Ed) / M(j,Rd) ≤ 1	0.89	0.88	0.75

The joint is classified as rigid according to EC3-1-8,

3.6.2 Moment resisting Column base connection

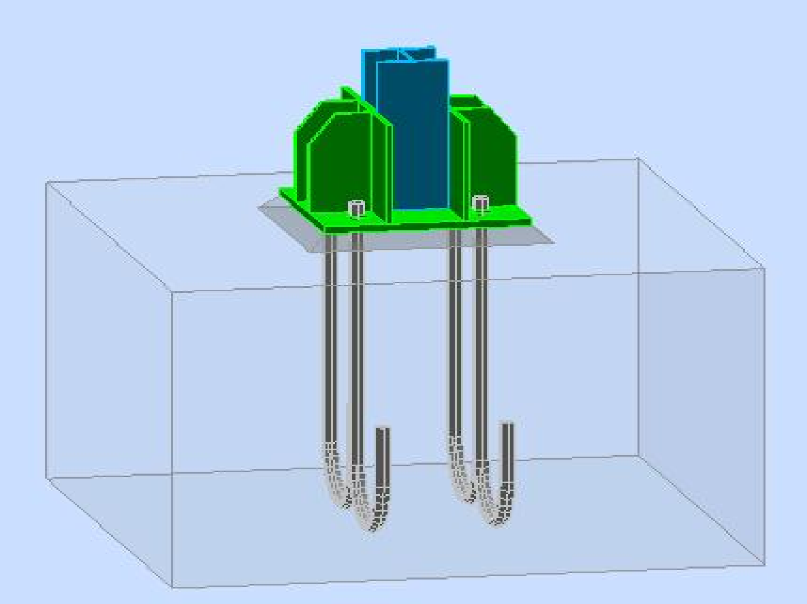


Fig.11. Rigid column base connection

The design of the column base is subjected to compression, bending moment and shear force the column base consists of a steel column, a base plate and an anchoring assembly. Connection consisting of fillet welds connecting column to base plate and anchor bolts with stiffeners connecting base plate to concrete Stiffened base plates to transfer high bending moments. The column base is supported by concrete foundation. The square spread footing was designed based on the soil’s bearing capacity assumed. Since the concrete columns resist both axial forces and moment forces, the footings were designed with to resist for vertical pressure and overturning. To avoid overturn failure, the footings are designed so that the entire footing applies downward on the soil and no uplift force is present. The design of a simple joint involves the verification of the resistance, Connection resistance to bending

- $M_{j,Ed,y} \,/\, M_{j,Rd,y} \leq 1$

It is required to verify the following:

Table 3.15.Moment resistance.

	Timisoara	*Coimbra*	*Lulea*
$M_{(j,Ed,y)} \,/\, M_{(j,Rd,y)} \leq 1$	0.89	0.76	0.85

3.6.3 Beam-beam connection

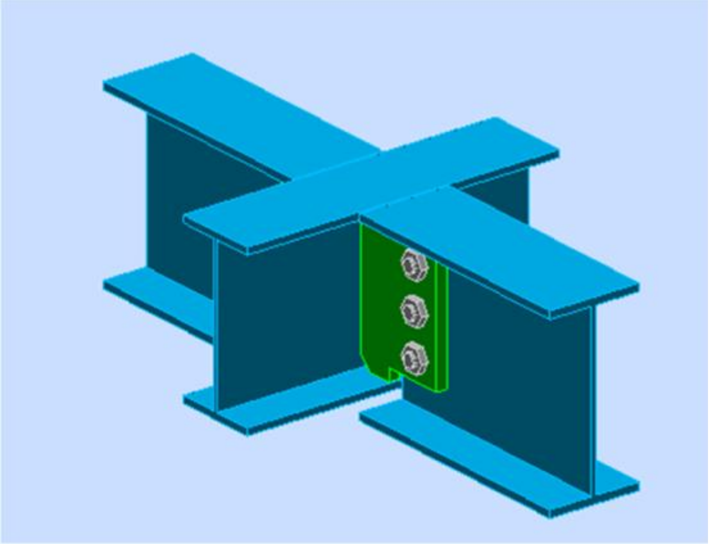


Fig.6.Bolted Pinned beam-beam connection

The design of the secondary beam and main beam is designed to be nominally pinned so that deformations of the secondary beam can occur without inducing moments in the main beams.

The connection was designed a shear connection using a fin plate, with bolt grade of M16.

Verification of the resistance of fin plate

- $V_{b,Ed} / \leq V_{eff,Rd}$

where

$$V_{effRd} = 0.5 \cdot f_u \cdot \frac{A_{nv}}{\gamma_{M2}} + \left(\frac{1}{\sqrt{3}}\right) \cdot fy \cdot \frac{A_{nv}}{\gamma_{M0}}$$

Table 3.16. Resistance of the fin plate

	Timisoara	*Coimbra*	*Lulea*
V (b,Ed) / ≤ V(eff,Rd)	-34.13 < 383.19	-36.54 < 409.93	-36.54 < 409.93

3.6.4 Bolted Pinned beam-column connection

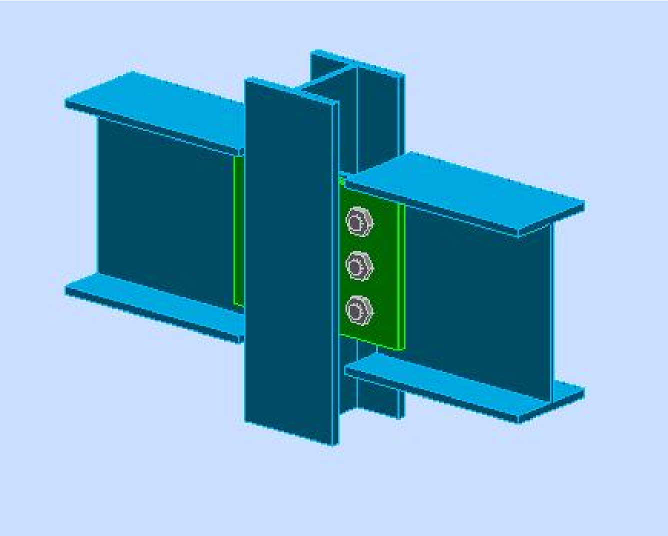


Fig.6. Bolted Pinned beam-column connection

The secondary beam to column connection is designed to resist to axial and shear forces only. As a consequence, the development of bending moment may be potentially unsafe. The connection, nominally pinned will be detailed so that rotation of the beam can occur without the connection attracting significant moments.

Verification of the resistance of fin plate

- $V_{b,Ed} / \leq V_{eff,Rd}$

where

$$V_{effRd} = 0.5 \cdot f_u \cdot \frac{A_{nv}}{\gamma_{M2}} + \left(\frac{1}{\sqrt{3}}\right) \cdot fy \cdot \frac{A_{nv}}{\gamma_{M0}}$$

Table 3.17. Resistance of the fin plate

	Timisoara	*Coimbra*	*Lulea*
$V_{(b,Ed)}$ / ≤ $V_{(eff,Rd)}$	-34.13 < 324.11	-34.13 < 336.41	36.54 < 267.71

3.7 Summary of result

As expected from the 3.18, the structure designed in Lulea was the lightest, between the two locations, due to its location in a non-seismic zone. In Coimbra and Timisoara, the elements were dimensioned from gravitational load conditions and seismic activity no dissipative zones were considered while Lulea was designed only based on gravitational loads. Calculations indicate that chosen structural element of the frame in the various locations differ slightly. The slight differ might be due to the heavy snow load experienced in Lulea that give rise to larger beams. Conclusively it can be assumed that the ‘Affordable house’ can be adapted to these EU climatic zones without a major increase in structural members.

Table.3.18 A summary of the structural elements as a result from the design.

Location	**Timisoara**	**Coimbra**	**Lulea**
Main beam material S355	**IPE200**	**IPE220**	**IPE240**
Secondary beam material S355	**IPE220**	**IPE220**	**IPE220**
Column material S355	**HE140B**	**HE120B**	**HE100B**
Braces material S235 [steel rod bar in mm]	**D20**		
(plate connections, bolts, studs) 25%	**1419.0**	**1378.73**	**1307.575**
Material use (kg)	**7098.54**	**6893.64**	**6566.82**

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4 ENVIRONMENTAL IMPACT ASSESMENT USING AMECO

4.1 Introduction

AMECO software relates solely to the main structure of the buildings, i.e. the floors, columns and beams. Developed by the Sustainability department of ArcelorMittal Global R&D, the Esch ArcelorMittal research center working on long products and CTICM (French Steel Construction Industry Technical Centre), it enables the comparison of steel and concrete structures in their production, transportation and end-of-life phases, including the recovery of concrete and the recycling of steel products.

AMECO Software is designed to deal with Life Cycle Assessment of bridges and buildings with structural steel and composite buildings. Evaluating the environmental footprint, in particular the associated energy consumption and greenhouse gas emissions. Their calculation is based on several international norms such as ISO-13370, ISO-13789 and ISO-13790 as well as European norm (EN 15316).Free tool developed by CTICM (France) on the behalf of ArcelorMittal.

- AMECO includes following modules:
- Module A: Production stage (Raw material supply, transport, manufacturing)
  Construction stage (transport, construction)
- Module B: Use stage Module added in AMECO version 3 in the frame of LVS3 project for buildings only
- Module C: End-of-life stage (deconstruction, transport, waste process, disposal)
- Module D: Benefits and loads beyond system boundaries (Reuse, recycling and recovery)
- Material list and selection of macro component

The simplified algorithm implemented in AMECO v3 allows predicting the building energy need for

- Space heating;
- Space cooling;
- Domestic hot water (DHW) supply.

4.2 Material list and selection- component

Most of the Constructive elements were predefined in AMECO, with their specific U-values, also introduce in the tool was the net weight of the structural members: columns, beams, studs, plate connects and bolts in table 3.18. Most of the parameters were fixed and could not be altered; therefore, the 3 locations have similar data .Table 4.1 below shows the input data considered for the various locations.

Table.4.1 A summary of input data considered for the locations

	Cfb	**Csb**	**Dfc**
Site	Timisoara	Coimbra	Lulea
Orientation	South		
Floor area m^2	150		
Area glazing S (%)	4		
Area glazing N (%)	0		
Area glazing W (%)	82		
Area glazing E (%)	82		
Glazing type	Double glazing low-Emissivity		
U-value glazing	1.7	1.4	1.2
Heating	Gas Fuel Heater		
Glazing Frame type	Wood		
Heating system	Electric resistance		
Cooling system	Split		
DHW System	Electric Boiler		
Ventilation type	Mechanic		
Heat recovery	0.6		
Winter room	20		
Summer room	26		
Air Flow rate, cooling	1		
Air Flow rate, heating	0.6		
Shading device	Interior transparent curtains Light		
Color of opaque	Light		dark
Ground floor type	Slab-on ground floor		
Soil type	Clay or Silt		

4.3 Impact assessment and interpretation of results

This section summarizes the results of the LCA of 2-story steel building for the three EU climatic zones. Taking into consideration seven impact categories described in Chapter 1.7, each macro-component has been analyzed in different stages,

- The environmental impact of each structural element to the building per m^2

- Construction stage of each building
- Complete LCA analysis (Construction stage +Use stage +End of life)

4.3.1 Environmental impact of each structural element per m^2

Figures below shows impacts per m^2 originating from energy and materials used for house construction.

The most significant element category is the Envelope which contributes to highest environmental impact in all the category except EP category followed by the Roof.

Envelope (steel panel) and beams (steel) contains steel and insulation EPs used in the external wall, which is known as one of the most impact-intensive construction materials.

It is observed that highest impact occurred in the Production stage in the entire impact categories. With envelope as the contributing factor in GWP, EP, POCP, ADP-e, ADP-f while steel beam in Lulea had the highest influences in ODP, AP.

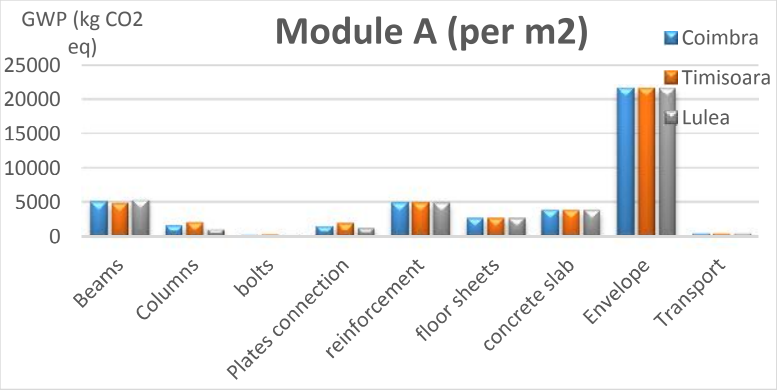

Figure.4.1. Global warming impact on production stage for components per m^2

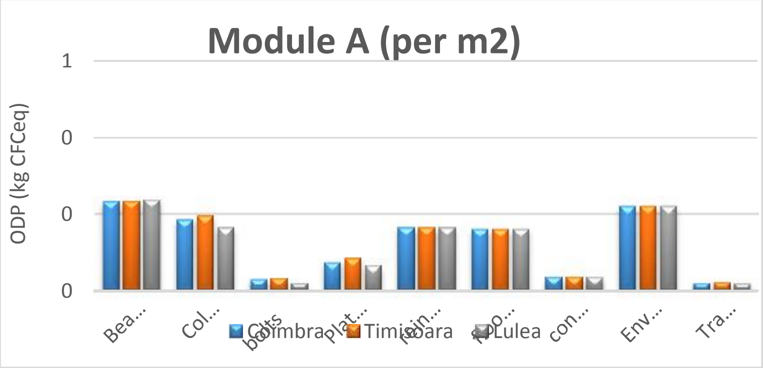

Figure.4.1. Ozone depletion impact on production stage for the components per m^2

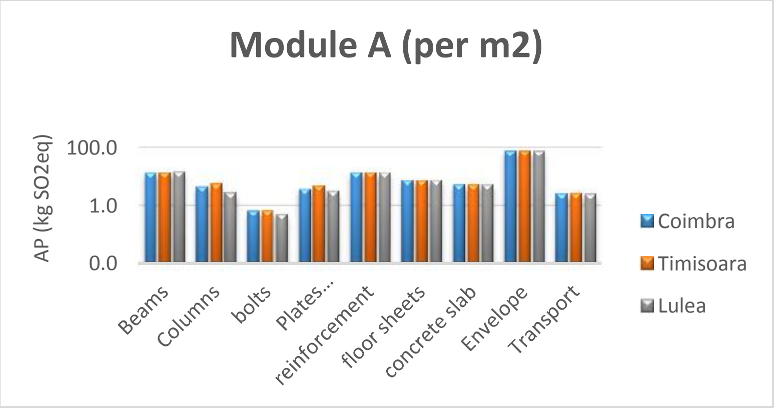

Figure.4.2. Acidification impact on production stage for the components per m^2

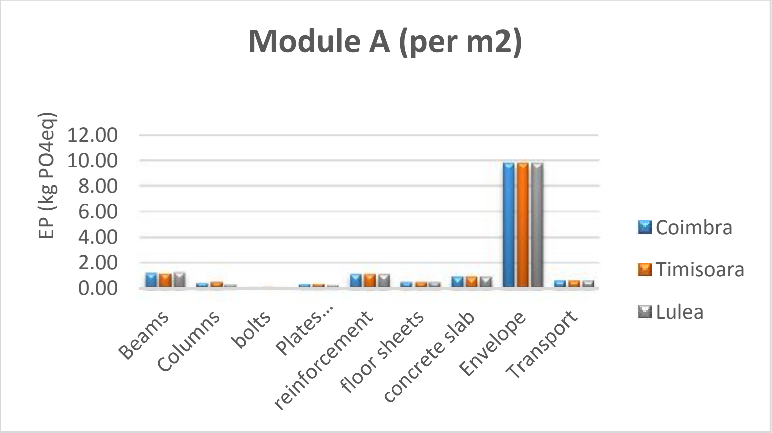

Figure.4.3 Eutrophication impact in production stage for the components per m^2

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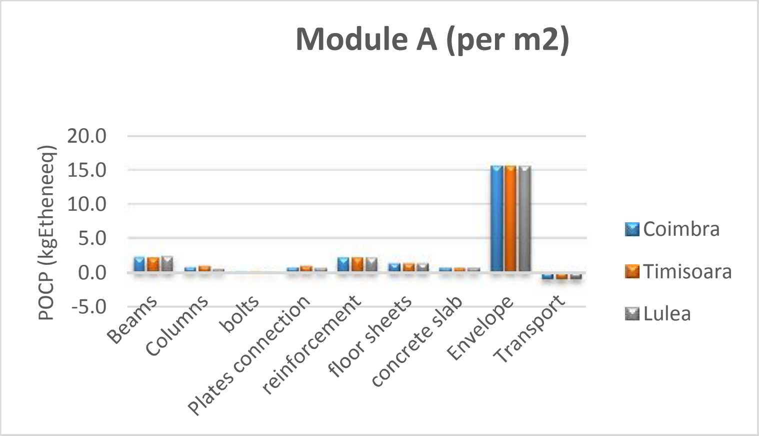

Figure.4.4. Photochemical ozone creation impact on production stage for the components per m^2

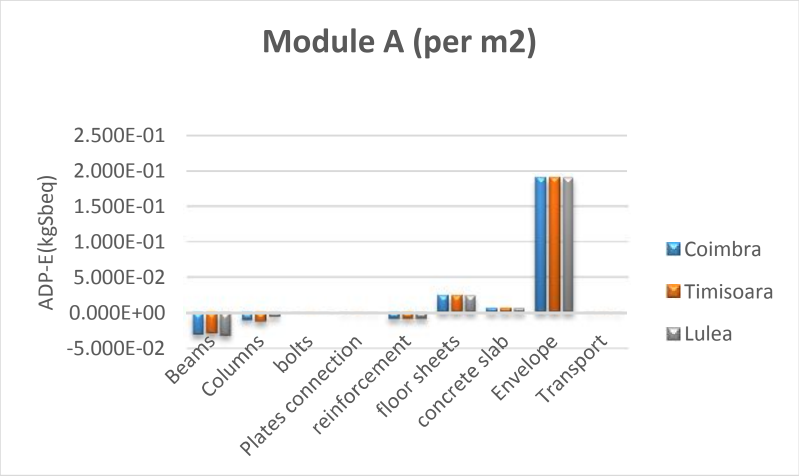

Figure.4.5. Abiotic depletion of mineral resource impact on production stage for the components per m^2

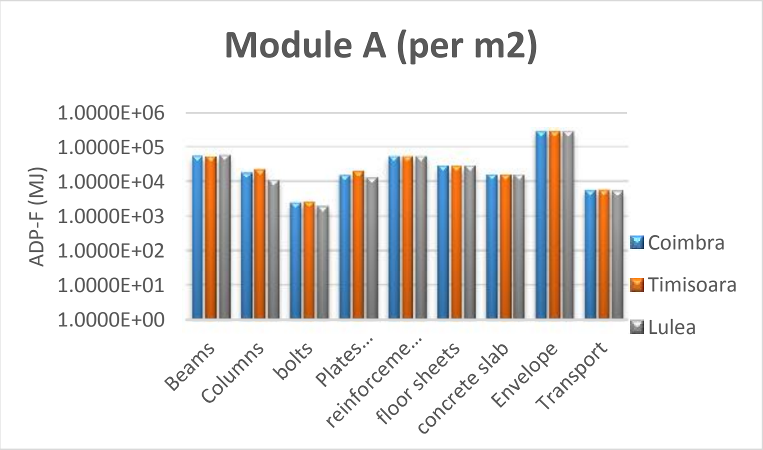

Figure 4.6. Abiotic depletion of fossil resource impact on Production stage for the components per m^2

4.3.2 Environmental Impact per house in the construction stage

The total results of the environmental impact obtained in the construction stage only, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators vary between 2 and 4% between the houses. The impacts are differ slightly between the houses Timisoara had the largest impact due to its large quantities weight in quantities, compared to Coimbra and while Lulea had the lowest impact due to its structural steel weight in the all the impact category except ADP- e. Lulea had the highest .

Table.4.2 Total environmental impact per house

Impact category	Coimbra	Timisoara	Lulea
Global warming	41970	42640	41300
Abiotic depletion-fossil fuel	476350	483430	469240
Acidification	128.566	130.361	126.735
Abiotic depletion-e	0.172792	0.1715383	0.1749725
Photochemical oxidation	22.5039	22.789	22.2309
Eutrophication	14.8154	14.9322	14.6432
Ozone layer depletion	0.00053373	0.00055403	0.00052581

Fig 4.7.Total GWP per house – Construction stage

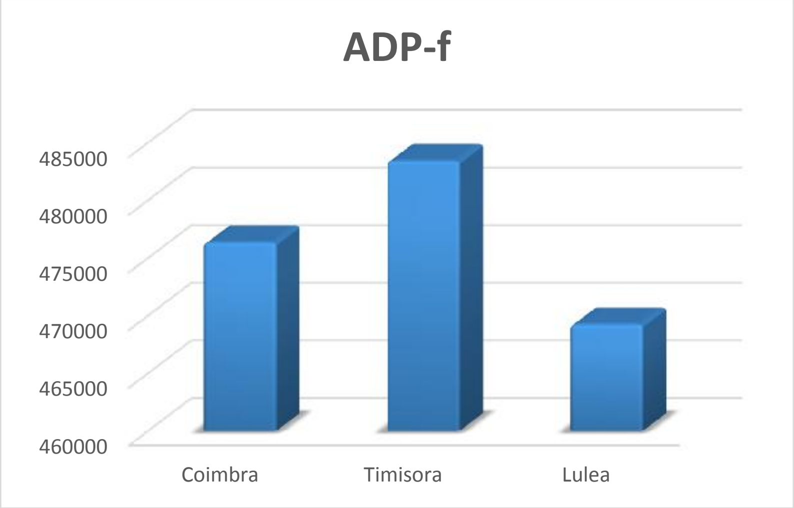

Fig 4.8. Total ADP-f per house – Construction stage

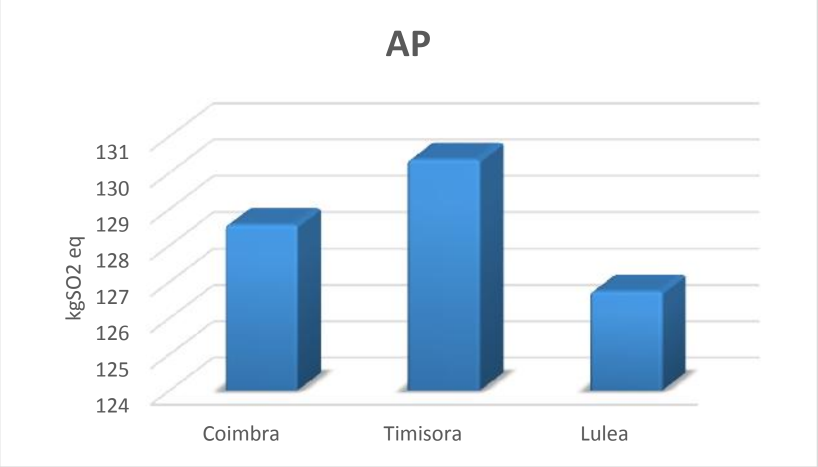

Fig.4.9. Total AP per house – Construction stage

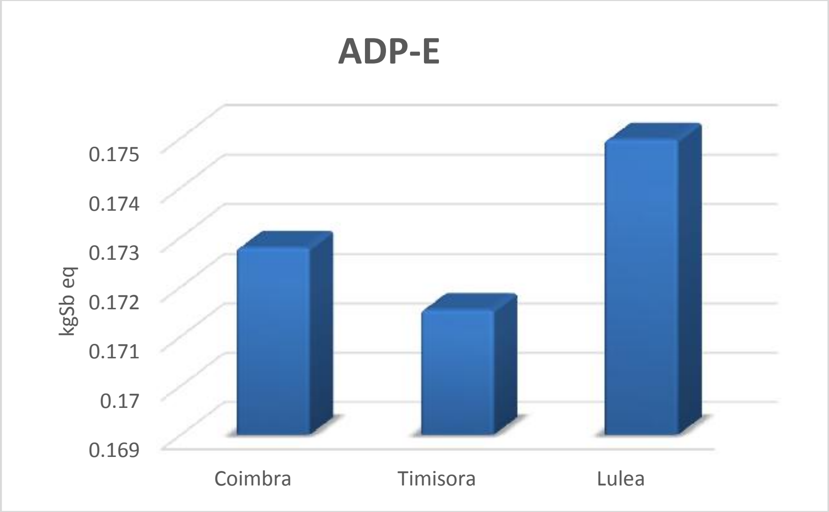

Fig.4.10. Total ADP-e per house – Construction stage

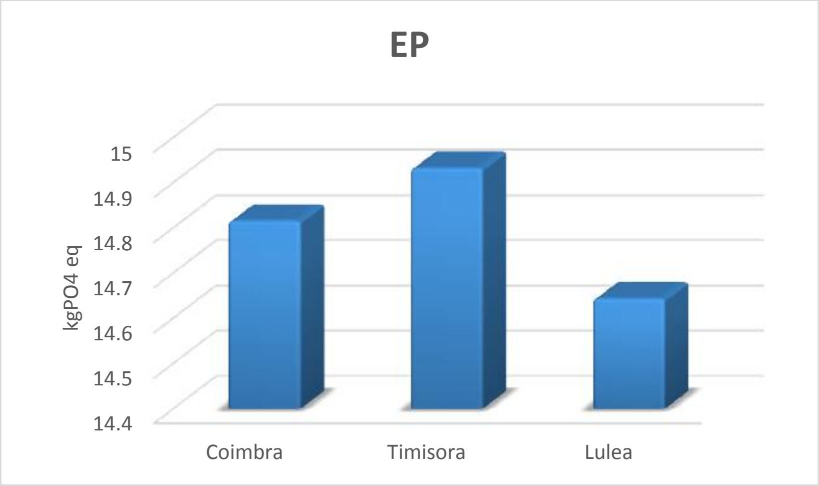

Fig.4.11. Total EP per house – Construction stage

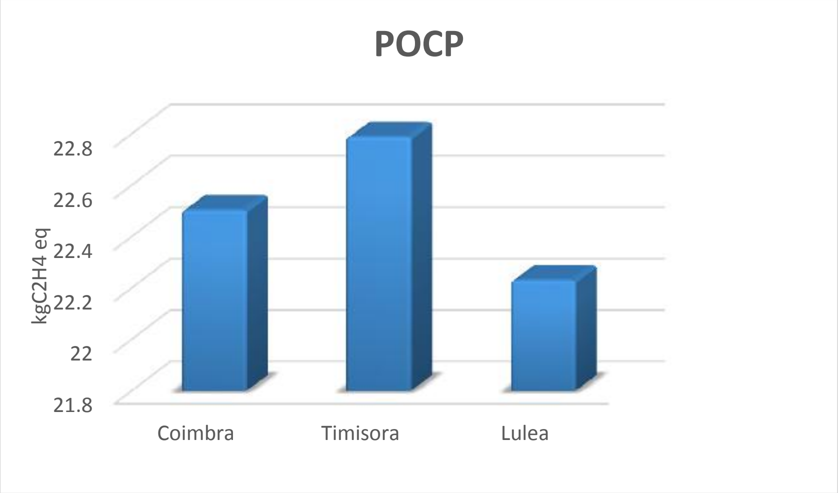

Fig.4.12. Total POCP per house – Construction stage

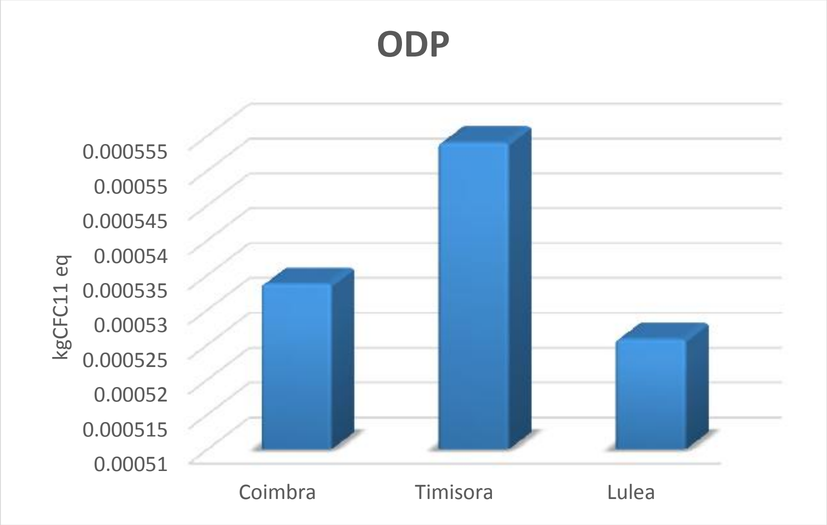

Fig.4.13. Total ODP per house – Construction stage

4.3.3 Total LCA Environmental Impact per house.

Complete LCA analysis was performed taking into account the building life cycles stages according to EN 15804: Construction stage, End of life scenario, Embodied energy and Operational energy.

The table 4.3 and figures below illustrates how the houses in different three climatic zone perform within each indicator at the building level. It can be seen that the influence on the indicators vary between 2 and 180%

between the houses results are higher compared to the conceptual LCA .Lulea, had the largest impact due to it cold climatic zone in almost all the indicators with the exception of ODP.

Table 4.3 Total Environmental Impact per house – LCA analysis

Impact category	Coimbra	Timisoara	Lulea
Global warming	3302820	3743960	4618240
Acidification	5.28832	5.33757	5.45555
Abiotic depletion-fossil fuel	67046490	122527920	343367370
Abiotic depletion-e	0.576	0.694	1.07
Photochemical oxidation	977	1350	2640
Eutrophication	821	883	893
Ozone layer depletion	0.00368	0.00369	0.00268

Fig.4.14.Total GWP per house – LCA analysis

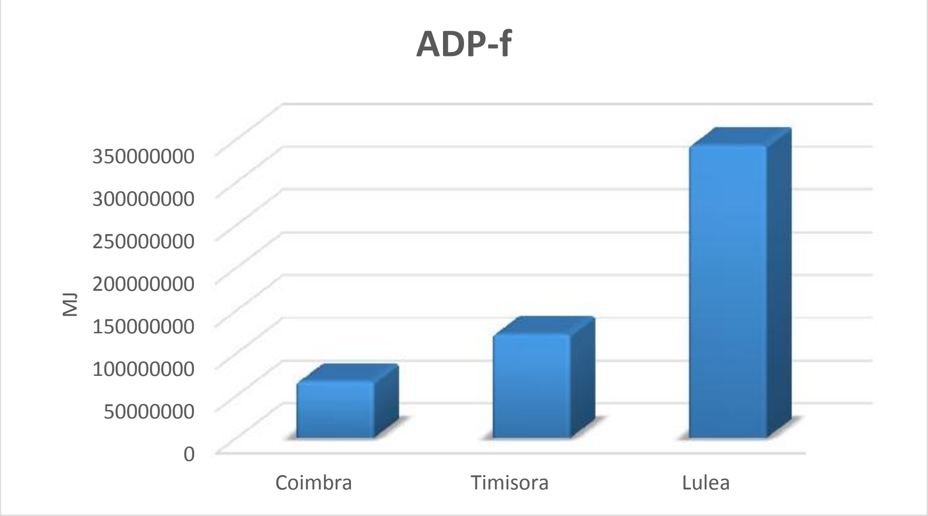

Fig4.15. Total ADP-f per house – LCA analysis

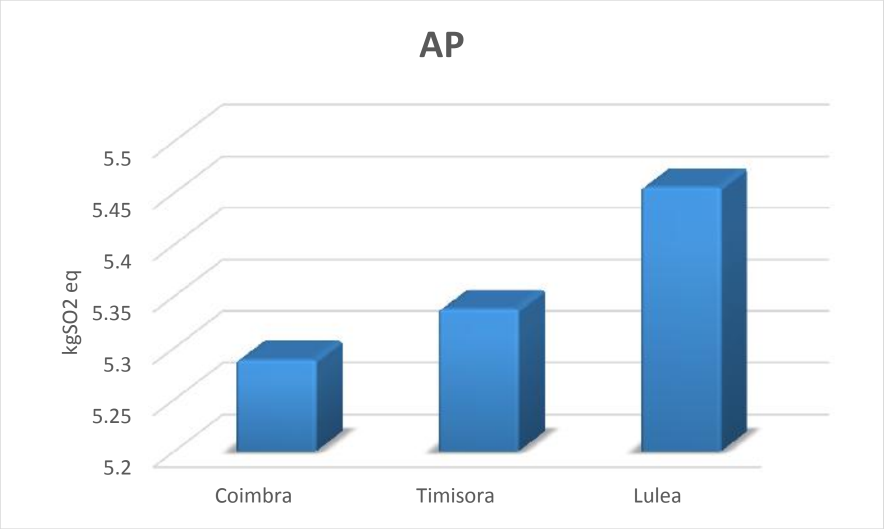

Fig 4.16. Total AP per house – LCA analysis

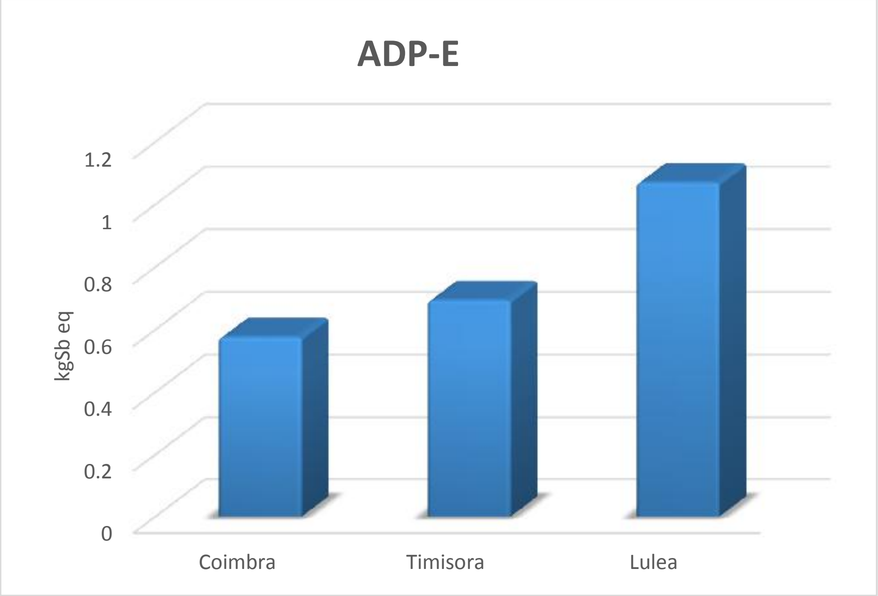

Fig 4.17. Total ADP-e per house – LCA analysis

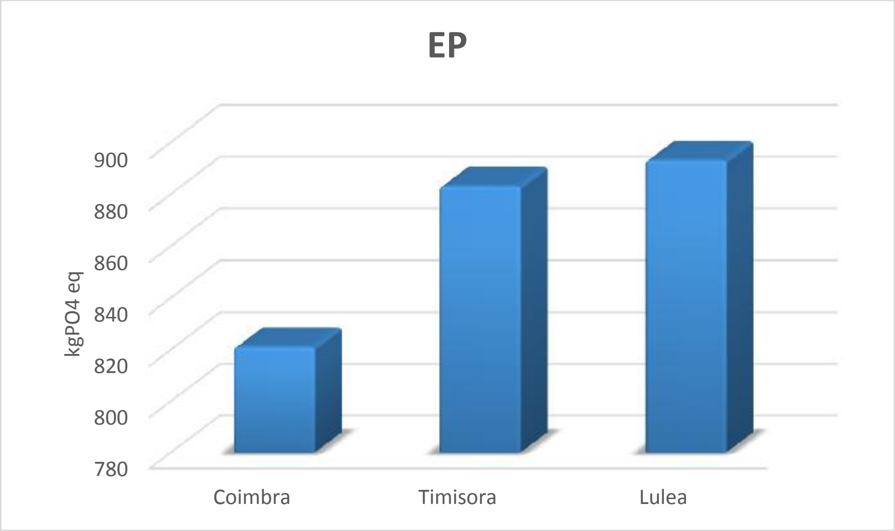

Fig.4.18. Total EP per house – LCA analysis

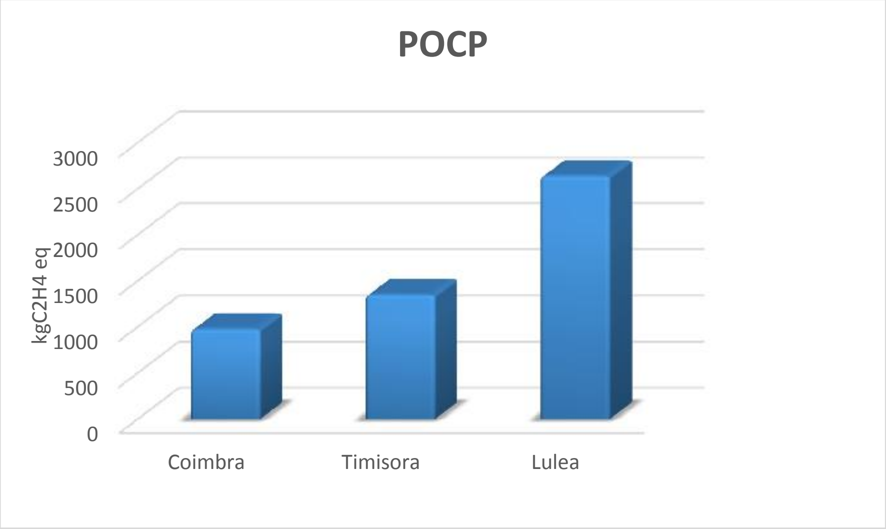

Fig 4.19. Total POCP per house – LCA analysis

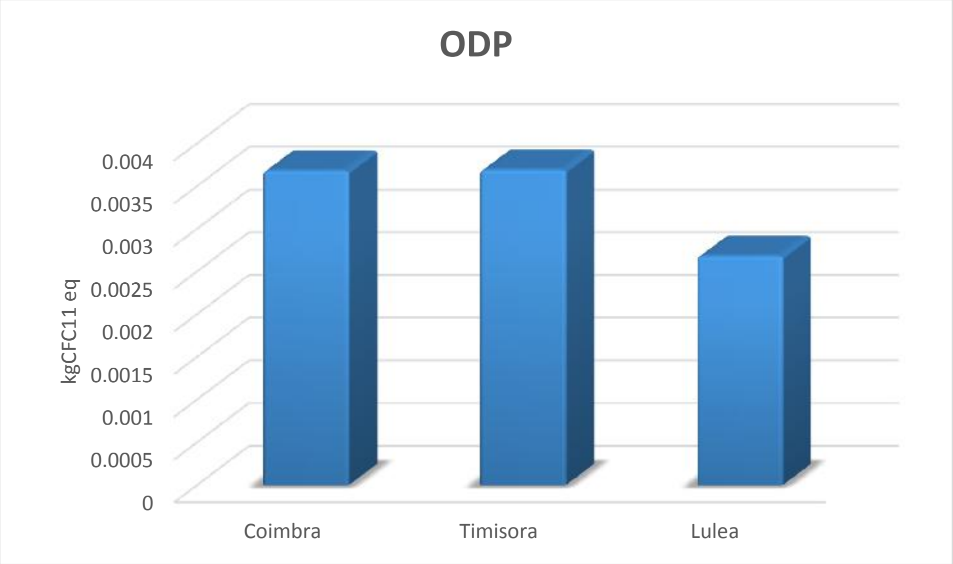

Fig 4.20.Total ODP per house – LCA analysis

4.4 Operational energy

4.4.1 The space heating energy

From the breakdown of the heat transfer contributions, it is easy to identify the most critical processes. In this case, Figure 8b shows that the glazing areas are the main contributor to the heat loss of the building, followed by the walls. The heat transfer by ventilation also contributes significantly to the losses. Little could be done to reduce the energy needed, because most of the building elements including U-values and airflow rate in the winter already defined and cannot be manipulated. The Lulea had the highest impact due to its heating demand zone.

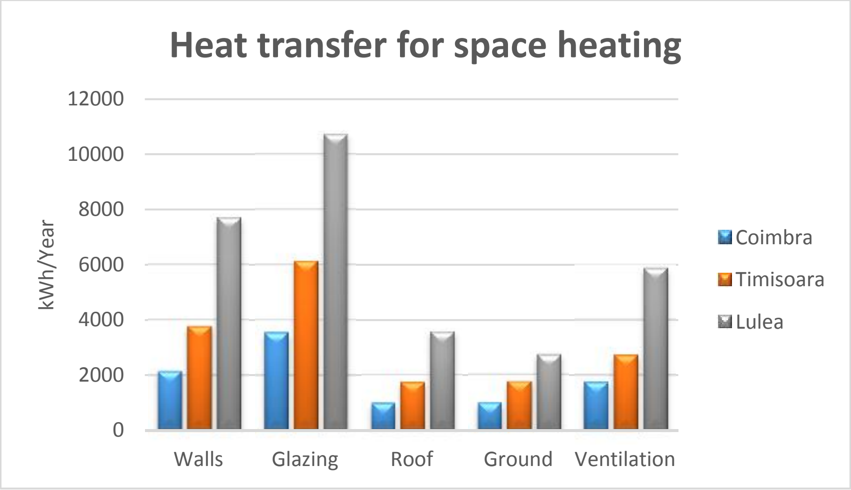

Fig4.21.The space heating energy

4.4.2 The space cooling energy

From Figure 8c, it is observed that the heat transfer is higher in the cooling mode due to the fixed high ventilation rate in the summer season of 1.0 ac/h. since the airflow rate could not be altered The cooling demand should be higher for Coimbra instead of Lulea because of their climatic locations . Lulea has a low outdoor temperature in summer thus requiring little or no cooling.

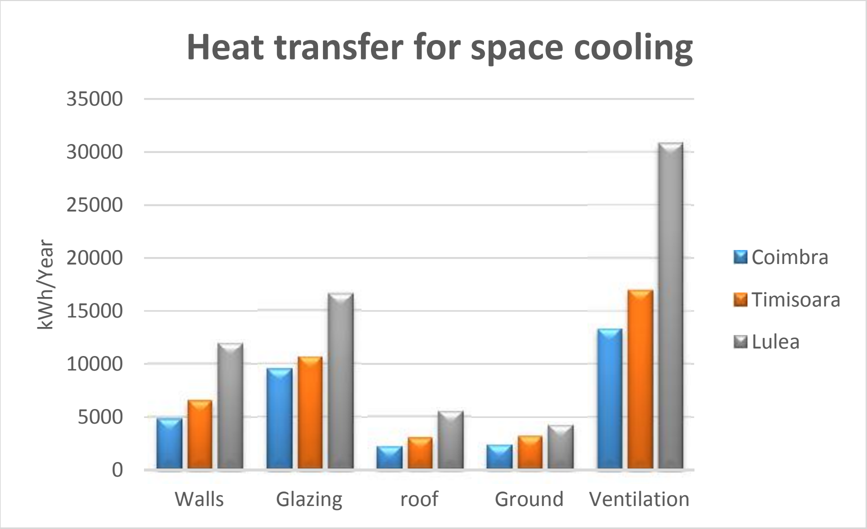

Fig 4.22 .The space cooling energy

A comparison of the enrgy calculated is given Table .4 between AMECO and SBsteel , showing the trend as well as a good approximation for the total results.

Table 4.4. Comparison of enegry needs of the steel buildings

(kwh)/ year	Software	Space heating	Space cooling	DHW	Total	Difference %
Coimbra	SBsteel	149.56	10102.0	2877.3	13130	-21.706
	AMECO	190.9	7217.65	2875.3	10280	
Timisoara	SBsteel	1971.41	7710.34	2877.3	12560	7.166
	AMECO	1185.9	9398.0	2875.3	13460	
Lulea	SBsteel	6521.8	2615.02	2877.3	12010	-12.157
	AMECO	5469.7	2202.6	2875.3	10550	

4.4.3 Comparison of the Use stage of AMECO and SBsteel per m^2.

The use stages of AMECO and SBsteel were excluded from the LCA assessment. AMECO values are too high while SBsteel has extremely low impact for the use stage over a life span of 50 years. Which is a major shortcoming because it is important to know how the materials and construction phases compare to the use phase. Presented below are

Table 4.5. Global warming potential of the Use stage- AMECO

GWP(kg CO2 eq)	Coimbra	Timisoara	Lulea
Heating	11025740.0	68492390.0	315901910.0
Cooling	28549970.0	26560270.0	0.0
DHW	27086590.0	27086590.0	27086590.0

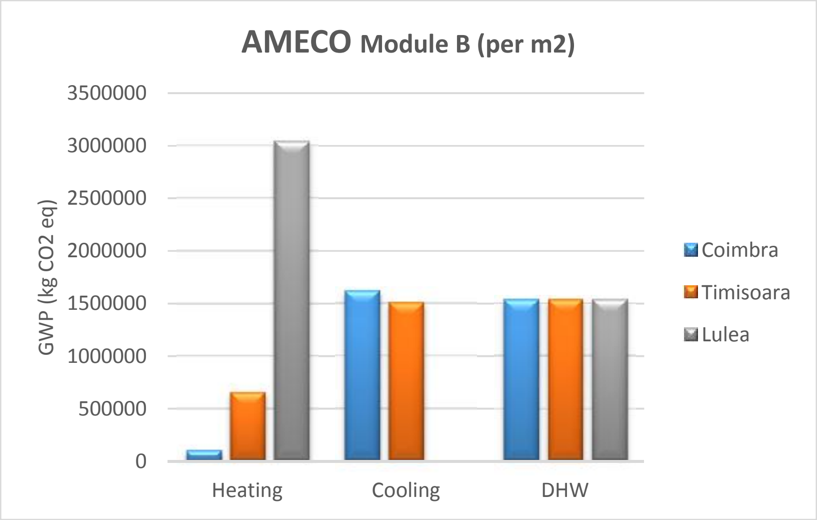

Figure 4.23. Global warming potential of the Use stage -AMECO

Table 4.6. Global warming potential of the Use stage- SBsteel

GWP(kg CO2 eq)	Coimbra	Timisoara	Lulea
Roof floor	1.08	1.08	1.08
Interior floor	0.00	0.00	0.00
Ground floor	0.00	0.00	0.00
External Wall	1.89	1.89	1.89
Interior Wall	4.69	4.69	6.92

Glazing	0.70	0.70	0.84

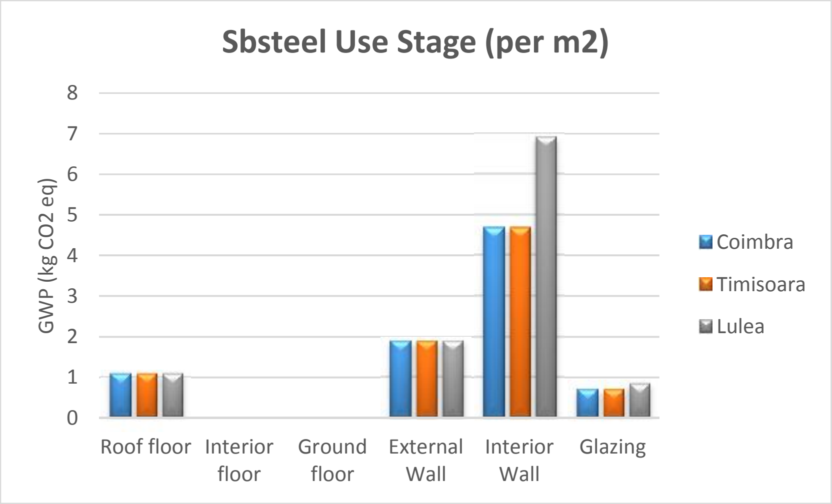

Figure4.24. Global warming potential of the Use stage -SBsteel

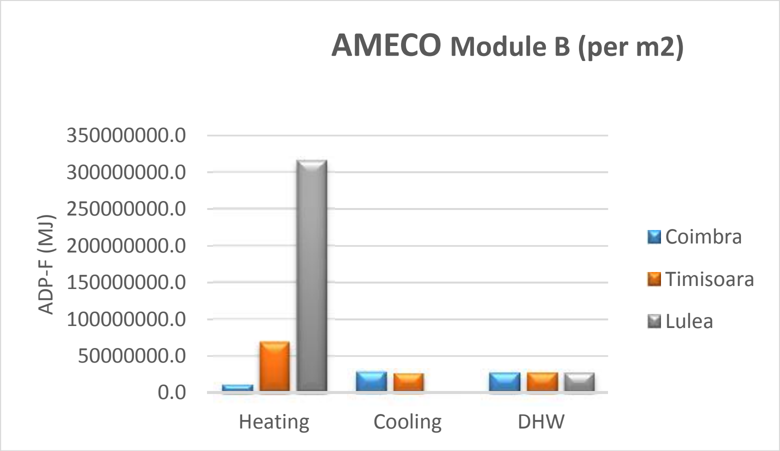

Figure 4.25 Abiotic depletion of fossil fuels of the Use stage -SBsteel

Table 4.6. Abiotic depletion of fossil fuels of the Use stage -AMECO

ADP-F (MJ)	Coimbra	Timisoara	Lulea
Heating	11025740.0	68492390.0	315901910.0
Cooling	28549970.0	26560270.0	0.0
DHW	27086590.0	27086590.0	27086590.0

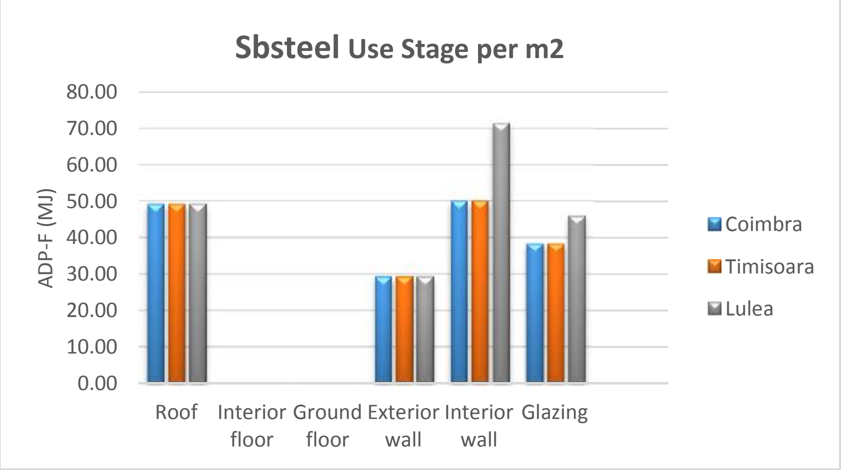

Figure4.26.Abiotic depletion of fossil fuels of the use stage-SBsteel

Table 4.7. Abiotic depletion of fossil fuels of the use stage-SBsteel

ADP-F (MJ)	Coimbra	Timisoara	Lulea
Roof	49.20	49.20	49.20
Interior floor	0.00	0.00	0.00
Ground floor	0.00	0.00	0.00
Exterior wall	29.20	29.20	29.20
Interior wall	50.10	50.10	71.40
Glazing	38.30	38.30	45.90

4.4.4 Chapter Conclusions;

This chapter compares the impacts of the three houses over their service life per unit floor area in the conceptual stage using AMECO. As can be observed from figures above, Lulea, Coimbra, Timisoara house had similar impacts per unit of floor area m^2, where the all the highest environment impact occurred in the production stage. Envelope in the production stage acted as the highest contributor in following environmental indicators occurring in production stage for ADP-FF, ADP-E and GWP, EP AND POCP. Material list and quantities for the interior floor for the various climate zones remained constant for the three locations. Main materials of the envelope are steel and insulation.

While the steel beam had the highest impact in the ODP, AP category, varied for the different locations depending on the quantity of steel beams calculated. Lulea had the largest quantity for steel beams.

While the steel beam had the highest impact in the ODP, AP category, varied for the different locations depending on the quantity of steel beams calculated. Lulea had the largest quantity for steel beams.

Quantifying the analysis of the construction only showed that the structural materials (concrete and reinforcing steel) had the greatest effect in AMECO. Residential buildings Timisoara cause had high impacts in the construction stage only due to the high amounts of reinforced concrete and steel used except ADP- e. Lulea had the highest.

In the LCA analysis, Lulea had the highest impact because of its energy heating demand. An important conclusion that can be drawn is that for a building not only the quantity of materials is important but mostly the processing of materials, in fact the latter being the responsible for the major impact on environment. Therefore, within the context of a sustainable development, only the materials with ‘green’ processing should be promoted.

Similarly, AMECO had same problems with the energy for Space cooling just like SBsteel. The results of operational energy demands for the different climatic zones, as discussed in the Chapter 1

As expected, the energy for space heating in Lulea is considerably more than Coimbra and timisoara heating energy demand, which it is due to that the heat loss in Lulea, is more than heat gain with compared to the Coimbra especially in cold seasons.

On the other hand, the space cooling energy demand in Timisoara, Lulea and Coimbra. However, the Lulea space cooling energy for cooling is not important because no cooling or less is required in case of using natural ventilation due to the low outdoor temperature in Lulea. The heat transfer for cooling obtained is 3 times that of heat transfer for cooling the values obtained could not be justified.

In the construction and Lulea had the largest impact due to it cold climatic zone, more insulation is necessary for comfort, while Coimbra has least impact because of it low quantities in insulation.

The results of operational energy demands for the different climatic zones

As expected, the energy for space heating in Lulea is considerably more than Coimbra and Timisoara, which is due to the fact that the heat loss in Lulea, is more than heat gain with compared to the Coimbra especially in cold seasons.

On the other hand, the space cooling energy demand in Timisoara, Lulea and Coimbra. However, the Lulea space cooling energy for cooling is not important because no cooling or less is required in case of using natural ventilation due to the low outdoor temperature in Lulea. The heat transfer for cooling obtained is 3 times that of heat transfer for cooling the values obtained could not be justified.

5 ADVANCED ENVIRONMENTAL IMPACT ASSESMENT BY SIMAPRO

5.1 Introduction

The presented advanced LCA study of the steel houses was conducted with the SimaPro software this software was used because it contains the most extensive set of life cycle impact assessment methods of all the tools we have surveyed Life cycle assessment (LCA) is one of the most acknowledged and widely used methodologies for the quantification of environmental impacts . It is based on a detailed documentation of the materials and processes required throughout the complete life cycle of the project, from raw material acquisition and initial construction to maintenance and end scenarios. In regards to construction, LCA takes into account five phases, namely the design (development), the constructional material production (resource extraction), the construction (production), the use (consumption) and finally the demolishment rehabilitation (end of life activities).

5.2 Theoretical parameters

In order to conduct an LCA study it is initially necessary to define a number of theoretical parameters, which will define the focus, and extent of the study. These parameters include the goal of the study, its scope and its subject (or system). The goal of the current LCA study is to identify the key areas responsible for the primary environmental impacts associated with the construction of the examined building and the environmental indicators mainly burdened.

5.3 Material lists and selection of macro components

In order to have a final comparison among the building, construction, constructive elements and macro elements were considered: the materials are grouped into parts;

- Envelope structures: exterior walls glazing, exterior wall, exterior material doors
- Other vertical structures: interior thin and thin walls stairs:
- finishes: for floor slab/terrace/walls/ curtain wall
- infrastructure
- Basement slab

- Secondary structures
- superstructure steel frames/plate connections/bracing

Table 2.2 presents the list of material, their weight per macro component, building, and shows the computed weight of materials per macro component, this data is used as input data for the environment impact analysis in the construction stage.

Table 5.1 Inventory analysis of the net weight of steel-framed building

	units	Timisoara	Lulea	Coimbra
Enclosure				
Ethylene-vinyl acetate foil	kg	45.684	45.684	45.684
Bitumen sealing	kg	780.208	780.208	780.208
Mineral wool	kg	583.2	874.8	583.2
Rock wool	kg	723.6	1085	434.16
Stucco	kg	222.488	222.488	222.488
Rockwool/foam	kg	1608	2412	1608
OSB	m^3	3.25	3.25	3.25
Metal flushing	kg	50	50	50
Fiberboard hard	kg	0.804	0.804	0.804
Finishes				
Ceramic tiles	kg	490.488	490.488	490.488
Adhesive mortar	kg	314.653	314.653	314.653
Bitumen sealing	kg	390.208	390.208	390.208
Acrylic vanish	kg	63.825	63.825	63.825
Cork slab	kg	17.02	17.02	17.02
Gypsum plaster	kg	7501	7501	7501
Glazed wall- double glazing	kg	13980	13980	13980
Interior doors	m^2	12.6	12.6	12.6
Glued laminated timber	m^3	1.489	1.489	1.489
Staircase				
Steel	kg	1974	1974	1974
Infrastructure				
Vapour foil	kg	93.6	93.6	93.6
Polystyrene XPS	kg	757.139	1262	550.647
Bitumen sealing	kg	390.208	390.208	390.208
Concrete in foundation	kg	6912	3072	4008
Concrete in Slab	kg	22962	22962	22962

Reinforced steel	kg	9005	9005	9005
Formwork wood	m^3	0.623	0.416	0.516
Secondary structure				
Steel- studs	kg	6180	6180	6180
Superstructure				
Steel column	kg	1620	979.539	1281
Steel Beam	kg	1002	1375	1175
Steel Secondary beams/braces/plates	kg	4480	4413	4438
Steel corrugated steel sheeting	kg	1067	1067	1067

5.4 Calculation of the consumable goods for the house

5.4.1 Evaluation of the of operational energy

The operational energy considered in this study is used for heating and cooling process, domestic hot water preparation, domestic use of electric devices including lighting and tap water use. The values taken into consideration in our comparison are based on average quantities of energy use per capita or per surface, while in the case of heating/cooling there have considered only the production stage, as they are finally consumed by inhabitants.in the LCA analysis it was

Three main energy sources considered as consumable goods by the inhabitant

- natural gas, employed partially in heating the house during cold months and slo for hot water preparation;
- electricity partially used for heating, lighting electrical devices and cooling system in summer
- Water used for domestic purposes as cold and hot the water is prepared home.

5.4.2 Evaluation of the annual natural gas requirement

The natural gas is considered the source for heating and hot water preparation. For this purpose, an estimation of the quantity of heat required during one year was calculated, this was performed based on the Romanian standard SR 1907-1:1997 and SR 1907-2 :1997 (ASRO,1997 a and b), in function of the interior and exterior temperature and construction elements.

The heat requirement computed based on 3 assumptions

i. The building is inhabited by 3 persons
ii. The external mean temperatures were considered for the location the building was built

iii. The interior ambient temperature considered is 20 °C.

Based on these assumptions, the daily requirement for, table.3 shows the heating requirement for one hour in a day in January, for the first floor in.

The total heat requirement given in table.4 in kilowatts.

The resistance to thermal transfer computed by

$$Q = Q_T[1 + (A_0 + A_c)/100] + Q_i$$

Where;

Q_T represent the thermal flux through the delimiting elements (walls, windows and doors)

Q_i required heat for warming the air flow, cooled due to doors and windows opening from the exterior to interior temperature

A_c addition for cold-surface compensation

A_0 North-South orientation addition

$$Q_T = A(m/R) \cdot \Delta t \cdot C_M + Q_p$$

A the area of the delimiting element

m the thermal massivity of material

R the element resistance to thermal transfer

Q_p the heat transmitted through the floor

C_M coefficient given function of the relative mass of the building taken as 0.94

Δt the interior-exterior thermal difference

Table 5.2 Heat requirement for kilowatts for one year

Month	No of days	Timisoara		Coimbra		Lulea	
		Heat req./day	Heat req./month	Heat req./day	Heat req./month	Heat req./day	Heat req./month
January	31	3.24	2413.23	1.663	1237	5.47	4069.68
February	29	2.8	1949.45	1.36	1012	3.98	2770.08
March	31	2.16	1609.86	1.19	828.24	3.2	1496.035
April	30	1.34	964.97			2.16	1557.614
May	31					2.01	1496.035
June	30						

July	31						
August	31						
September	30						
October	31	1.34	997.14			2.01	1496.035
November	30	2.16	1557.93	0.88	633.6	3.21	2311.2
December	31	2.52	2172.59	1.927	1387	4.56	3392.64
Total			**11231.37**		**5093.21**		**19401.87**

The required hot water/day fixed at 110L with three inhabitants of the house this results in a total amount of 330l.

$$Q_{\text{tot}} = Q_{ac} + Q_{inc}$$

Where;

Q_{inc} is the required energy for heating

$$M = Q_{\text{tot}}/q_{gas}$$

q_{gas} is the thermal power of gas taken as 8.5mc/kW

Table .5.3. Energy needed - Kilowatt

	Timisoara	Coimbra	Lulea
Q_{inc} [kilowatts]	11231.37	5093.21	19401.87
Q_{ac} [kilowatts]	4902	4085	7353
Q_{tot} [kilowatts]	16133.37	9178.21	26754.87
M [m^3]	1898.04	1079.79	3147

Estimation of the annual domestic electrical power

In order to compute the annual digestion power consumed by the inhabitant it was considered the following configuration of the electric board see table (5)

Table5.4 Electric board scenario for the building;

Nº	**Circuit Nº**	**Consumer denomination**	**P_i [kW]**	**P_f [kW]**	**K_u**	**Cos fi**	**Tg fi**	**CHARGE**		
								Active	Reactive	Apparent
								P_a	Q_{ncc}	S
								[kW]	[kVar]	[kVA]
1	TD1.1	1st floor lighting	1.00	1.00	0.60	0.80	0.75	0.6	0.19	0.8
2	TD1.2	2nd floor lighting	1.00	1.00	0.60	0.80	0.75	0.6	0.19	0.8
3	TD1.3	Socket-1st floor	2.50	2.50	0.60	0.80	0.75	1.5	0.49	1.9
4	TD1.4	Socket-2nd floor	2.50	2.50	0.60	0.80	0.75	1.5	0.49	1.9
5	TD1.5	Ac split	3.00	3.00	0.60	0.80	0.75	1.8	0.58	2.3
6	TD1.6	Washing machine	1.50	1.50	0.60	0.80	0.75	0.9	0.29	1.1
Total			8.5	11.50				6.9	2.2	8.6

Taking into account the temperature fluctuation during the summer months, a monthly consumption of 200kWh and 120kWh for summer and winter months respectively considered.
The difference is due the AC split.
Consequently, the annual electric power consumption **Timisoara** is:

$$W = (6x120) + (6x200) = 1920kWh$$

Resulting for the entire life of the house 50 years a value of 96000kWh

Consequently, the annual electric power consumption **Coimbra** is:

$$W = (4x120) + (8x200) = 2080kWh$$

Resulting for the entire life of the house 50 years a value of 104000kWh

Consequently, the annual electric power consumption **Lulea** is:

$W = (9x140) + (3x200) = 1860kWh$

Resulting for the entire life of the house 50 years a value of 93000kWh

Estimation of the annual water used

Considering the house in mean by 3 mean by 3 persons, the water requirement was considered as 10m^3 for cold and hot water respectively

$$C = 12x20x3 = 720\ m^3$$

Resulting 36000 m^3 for the entire 50 years.

5.5 End of life scenario

The LCA analysis includes certain assumptions, made about the events that take place at the end of the life cycle of the subject or system under examination. These assumptions include procedures such as disposal in sanitary landfills, recycling, reuse etc. and collectively constitute an end scenario. In this case, it is assumed that at the end of the building's service life and/or after the decision for demolition has been made, the largest percentage of steel panels are suitable for reuse in similar residential buildings which are to be constructed. Fig below present the end of life considered for the scenarios for the buildings.

Building material	Reuse [%]	Recycling [%]	Burn [%]	Landfill [%]
Steel – steel profiles, steel tiled sheets	---	100	---	---
Steel – reinforcement	---	80	---	20
Bricks, ceramic tiles	---	---	---	100
Structural timber – wall studs	20	---	80	---
Timber for formworks	60	---	40	---
OSB	40	---	60	---
Ballast	80	---	---	20
Concrete, mortar	---	---	---	100
Other inert materials	---	---	---	100
Other combustible materials	---	---	100	---

Fig. recycling scenario

5.6 Life Cycle Assessment and Interpretation

This section studies the environmental impacts and the construction stage and the complete LCA analysis The environmental impact results referring to the life cycle of the three steel houses are presented are presented below in graphs, tree diagrams and tables to make it easy for comparison. Only six each environmental indicators will be examine for the following stages

- embodied energy results of the grouped constructive elements,
- Construction stage
- Complete LCA analysis

5.6.1 Embodied energy from the group building elements for the building.

Embodied energy associated with the complete LCA analysis the grouped building material for the building.

It is observed that the finishes of the building and the infrastructure which consist of- concrete, steel reinforcement, formwork as its main source of importance. Wall and floor finishes have a large impact on the indoor air quality of buildings because they often emit toxins, such as VOCs, directly to the space. In addition, the products used to maintain interior finishes often contain toxins that are also released to the indoor environment.

The embodied Global warming potential (GWP) of the steel house per is shown in Figures below the large GWP impact occurred in the Finishes In all the three steel houses.

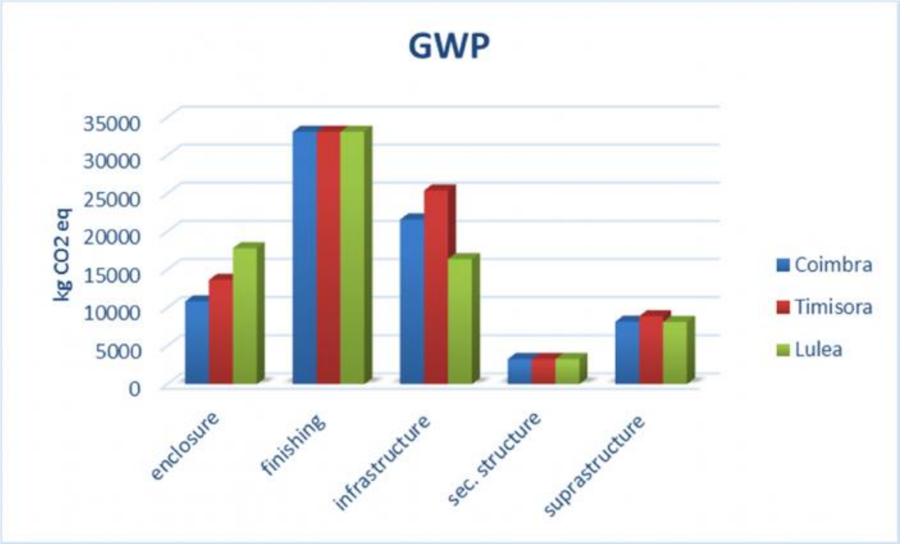

Fig 5.1 Global warming impact on LCA for the 3 houses in accordance to the building component

The embodied Depletion of abiotic resources – mineral resources (ADP-E) of the steel house per m2 is shown in Figures below the large ADP-E impact occurred in the Finishes In all the 3 steel houses.

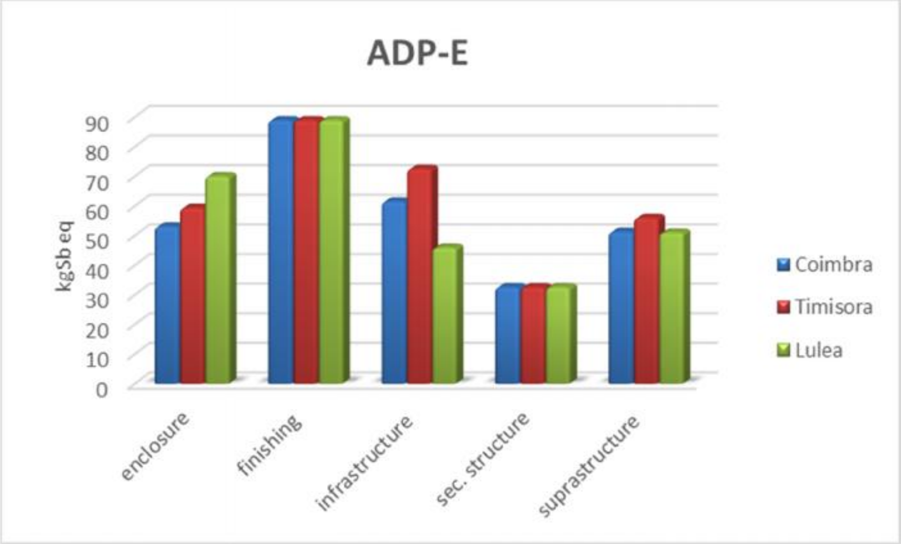

Fig.5.2 impact on LCA for the three houses in accordance to the building component

The embodied Acidification potential (ADP-E) of the steel house per m^2 is shown in Figures below the large ADP-E impact occurred in the Finishes In all the three steel houses.

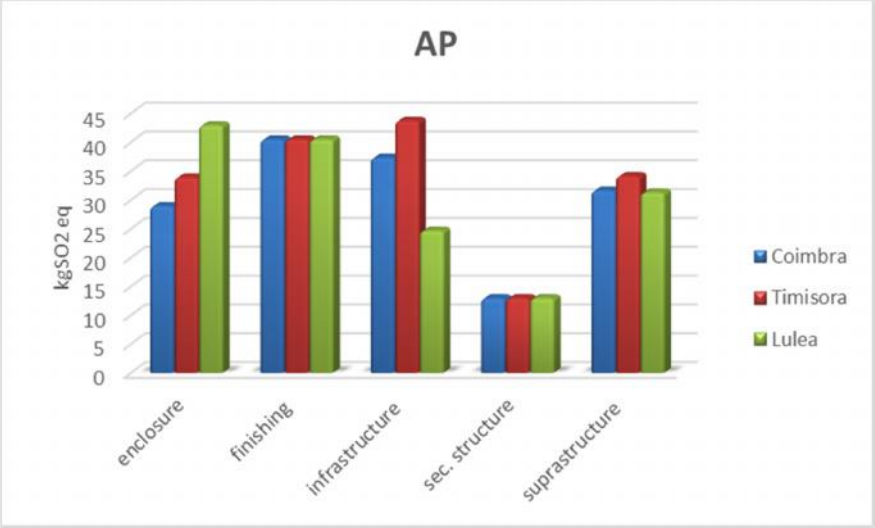

Figure.5.3. Acidification impact on LCA for the 3 houses in accordance to the building component

The embodied Photochemical ozone creation potential (POCP) of the steel house per m^2 is shown in Figures below the large POCP impact occurred in the infrastructure with Timisoara being the highest steel houses.

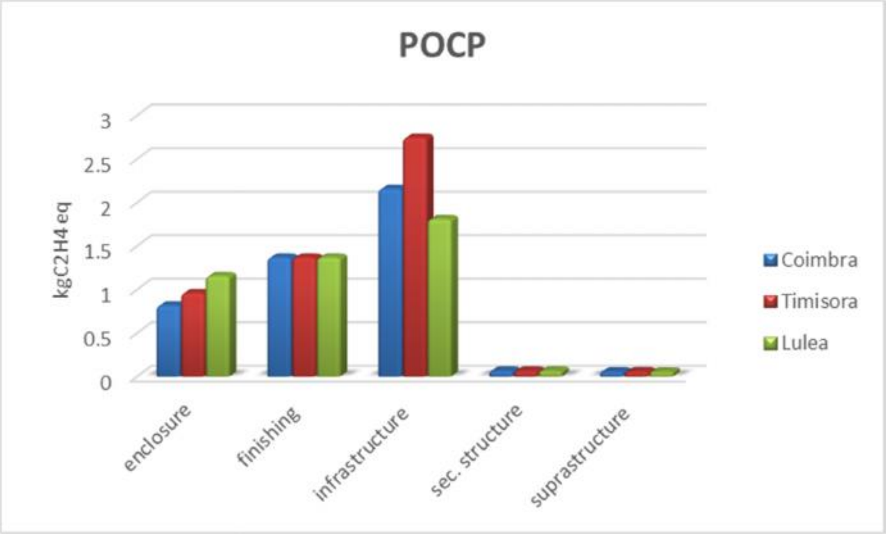

Figure.5.4. Photochemical ozone creation impact on LCA for the 3 houses in accordance to the building component

The embodied Eutrophication potential (EP) of the steel house per m^2 is shown in Figures below the large EP impact occurred in the Finishes In all the 3 steel houses.

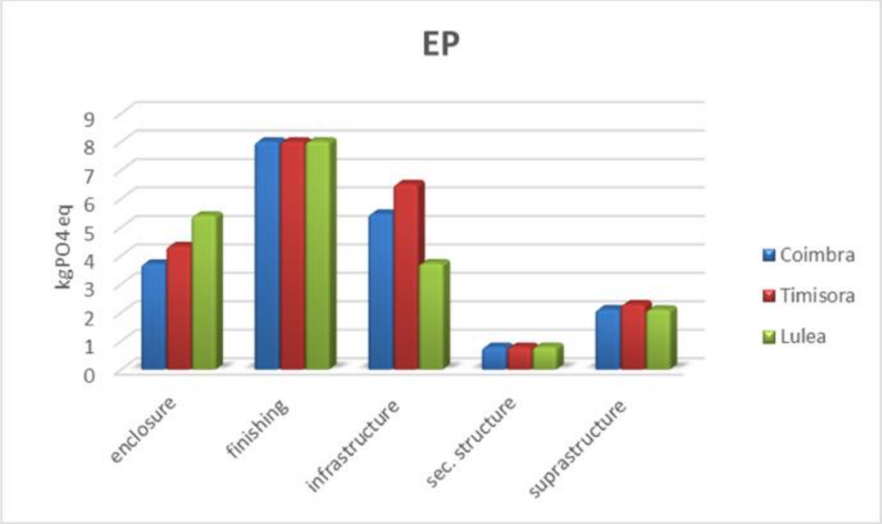

Figure.5.5. Eutrophication impact on LCA for the 3 houses in accordance to the building component

The embodied Eutrophication potential (EP) of the steel house per m^2 is shown in Figures below the large EP impact occurred in the infrastructure with Timisoara being the highest steel houses.

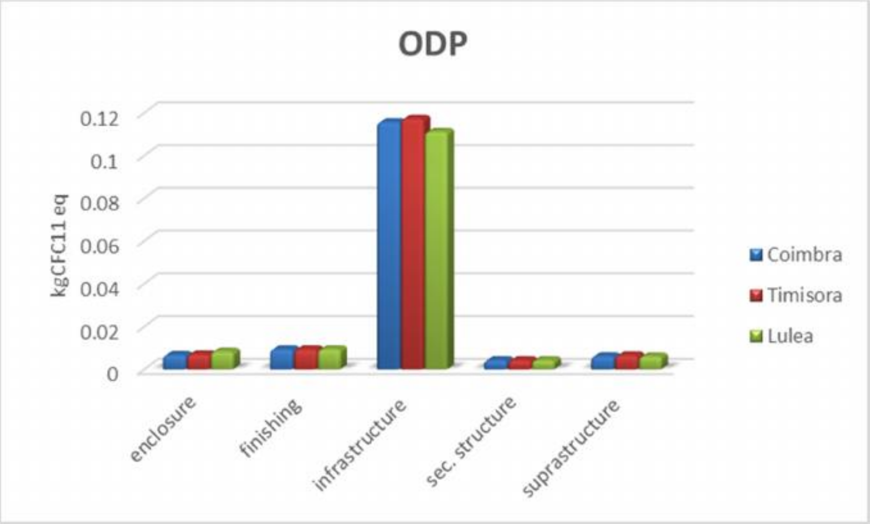

Figure.5.6. Ozone Depletion impact on LCA for the 3 houses in accordance to the building component

5.6.2 Total Environmental impact assessment - Construction stage

The total results of the environmental impact obtained in the construction stage only, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators vary between 2 and 4% between the houses. The impacts are differ slightly between the houses Timisoara had the largest impact due to its large quantities weight in quantities, compared to Coimbra and while Lulea had the lowest impact due to its structural steel weight in the all the impact category except ODP- e.- Coimbra had the highest.

Table.5.5 Total POCP per house – Construction stage

Impact category	Coimbra	Timisoara	Lulea
Photochemical oxidation	4.547353283	5.260934846	4.589819057
Abiotic depletion	286.3721659	307.2957424	290.2167596
Acidification	159.2361255	172.4266637	162.0346092
Eutrophication	17.57432361	19.1879403	17.80154839
Ozone layer depletion	0.169543819	0.172094683	0.140319056

Global warming	69846.05007	76600.21919	72084.60629

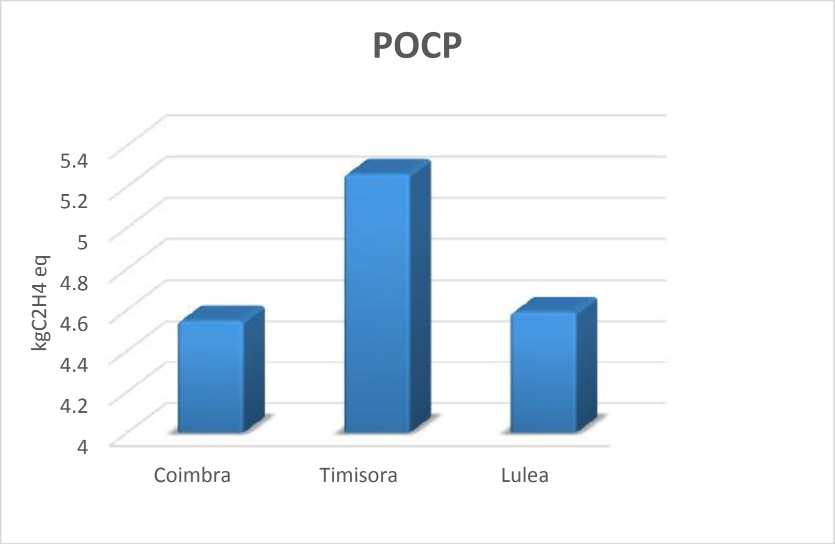

Fig.5.7 Total POCP per house – Construction stage

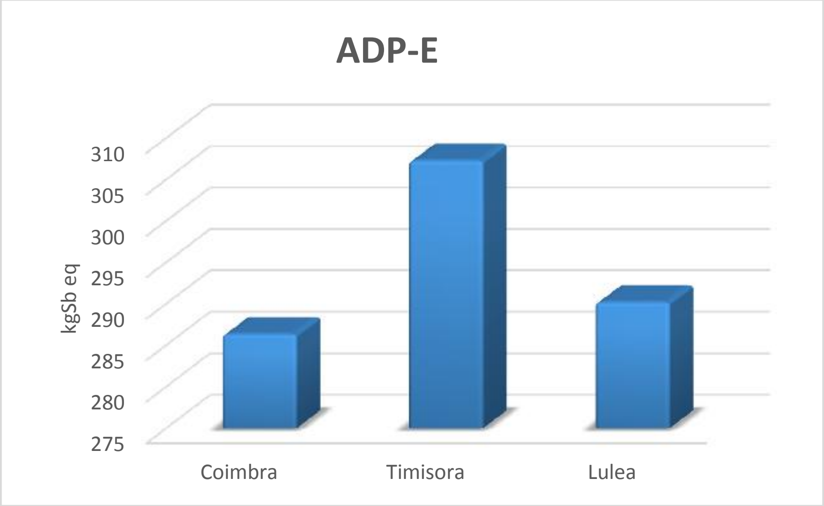

Fig 5.8. Total ADP-e per house – Construction stage

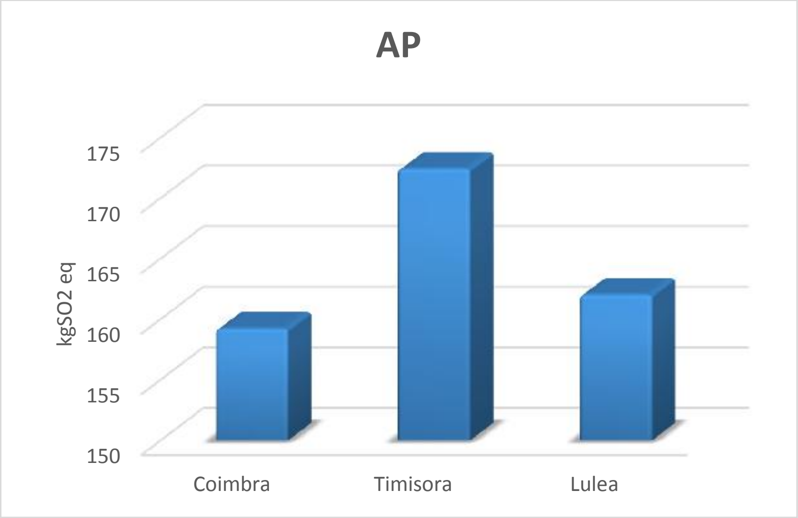

Fig.5.9. Total AP per house – Construction stage

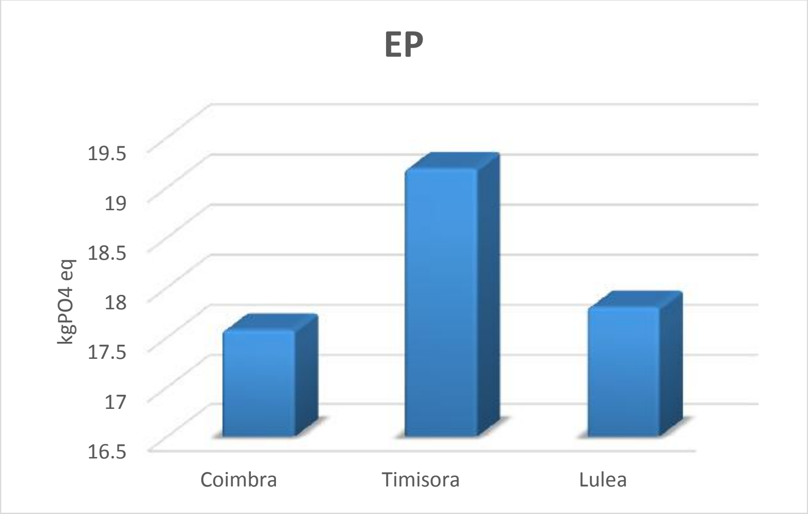

Fig.5.10.Total EP per house – Construction stage

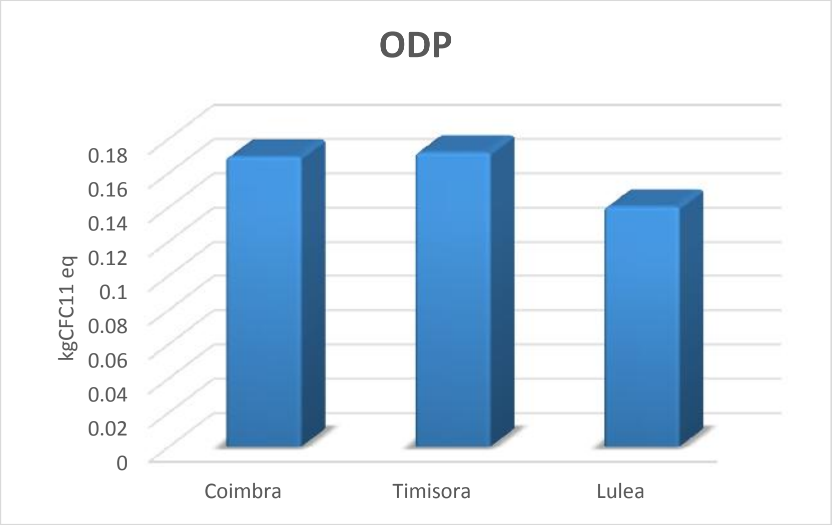

Fig.5.11. Total ODP per house – Construction stage

Fig 5.12 Total GWP per house – Construction stage

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5.6.3 Total LCA Environmental Impact per house.

Complete LCA analysis was performed taking into account the building life cycles stages according to EN 15804: Construction stage, End of life scenario, Embodied energy and Operational energy.

The total results of the environmental impact obtained in the complete LCA analysis, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators vary between 2 and 18% between the houses. Lulea had the largest impact due to its large quantities of insulation compared to Timisoara and while Coimbra had the lowest impact due to its structural steel weight in the all the impact category. The results obtained from Sima Pro impacts differ greatly between the houses, can still be concluded that Lulea had the highest Impact in almost all the categories.

Impact category	Coimbra	Timisoara	Lulea
Global warming	439484.2784	707865.6982	1102401.707
Ozone layer depletion	0.343469535	0.496503887	0.721484665
Eutrophication	39.75785628	54.06631143	71.48886737
Acidification	291.2676496	388.5787584	505.5640616
Photochemical oxidation	14.32990702	22.04254091	32.01345987
Abiotic depletion-e	1226.396087	1935.363975	2966.733629

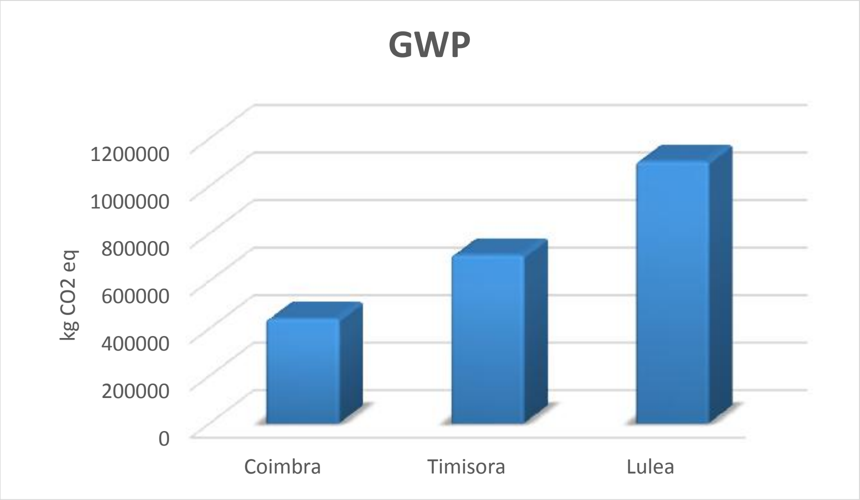

Fig 5.13. Total GWP per house – LCA analysis

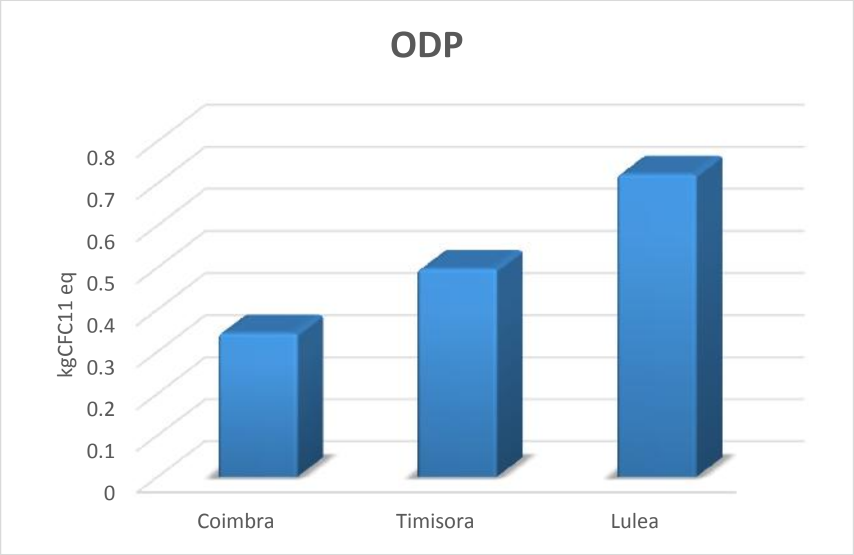

Fig 5.14. Total ODP per house – LCA analysis

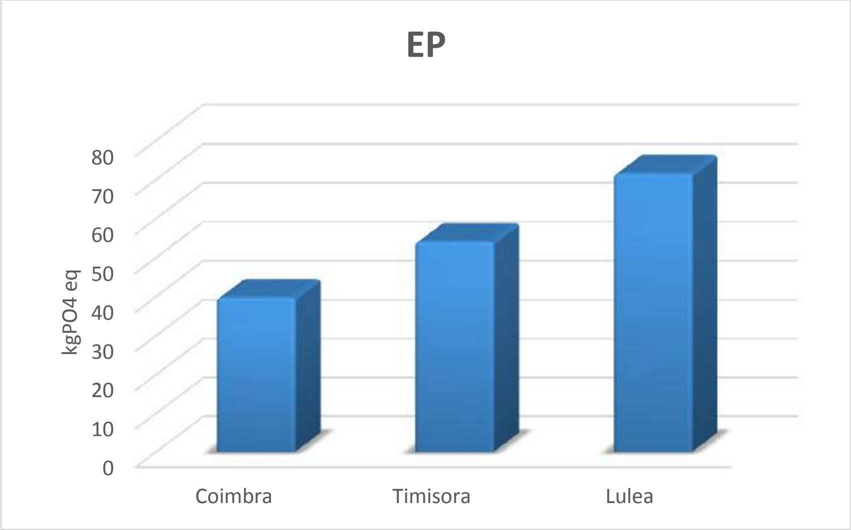

Fig 5.15.Total EP per house – LCA analysis

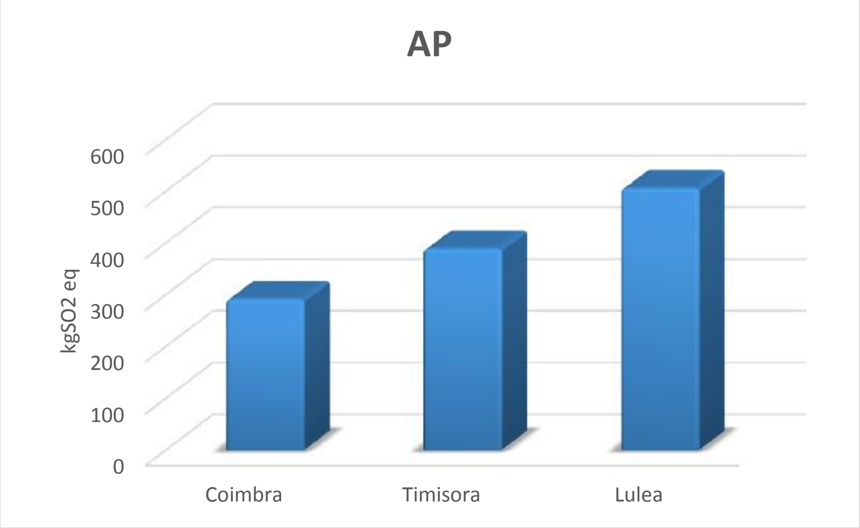

Fig 5.16.Total AP per house – LCA analysis

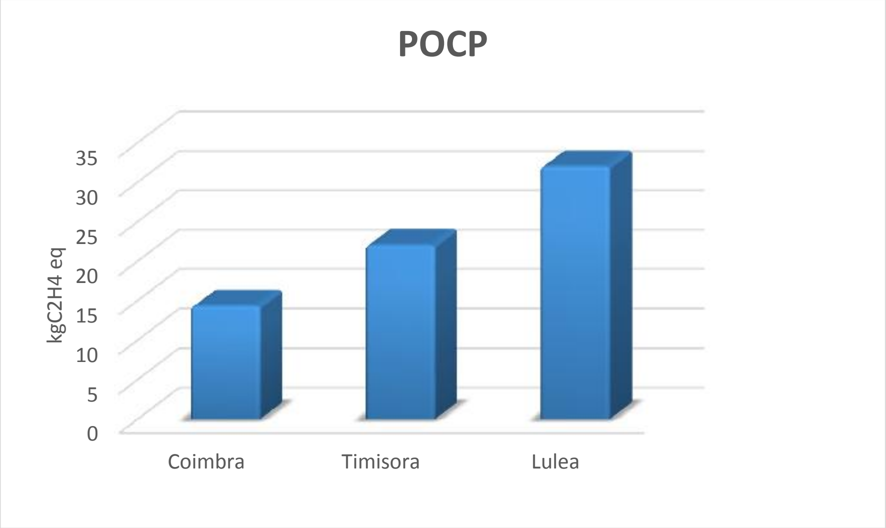

Fig 5.17. Total POCP per house – LCA analysis

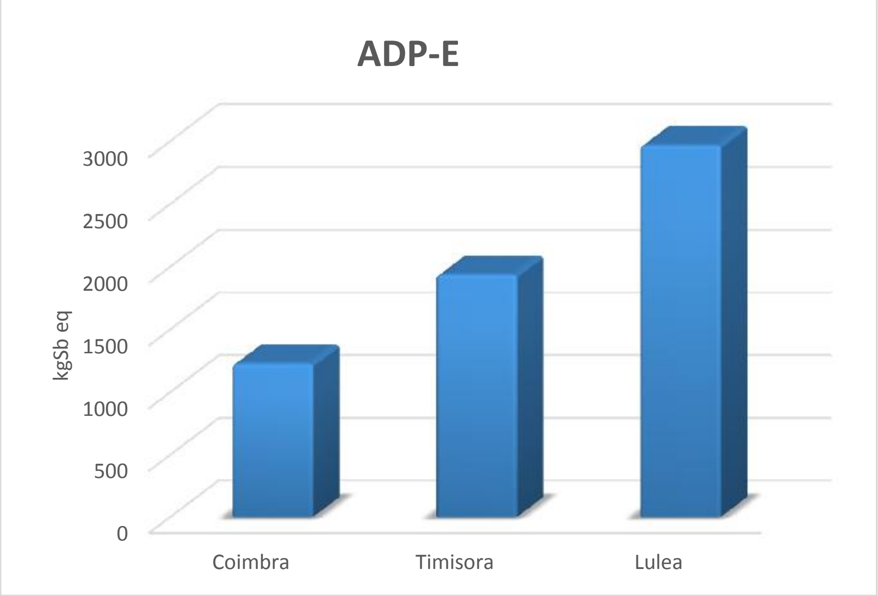

Fig 5.18. Total ADP-e per house – LCA analysis

5.6.4 Total Environmental impact assessment – complete LCA analysis

The analysis indicate that Use stage create more CO_2, contributed as much as 90%, 84% and 76.6% impact in the respective climatic zones Lulea, Timisoara and Coimbra. The impact contributed respectively by natural gas used for heating and DHW and electricity. Lulea had the highest impact (90%) followed by Timisoara and lastly Coimbra. The total results of the environmental impact obtained in the construction analysis, as illustrated in the *Tables* below. They show how the houses in different three climatic zone perform within each indicator. It can be seen that the influence on the indicators vary between 2 and 4% between the houses. The impacts are differ slightly between the houses Timisoara had the largest impact due to its large quantities weight in quantities, compared to Coimbra and while Lulea had the lowest impact due to its structural steel weight in the all the impact category except ADP- e. Lulea had the highest.

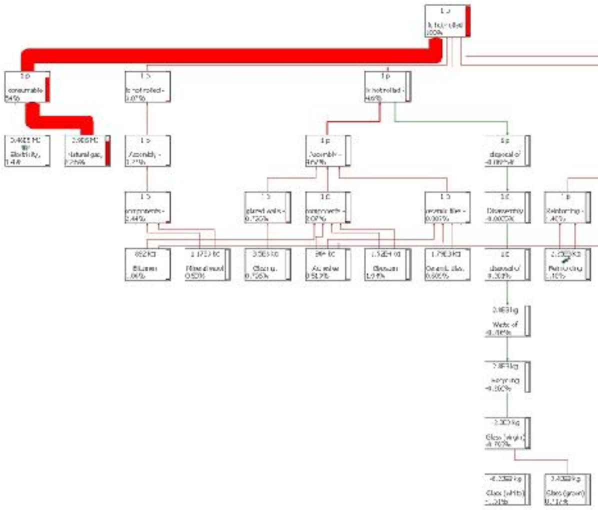

Fig 5.19. Tree analysis showing the consumable energy contributed to 84 % of the building in Timisoara

The thickness of the lines is proportional to the environmental impact.

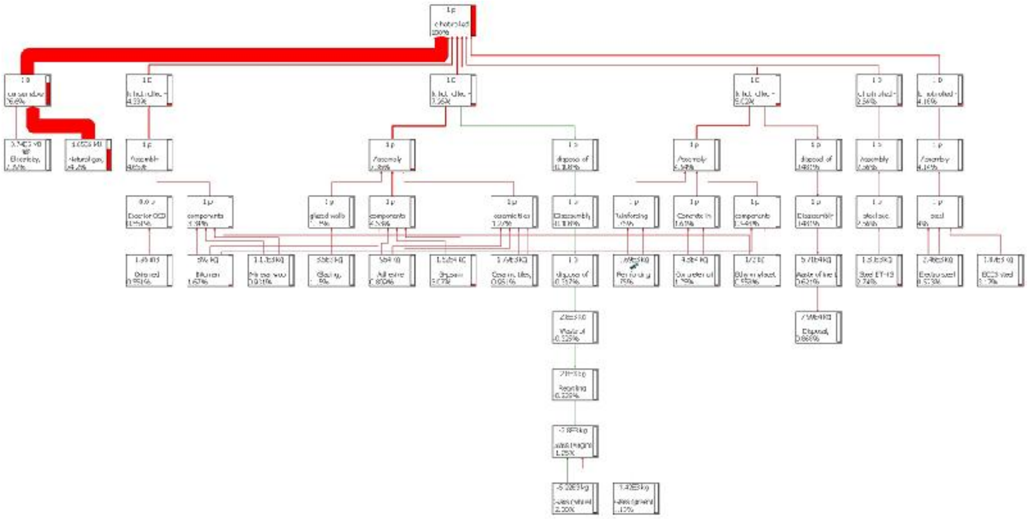

Fig 5.20.Tree analysis showing the consumable energy contributed to 76.6 % of the building in Coimbra

The thickness of the lines is proportional to the environmental impact.

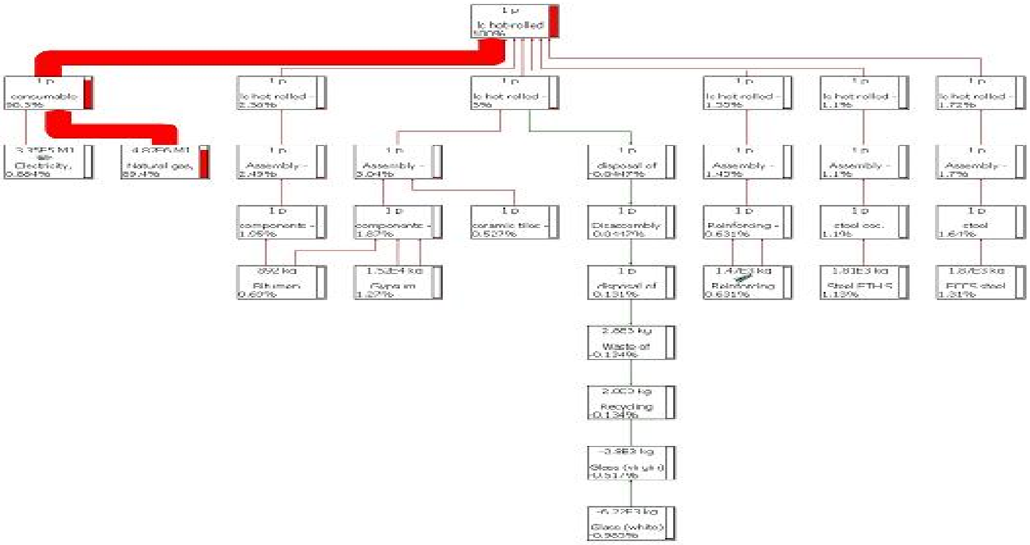

Fig 5.21. Tree analysis showing the consumable energy contributed to 90.4 % of the building in Lulea The thickness of the lines is proportional to the environmental impact.

Table. 5.7. Environmental impact on LCA of the Consumable energy.

Impact category	Photochemical ozone creation	Depletion of abiotic resource - elements	Acidification potential	Eutrophication potential	Ozone Depletion	Global Warming
Coimbra	9.859	938.8331	139.7832	19.63085	0.200917	362445.5
Timisoara	16.8392	1625.894	223.2195	32.10753	0.351612	623454.4
Lulea	27.5533	2678.051	353.0671	51.42197	0.581981	1023626

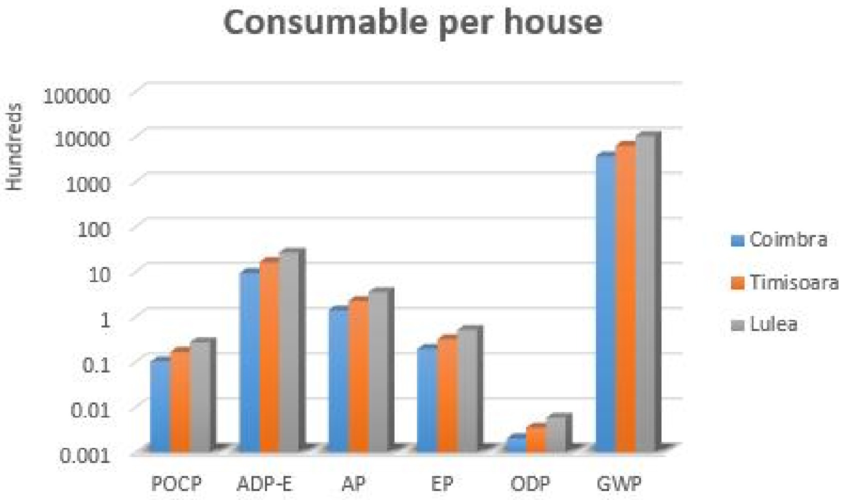

Fig 5.22. Environmental impact on LCA of the Consumable energy.

The consumable energy resulted in a wide range of impacts on the environment depending on the location. The greenhouse gas (GHG) emissions produced from the combustion of natural gas and the electrical power, amounted to 84% in Timisoara, 76.6% Coimbra and 90.4% Lulea of the overall environmental impact. Overall it can be seen from the pic 1, pic 2, pic 3 and the table 3 the Consumable energy, is one of the main contributors to the buildings current environmental impact, global warming.

5.6.5 Chapter Conclusion

This chapter compares the impacts of the three houses over their service life using Sima Pro. As can be observed from figures above, Lulea, Coimbra, Timisoara house had where the all the highest environment impact occurred due to finishing elements While the smallest impact is for the secondary structure ,which have a large impact on the indoor air quality of buildings because they often emit toxins, directly to the space. In addition, the products used to maintain interior finishes often contain toxins that are also released to the indoor environment. varied for the different locations depending on the quantities.

Quantifying the analysis of the construction only showed that the structural materials (concrete and reinforcing steel) had the greatest effect in SimaPro. Residential buildings Timisoara cause had high impacts in the construction stage only due to the high amounts of reinforced concrete and steel used except ODP- e. Coimbra had the highest, due to cooling demand.

As excepted Lulea, had the highest environmental among the houses impact due to its high demand in heatin The most significant environmental impacts are not from construction materials but from the production of electricity and natural gas and the use of electricity and natural gas in the houses by the occupants. Furthermore, the largest impacts from these uses are in the form of depletion of fossil fuel reserves (categorized as damage to natural resources) and release to the air of respiratory inorganics (categorized as damage to human health). The household use of electricity and natural gas represents 90% of the negative impacts in the house designed for Lulea house, 84% for Timisoara and 76.6 % for Coimbra house of the negative impacts in the wood frame house. For this reason, energy use is a predictor of LCA results.

6 SUMMARY AND CONCLUSION

6.1 Comparing SBsteel, AMECO, and Sima Pro

This chart illustrates how the houses in different three climatic zone perform within each indicator at the building level. However, the different indicators (e.g. GWP and ODP, etc.) cannot be compared in their relation to one another due to their different absolute values. SimaPro is taken as the based tool. AMECO and SBsteel are compared to pot it.

6.1.1 Comparison in the Construction stage

Table 6.1 Lulea **-**comparison environmental impacts associated with the construction stage for the LCA tools.

	SB steel	**AMECO**	**SIMApro**
ODP	0.000303891	0.00052581	0.140319056
AP	5.45555	126.735	162.0346092
EP	0.634877	14.6432	17.80154839
POCP	0.3679503	22.2309	4.589819057
ADP-E	6.59094	0.1749725	290.2167596
ADP-F	13028.36	469240	
GWP	1639.568	41300	72084.60629

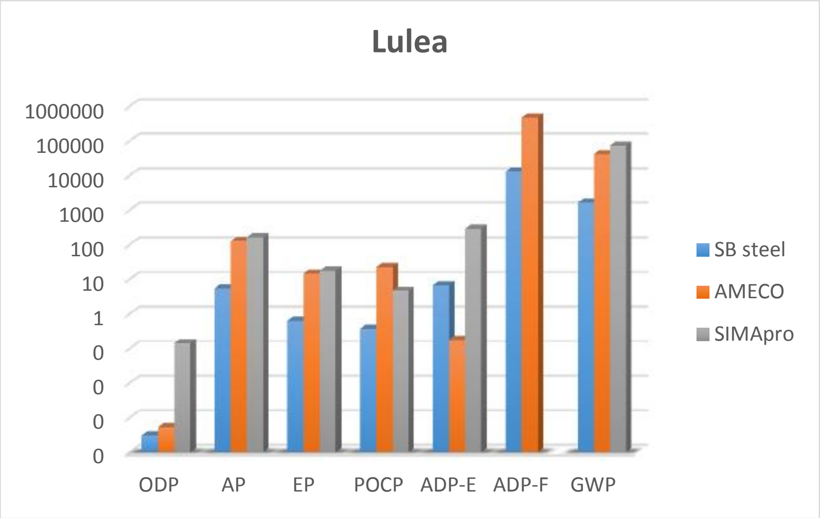

Fig 6.1 Lulea – comparison of construction stage for the LCA tools

Table 6.2 Timisoara- environmental impacts associated with the construction stage for the LCA tools.

	SB steel	AMECO	SIMApro
ODP	0.000302868	0.00055403	0.172094683
AP	5.33757	130.361	172.42
EP	0.624741	14.9322	19.187
POCP	0.3302574	22.789	5.260
ADP-E	6.43952	0.1715383	307.29
ADP-F	13028.36	483430	
GWP	1604.549	42640	76600.2

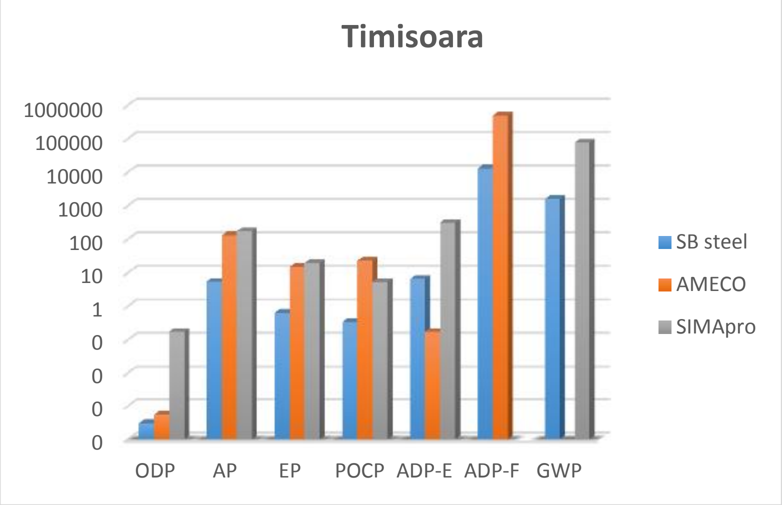

Fig 6.2 Coimbra - comparison of construction stage for the LCA tools

Table 6.3.Coimbra -comparison environmental impacts associated with the construction stage for the LCA tools.

	SBsteel	AMECO	SImaPro
ODP	0.000302681	0.00053373	0.169543819
AP	5.28832	128.566	159.2361255
EP	0.619728	14.8154	17.57432361
POCP	0.3179598	22.5039	4.547353283
ADP-E	6.3912	0.17	286.3721659
ADP-F	11778.7	476350	

GWP	1591.312	41970	69846.05007

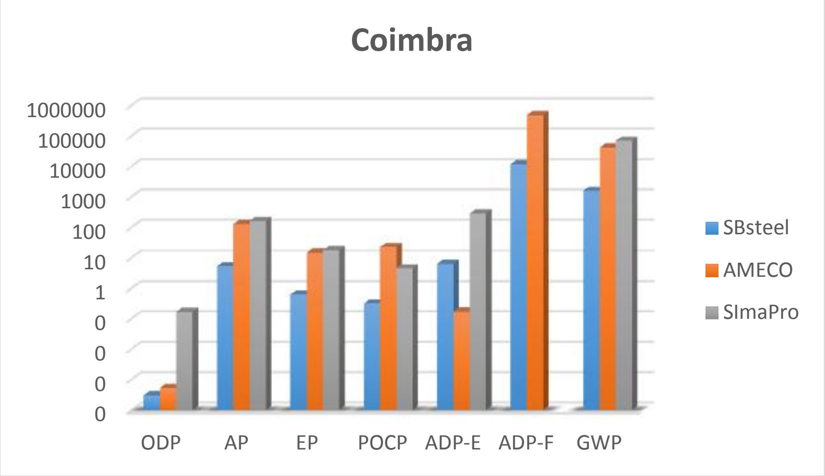

Fig.6.3 Coimbra - comparison of construction stage for the LCA tools

6.1.2 Comparison in the Complete LCA analysis

Table 6.4. Lulea-- comparison complete LCA analysis for the LCA tools

	SB steel	AMECO	SIMApro
ODP	0.03300	0.00268	0.721485
AP	833	17500	505.5641
EP	138.0	893	71.48887
POCP	37.60	2640	32.01346
ADP-E	919.0000	1.07	0
ADP-F	1950000.0	343367370	2966.734
GWP	165000.00	4618240.00	1102402

Fig 6.4 Lulea- comparison complete LCA analysis for the LCA tools

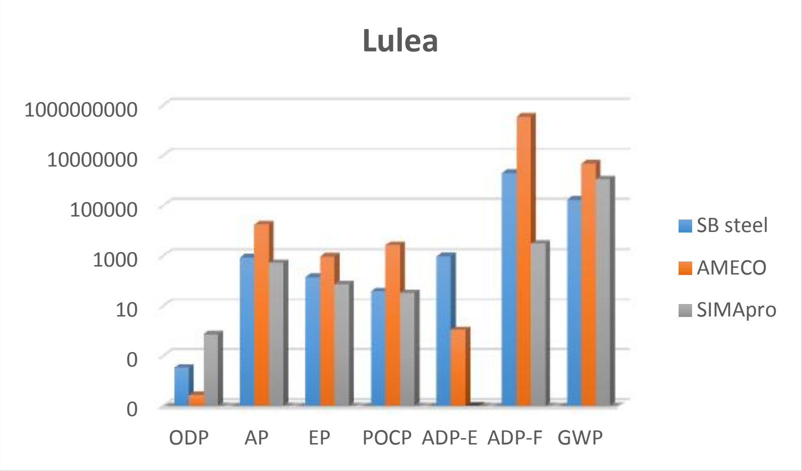

Fig 6.5 Timisoara - comparison complete LCA analysis for the LCA tools

Table 6.6 Timisoara- comparison complete LCA analysis for the LCA tools

	SB steel	AMECO	SimaPro
ODP	0.03280	0.00369	0.496504
AP	822	16700	388.5788
EP	134.0	883	54.06631
POCP	33.10	1350	22.04254
ADP-E	892.0000	0.694	0
ADP-F	1870000.0	122527920	1935.364
GWP	161000.00	3743960.0	707865.7

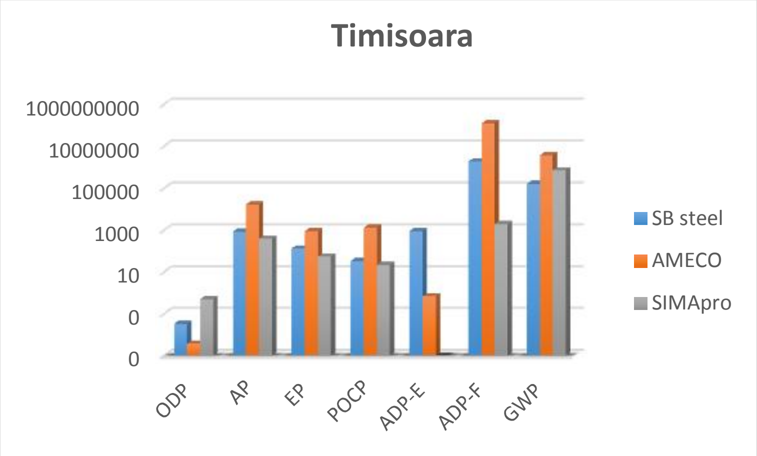

Fig 6.6 Coimbra - comparison complete LCA analysis for the LCA tools

Table 6.7 Coimbra - comparison complete LCA analysis for the LCA tools

	SBsteel	AMECO	Sima Pro
ODP	0.03280	0.00368	0.34347
AP	818	15400.00	291.2676
EP	133.0	821.00	39.75786
POCP	31.90	977.00	14.32991
ADP-E	884.0000	0.58	0
ADP-F	1840000.0	67046490.00	1226.396
GWP	159000.00	3302820.0	439484.3

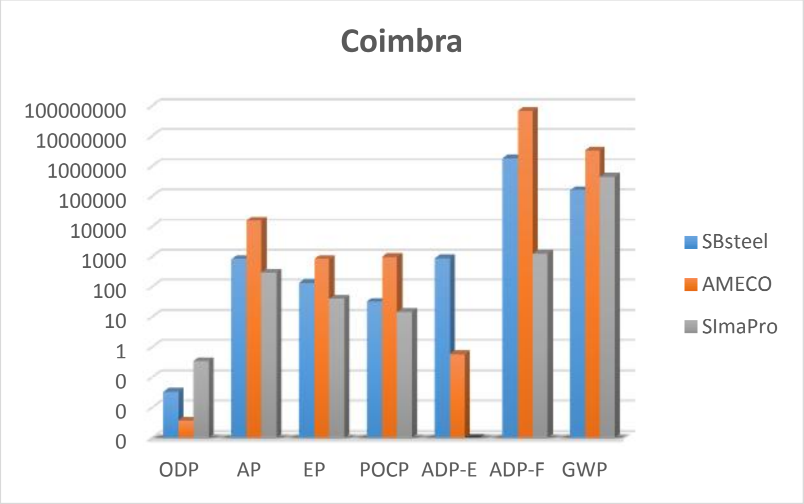

Fig 6.7 Coimbra - comparison complete LCA analysis for the LCA tools

Table 6.8 Total GWP produced per house associated with construction LCA stage by the LCA tools

	Coimbra	Timisoara	Lulea
SBsteel	1591.312	1604.549	1639.568
AMECO	41970	42640	41300
Sima Pro	69846.05	76600.22	72084.61

Table 6.9 Total GWP produced per house associated with the complete LCA analysis by the LCA tools

	Coimbra	Timisoara	Lulea
SBsteel	159000	161000	165000
AMECO	3302820	3743960	4618240
Sima Pro	439484.28	707865.7	1102401.7

Assessment of environment impact indices: A general comparison of the assessment result from the application of the three LCA assessment results. Depicts that SBsteel is the most ‘’conservative’ one of all. The impact indices evaluated by SBsteel are much lower than the two. From the table 6.8 and 6.9 , the greenhouse gas emission-GWP assessed by SBsteel is 43 times smaller than of Sima Pro and 26 times than that of AMECO in the construction phase may be due to, While in the total GWP of the building AMECO is 20 times higher than SBsteel and 5 times that of Sima Pro. Results obtained from AMECO can be compared to SimaPro the in the Construction stage and complete LCA analysis. In AMECO, the following environmental impacts; GWP, AP, ADP-f, POCP and EP for all the houses were significantly higher impacts than the SBsteel and Sima Pro in the complete LCA analysis. , the difference between houses is practically very huge in the complete life cycle analysis.

SBsteel underestimates the environmental impact of the building this may be due fact that SBsteel does not take into account the structural elements. AMECO produced higher environmental impacts may be due to the shortage of data to and offers little flexibility to suit any given Climate.

6.1.3 Comparison of the energy need for the 3 LCA tools

Table 5.8 represents the Energy need for space cooling, space heating and DHW- the major process/product stage that contribute to the main environmental impact of the building during its lifetime.

Table. 5.8. Comparison of the energy needed for the LCA tools used

		Heating kWh	Cooling kWh	DHW kWh	Total kWh	kWh/m^2
Timisoara	SBsteel	1971.41	7710.34	2877.57	12559.32	84
	AMECO	1185.9	9398.0	2875.3	13459.2	90
	Sima Pro	11231.35	1920	4902	18053.35	120
Coimbra	SBsteel	149.56	7217.65	2877.57	10244.78	68

	AMECO	190.9	10102.0	2875.3	13168.2	88
	Sima Pro	5093.21	2080	4085	11258.21	75
Lulea	SBsteel	6521.8	2615.02	2877.57	12014.39	80
	AMECO	5469.7	2202.6	2875.3	10547.6	70
	Sima Pro	19401.89	1860	7353	28614.89	191

Obtained results for SBsteel and AMECO both in individual results (space heating, space cooling, DHW) and their totals are very similar for all the energies and the houses considered.

In comparison of AMECO and SBsteel with SimaPro, the values individual results differ greatly. This might be due to the different percentages of heating/cooling and DHW considered for the tools. Especially the Cooling energy are doubtable. In order to find how sustainable the 3 buildings are, a comparison is made based on a sustainable building as one having an annual requirement has an overall end-use operating energy of about 120 kWh/m2 year; that can be converted into about 200 kWh/ m^2 year of primary energy requirement.

From this conclusion, the buildings designed for Timisoara and Coimbra can be said to be sustainable buildings in reference to all the LCA tools used. While Sustainable building was achieve with AMECO AMECO and SBsteel, for Lulea in SimaPro it can only be considered as a Standard house.

6.1.4 Adaption of the building to 3 climatic zones

6.1.5 Conclusion

The affordable housing originally designed in Timisoara (Cfb) is be adaptable to the two European countries Lulea (Dfc), and Coimbra. (Csb). From Table 1.2 It is however clear that the between the different locations there is little difference in the between the structural steel elements, considering structural adaptation of the building. The performance the building was performed under climate and soil - Coimbra and Timisoara were design with seismic activities, Lulea without any seismic activities. Lulea and Timisoara with snow load. Coimbra with no snow load.

Table.7 A summary of the structural elements as a result from the design.

Location	Timisoara	Coimbra	Lulea
Main beam material S355	**IPE200**	**IPE220**	**IPE240**
Secondary beam material S355	**IPE220**	**IPE220**	**IPE220**
Column material S355	**HE140B**	**HE120B**	**HE100B**
Braces material S235 [steel rod	**D20**		
(plate connections, bolts, studs)	**1419.0**	**1378.73**	**1307.575**
	7098.54	**6893.64**	**6566.82**

The results and discussions of the study including a lifecycle assessment can be further summarized as the following;

- Among the LCA analysis, Sima Pro appears to be more applicable one based on its database comprehensiveness and user-friendliness followed by AMECO, which appears to be more similar to Sima Pro than SBsteel.

6.2 Summary of discussions

The previous sections of this chapter has outlined the current situation and influence regarding assessment tools and indicators in the affordable houses and the three climatic zones there were analyzed.

In each of the three affordable houses was assessed using SBsteel, AMECO and Sima Pro. There are doubt about the effectiveness of the SBsteel and AMECO to account for energy need for cooling. all the houses seem to perform badly thus have high value in the energy need for cooling leading to a bad performance in the energy need, There seem to appear some anomalies with the simulation process for cooling, which I hope will be addressed in the updated versions of these LCA tools.

Where do ‘Affordable Houses’ stand relative to sustainability when reviewed by assessment tools? It is obvious it varies depending on the tool used. A comparison made based on sustainable building having a maximum of 120 kWh/m$^{2.}$ where AMECO and SBsteel shows that all the 3 houses are sustainable in all the climatic zones, with the exception of with Lulea with 190kWh/m^{2} during the evaluation of the operational energy Overall, the performance of the affordable house can be improved to be more sustainable. Some adaptations however are more likely to achieve benefit to the building than other interventions. Suggested list of recommendations for improving the reduction of the energy performance of the building.

- The glazing area of the building should be reduce: depending on the local climate, between 20 and 30% of glazed surface compared to the floor area for residential building.
- The better the thermal performance of a building material the less energy is needed for the operation of the building, Its U-value (thermal transmittance) expresses the thermal performance of a building material. It is a measure of how well the material keeps heat /coolth inside a building. Glass size and type should be selected according to the climate. A low U-value indicates a low thermal transmittance and, therefore, high insulating quality. In temperate climates, like Lulea, maintaining warm conditions within buildings and, generally, seek building components with low U-values. For example, a triple-glazed window with a U-value of 1.2 W/m2K would insulate better than a window with a U-value of 1.8 W/m2K.
- During summer, vertical shadings outside south windows are more efficient and for windows facing east or west, vertical shading devices are always, essential horizontal overhangs do not cut off the radiation at lower angles.
- Increase airtightness in the building envelope a high level of airtightness is also important to keep a uniform indoor temperature. Furthermore, high infiltration rates will lead to an increase in air that does not pass through the heat exchanger of the ventilation system, causing additional need for space heating.
- Good air tightness for controlled ventilation and reduction of heat losses and moisture damages

6.3 Discussions and recommendations on the LCA tools

Discrepancies between the LCA tools were related to:

- Quantities of materials used
- Amount of surplus or waste
- Steel content of reinforced concrete
- Assumption made about the use of recycled steel
- Transport of materials during construction and at end of building life
- Life span of building components
- End of life processes

Results of the three studies have suggested list of recommendations for improving existing assessment tools and for designing new tools. Important examples are:

- Use of recycled material in construction phase and potential recycling processes at the end of life should be accounted for in a consistent and transparent way in AMECO and SBsteel.
- LCI data should be consistent and clear (e.g. same system boundary; clear allocation methods; no mixing of data from different sources).

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