GRAU EN ARQUITECTURA TÈCNICA I EDIFICACIÓ

TREBALL DE FI DE GRAU

Programes de mobilitat”outgoing”(EPSEB)

LIFE CYCLE ASSESSMENT OF A BUILDING IN BARCELONA

Projectista/es: Xavier Pérez Benitez
Director/s: Karel Struhala
Convocatòria: Setembre 2016
Universitat d’acollida: Brno University of Technology

Bachelor’s Final Project

[Life Cycle Assessment of a building in Barcelona]

Xavier Pérez Benítez
January 2017

BRNO UNIVERSITY OF TECHNOLOGY

Index

Introduction

Objective

The aim of this project is to calculate the total environmental impacts of a building during its life cycle, and compare which of the three phases of this life cycle (construction, operation and demolition) consumes the most.

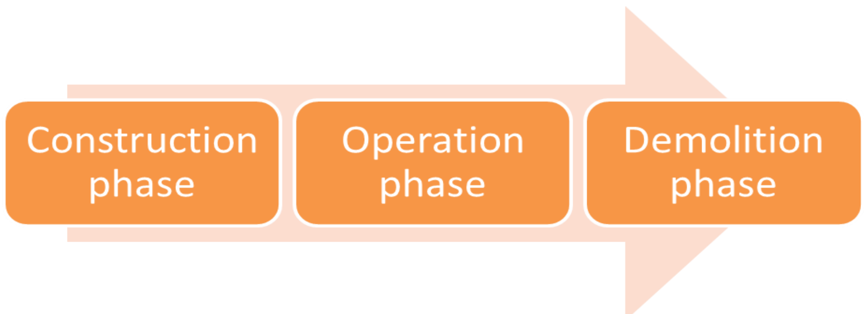


Figure 1. Shows a basic scheme of the building phases.

Reading through literature about this subject [11, 12, 13] I found out that the phases of construction, demolition and relative transportation of materials, all show that the sum of the energy needed for these phases either is negligible or settled at approximately 10-20 % of the total life cycle energy need.

I found this huge, since being the phase of operation the one with the highest percentage (80-90%), and the one which we can decrease the most by improving the energetic efficiency of the buildings.

Therefore using an example of a conventional building, we will:

1. Explain what is a Life Cycle Assessment
2. Calculate the total energy of one building in each of the three phases
3. Compare the percentages of each phase
4. Discuss the results and compare it with another paperwork

Literature review

Of the total population of the planet, as of today, more than half of them are located in urban settings. In developed countries, about 40% of the population is concentrated in the cities, a fact that contrasts strongly with the fact that that in 1950s, the percentage of people living in cities was only the 20%.

On the other hand, it is estimated that the human being uses between 80% and 90% of his daily time inside some kind of building (housing, work, gym, etc.).

The above data allow easy glance at the high existing demand, at a global level, for the construction of buildings and infrastructures. To put an example, the World Bank estimates that by 2015, more than half of the stock of residential and commercial buildings of China will have been built during the previous fifteen years. In the case of developing countries, this demand for new buildings (especially residential buildings) is so high that can't be covered.

The imbalance between supply and demand leads, in in many cases, the construction of low-quality housing ("shacks"), whose characteristics can be summarized in their illegality and the absence of the infrastructure. Inevitably, this high volume of production gives rise to a series of effects, of high and increasing repercussion, on different social factors, economic and environmental impacts for the planet [1].

In the OECD countries, the construction sector, in its most global concept (considering also the production and transportation processes of the materials needed for it) accounts for between 25 and 40% of total energy consumed annually, a figure that, in some countries, reaches values of up to 50%. In addition, the share of total energy consumed in these countries is attributed to this sector, which has been increasing practically steadily over the last decades, and this trend is expected to continue in the coming years.

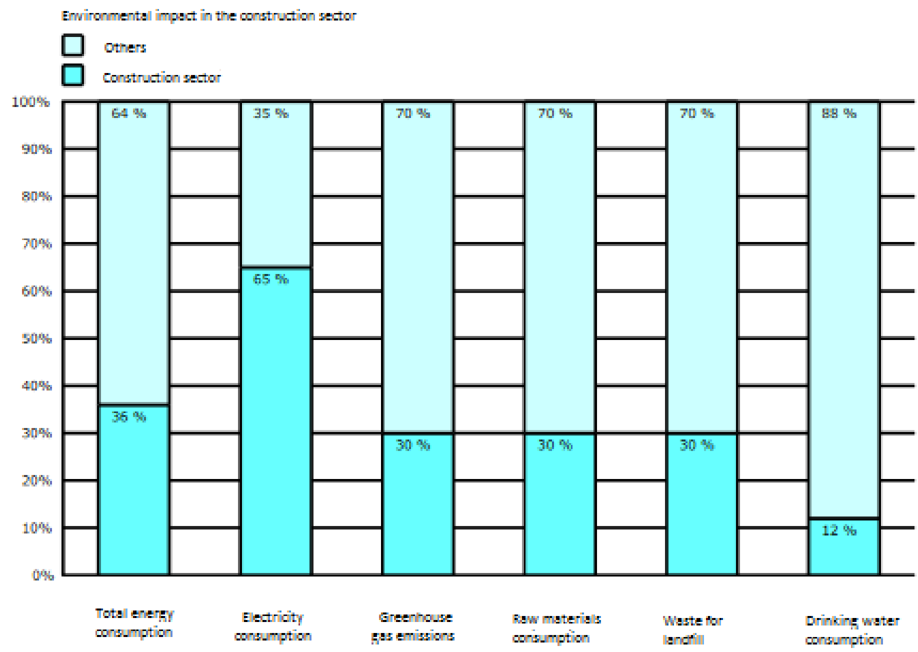


Figure 2. The graph shows environmental impact in the construction sector in comparison to the rest [2].

The International Energy Agency estimates that one-third of the final energy consumed in the world goes to the heating, cooling, lighting, etc… All those are services of non-industrial buildings (residential buildings, shops, etc.). Among all of them, it is the demand for heating which, on the overall consumption of the building, has the largest share of participation, especially in European countries.

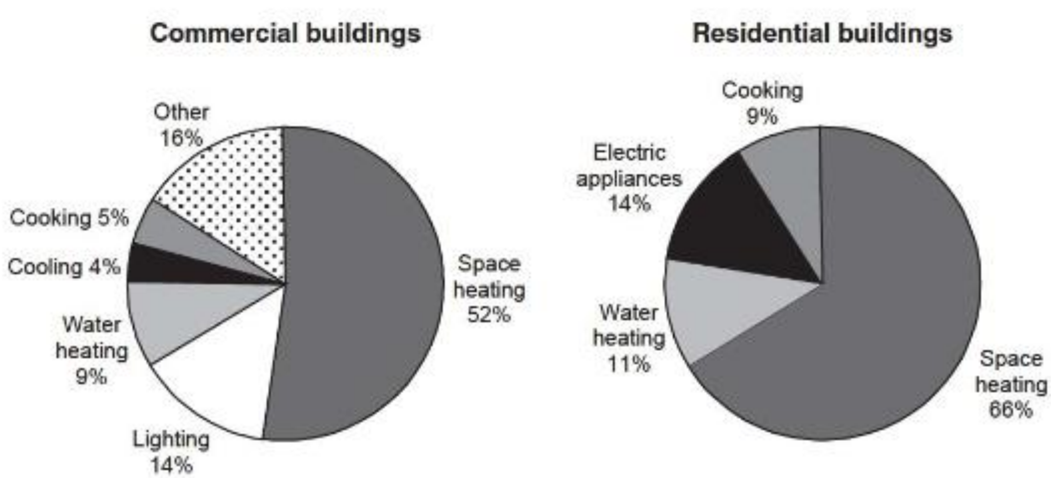


Figure 3. The graphs above show the distribution by uses in the construction sector in the EU [2].

Taking into account the fact that most of the energy consumption of a building is attributable to the operation of the building, the need to improve its energy efficiency in order to reduce the final consumption of the sector is more than evident.

In this sense, the range of possibilities available to reduce the energy consumption of the building is certainly extensive, ranging from basic design concepts (the orientation of the building, the chosen glazed surface, etc.) to small details of execution (thermal bridge elimination methods, correct sealing of the envelope), without neglecting the need to use new and better building materials (insulation of lower thermal conductivity, radiation selector glasses, etc.). The proper combination of all or a part of these criteria, which are particularly relevant during the project phase, will enable the objective of reducing energy consumption to be achieved to a greater or lesser extent.

With this, it is easy to understand how, as the energy efficiency of buildings increases, their demand for energy over its useful life will tend to decrease. There is then a change in the distribution that, by use, can be established on the total energy consumption of the sector, decreasing the relative importance that the consumption associated with the operation of the buildings supposes in the global, while increasing the part corresponding to the other processes of the sector (manufacturing, transport and placement of materials).

This energy consumed by "other processes in the sector", and usually referred to as "embedded energy", can then be reduced thanks to the new and better materials, whose manufacture and assembly will be more optimized and requires a lower energy consumption, thus reducing demand of the sector [2, 3, 4].

.

Life Cycle Assessment. Basic concepts

Introduction

The standard UNE EN ISO 14.040 [10] defines the life cycle analysis as a technique quantitative assessment of the environmental and potential impacts associated to a particular product, good or service by:

1. The compilation, in an inventory, of all flows of energy and matter employees in their manufacture, use, dismantling, etc.
2. The assessment of the environmental impact potential associated with each entry or output of the system under analysis.
3. The interpretation of the results obtained with a view to improving the processes of production, development, etc.

This normalizing effort is reflected in the series of standards UNE EN ISO 14.040 to 14.044, its main advantage being the standardization of procedures and results of the study. But there are also other standards which must be followed, considering this project as a study of a concrete building. In this case we will focus on EN 15978 which provides calculation rules for the assessment of the environmental performance of new and existing buildings based on a life cycle approach [4, 5].

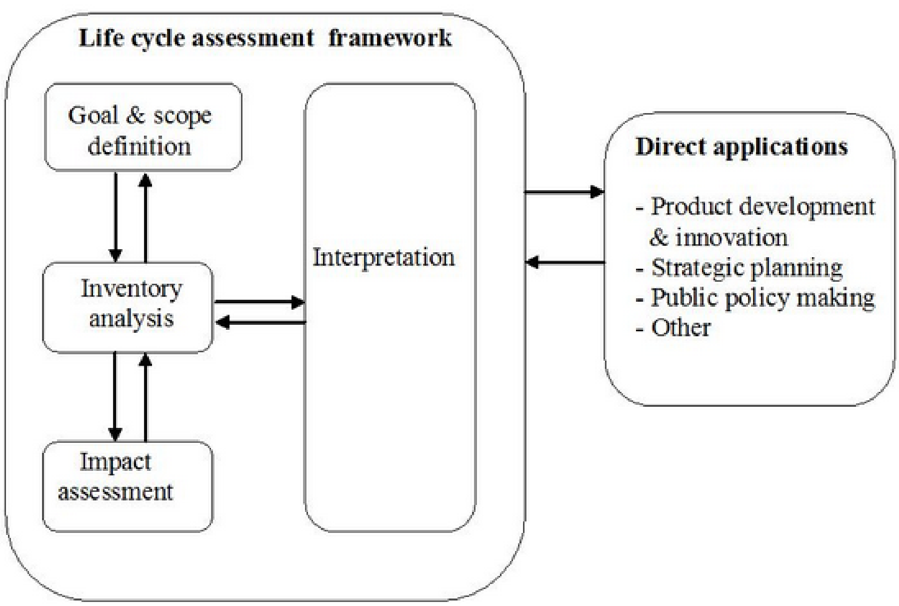


Figure 4. The figure from ISO 14040 [10] shows how any LCA should be carried out in four distinct phases.

We will be following then some EN standards such as EN ISO 14.040 [10], EN 15978 [16] and EN 15804, focusing on the parameters that EN 15978 tells, about how to do the calculations in a Life Cycle Assessment. Reading through the standard, we can see how it gives:

1. The description of the object assessment
2. The system boundary that applies at the building level
3. The procedure to be used for the inventory analysis
4. The list of indicators and procedures for the calculation of these indicators
5. The requirements for presentation of the results
6. The requirements for the data necessary for the calculation

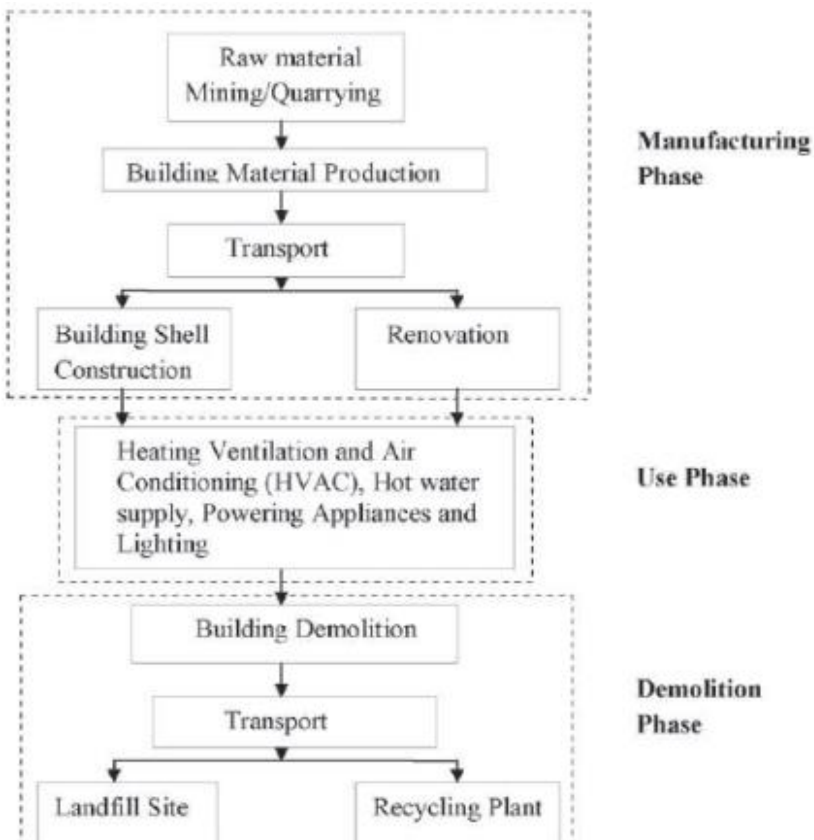


Figure 5. The scheme above from ISO 14040 [10] shows the general scheme for any building's service life.

As you can see in the previous scheme taken from ISO 14040, the building's life includes the phases of Manufacturing, Use and Demolition. A similar scheme was adopted in the standard EN 15978 with more details and standard nomenclature for each of the phases. You can see the standardized scheme of building service life in Figure 6.

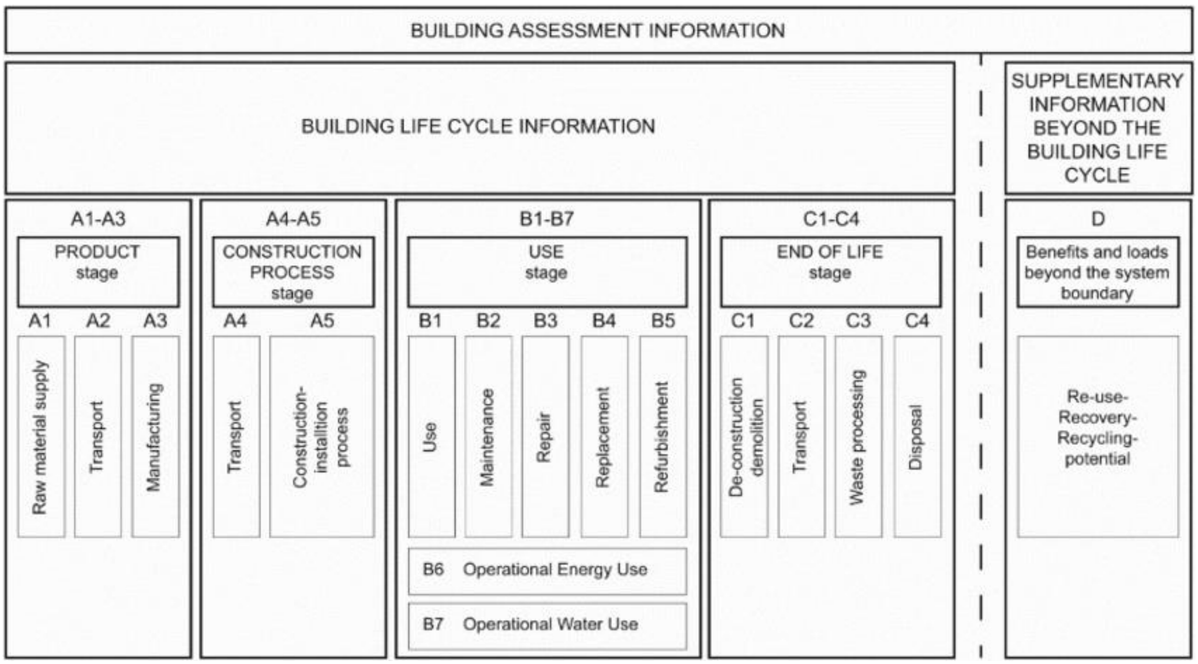


Figure 6. Standardized scheme of building assessment information from EN 15978 [16].

Definition of objectives and scope of the study

This is the first stage of any LCA study. At this stage the boundary conditions of the LCA study have to be defined.

It includes an exhaustive definition of the product, good or service to analyze, its main characteristics, the causes that originate the analysis, the expected expectations and objectives of application of results obtained, etc.

It is necessary to specify, in a clear and concise manner, all those premises and limitations that will be considered in the study, the different approximation techniques that are intended to be used

to obtain certain results (for example, the relocation methodology in the assumption That it will be necessary), the quality requirements that will be required on the data to be collected, the accuracy that is intended to be achieved in the results, etc.
Another aspect of crucial importance that should be specified in this point is the type of data that is intended to provide the client, as well as the minimum structure and contents that should appear in the results report.

From all of the above, it is clear that any decision taken in this phase of the study will lead to a certain impact on the rest of the stages of the process, and therefore a high degree of definition is recommended in the aspects discussed above [4, 5].

Life Cycle Inventory

This phase consists of the quantification of the inputs and outputs of the system being studied, which may include all or some of the following: use of resources (raw materials and energy), emissions to the atmosphere, soil and water, waste generation, etc.
According to the US Environmental Protection Agency (EPA), the following are the key aspects that should guide the inventory process:

1. Development of a flow diagram of the process under analysis. It allows to visualize in a simple and easy way, the main flows of matter, energy or any other resource or emission generated in the process. Likewise, the limits on the scope of the study are clearly expressed.
2. Development of a data collection plan to ensure that existing expectations are met for the quality and accuracy of the data collected.
3. Data collection. In order to minimize the time invested in the construction of the inventory, the use of some kind of specialized software in the matter can be productive.
4. Presentation of the data. The presentation of data in the form of tables and graphs is often particularly intuitive and concise [4, 5].

Life Cycle Impact Assessment

It is at this stage that the allocation of the potential impact on human health and the environment of the results obtained in the life cycle inventory is carried out.

This phase is the main difference between the life cycle analysis and other techniques of environmental analysis, since it does not attempt to quantify a certain current impact related to the process / product, but to establish a relation between said system and its potential environmental effects considered globally [4, 5].

According to ISO 14040 [10] the Impact Assessment (or Life Cycle Impact Assessment, LCIA) is the next step of any LCA. It is aimed at evaluating the significance of potential environmental impacts using the LCI results. The data gathered during LCI are associated with specific environmental impact categories. Various LCIA methods exist for calculating environmental impacts like excel tables or specialized software like GaBi and others – see [14] or [15] for more information.

Interpretation of results

The interpretation is a systematic evaluation of the results obtained in the previous phases of the analysis. According to the norm UNE EN ISO 14.040 [10], the main objectives of this stage are:

1. Analyze the results, extract conclusions, explain the limitations, and establish recommendations based on the data obtained in the previous stages of the analysis, reproducing the results obtained in a transparent way.
2. Present in a simple and easily comprehensible, complete and consistent the results of the analysis, in accordance with the guidelines set out in the scope and objectives definition section.

In this respect, it should be noted that the interpretation of the results will not always be simple, due, among other things, to the estimates, approximations, and hypotheses that would have been necessary during the process.

In a comparative study, it may be the case that the results obtained do not allow to establish clearly which of the two options is preferable due to the uncertainty of the results, without it being necessary to consider that the analysis has been unsuccessful since Will always mean an effective increase in the amount of information available for decision-making [4, 5].

Critical review

This concept appears as a requirement in the norm UNE EN ISO 14.040, especially in those studies whose objective is comparative. The critical review of the research will be done after the results of the LCIA and together with the Interpretation of results. The main objectives pursued at this stage are to verify the following aspects:

1. The methodology used in the analysis is consistent with that developed by the cited standard.
2. The methods used are technically and scientifically valid.
3. The data used are reasonable and in accordance with the purpose of the study.
4. Interpretations reflect the limitations identified and the purpose of the study.
5. The report is clear and consistent.

Life Cycle Assessment of a building in Barcelona

Goal and scope of the project

The project described in the following sections focuses on the study of the incoming and outgoing energy and material flows that occur throughout the life cycle of a building. Paying special attention to the different stages that compose it (construction, use and demolition). EN 15978 [16] tells us the modules to study which are: A1-A5, B1 (municipal waste), B4 (renovations, including materials, energy, water, construction work and construction waste), B6 (electricity and gas for use of the building), B7 (water for use of the building) and C1 to C4. Once we have obtained the results of the three stages, we will compare and discuss the data obtained.

First of all, we will define the building and what should we study of it. In the model we will take in count all of those elements that EN 15978 (page 74) tells us to study which are: Foundations, frames, walls, façade, energy system and facilities and water supply.

Building example

The building under study is located in Barcelona, Spain. It is a three storey building of 14 meters height, with two residential use storeys of 150m^2 and commercial use in floor 0. It is located in a residential neighborhood with only two seen facades facing East and South East.

Figure 7. Location of the building in Barcelona.

The building was built in 1952 with a structure made of 15 isolated foundations (1m^2 each), of concrete and reinforced steel, as so are the rest of the structural items of the building, pillars of concrete and reinforced steel, and slabs of concrete, steel and concrete blocks to reduce the amount of fresh concrete.

The divisions inside the building are made of ceramic bricks (9 cm) and the exterior enclosure and covering configure a ventilated façade with two sheets. The first sheet include the brick wall, which will support the weight of the façade, and the thermal isolation. The second sheet will be the covering of the enclosure, made of plastic panels attached to an aluminum structure.

Refereeing to the openings of the building, these will be made of an aluminum frame, and a double laminated security glazing. The inner doors are made from wood, and the outside doors will be made of wood covered with aluminum.

The roof of the building consists in a classical building method from Catalunya. As it can be seen on the drawings in the Annex, it consists on a layer of bricks, over a plastic film to protect it from the rain, and a layer of concrete to give it the proper inclination to deviate the water to the appropriate scrapping.

What for the facilities matter, the system of pipelines are made of PVC, and they are found in the kitchen and toilets, connecting them with two major pipelines that go to the main pipeline system in the street.

The electrical installation is made of cooper wire in all the building, all connected to the grounding in case of electric overload. The lightning system is made of regular light bulbs. The heating system is made of radiators, all around the apartments, powered by natural gas.

Life Cycle Inventory

In this section we will measure all the elements cited in EN 15978 referring to the building example. A bill of quantities will show all the elements taken in count to the study, and later, in the Life-Cycle Impact Assessment, the results will be shown. Some of the data and the weight of some materials are found through literature [7, 8]. The items listed, are a basic version of the actual building, and it has only kept in mind the major elements which compose it. Little elements such as furniture, paintings, or other little finishes have been despised.

As we saw previously in Figure 6, there is a subdivision of the Life cycle of the product studied in three differentiated parts. Details of the methodology of calculation for this LCA can be found below.

Also we will estimate a life time of the building for 100 years. This will be needed to calculate the total amount of waste in its whole life.

1. Construction phase

As its name implies, this stage refers to the different processes associated with the making of the building. Included in the manufacture and transport to the place of products, equipment and facilities that will be part of the building once complete this stage, as well as the different construction processes necessary for the execution of the same (excavation of the land, concrete, pile drilling, etc.). Using the software GaBi, and introducing the data obtained in the Life Cycle Inventory, we will obtain the results.

Material	Units	Measurement
Foundations		
Concrete C20/25	m^3	15,00
Reinforcing steel B500S	kg	1.050,00
Plastic film, extrusion	kg	0,31
Structure		
Concrete C20/25, for pilars	m^3	18,90
Reinforcing steel B500S for pilars	kg	1.512,00

Concrete C20/25 for slabs	m^3	86,18
Reinforcing steel B500S for slabs	kg	7.440,00
Concrete block for slabs	kg	9.151,20
Roof		
Concrete C20/25 roof inclination	m^3	7,75
Thermal isolation. Polystyrene, extruded (XPS)	m^2	155,00
Brick, at plant	kg	310,00
Encolusures and coverings		
Polycarbonate, covering facade	kg	3.497,90
Thermal isolation. Polystyrene, extruded (XPS)	m^2	478,80
Brick, indoor walls (9cm)	kg	2.726,46
Brick, outdoor walls (15cm)	kg	82.040,00
Carpentry		
Door, inner, wood, at plant	m^2	21,84
Door, outer, wood-aluminium, at plant	m^2	3,36
Window frame, aluminium, U=1.6 W/m2K, at plant	m^2	3,85
Glazing, double (2-IV), U<1.1 W/m2K, laminated safety glass, at plant	m^2	77,15
Facilities		
Propylene, pipeline system	kg	90,09
Wire drawing, copper	kg	91,00
Copper concentrate, at beneficiation	kg	91,00
Others		
Electricity, high voltage, at grid	MJ	23.250,00
Excavation, hydraulic digger	m3	61,50
Building machine	ut	1,00
Disposal, inert waste, 5% water, to inert material landfill	m3	156.825,00
Transport, municipal waste collection, lorry 21t	m3	3.136,50

Table 1. Bill of quantities of the building studied.

2. Operation phase

It is considered included in this stage the set of processes derived from the daily use of the analyzed product. In this case we will be analyzing the electricity and gas consumption between the years 2015 and 2016. Usually these processes will include the energy consumption associated with the maintenance of certain thermal conditions, the consumption daily water and waste production, painted walls, replacement of finishes, etc... But in this case we will focus on elements referring heating and water use, due to the technical aim of the paper.

The methodology will be done, then, by collecting all the electricity, gas and water bills during the period of study, and taking the amount of KW per month into a table which we can see below. Also we will have to take in count the debris waste of the users, which will be provided by official documents of the government of Spain, and the maintenance ratio of some elements of the building that must be replaced during its lifetime. Once we have the KW·m^2/year, we will estimate a life cycle of 100 years, to obtain how many KW did the building use in its lifetime.

By collecting the bills of electricity, gas and water, we can measure the consume done in a whole year. The following charts are a summary of the data collected.

Electricity Inventory

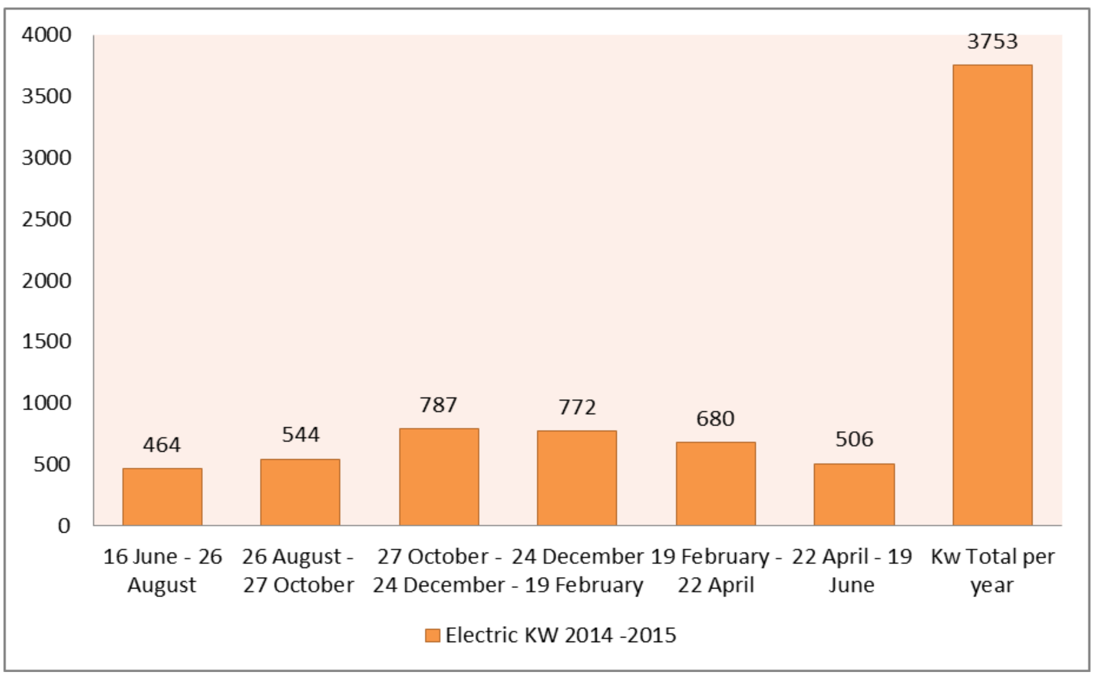


Figure 9. The graph shows the consume of electricity in one of the apartments (KW) during the year 2014.

Since the study was made with the Electricity bills of the building, we had acces to the parameters of the electric billing in Spain. Just as a mere information fact, we can see in the chard below, that the price of electricity is just the 49% of the price. One more reason to think about a sustainable design of our buildings.

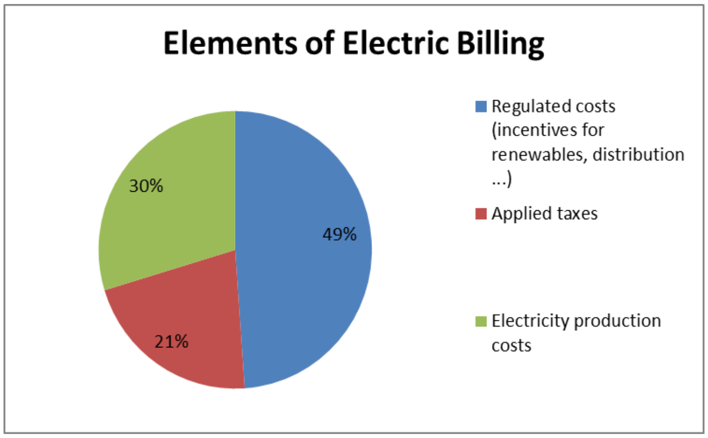


Figure 10. The chart above, represents the percentage of an electric bill in Spain and its elements.

Gas Inventory

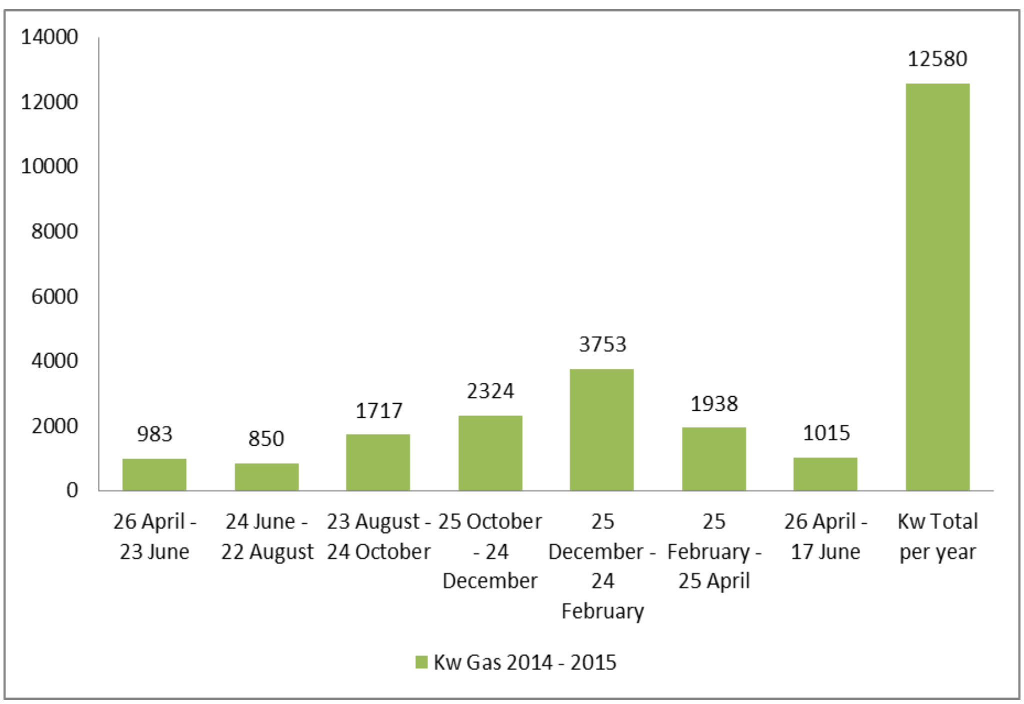


Figure 11. The graph shows the amount of Natural Gas consumed in one of the apartments (KW).

Following the same procedure as with the electricity, the following chart reflects the elements of a gas bill in Spain.

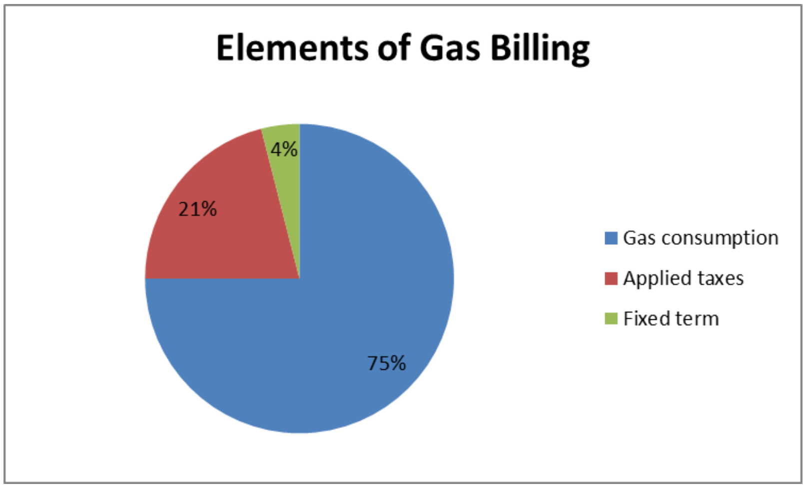


Figure 12. The chart above, represents the percentage of an electric bill in Spain and its elements.

Water Inventory

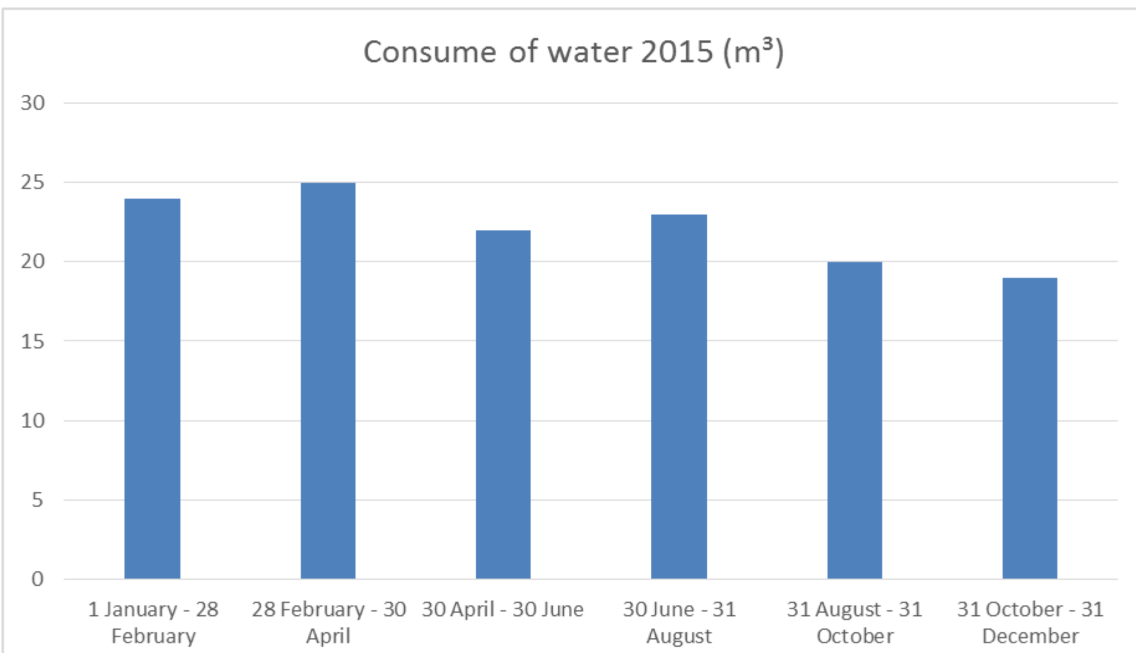


Figure 13. The graph shows the amount of Water consumed in one of the apartments (m³).

Debris waste Inventory

In order to calculate the amount waste the building generates, it's needed to find an estimation in another paperwork.

According to the National Statistical Institute of Spain [9] every person generates 484,8 kg/year of waste. With this data we can obtain the amount of waste our building generates every year.

Maintenance Inventory

Following the instructions of ISO 15686:1 it should be taken in count that some of the elements that conform the building will be replaced during its lifetime. Using the table B.1 of the same document, we will make a calculation of which elements have to be replaced and in which frequency we have to do it. In this case the building design life should be 100 years.

Building Design Life	Inaccessible or structural components	Components where replacement expensive or difficult	Major replaceable components	Building services
Unlimited	Unlimited	100	40	25
150	150	100	40	25
100	100	100	40	25
60	60	60	40	25
25	25	25	25	25
15	15	15	15	15
10	10	10	10	10

Figure 14. Table B.1 of the ISO 15686:1

Focusing on the 100 year old design building, we will have to study the elements which are considered as "Major replaceable components" and "Building services".

3. Demolition

It is the last stage of the building's life cycle, and includes demolition work, the removal of debris to landfills and recycling plants, etc. Using the software GaBi, and introducing the data obtained in the Life Cycle Inventory, we will obtain the results.

Life-Cycle Impact Assessment

Regarding the impact category that we will be evaluating, it is called Global Warming Potential (GWP) and their results are represented in kilograms of CO2-equivalents. This kind of units includes the concentration of CO2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas, and that are also included in the process of any material. Examples of such greenhouse gases are methane, perfluorocarbons, and nitrous oxide.

The presented assessment uses the CML2001 method developed by the Institute of Environmental Sciences, University of Leuven, Netherlands [X] with impact categories and characterization factors in version Nov. 10. Only seven out of all impact categories within the characterization model are taken into account for the presentation of results in the following sections. The GaBi 4 software tool is used as a main tool during the LCIA.

Results

Phase of construction

Using the software GaBi and after doing the Life Cycle Inventory, we obtained the results regarding energy content of materials and construction processes. The full version of the Life Cycle Inventory is found in the Annex of the paperwork, due to its size. In it, there are also included the other units of measurement which are: Global Warming Potential (kg CO2-Equiv.), Abiotic depletion (kg Sb-Equiv.), Abiotic depletion (MJ), Acidification Potential (kg SO2-Equiv.), Eutrophication Potential (kg Phosphate-Equiv.), Ozone Layer Depletion Potential (kg R11-Equiv.) and Photochem. Ozone Creation Potential (kg Ethene-Equiv.).

Here we have a short version just the units we will be dealing with, their measurement, and their impact in the most common unit Kg CO_2-equiv.

Material	Units	Measurement	[kg CO2-equiv]
Foundations			
Concrete C20/25	m^3	15,00	4.000,29
Reinforcing steel B500S	kg	1.050,00	1.526,42
Plastic film, extrusion	kg	0,31	0,13
Structure			
Concrete C20/25, for pilars	m^3	18,90	5.040,36
Reinforcing steel B500S for pilars	kg	1.512,00	2.198,05
Concrete C20/25 for slabs	m^3	86,18	22.982,98
Reinforcing steel B500S for slabs	kg	7.440,00	10.815,81
Concrete block for slabs	kg	9.151,20	1.132,81
Roof			
Concrete C20/25 roof inclination	m^3	7,75	2.066,81
Thermal isolation. Polystyrene, extruded (XPS)	m^2	155,00	1.569,80
Brick, at plant	kg	310,00	68,06
Encolusures and coverings			
Polycarbonate, covering facade	kg	3.497,90	27.137,08
Thermal isolation. Polystyrene, extruded (XPS)	m^2	478,80	4.849,15
Brick, indoor walls (9cm)	kg	2.726,46	598,57
Brick, outdoor walls (15cm)	kg	82.040,00	18.011,22
Carpentry			
Door, inner, wood, at plant	m^2	21,84	-829,70
Door, outer, wood-aluminium, at plant	m^2	3,36	168,21
Window frame, aluminium, U=1.6 W/m2K, at plant	m^2	3,85	1.865,84
Glazing, double (2-IV), U<1.1 W/m2K, laminated safety glass, at plant	m^2	77,15	2.577,57
Facilities			
Propylene, pipeline system	kg	90,09	143,28

Wire drawing, copper	kg	91,00	197,81
Copper concentrate, at beneficiation	kg	91,00	19,40
Others			
Electricity, high voltage, at grid	MJ	23.250,00	3.273,08
Excavation, hydraulic digger	m3	61,50	32,51
Building machine	ut	1,00	27.529,28
Disposal, inert waste, 5% water, to inert material landfill	m3	156.825,00	1.110,57
Transport, municipal waste collection, lorry 21t	m3	3.136,50	3.136,50
TOTAL			**141.221,87**

Table 2. The table shows the amount of Kg CO_2-equiv that the processes of the LCI contain.

With the data obtained in the table, we will make a graph, to make more understandable which are the elements that consume the most.

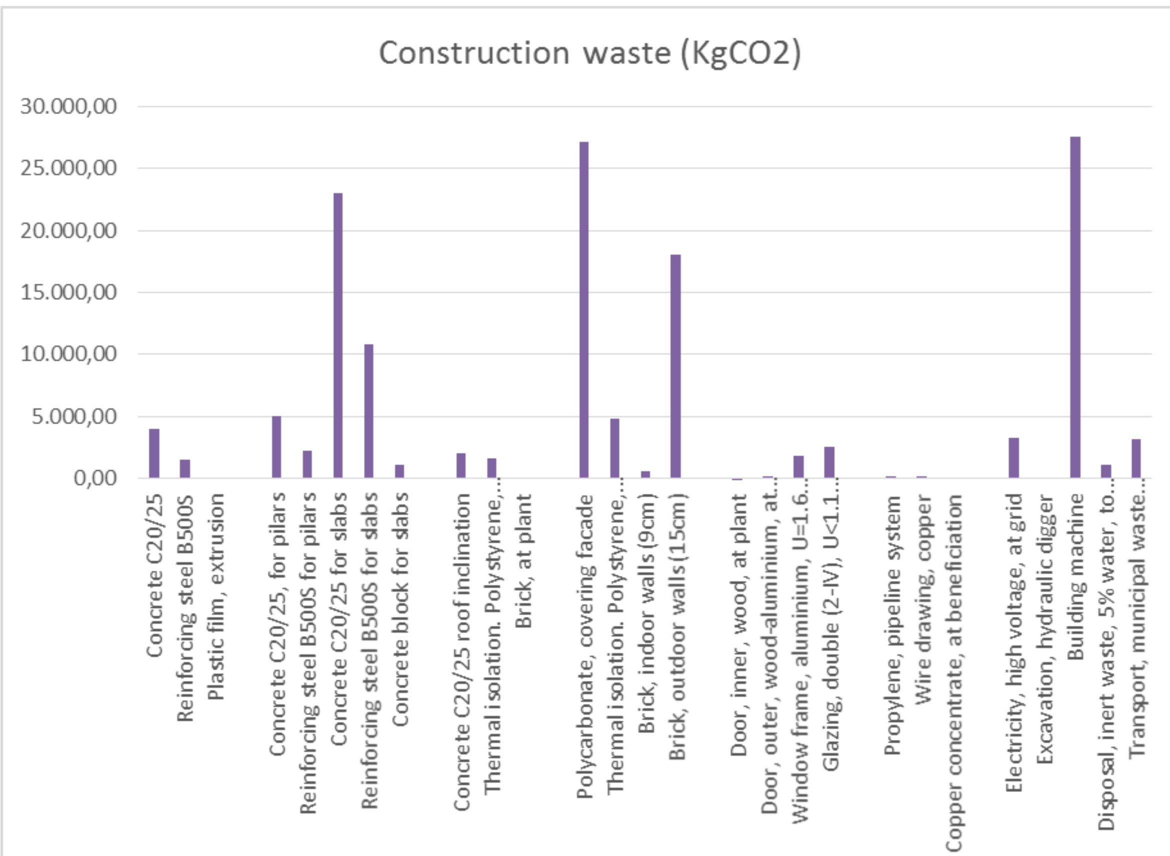


Figure 8. The graph shows the amount of Kg CO_2 that the processes of the LCI contain.

The total amount of Kg CO_2 consumed by the whole building will be: **141.221,87** $KgCO_2$-equiv.

Phase of operation

With the data collected in the LCI and with the methodology explained before, the results of electricity, gas and consumption are:

Electricity

The electricity consumption and expected building service life are defined in section 3.2.2. Using conversion factors of CML characterization model we will determine the amount of $KgCO_2$ equivalent consumed:

First we must obtain an estimation of the amount of KW consumed by the whole building.

3.753 x 5 = 18.765 KW/year

Using conversion factors we will determine the amount of $KgCO_2$ consumed:

1 KWh of electricity = 0,523 $KgCO_2$ / KWh

3.753 KWh x 0,523 $KgCO_2$ / KWh = **1962,8** $KgCO_2$-equiv.

Gas

The gas consumption and expected building service life are defined in section 3.2.2. Using conversion factors of CML characterization model we will determine the amount of $KgCO_2$ equivalent consumed:

First we must obtain an estimation of the amount of KW consumed by the whole building.

12.580 x 5 = 62.900 KW/year

Using conversion factors we will determine the amount of $KgCO_2$ consumed:

1 KWh of Gas = 0,185 $KgCO_2$ / KWh

62.900 KWh x 0,185 $KgCO_2$ / KWh = **11.636,5** $KgCO_2$-equiv.

Water

The water consumption and expected building service life are defined in section 3.2.2. Using conversion factors of CML characterization model we will determine the amount of $KgCO_2$ equivalent consumed. First we need to find out the amount of water consumed by the whole building.

$$133 \times 5 = 665\ m^3/year$$

Then using conversion factors found in GaBi's database we will determine the amount of $KgCO_2$ consumed:

$$1\ m^3 \text{ of Water} = 0{,}000154445858968535\ KgCO_2 / KWh$$

$$665\ m^3 \times 0{,}000154445858968535\ KgCO_2 / m^3 = 0{,}1027\ KgCO_2\text{-equiv}$$

In this case we will also have to keep in mind the process of water treatment which we can find in GaBi's database. After that we will sum the both results for the final water waste.

$$665\ m^3/year \times 0{,}529556845 = 352{,}1553016\ KgCO_2\text{-equiv.}$$

$$352{,}1553016 + 0{,}1027 \mathbf{= 352{,}2580016}\ KgCO_2\text{-equiv.}$$

Debris waste

In every apartment of the building we can differentiate three bedrooms, so we will estimate 3 people per house. Then using the data in section 3.2.2 we can calculate:

$$484{,}8 \times 3 = 1.454{,}4\ Kg/year$$

Now to find out the amount for the whole building:

$$1.454{,}4 \times 5 = 7.272\ Kg/year$$

Finally, and using GaBi's database, and as we did in the previous chapters, we can convert the Kg of waste into CO_2.

$$7.272\ Kg/year \times 1{,}47857872624125 \times 10^{08} = \mathbf{1{,}075 \times 10^{-04}}\ KgCO_2\text{-equiv.}$$

Maintenance

Major replaceable components will be replaced every 40 years, so two times in our building lifetime. In here we should count items like non-bearing parts of the building, such as interior partition walls, doors, windows, façade components, floors, wall finishes…

Building services components will be replaced every 25 years, so four times in our building lifetime. In here we will count elements that degrade the most, such as pipelines, wires, and other facilities.

Using the same data as used in the LCI, we can determine an approximation of the energetic cost of the maintenance, which will be: **74.175,36042** KgCO_2-equiv.

Phase of Demolition

At this point, the building will be demolished, finishing its life cycle. To demolish it, it will be necessary the proper machines, and the transport of the demolition debris to the municipal waste collection.

Using the GaBi's database, we can estimate the energetic cost of the operation by using a demolition machine, excavator for the foundations, and then, knowing the volume of debris that result from the demolition, we can calculate the cost of bringing those to the waste collection.

The results we got by using this data are **27.542,87231** KgCO_2-equiv.

Final results

Once we have calculated the three phases of the building we will continue to resume the data obtained.

1. Construction process

We found out the total amount of waste taken in the construction process was **141.221,87** $KgCO_2$-equiv.

2. Use stage

The sum of the resources studied before (electricity, gas, water and debris waste) showed up that the total amount of waste was 13.599,40 $KgCO_2$/year as it is shown on the next table.

Resources	Consume (KgCO2-equiv/year)
Electricity	1.962,80
Gas	11.636,50
Water	352,25
Debris waste	$1{,}075\text{x}10^{-04}$
TOTAL	**13.951,55**

Table 3. Waste ($KgCO_2$) of the different resources taken in the Use stage of the building.

Since the construction and the demolition process are just done once, the data obtained should work. It's not the same in the case of Use stage.

Until now we have calculated the total waste per year, of the whole building. Now, we will suppose a lifetime of the building of 100 years, so the total results have to be multiplied by the number of ages the users will be using the facilities of the building.

13.951,55 x 100 = **1.395.155,011** $KgCO_2$-equiv.

In addition to this, we will add the amount of waste made by the maintenance part of the building. Done now, for this data is already calculated for the whole lifetime of the building, and there is no need to multiply it.

1.395.155,011 + 74.175,36 = **1.469.330,371** $KgCO_2$-equiv.

3. Demolition

We found out the estimated amount of waste generated on the demolition process is **27.542,87231** KgCO_2-equiv.

Discussion

Now that all the data is collected, we can estimate that the total amount of waste on our building example is **1.638.095,11** KgCO_2-equiv.

Now, in order to compare the three stages, we will calculate the percentage that each process represents.

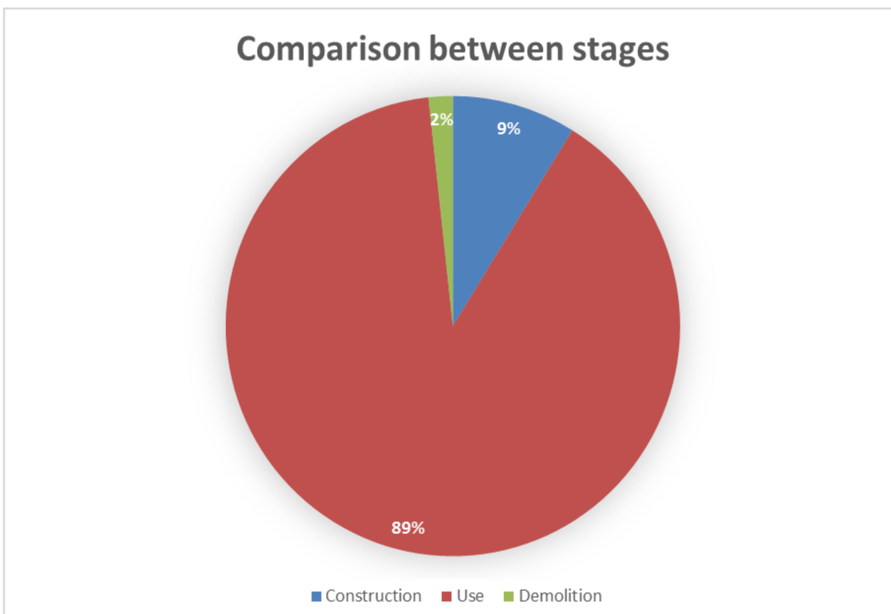


Figure 15. The chart above shows the comparison and percentages of the different stages of the building.

As we can see, the construction phase represents the 9%, the use phase the 89% and the demolition 2%. So, our first prediction was right. The construction and demolition phase's percentage either is negligible or settled in 10%. Is in the Use stage the one that has more impact, and the one we can decrease the most, by improving the efficiency of our buildings.

And, for the buildings that are already built, we can improve their behavior respect the environment by changing its elements, for more sustainable ones. For example the installation of LED's, the reduction of the "ghost consume" or "passive consume", or changing home appliances with a high electricity consume, such as the fridge, washing machine, dryer and dishwasher, for new versions of it with an A+ label.

It is at this point we should compare our results with the previous articles that encouraged us to do this study in the beginning. Reading through literature [11, 12, 13], all this works show that the amount of energy in construction and demolition phases is around the 10% and we should focus on the Use stage, and improve its efficiency, for it's the one with the biggest percentage. After doing the calculations, we can see how the results matches with these articles.

Conclusion

Finally, analyzing the main impacts that the construction sector presents at a global level, it is feasible to propose a series of actions (both short and medium-long term) that would improve the sustainability of the sector and which can be summarized as:

Short-term measures:

1. Reduction of the residues derived from the processes of manufacture of materials and constructive processes. Measure that can be incentivized by increasing rates and taxes of discharges.
2. Increase in the amount of recycled or reused material.
3. **Improve the energy efficiency of buildings.**
4. Rationalize the consumption of water in buildings.
5. Increase the useful life of structures.

Medium-long-term measures:

1. Reorientation of policies affecting the sector, including financial policies.

2. Promotion of environmental responsibility at corporate and social level through the use of information mechanisms for users.
3. Innovation with regard to materials manufacturing technologies, construction processes, etc.

Bibliography

[1] CIB y CSIR, Agenda 21 for sustainable construction in developing countries: a discussion document. Pretoria: 2002.

[2] UNEP, «Sustainable Building and Construction. Facts and figures», Industry and Environment, vol. 26, pp. 5 –8, 2003.

[3] Departamento de Planificación. Ministerio de Industria, Turismo y Comercio, «Informe Anual de Consumos Energéticos», 2010.

[4] M. Erlandsson, «Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs», Building and Environment, vol. 38, n.7, pp. 919–938, jul. 2003.

[5] A. Forsberg y F. von Malmborg, «Tools for environmental assessment of the built environment», Building and Environment, vol. 39, n. 2, pp.223–228, feb. 2004.

[6]Peso de los elementos constructivos. www.miliarium.com/Prontuario/Tablas/NormasMV/Tabla_2-5.asp

[7] Euroimportadora «Peso de los materiales». 2013. www.euroimportadora.com.mx/SYS_user/tips_tecnicos/es/Peso_Especifico_de_Materiales.pdf

[8] Ulma Architectural Solutions . «Catálogo de fachadas ventiladas». www.ulmaarchitectural.com/es/fachadas-ventiladas/descargas/dossier-fachadas-ventiladas-ulma.pdf.

[9] Instituto Nacional de Estadistica. «Estadísticas sobre la recogida y tratamiento de residuos», 2014.

[10] ISO, ISO 14040. Environmental Management—Life Cycle Assessment—Principles and Framework. International Organization for Standardization (1997)

[11] T. Ramesh, Ravi Prakash, K.K. Shukla. «Life cycle analysis of buildings: An overview», 2010.

[12] I. Sartori, A.G Hestnes «Energy use in the life cycle of conventional and low-energy buildings: A review article», 2006.

[13] Aashish Sharmaa, Abhishek Saxenab, Muneesh Sethic, Venu Shreed, Varun «Life Cycle Assesment: A review», 2010.

[14] L. Barnthouse et al. (1998), Life cycle impact assessment: the state-of-the-art. SETAC Press, Pensacola.

[15] M. Z. Hauschild et al. (2013), Identifying best existing practice for characterization modelling in life cycle impact assessment, Int J Life Cycle Assess 18 (3), pp 683–697

[16] EN 15978. Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method, 2012.

Annex

endesa

llum

Endesa Energia XXI S.L.U.
Cif: B82846825
C/ Ribera del Loira 60. 28042 Madrid

DADES DE LA FACTURA

IMPORT FACTURA: 79,42 €
Núm. factura: SM6601N0280129
Referència: 040029125824/0258
Període de consum: 01/02/2016 a 18/03/2016
Data de càrrec: 29 de març de 2016

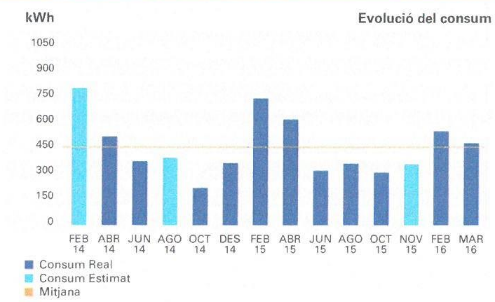
FACTURA RESUM

Per potència contractada	17,44 €
Per energia consumida	44,24 €
Impost electricitat	3,15 €
Lloguer equips de mesura i control	0,81 €
IVA NORMAL (21%)	13,78 €
TOTAL IMPORT FACTURA	**79,42 €**

INFORMACIÓ DEL CONSUM ELÈCTRIC

	Consum en el Període pla De 0h a 24h
Lectura anterior (real) (01-Febrer-2016)	67.836 kWh
Lectura actual (real) (18-Març-2016)	68.318 kWh
Consum en el període (*)	482 kWh

(*) Per confirmar que el consum està ben facturat, introdueixi les dades de consum del període, dades de lectura i potència contractada (marcats en color), a l'eina publicada a la pàgina web de la Comissió Nacional dels Mercats i Competència www.cnmc.es.



El consum mitjà diari del període facturat ha estat de 1,73 €
El consum mitjà diari els últims 14 mesos ha estat de 1,11 €
El consum acumulat l'últim any ha estat de 3.003 kWh

DADES DEL CONTRACTE

Adreça de subministrament: LONDRES 19 ENTL-2 BARCELONA, , BARCELONA
TIPUS DE CONTRACTE: **PVPC sense discriminació horària.**
TIPUS DE COMPTADOR: **Sense comptador intel·ligent integrat efectivament en el sistema de telegestió.**
Facturació amb perfil mitjà del període de facturació.

Peatge d'accés: 2.0A
Número de comptador: 003406360
Potència contractada: 3,30 kW
Referència del contracte de subministrament (EEXXI): 040029125824
Referència del contracte d'accés (ENDESA DISTRIBUCION ELECTRICA): 000478515630
Data fi de contracte: 04 d'octubre de 2016
(renovació anual automàtica)
Codi unificat de punt de subministrament CUPS:
ES0031405445838008JK0F

- **Atenció al client (EEXXI):** 800760333 (gratuït) www.endesaclientes.com
- **Avaries i urgències (ENDESA DISTRIBUCION ELECTRICA):** 800760706 (gratuït)
- **Reclamacions (EEXXI):** 800760333 (atencionalcliente@endesaonline.com)
- **Adreça postal reclamacions (EEXXI):** C/Ribera del Loira 60 28042 Madrid

Si no està d'acord amb la nostra resposta a la seva reclamació, pot reclamar a l'organisme administratiu competent: INFORMI-SE'N AL 012 (Telèfon d'Atenció Ciutadana).

Forma de pagament: Domiciliat
Entitat: 2100 **Sucursal:** 822 DC: 94 **Compte Corrent:** 01003***** **IBAN:** ES08210008229401003*****
El seu pagament es justifica amb el corresponent apunt bancari

Gas Natural S.U.R. SDG, S.A.
Data d'emissió: 19.05.2016
Núm. factura: FE16371081095574

393/2389

Aquesta factura serà carregada en compte seguint el mandat 000039968292

Són correctes les vostres dades personals?
Podeu actualitzar-les *online* a la vostra Àrea Privada del web entrant a **www.gasnaturalfenosa.cat/lesmevesdades**

Total a pagar **48,44 €**

gas natural TUR.1 Contracte: 81413004
Del 03.03.2016 al 03.05.2016 (62 dies = 2,038356 mesos)

Consum gas			
Període de 03.03.2016 a 31.03.2016	258 kWh	0,049393 €/kWh	12,74 €
Període de 01.04.2016 a 03.05.2016	306 kWh	0,047624 €/kWh	14,57 €
Impost Especial sobre hidrocarburs	564 kWh	0,00234 €/kWh	1,32 €
Terme fix	62 dies	0,142685 €/dia	8,85 €
Altres conceptes gas			
Lloguer de comptador	62 dies	0,041096 €/dia	2,55 €
Total gas natural			**40,03 €**
Base imposable			40,03 €
IVA 21%			8,41 €
Total factura			**48,44 €**

Canals per contactar amb Gas Natural Fenosa

24 hores / 365 dies l'any
Web — www.gasnaturalfenosa.cat
Lectura del comptador — 900 234 000
www.gasnaturalfenosa.cat/lectures
Urgències de gas — 900 750 750

De dilluns a dissabte, de 8 a 22 hores
Reclamacions i incidències — 900 100 502
serviciatencioncliente@gasnaturalfenosa.com
Plaça del Gas, 1. 08003 Barcelona
Gas Natural Fenosa Clientes España
@GNFclientes_es

Si voleu una atenció més personalitzada podeu anar a algun dels centres que Gas Natural Fenosa té al vostre servei. Trobeu el més proper a www.gasnaturalfenosa.cat/centres.

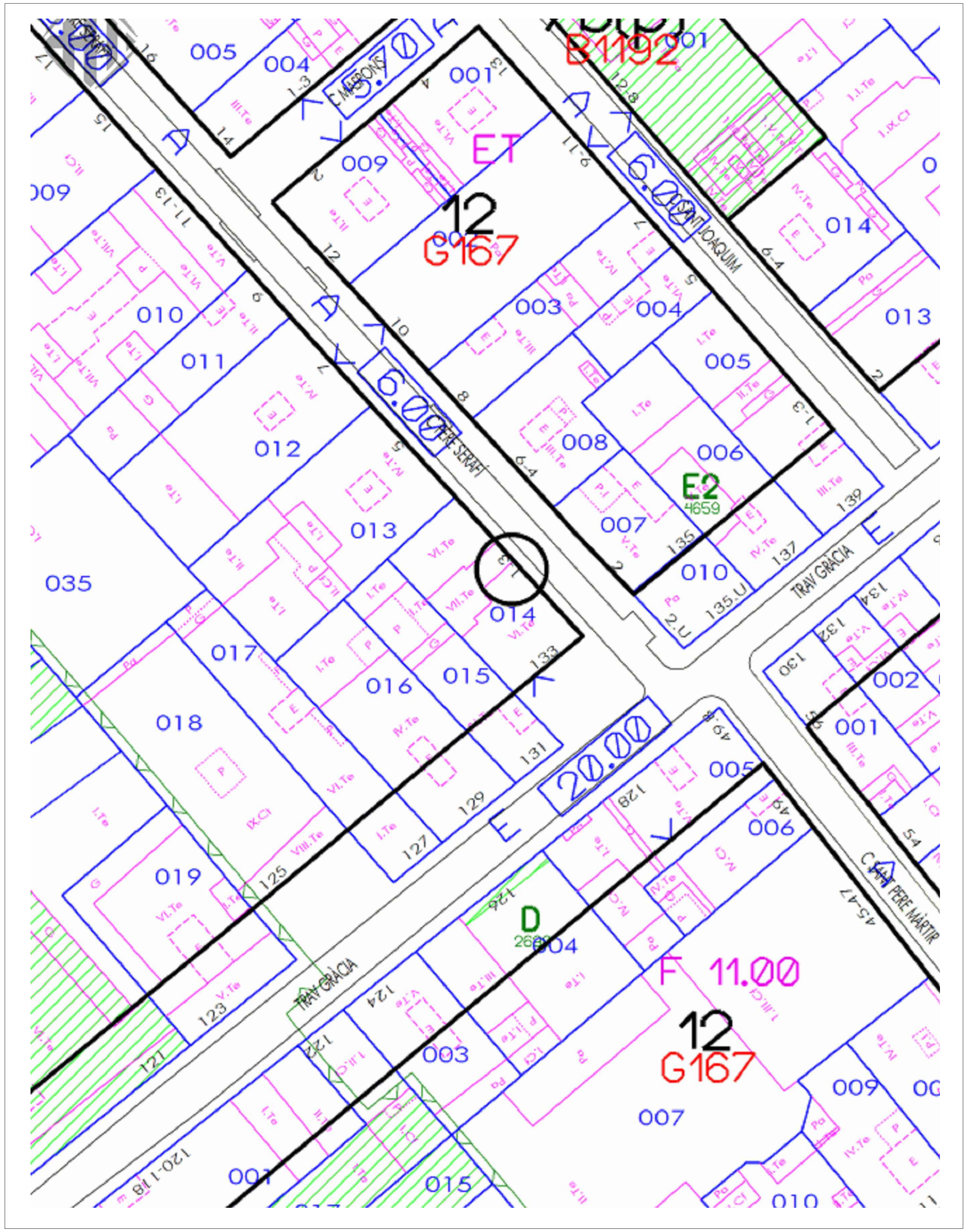
AENOR Seguridad y Salud Laboral OHSAS 18001 SST-0007/2012
AENOR Empresa Registrada ISO 9001 ER-0899/2011
AENOR Gestión Ambiental ISO 14001 GA-2011/0302

@facturaonline Doneu-vos d'alta gratis a **areaprivada.gasnaturalfenosa.es/lamevafactura**

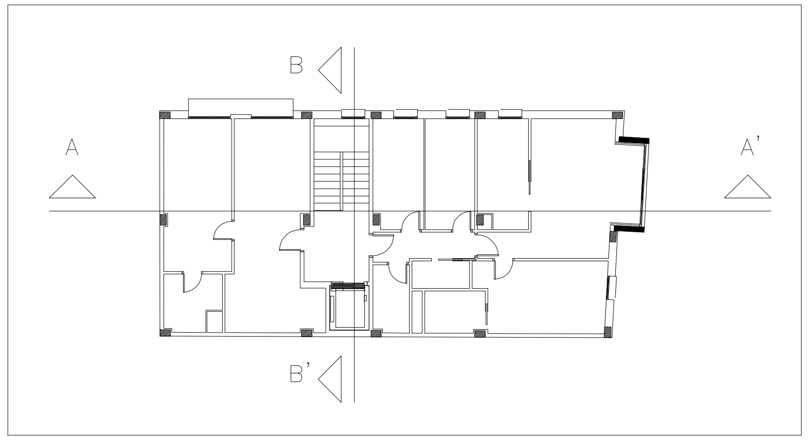
SP37Z1

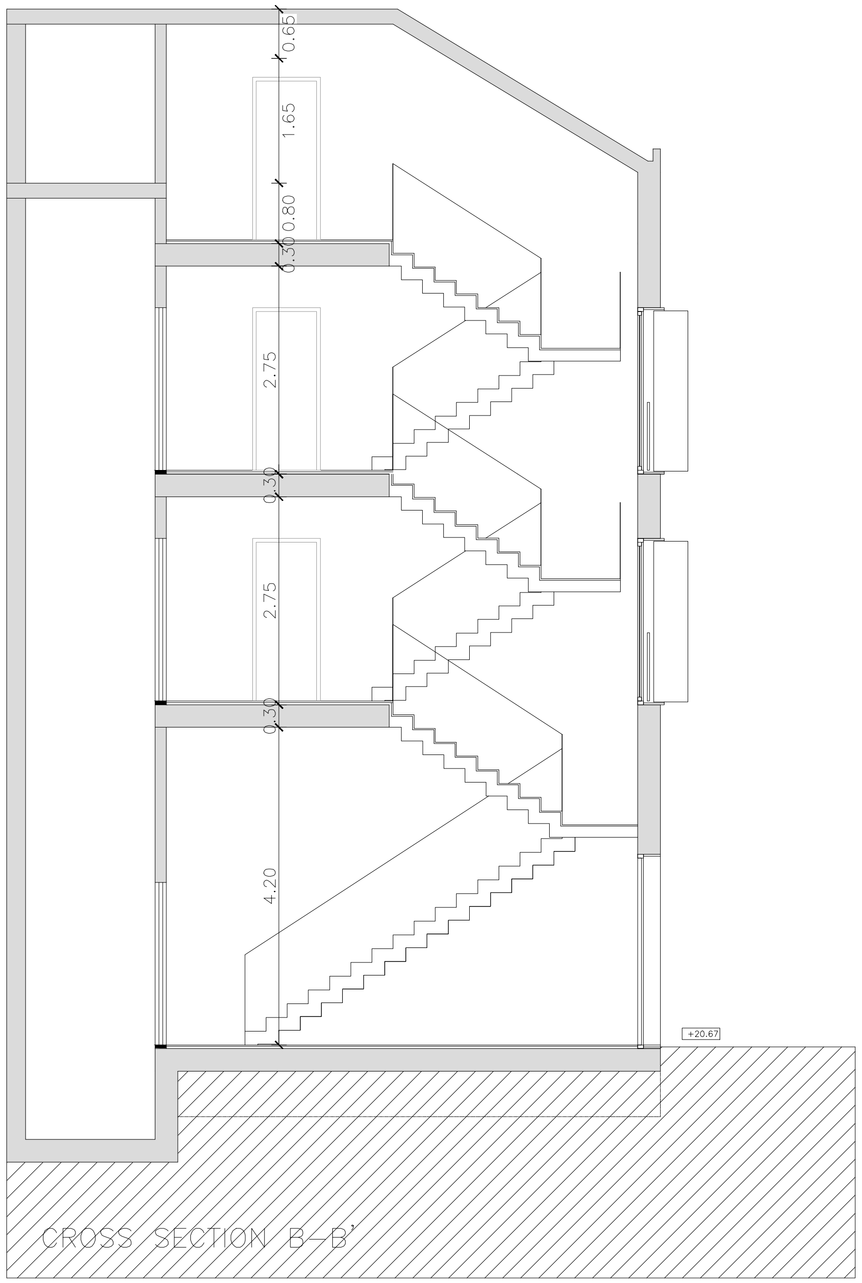
Life Cycle Inventory

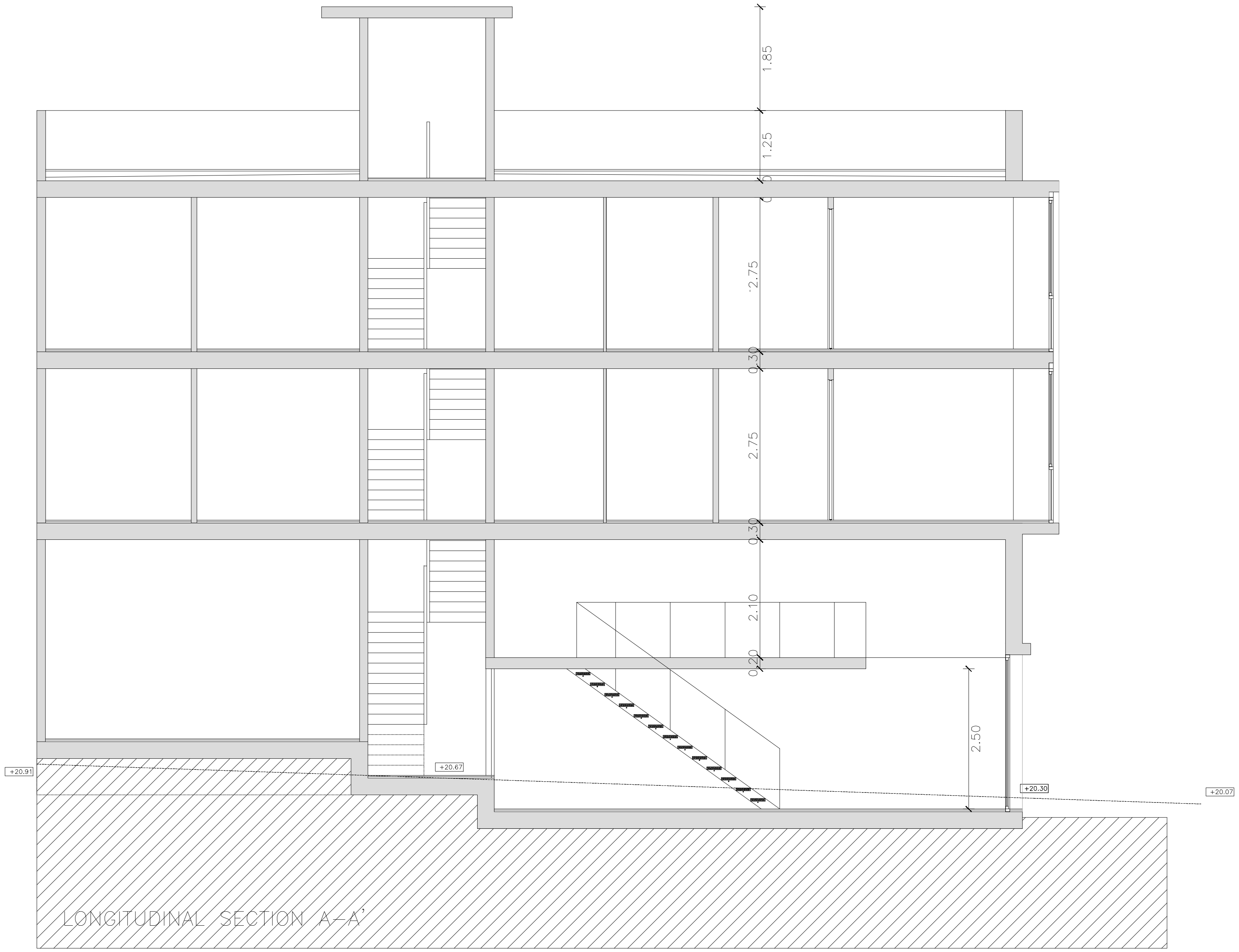
Material	Units	Measurement	Global Warming Potential [kg CO2-Equiv.]	Abiotic depletion (ADP elements) [kg Sb-Equiv.]	Abiotic depletion (ADP fossil) [MJ]	Acidification Potential (AP) [kg SO2-Equiv.]	Eutrophication Potential (EP) [kg Phosphate-Equiv.]	Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
Foundations									
Concrete C20/25	m^3	15,00	4.000,2860236	0,0036119	18,6950187	6,5935392	1,1601091	0,0001321	0,7968766
Reinforcing steel B500S	kg	1.050,00	1.526,4244743	0,0016162	39,3937806	5,5121405	1,2403395	0,0000636	1,2314752
Plastic film, extrusion	kg	0,31	0,1331377	0,0000002	0,0048696	0,0006532	0,0000577	0,0000000	0,0000514
Structure									
Concrete C20/25, for pilars	m^3	18,90	5.040,3603898	0,0045510	23,5557236	8,3078594	1,4617375	0,0001665	1,0040645
Reinforcing steel B500S for pilars	kg	1.512,00	2.198,0512430	0,0023274	56,7270440	7,9374823	1,7860888	0,0000915	1,7733243
Concrete C20/25 for slabs	m^3	86,18	22.982,9766344	0,0207518	107,4091142	37,8820805	6,6652137	0,0007591	4,5783218
Reinforcing steel B500S for slabs	kg	7.440,00	10.815,8077038	0,0114521	279,1330737	39,0574525	8,7886910	0,0004504	8,7258815
Concrete block for slabs	kg	9.151,20	1.132,8136939	0,0062059	7,4948848	2,2592131	0,4095971	0,0000408	0,2828493
Roof									
Concrete C20/25 roof inclination	m^3	7,75	2.066,8144455	0,0018662	9,6590930	3,4066619	0,5993897	0,0000683	0,4117196
Thermal isolation. Polystyrene, extruded (XPS)	m^2	155,00	1.569,7960301	0,0007924	9,4948182	2,3892845	0,2063641	0,0281227	0,4351618
Brick, at plant	kg	310,00	68,0571721	0,0000868	0,7145774	0,1783905	0,0248411	0,0000055	0,0316644
Encolusures and coverings									
Polycarbonate, covering facade	kg	3.497,90	27.137,0815162	0,0500805	270,6154414	87,3796029	8,7142766	0,0000026	11,2060605
Thermal isolation. Polystyrene, extruded (XPS)	m^2	478,80	4.849,1505756	0,0024478	29,3297996	7,3805770	0,6374654	0,0868720	1,3442288
Brick, indoor walls (9cm)	kg	2.726,46	598,5650241	0,0007633	6,2847314	1,5689502	0,2184784	0,0000486	0,2784893
Brick, outdoor walls (15cm)	kg	82.040,00	18.011,0012893	0,0229687	189,1094558	47,2101821	6,5740814	0,0014622	8,3798259
Carpentry									
Door, inner, wood, at plant	m^2	21,84	-829,7002913	0,0036336	19,2189752	3,8146885	0,8521574	0,0000713	0,6387912
Door, outer, wood-aluminium, at plant	m^2	3,36	168,2120103	0,0038063	5,6623218	1,9676931	0,3138007	0,0000202	0,1930598
Window frame, aluminium, U=1.6 W/m2K, at plant	m^2	3,85	1.865,8391349	0,0054683	34,4972720	8,2200027	1,0578721	0,0001366	0,9079209
Glazing, double (2-IV), U<1.1 W/m2K, laminated safety glass, at	m^2	77,15	2.577,5653808	0,0165134	62,4213650	23,3058268	2,2795606	0,0002642	1,6440258
Facilities									
Propylene, pipeline system	kg	90,09	143,2776188	0,0000018	3,3579849	0,3025912	0,0299659	0,0000000	0,0995628
Wire drawing, copper	kg	91,00	197,8094234	0,0041874	7,3470087	1,3685675	0,0789045	0,0000111	0,1066600
Copper concentrate, at beneficiation	kg	91,00	19,3963884	0,0419193	0,4959249	0,3798621	0,0911476	0,0000012	0,0448542
Others									
Electricity, high voltage, at grid	MJ	23.250,00	3.273,0833300	0,0025487	241,8822489	112,2129966	6,5129664	0,0006999	5,7880301
Excavation, hydraulic digger	m3	61,50	32,5121537	0,0000735	0,3177553	0,2461892	0,0633770	0,0000040	0,0368273
Building machine	ut	1,00	27.529,2772485	0,7467537	665,1633237	90,0839777	15,3776543	0,0019119	15,1887314
Disposal, inert waste, 5% water, to inert material landfill	m3	156.825,00	1.110,5685954	0,0023188	17,9192474	6,6170850	1,6740520	0,0003336	1,3492998
Transport, municipal waste collection, lorry 21t	m3	3.136,50	3.136,5000000	0,0024644	34,2921702	18,0959559	4,6801844	0,0006150	6,2958457
TOTAL			**141.221,6603465**	**0,9592114**	**2.140,1970240**	**523,6795061**	**71,4983744**	**0,1223548**	**72,7736041**



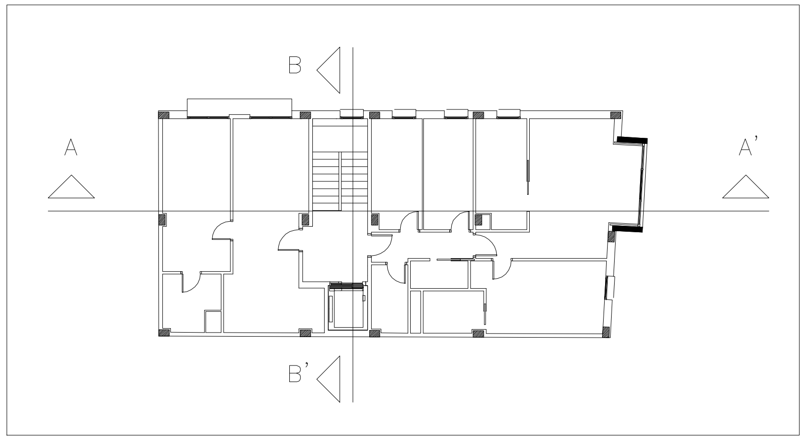
Project: LCA of a residential building	Date: 20 of December, 2016	Student: Pérez, Xavier	Teacher: Struhala, Karel	Plane: Location and emplacement	Scale: 1/1000 1/500	Plane n°: 01	BRNO UNIVERSITY OF TECHNOLOGY

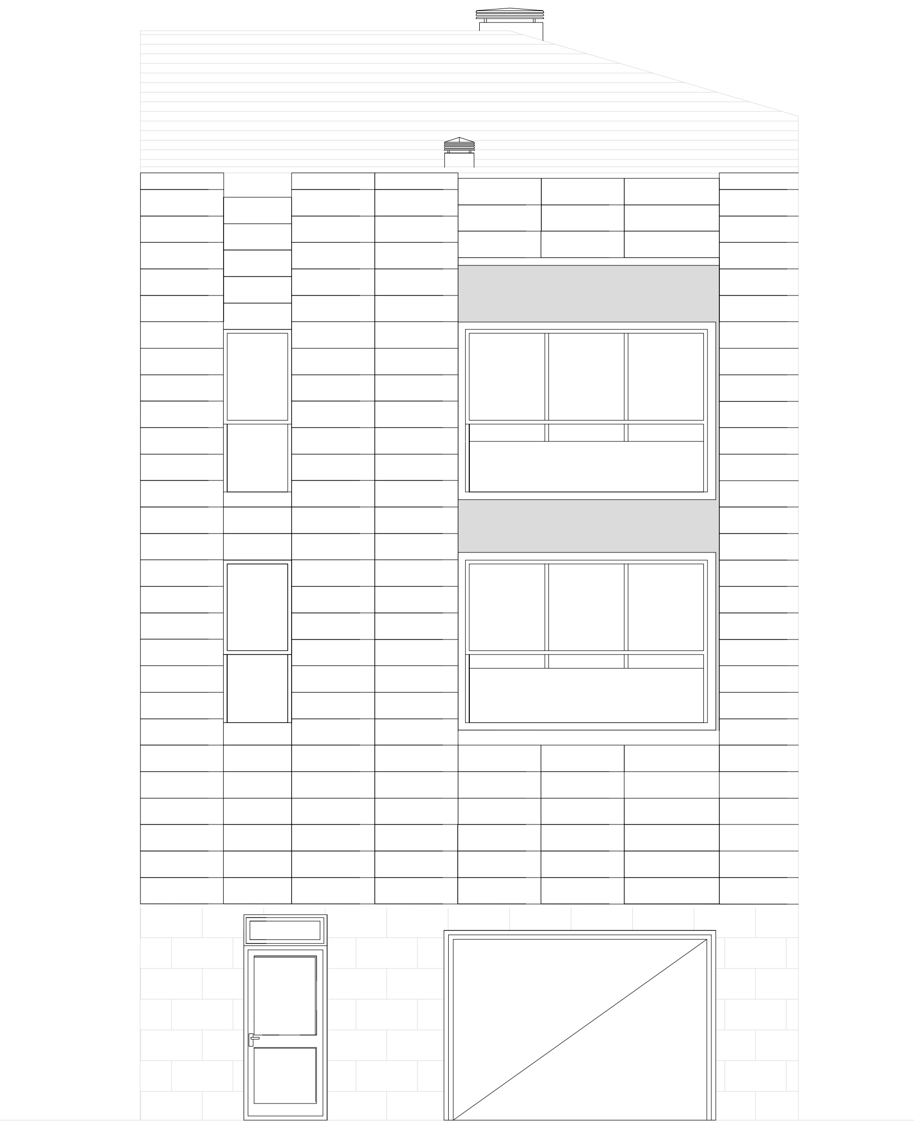


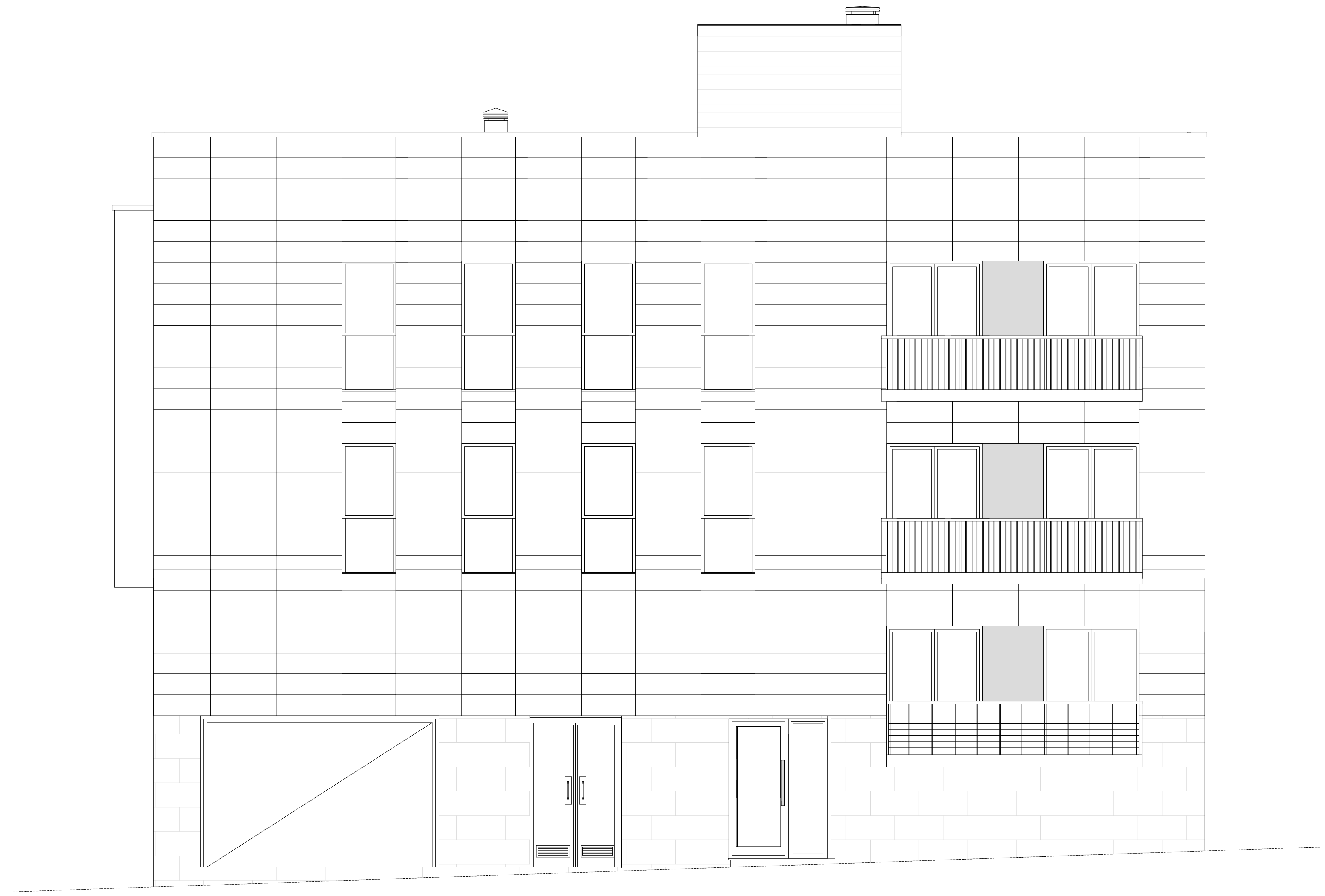




Project:	Date:	Student:	Teacher:	Plane:	Scale:		Plane	
LCA of a residential building	20 of December, 2016	Pérez, Xavier	Struhala, Karel	Cross and Longitudinal sections	1/100		n°: 02	BRNO UNIVERSITY OF TECHNOLOGY

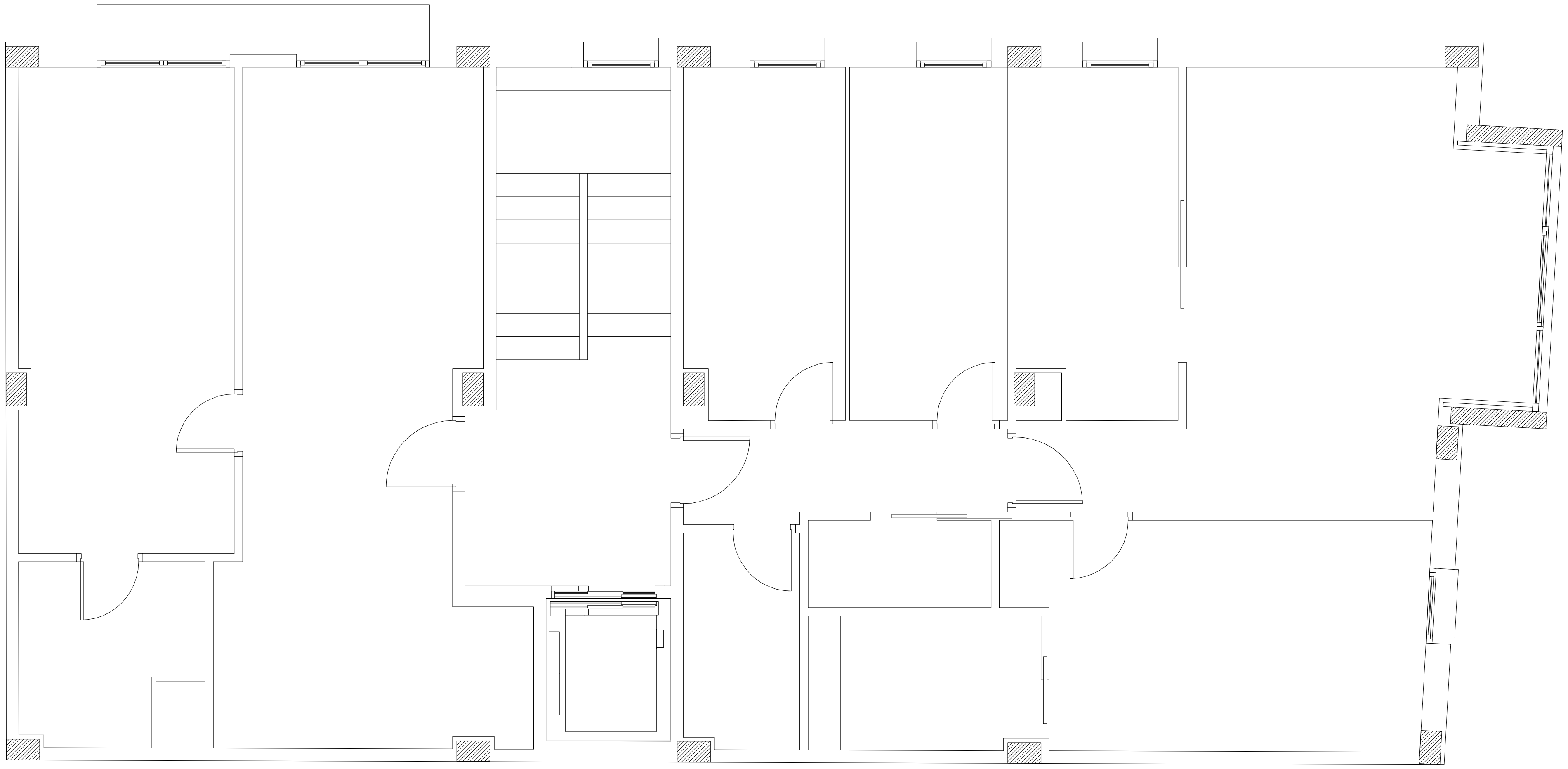


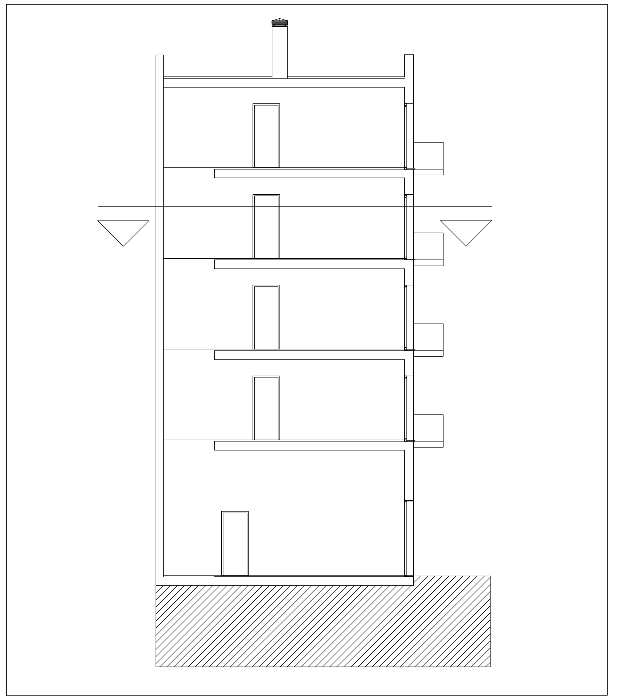




Project:	Date:	Student:	Teacher:	Plane:	Scale:		Plane
LCA of a residential building	20 of December, 2016	Pérez, Xavier	Struhala, Karel	East and South East facades	1/100		n°: 03

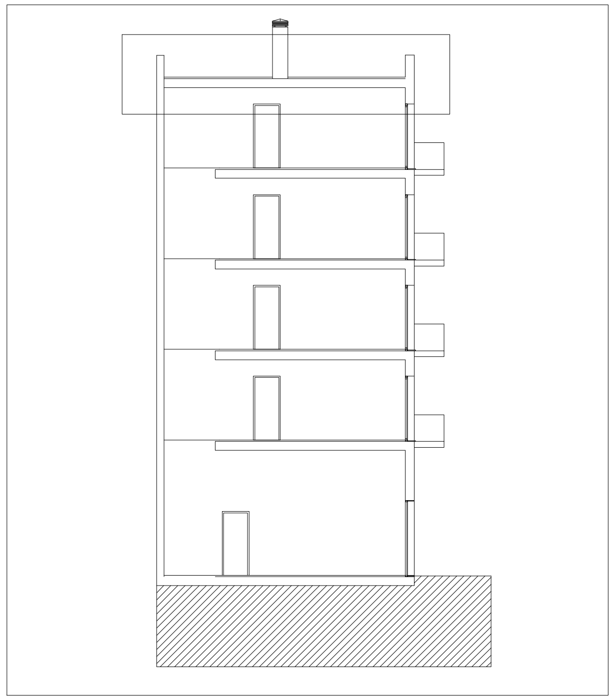
BRNO UNIVERSITY OF TECHNOLOGY

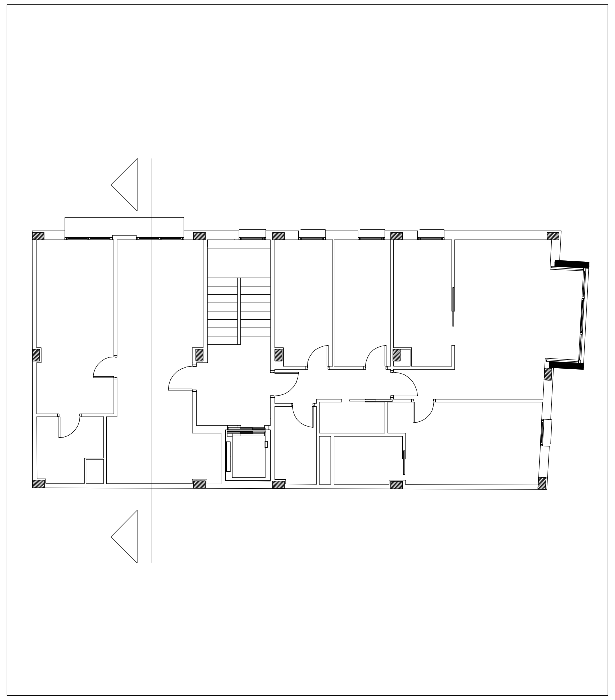


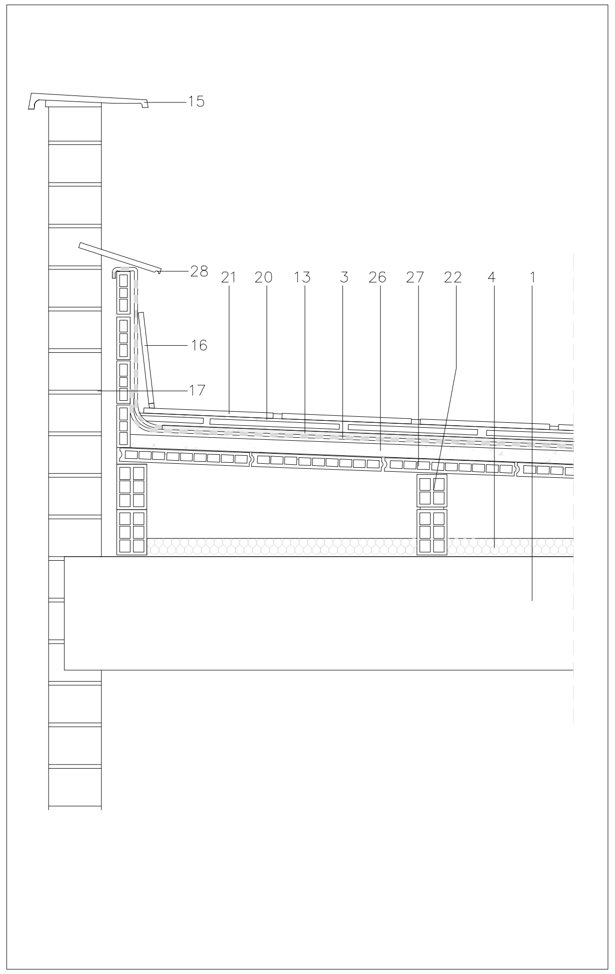


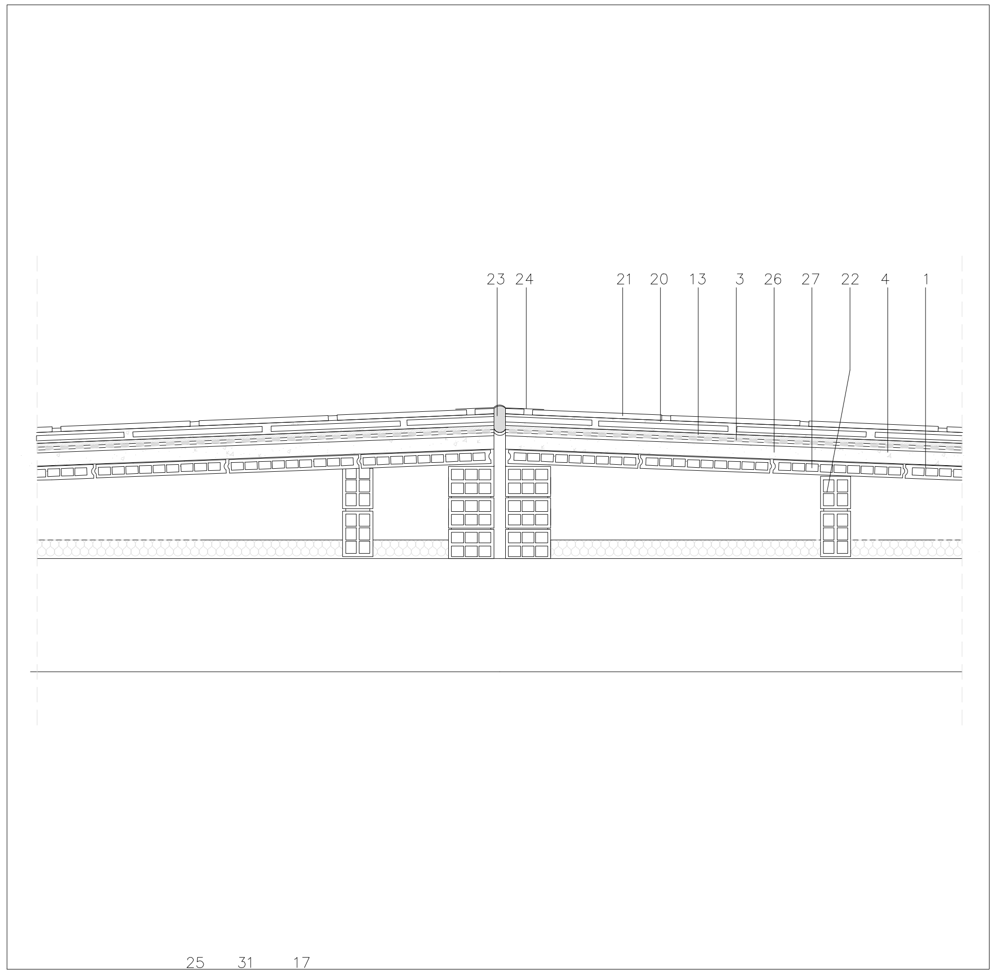
Project: LCA of a residential building	Date: 20 of December, 2016	Student: Pérez, Xavier	Teacher: Struhala, Karel	Plane: Plant view	Scale: 1/75	Plane n°:04

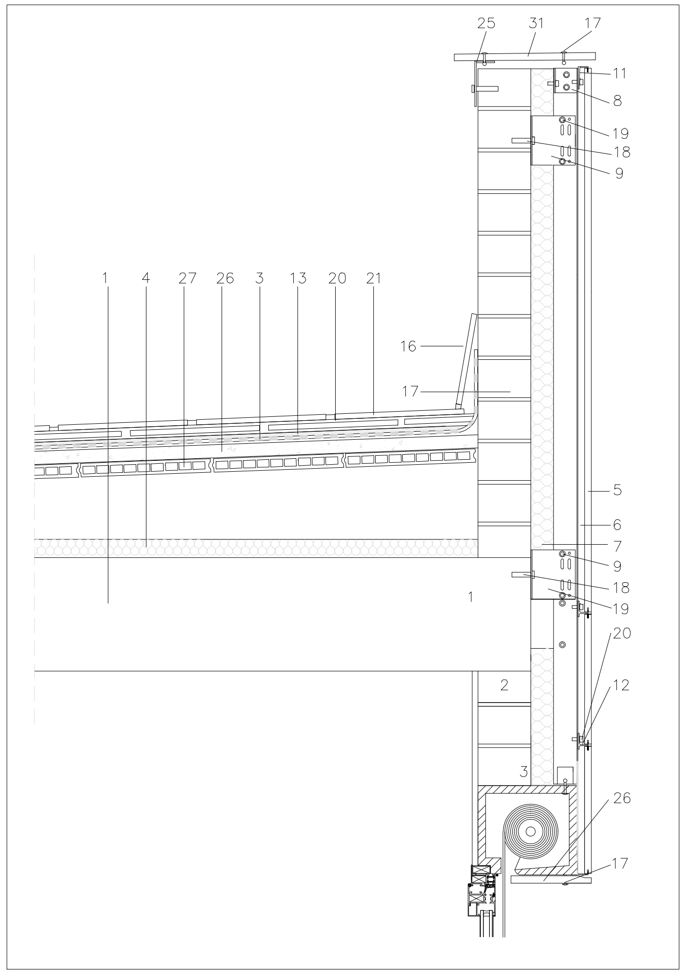
BRNO UNIVERSITY OF TECHNOLOGY









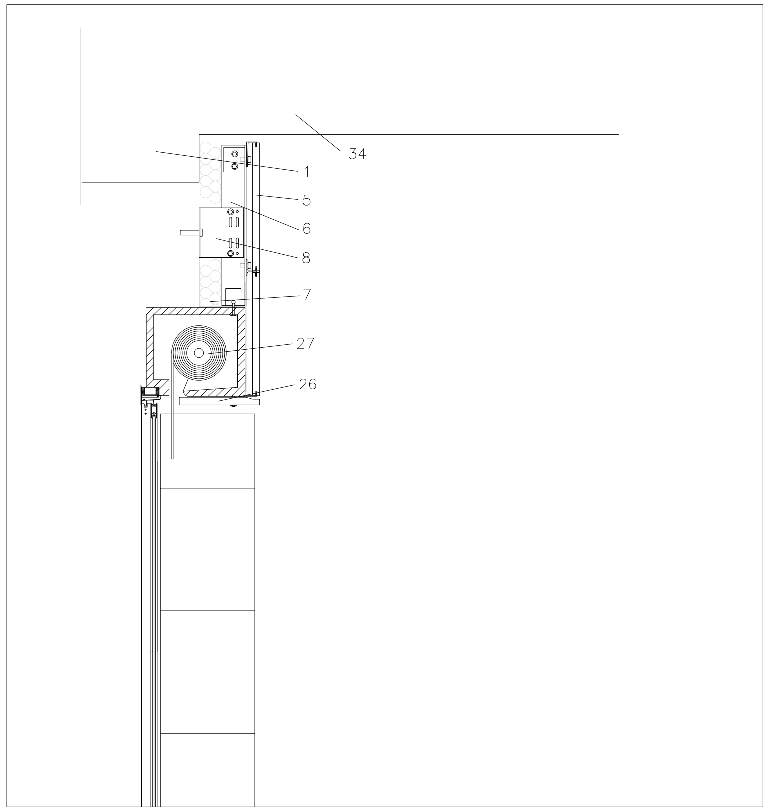


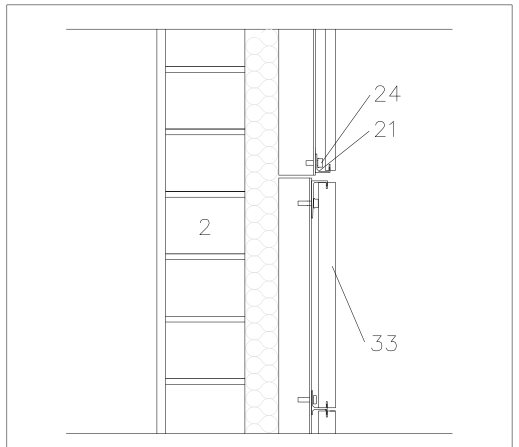
Covers

1. Forged reinforced concrete e = 30 cm.
2. Formation of slopes with mortar.
3. EPDM waterproofing sheet.
4. Thermal insulation panels made of wool, e = 5 cm.
5. Layer microventilació.
6. Rake / wood strip to receive ceramic tiles; fixing mechanical rake with the bar and tile.
7. Arabic tile roof 15x20x40 cm.
8. Tile Arabic channel 15x20x40 cm.
9. Strengthening comeback EPDM waterproofing sheet of 20 cm above the parapet and making mortar.
10. Part of galvanized mechanically fixed to the wall construction.
11. Formation of outstanding lightweight concrete, variable thickness, maintaining a uniform slope of 2.5%.
12. Layer M5 cement mortar, e = 1 cm.
13. Geotextile. Separating layer of polypropylene with 25% glass fiber, e = 1 cm.
14. layer of gravel aggregate traffic, e = 15 cm.
15. Piece of pottery auction to empits facades.
16. Mimbell ceramic tile 28x14x1 cm.
17. solid brick of 29x14x5 cm.
18. Material "stuffing" of mastic in el·làstic expansion joint.
19. Double hollow brick.
20. Mortar bonding.
21. Rasilla double.
22. pottery pieces for support and training slopes.
23. Sheet metal crown.
24. Foil to protect the joint.
25. Bonera.
26. Layer Compression mortar.
27. Solera machihembradas plates.
28. washes polymer concrete.
29. Plastic Gutter for rainwater collection to mechanically fixed wrought.
30. Layer E = 15cm topsoil.
31. Piece galvanized steel 25 cm finish in transition several terraces, anchored, anchored mechanically on brick parapet double drilling.
32. drainage layer, Floradain FD-25E.
33. Filter 21 Drainage TGV.
34. Cover drainage layer and filter draining.
35. Insulation EPDM in sifònica cassoulet.
36. Part of galvanized mechanically fixed to the wall construction..

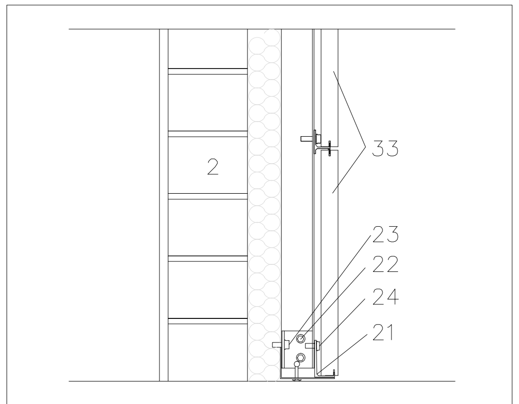
Project:	Date:	Student:	Teacher:	Plane:	Scale:	Plane
LCA of a residential building	20 of December, 2016	Pérez, Xavier	Struhala, Karel	Covering sections	1/20	n°: 05

BRNO UNIVERSITY OF TECHNOLOGY

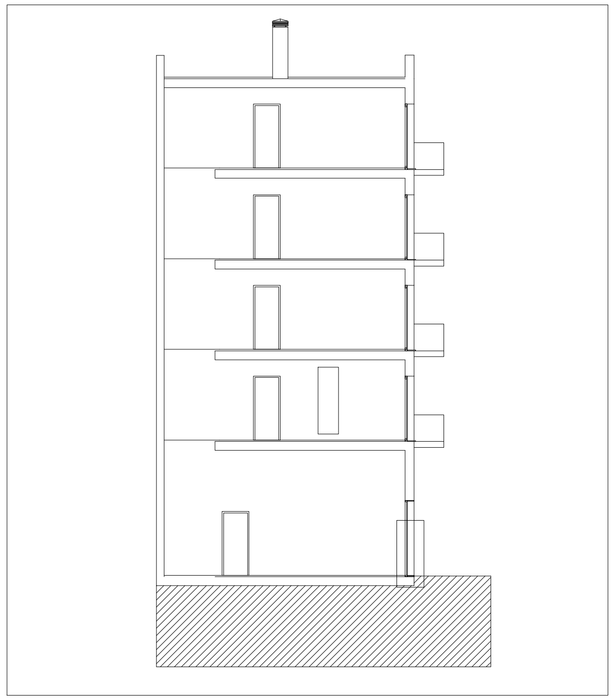


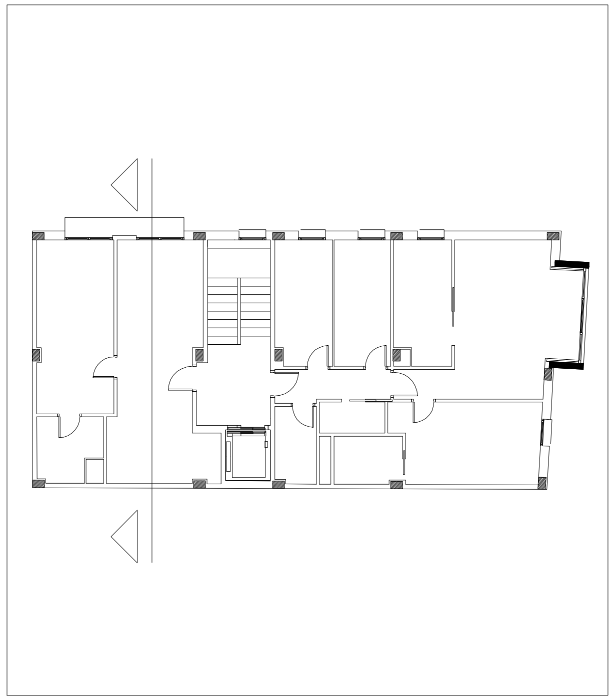


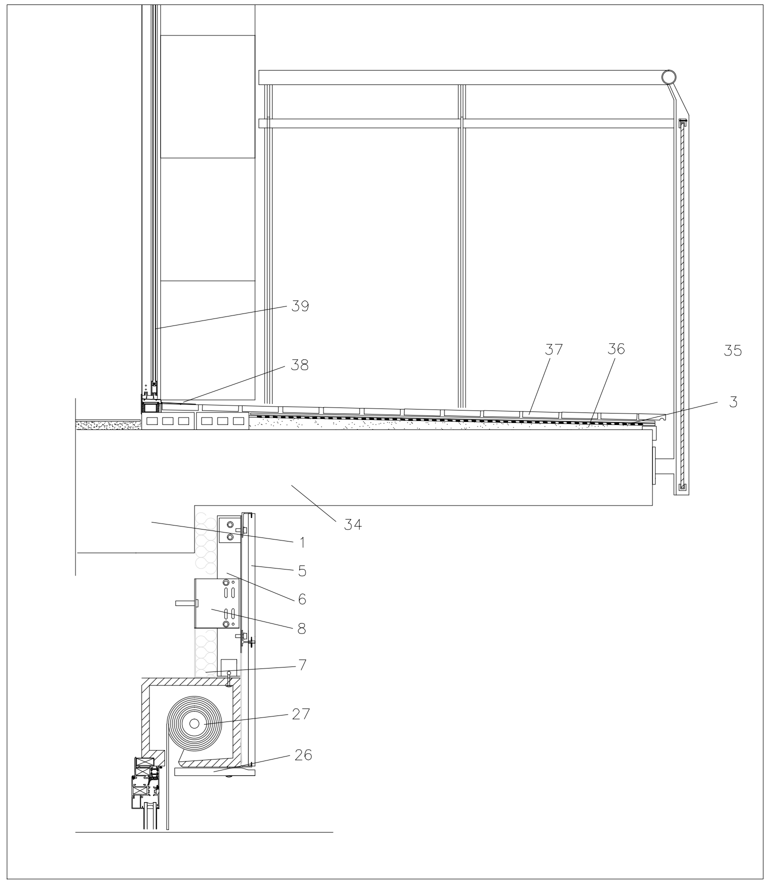
FACADE SECTION

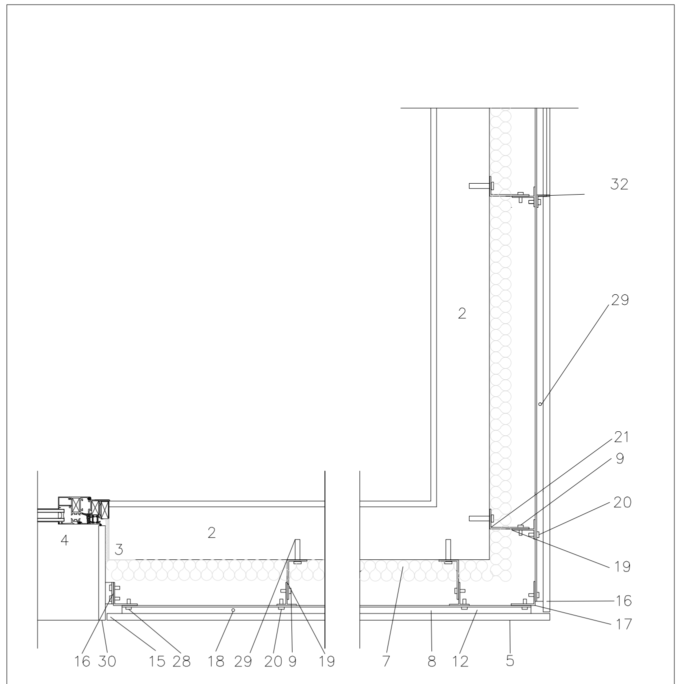


MEETING FLOOR SECTION



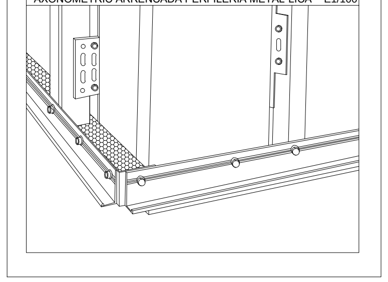




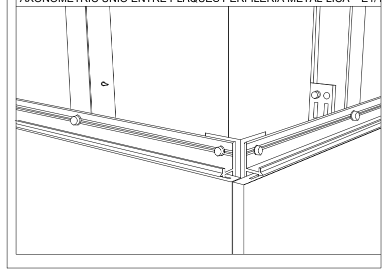


PLANTA FACHADA VENTILADA

AXONOMÈTRIC ARRENCADA PERFILERIA METÀL·LICA E1/100



AXONOMÈTRIC UNIÓ ENTRE PLAQUES PERFILERIA METÀL·LICA E1/1



Facades

1. Forged reinforced concrete e = 30 cm.
2. solid brick of 29x14x5 cm.
3. EPDM waterproofing sheet.
4. Double blade tilt window with aluminum frame.
5. plate polymer concrete facade, e = 2 cm.
6. Mounting vertical.
7. Thermal insulation panels made of wool, e = 6 cm.
8. anchor for binding profile boot invested amount.
9. self-tapping screw anchor binding riding.
10 self-tapping screw anchor binding profile to boot reversed.
11. Profile invested boot.
12. Profile continuous guide.
13. washes polymer concrete.
14. Adhesive el·àstic to the breakwater.
15. Adhesive el·àstic the corner plate on the profile guide.
16. Angular the meeting corner.
17. Rivet.
18. Taco fixing forged a close basis.
19. Anchorage and forged a close basis.
20 self-tapping screw binding profile mounting guide.
21. Profile boot.
22. Anchorage by the union of angular mounting support.
23. union of self-tapping screw support angular anchor.
24 self-tapping screw anchor binding profile to boot.
25. Angular support.
26. polymer concrete lintels.
27. Safety shutter.
28. union of self-tapping screw angular profile corner guide.
29. hole of water evacuation.
30. Tooth polymer concrete.
31. Knight of polymer concrete.
32. Piece lock.
33. plate polymer concrete facade, e = 3 cm.
34. Forged reinforced concrete e = 20 cm.

Project:	Date:	Student:	Teacher:	Plane:	Scale:	Plane n°:	
LCA of a residential building	20 of December, 2016	Pérez, Xavier	Struhala, Karel	Facade details	1/20	06	BRNO UNIVERSITY OF TECHNOLOGY