ESCOLA TÈCNICA SUPERIOR
D'ENGINYERIA D'EDIFICACIÓ

UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

Practical use of Life Cycle Assessment for buildings

Degree: Technical Architecture.

Student: Mollá Muñoz, Clara María.

Academic Director PFG: Orozco Messana, Javier.

Modality: Technical_ Scientific.

July - 2013

1. TABLE OF CONTENTS

2. INTRODUCTION

Nowadays the concern for the environment has grown considerably, since the impact caused by the evolution of the human being is rising to unacceptable limits, for the planet's health as well as for the human's. The civilization has always advanced in a destructive way without taking into account the effects of its activity in the long term.

Thanks to the rising awareness of the human being, brand new philosophies had born. As for example, "Cradle to Cradle", founded by McDonough and Michael Braungart, which even came to be called "...the next Industrial Revolution". Its goal is to fix the mistakes of design of the Industrial Revolution of the XIX century, which is riddled with operation mistakes and errors unforeseen by then owing to the spontaneous nature of its evolution process, developing towards where the market needs dictated rather than towards sustainability. Due to that alternatives had to be considered to set the right course for such an unsustainable system, seeking ways to fix its multiple flaws. This particular philosophy encourages to mimic the nature, where there is no such thing as wastes, and everything has a beneficial purpose at any moment of its existence.

The ultimate goal pursued is to study the possibility of better adaptation of an environmentally friendly mentality for the current construction market. In order to be suitable for the market, as any product, the future buyer will have to find worthy the cost of opportunity, allowing it to compete with more traditional solutions.

So in order to enter an established market and be embraced by the sector it is directed to, a product has to be worthwhile for the consumer, involving him into environmental ideology, and having a well-cared ethics marketing approach.

The five pillars on which the sustainable architecture lies are: reducing the emissions and wastes generated, reducing energy consumption, optimising the materials and resources used, improving human health and general well-being, and finally reduce the maintenance and cost of the building.

The main advantage of the sustainable architecture is, without a doubt, an environment-friendly approach and the search for ways to reduce the environmental mark the industry leaves behind. Especially since we are already perceiving some of the direct effects on the nature as well as on the human health. Another important aspect of it is that once a precise analysis is performed, with a proper material selection, design and execution of the construction process, the outcome provides a building energy efficient enough for the consumer to notice the economization in energy and heat savings, as well as in air conditioning. Such a saving is capable of justifying the extra cost of the house in just a few years of active use. So throughout a minimum life expectancy of 50 years for buildings, the final result becomes as profitable for the user, as it is for the environment.

This project bears the purpose of executing a comparison of life cycles of a "standard house" and "energy efficient house" in order to achieve an acceptable balance between environmental and economic efficiency. Above everything this analysis focuses on choosing the most sustainable materials which work efficiently as a group and could get a significant reduction of use energy along the life of the house. With this comparison we expect to find a balance competitive enough to make a place for itself in the current market.

2.2. History of Life Cycle:

Environmental life cycle assessment (LCA) has developed fast over the last three decades. Whereas LCA developed from merely energy analysis to a comprehensive environmental burden analysis in the 1970s, full-fledged life cycle impact assessment and life cycle costing models were introduced in the 1980s and 1990s, and social-LCA and particularly consequential LCA gained ground in the first decade of the 21st century. Many of the more recent developments were initiated to broaden traditional environmental LCA to a more comprehensive Life Cycle Sustainability Analysis (LCSA).

It is possible to distinguish two main periods in the past of the LCA (1970-2000): the first period is from 1970 to 1990: Decades of conception. And the second period is from 1990 to 2000: Decade of Standardization.

In the first period: Decades of conception, the first studies to look at life cycle aspects of products and materials date from the late sixties and early seventies, and focused on issues such as energy efficiency, the consumption of raw materials and, to some extent, waste disposal. In 1969, for example, the Coca Cola Company funded a study to compare resource consumption and environmental releases associated with beverage containers. Initially, energy use was considered a higher priority than waste and outputs. Because of this, there was little distinction, at the time, between inventory development and the interpretation of total associated impacts.

The period 1970-1990 comprised the decades of conception of LCA with widely diverging approaches, terminologies, and results.

In the second period: Decade of Standardization. The 1990s saw a remarkable growth of scientific and coordination activities worldwide, which is reflected in the number of workshops and other forums that have been organized in this decade and in the number LCA guides and handbooks produced. Also the first scientific journal papers started to appear in the Journal of Cleaner Production, in Resources, Conservation and Recycling, in the International Journal of LCA, in Environmental Science & Technology, in the Journal of Industrial Ecology, and in other journals.

Through its North American and European branches, the Society of Environmental Toxicology and Chemistry (SETAC) started playing a leading and coordinating role in bringing LCA practitioners, users, and scientists together to collaborate on the continuous improvement and harmonization of LCA framework, terminology and methodology. The SETAC "Code of Practice" was one of the key results of this coordination process. Next to SETAC, the International Organization for Standardization (ISO) has been involved in LCA since 1994. Whereas SETAC working groups focused at development and harmonization of methods, ISO adopted the formal task of standardization of methods, and procedures. There are currently two international standards: *(Figure 1)*

Figure 1

-ISO 14040(2006): "Environmental management- Life cycle assessment- Principles and framework"

-ISO 14011 (2006): "Environmental management – Life cycle assessment – Requirements and guidelines"

The period of 1990-2000 can therefore be characterized as a period of convergence through SETAC's coordination and ISO's standardization activities, providing standardized framework and terminology, and platform for debate and harmonization of LCA methods. Note, however, that ISO never aimed to standardize LCA methods in detail: “there is no single method for conducting LCA”. [8]

The rapid surge of interest in “cradle to grave” assessments of materials and products through the late 1980s and early 1990s meant that by the 1992 UN Earth Summit there was a ground-swell of opinion that life-cycle assessment methodologies were among the most promising new tools for a wide range of environmental management tasks. The most comprehensive international survey of LCA activity to date, The LCA Sourcebook, was published in 1993.

Although the pace of development is slowing, the methodology is beginning to consolidate, moving the field toward a long-awaited maturity. Yet the usefulness of the technique to practitioners is still very much in debate. [10]

2.2. Definition:

Life cycle assessment (LCA, also known as life cycle analysis, ecobalance, and cradle to grave analysis) is a technique to assess environmental impacts associated with all the stages of a product’s life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

Previous applications of LCA for product evaluations have produced a fairly standard set of possible environmental effects for consideration. LCA generally incorporates indicators in three categories: consumption of scarce resources, ecosystem quality and damage to human health. The environmental impact assessment categories will be explained in point (*2.5.The environmental impacts categories.)*

This project describes the process of life cycle assessment, or LCA, as it is applied to building design and construction. LCA is a tool that allows architects and other professionals to understand the energy use and other environmental impacts associated with all life cycle phases of the building: procurement, construction, operation, and decommissioning.

Today, state building codes and the model codes on which they are based have adopted modest improvements in energy efficiency. Legislation on the energy efficiency of buildings has been proposed and debated in both US Senate and House of Representatives at the time of this report that will require more aggressive energy efficiency improvements. .

A significant number of new buildings' owners are choosing to follow elective green-building scorecard and branding schemes such as Energy-Star, "LEED", and Green Globes and highly progressive systems such as the Living Building Challenge. [1]

The LCA process is governed under ISO 14000, the series of international standards addressing environmental management. According to International Standard ISO 14040, LCA is a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle." [6]

2.3. Life cycle phases for buildings:

Pre- use phase:

"Pre-use" phase activities include raw materials extraction and processing, construction materials fabrication, transportation, and home construction. Major processes are elaborated here:

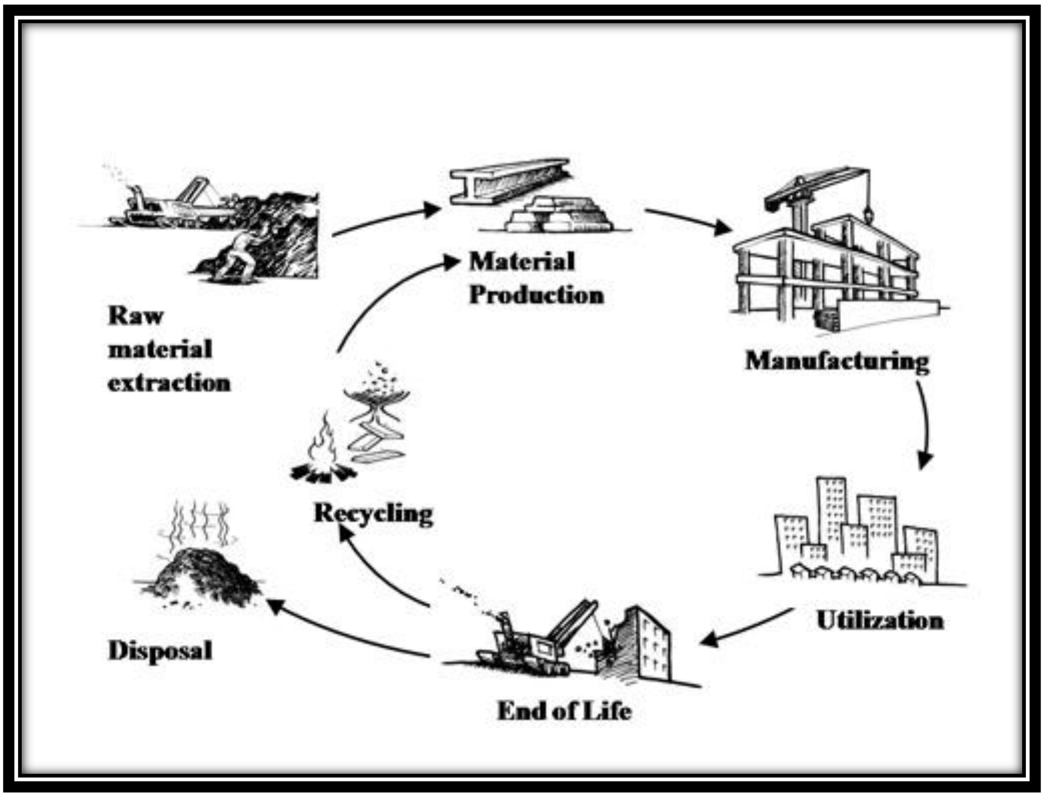
- Raw materials extraction includes processes such as mining, growing/harvesting, and drilling processes that yield iron ores, bauxite timber, and petroleum. Primary materials are then converted into engineered materials such as steel, aluminum, lumber, Polystyrene, and nylon through steelmaking, refining/smelting, milling, and refining/polymerization processes.
- These materials are then fabricated and assembled into building components (e.g., roof trusses, windows, and exterior siding), furnishings (e.g., nylon carpeting), and appliances.
- Construction of the home at the building site also includes site earthwork.
- Transportation of materials from raw materials extraction to part fabrication, and then to the construction site is inventoried as well.
  [2]

Use phase:

Activities were threefold: the supply of natural gas for home heating, the supply of electricity for air-conditioning and all appliances, and all activities related to home improvement and maintenance. The last activity includes the production and installation of maintenance and improvement components, such as shingles and carpeting. For consistency, the energy intensities (manufacturing) and GWP of all maintenance and improvement materials were the same as those for identical materials used in construction ("pre-use" phase). [2]

End of life phase:

All activities related to the eventual demolition of the built and includes the energy to demolish the build, except for the concrete foundation, which was assumed to remain in place. It also includes transportation energy to deliver all materials to landfills or recycling facilities. [2] Recycling and reuse activities related to demolition waste can also be included in this stage, depending on the availability of data.

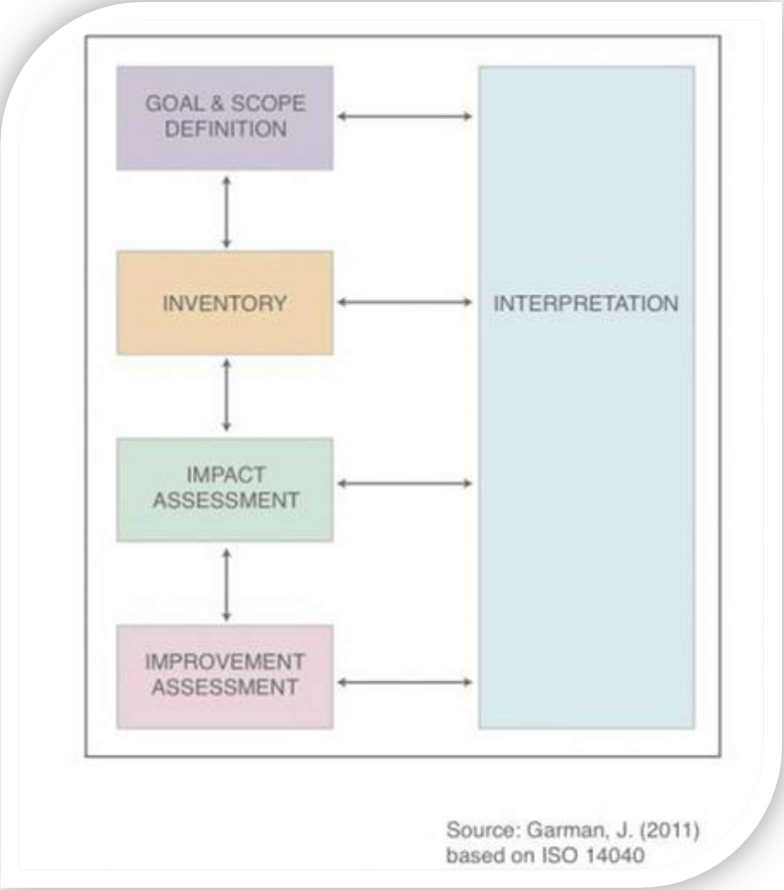


Phases of Life Cycle Assessment

Although the "use" phase currently dominates the life-cycle energy consumption, the importance of materials production and manufacturing/construction are expected to increase as designs become more energy-efficient.

2.4. Steps in a LCA:

Life Cycle Assessment Framework:



Source: Garman, J. (2011) based on ISO 14040

An LCA consists of four distinct "methodology steps" as shown in the text box above. Successful application of these steps requires a clear identification of the product, its life cycle, the choice of technical systems to be represented in the system boundaries and statements of basic anticipations.

The term Life Cycle Inventory Analysis (LCI) is often used as name for steps one and two of a Life Cycle Assessment.

The term Life Cycle Impact Assessment (LCIA) is often used as name for steps one to three.

Importance of clear basic definitions.

Before starting with any data inventory for the investigated product, a set of definitions has to be made within the goal and scope definition. These basic definitions are needed:

1. For users to understand the results of the study.

2. To enable a clear structure of the analysis.

3. To clearly identify the object and the objective of the study.

The basic definitions have a large influence on the following steps in the assessment procedure. Meanwhile, the character of an LCA study is often iterative, as initial definitions may have to be changed, adapted and refined during the conduct of the study. Disregarding or mistreating the first steps will necessarily lead to poor quality results. [14]

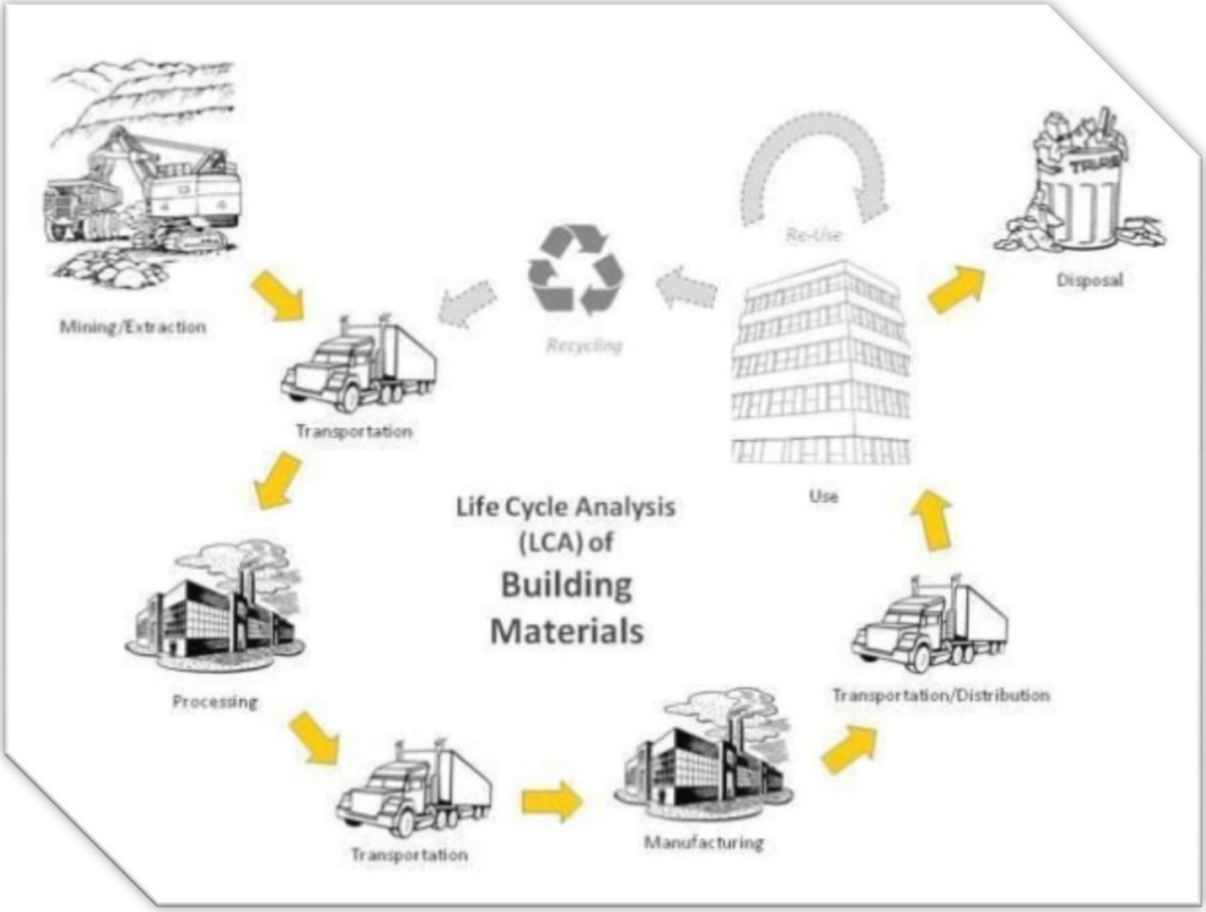
Step 1.Goal and scope definition.

The first important step of any LCA is the definition of the Goal and Scope – including, Functional units, System boundaries, Data quality requirements, and a Critical review process.

These basic definitions have to be carried out carefully, as the results obtained will only be valid for those definitions. Interpretation of results in situations similar to, but varying from the preconditions of the study, may remain unsupported by the study.

Life cycle definition:

The entire life cycle of the product must be included in LCA from the outset, although boundary setting may later exclude specific life stages. This means that those systems required for generating, using and disposal of the product are all relevant. This “cradle to grave” or “cradle to cradle” approach necessitates identification of the products life cycle and of the processes participating in it. In case of long lived products, such as a building, the definition of the product’s life cycle incorporates assumptions or estimates of the:



- Functional service life time.
- Use and maintenance scenarios.
- Repair and replacement of components.
- Major refurbishment or renovation scenarios for the building.
- Demolition and recycling scenarios.

Functional units.

The usefulness of a product is identified through its Functional Unit (FU), which can be expressed by various measures. It has to be clearly identified and measurable. The FU serves as a basis of comparison and as a basis for normalisation reference for the input and output flows.

In comparative studies, evaluation of different products or design solutions is valid only when the products fulfil the same functional unit.

System boundaries and data quality requirements.

According to the goal and the scope of the study, boundaries identify the extent to which specific processes are included or excluded. The system boundaries define and structure the technical system under assessment. A balance is desired between practicability of the study and validity of the results.

The quality requirements for gathered data can be defined and quality indicators can be established. Data quality requirements may address aspects such as time, geographical and technology-related coverage of the included data.

Critical review process.

A critical review process may serve to ensure the quality of the study. If reasonable, a reviewer or a review panel may be consulted in order to ensure that methods used are: consistent with ISO standards; scientifically and technically valid; that data is appropriate and reasonable in relation to the goal; that interpretations made reflect the limitations and the goal; that the report is transparent and consistent.

Step 2.Inventory analysis.

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. This step consists of data collection and the refining of system boundaries. Decisions are made about allocation of energy and material flows. Data is reviewed to ensure it is valid for the specific system under study. System boundaries are refined, in consideration of the defined scope of the study. Data handling is restricted only to inputs and outputs that are significant to the goal of the study.

Inventory data is to be related to reference flows for each unit process in order to quantify and normalize input and output to the studied functional unit. Data will then be aggregated in order to result in an input-output table for the studied product or service.

***Step 3.Impact assessment**.*

The life cycle impact assessment phase (LCIA), that purpose is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

This step can be subdivided into four sub-steps:

1. Category definition: the aim is to provide guidance for selecting and defining the environmental categories addressed by the study. The selection of categories should be consistent with the goal and scope of the study.

2. Classification: this step is performed to assign in inventory input and output data to the defined impact categories. It is a qualitative step based on scientific analysis or an understanding of the relevant environmental processes.

3. Characterization: for each impact category, the relative importance of the contributing substances can be modelled and quantified. Essentially the impacts are converted to a proxy using an equivalency factor.
   The characterization step necessitates the ability to model the categories in terms of standardised indicators. The chosen indicator is used to represent the overall change or loading in the category. Equivalency factors do not yet exist for all impact categories.
   The result is the expression of contributions to impact categories in terms of equivalent amounts of emitted reference substance for each impact category.

4. Weighting: for ease and clarity of decision-making, it is sometimes useful to further combine impact categories. This is accomplished by means of weighting –a process that ranks categories according to their relative importance to each other, and assigns numerical values to represent degrees of significance. Weighting often involves ethical or societal value judgements rather than scientific information. Weighting factors for such aggregation may be based on:

- Proxy methods.
- Monetisation.
- Environmental state indicators.
- Environmental political goals.

Step 4. Interpretation.

Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI o an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

The interpretation procedures should be evaluated for completeness, sensitivity and consistency. Any interpretation of results has to reconsider the definitions established during goal and scope setting. [5], [6] and, [14].

2.5. Environmental impact categories:

The impact categories of LCA methodologies vary from system to system. Environmental Impact Categories are mappings from quantities of emissions to the environmental impacts that these emissions cause. These categories have been established from nationally recognized standards established by agencies such as the Environmental Protection Agency, Occupational Safety and Health Administration, and National Institutes of Health. [1]

A set of impact categories common to many LCA methods are also provided below.

-Global Warming Potential. (GWP)

GWP has been developed to characterize the change in the greenhouse effect due to emissions and absorptions attributable to humans. The unit for measurement is grams equivalent of CO_2per functional unit of product (note that other greenhouse gases, such as methane, are included in this category, thus the term "CO_2 equivalent" is an impact and not an emission.

-Acidification Potential. (AP)

Acidifying compounds emitted in a gaseous state either dissolve in atmospheric water or fixed on solid particles. They reach ecosystems through dissolution in rain. The two compounds principally involved in acidification are sulfur and nitrogen compounds. The unit of measurement is grams of hydrogen ions per functional unit of product.

-Eutrophication Potential.

Eutrophication is the addition of mineral nutrients to the soil or water. In both media, the addition of large quantities of mineral nutrients such as nitrogen and phosphorous results in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. The unit of measurement is grams of nitrogen per functional unit of product.

-Fossil fuel depletion.

This impact addresses only the depletion aspect of fossil fuel extraction, not the fact that the extraction itself may generate impacts. The unit for measurement is mega joules (MJ) of fossil-based energy per functional unit of the product.

-Smog formation potential.

Under certain climatic conditions, air emissions from industry and fossil-fueled transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog. The contribution of a product or system to smog formation is quantified by this category. The unit of measurement is grams of nitrogen oxide per functional unit of product. Certain regions of the world are climatically more susceptible to smog. *(Figure 2)*

Figure 2

-Ozone depletion potential.

Emissions from some processes may result in the thinning of the ozone layer, which protects the earth from certain parts of the solar radiation spectrum. Ozone depletion potential measures the extent of this impact for a product or system. *(Figure 3)* The unit of measurement is CFC-11 per functional unit of the product.

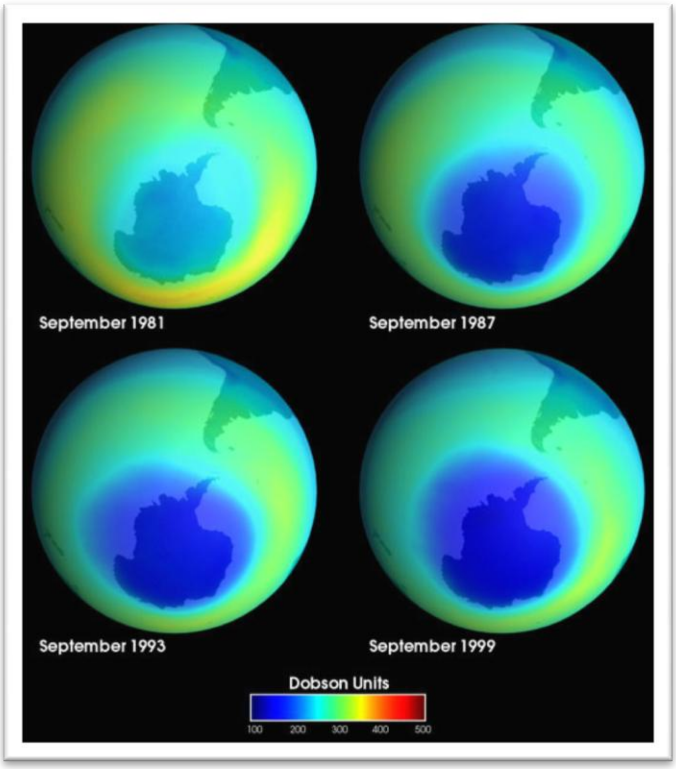


Figure 3. These images from the Total Ozone Mapping Spectrometer (TOMS) show the progressive depletion of ozone over Antarctica from 1979 to 1999.

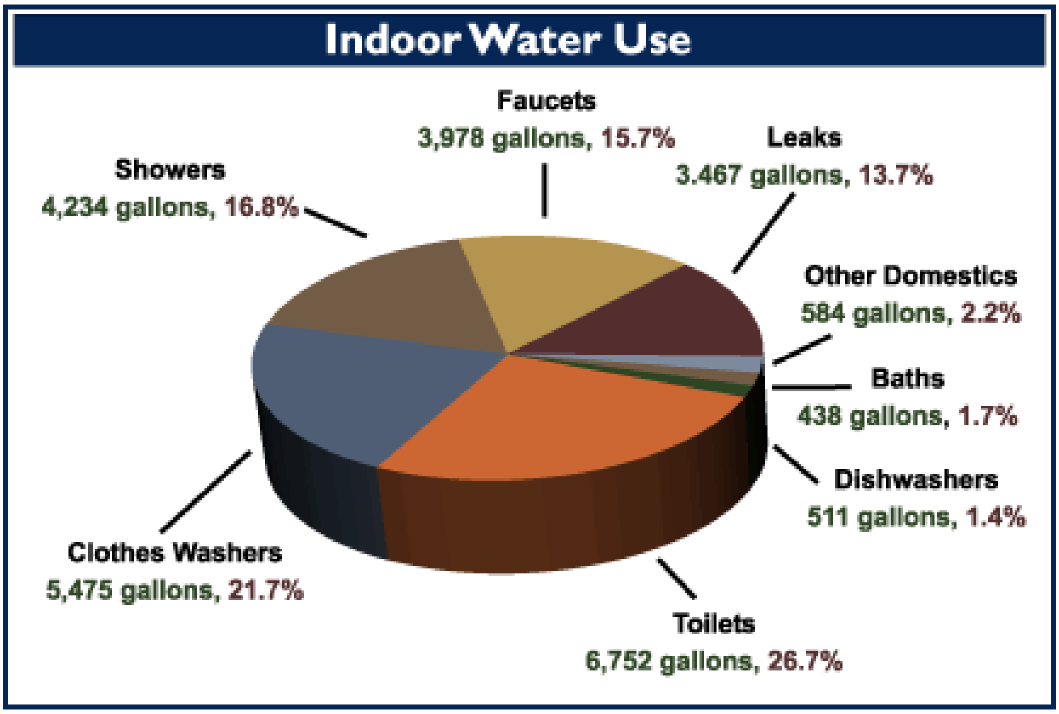
-Ecological toxicity.

The ecological toxicity impact measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems. The unit of measurement is grams of 2, 4-dichlorophenoxy-acetic acid per functional unit of product.

-Water use.

Water resource depletion has not been routinely assessed in LCAs to date, buy researchers are beginning to address this issue to account for areas where water is scarce, such as the western United States. The unit of measurement is liters per functional unit.

[1]



Graph 1: water use in housing

3. METHODOLOGIES

3.1. Variants of Life Cycle Assessment:

Here is a short introduction to some of the methodologies used in Life Cycle Assessment. The preliminary selection of methodologies to review has been carried out according to its capability to measure data related specifically to building-related LCA.

Those are the strongest candidates:

3.1.1. Cradle-to-Grave.

“Cradle-to-grave” is the full Life Cycle Assessment from resource extraction ('cradle') to “use” phase and disposal phase ('grave').

For example, trees produce paper, which can be recycled into low-energy production cellulose (fiberized paper) insulation, then used as an energy-saving device in the ceiling of a home for 40 years, saving 2.000 times the fossil-fuel energy used in it’s production. After 40 years the cellulose fibers are replaced and the old fibers are disposed of, possibly incinerated. All inputs and outputs are considered for all the phases of the life cycle.

3.1.2. Cradle-to-Gate.

“Cradle to gate” is an assessment of a partial product life cycle from manufacture, “cradle”, to the factory gate, before it is transported to the consumer. “Cradle to gate” assessments are sometimes the basis for Environmental Product Declarations (EPDs). Used for buildings, this would only include the manufacturing, and perhaps, depending on how the LCA was carried out, the construction stage. For building LCA tools based on assemblies, the starting point for the assessment might be a collection of cradle to gate LCAs completed on major building systems, for example, curtain wall, roof systems, load bearing frames, etc., which are then assembled into a complete cradle to grave assessment of the entire building. [1]

3.1.3. Cradle-to-Cradle.

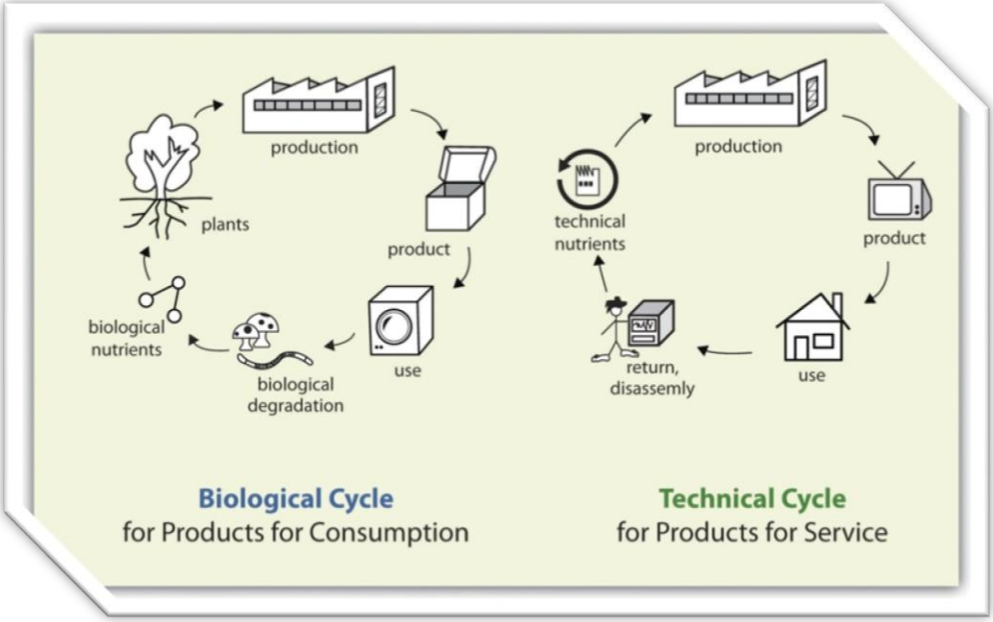
The term “cradle to cradle” or “C2C” is used to describe a sustainability model which is imitative of natural processes, with the goal of enriching and benefiting the environment even as products are manufactured and used. The underlying principle of this concept is that in nature, there is no waste: when a tree falls, for example, it isn´t thrown away, but it is rather broken down into component parts which benefit the surrounding environment. Using “cradle to cradle” techniques, manufactures can mimic nature and ensure that little to nothing is wasted. [11]

The term “cradle to cradle” is a registered trademark of McDonough Braungart Design Chemistry (MBDC) consultants. “Cradle to cradle” product certification began as a proprietary system; however, in 2012 MBDC turned the certification over to an independent non-profit called the “cradle to cradle” Products Innovation Institute. Independence, openness, and transparency are the Institute’s first objectives for the certification protocols. The phrase “cradle to cradle” itself was coined by Walter R. Stahel in the 1970s. The current model is based on a system of “lifecycle development” initiated by Michael Braungart and colleagues at the Environmental Protection Encouragement Agency (EPEA) in the 1990s and explored through the publication *A Technical Framework for Life-Cycle Assessment.*

In 2002, Braungart and William McDonough published a book called “cradle to cradle”: Remaking the Way We Make Things, a manifesto for “cradle to cradle” design that gives specific details of how to achieve the model. [12]

In “cradle to cradle” manufacturing, components are broken into “technical” and “biological” categories. A technical component is a synthetic product which is not toxic, and created in an environmentally friendly way. It is also designed to be used again and again in a closed loop, with the manufacturer avoiding “downcycling”. A classic example of downcycling is paper, which may start out as a sheet of bleached writing paper before being recycled to make a lesser quality recycled paper, which may be recycled again to make an even coarser paper or cardboard product and so forth.

Biological components are of biological origin, and they can be naturally broken down and returned to the environment after use. A cornstarch cup is an example of a biological component, as it can be used and then composted, with the compost supplying nutrients to a crop, garden, or natural area.



Companies which espouse the "cradle to cradle" philosophy work on creating products which can actively benefit the environment, and on creating closed manufacturing cycles which allow them to keep using the same technical components over and over again, rather than discarding them. One of the key concepts is the idea that "waste is food", which really means that there should be no waste products in "cradle to cradle" manufacturing, because products can either be reused and returned to the cycle, or organically broken down for use as food for the natural environment.

"Cradle-to-cradle" analyses, are a way to look at all the inputs (raw materials, energy, etc) associated with manufacturing a product and getting it to consumers and all the outputs created from the production, use, and disposal of the product (the product itself, pollution, waste by products during manufacture, etc). In the cradle-to-cradle scenario, there is an attempt to make a plan for a product beyond when the first consumer finishes with it so it can go on to meet another need. The life cycle assessment helps all of us make informed choices at various stages in the product's life.

This environmentally friendly approach to manufacturing can also be applied to other areas of life, such as running a household. Some critics of the "cradle to cradle" philosophy argue that the restriction of the ability to issue certification to a small group of individuals goes against the stated goal of spreading the concept and encouraging people to adopt it.[11]

3.1.4. Gate-to-gate.

"Gate to Gate" is a partial LCA that examines only one value-added process in the entire production chain, for example by evaluating the environmental impact due to the construction stage of a building.

"Gate to Gate" modules may also later be linked in their appropriate production chain to form a complete cradle to gate evaluation.

3.1.5. Leadership in Energy and Environmental Design (LEED).

"Leadership in Energy and Environmental Design" (LEED) consists of a suite of rating systems for the design, construction and operation of high performance green buildings, homes and neighborhoods.

Developed by the U.S. Green Building Council (USGBC), "LEED" is intended to provide building owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.

"LEED" is helping to deliver energy and water efficient, healthy, environmentally-friendly cost saving buildings, homes and communities. [13]

In "LEED" 2009 there are 100 possible base points distributed across five major credit categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, plus an additional 6 points for Innovation in Design and an additional 4 points for Regional Priority. Buildings can qualify for four levels of certification: *(Figure 4)*

-Certified: 40-49 points.

-Silver: 50-59 points.

-Gold: 60-79 points.

-Platinum: 80 points and above.

Figure 4

3.1.6. Cambridge Engineering Selector (CES).

The CES methodology is a technique of the LCA in which the analysis process is based on the calculation of embodied energy and CO_2 footprint of material's life cycle. Through the results of the analysis, the evaluation will show whether the material is sustainable or not. Right below there are the two parameters the analysis accounts for.

- **Embodied Energy** is the sum of all the energy required to produce goods or services, considered as if that energy was incorporated or "embodied" in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy-saving devices, of buildings, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming.

  Embodied energy is an accounting method which aims to find the total sum of the energy necessary for an entire product life-cycle. Determining what constitutes this life-cycle includes assessing the relevance and extent of energy into raw material extraction, transport, manufacture, assembly, installation, dis-assembly, deconstruction, and decomposition as well as human and secondary resources. Different methodologies produce different understandings of the scale and scope of application and the type of energy embodied.

- **A carbon footprint** has historically been defined by Championne as "the total sets of greenhouse gas (GHG) emissions caused by an organization, event, product or person.

Greenhouse gases can be emitted through transport, land clearance, and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings, and services. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide, or its equivalent of other GHGs, emitted.

The concept name of the carbon footprint originates from ecological footprint, discussion, which was developed by Rees and Wackernagel in the 1990s which estimates the number of "earths" that would theoretically be required if everyone on the planet consumed resources at the same level as the person calculating their ecological footprint. However, carbon footprints are much more specific than ecological footprints since they measure direct emissions of gasses that cause climate change into the atmosphere.

4. COMPARING METHODOLOGIES.

Given the information introduced in the previous point, a comparison between all of them will be carried out in order to find the most suitable option for this specific type of LCA oriented to a building-focused application, where every phase of a life cycle must be taken into account: “pre-use”, “use” and “demolition” of the building.

The “cradle to grave”, “cradle to gate” and “gate to gate” have been dismissed immediately, as they don’t cover some of the most essential parts of the process.

Here is the reasoning behind the selection process, explained for every methodology with detail.

- The “cradle to grave” methodology leaves the demolition, recycle, and re-use disregarded, which would prevent as from calculating the environmental impact with required precision.

- “Cradle to gate” methodology possesses a very limited view of the material LCA, as it leaves the transport, “use” and the “demolition” of building out of the study.
- “Gate to gate” is mainly used to analyseonly one value-added process in the entire production chain, rather than a complete LCA.

While “LEED” and “Cradle to Cradle” were among the strongest candidates in face of “CES”, both had to be put aside due to several flaws in the compatibility with the goal of this study.

Even though all of them search similar goals, the differences between them are extensive. Whereas “C2C” is but a philosophic approach born through a rising awareness of a human being towards the environmental issues, it seeks to evaluate a product’s safety for humans, environment, and the design itself: whether it can be used once again for the future life cycles of other products. “LEED” on the other hand, has no such philosophy on its background, but it does follow, as it has already been said, a very similar principles and even same steps used in “C2C” in the evaluation of the design of ecological buildings and the measurement of constructive solutions of the execution and maintenance.

Both of them are certifications, main differentiation of which lies in the scale of the sample they evaluate. “C2C” seeks but to evaluate the materials individually, so the owners of the certifications will be the manufacturer and the provider of the material, once they fulfill the requisites proposed by “C2C”. “LEED”, on the other hand, evaluates the building altogether. The whole life cycle is analyzed, and tested to fulfill energy efficiency requisites, thus lowering the environmental impact. The building or the material then will obtain one of the four different levels of certifications which will reflect the reach of the accomplishment of the criteria that the systems of certification impose (“LEED” or “C2C”).

However, “CES” is just a LCA technique, which is used to analyze life cycle of the materials. It has no certification on its own, although it can be focused, amplifying the assessment, towards the obtainment of either “C2C” or “LEED”. But simple adjustments are enough to where the goals of a desired certification are. In case of “C2C”, using the materials which already possess this certification is enough. “LEED” meanwhile will require an adjustment towards energy efficiency of the building, a usage of sustainable materials with high compatibility with thermal transmission or an addition of renewable energy systems and bioclimatic architecture designs. So the main similarity between “CES” and “C2C” is their concern about the energy used during the manufacturing, reuse and recycling process, whereas “LEED” resembles to “CES” in the evaluation of the impact of the resources used throughout the life of the building on the economic and energetic aspects.

The reasoning behind the dismissal of LEED is it taking into account many parameters which are irrelevant for our project on one hand, and on the other its main focus is energy efficiency. While we are greatly interested in this last issue, we must not forget that a lot of our attention is put into “end-of-life” of the materials and LEED considers it rather vaguely.

Since the main focus of this study is to find a balanced relationship between environment-friendly and economic aspects of the house-building, a decision to disregard this assessment has been taken.

The “Cradle to Cradle” study has been one of the very best options from the ones named previously as far as its environmental philosophy goes. Mainly its intention to mimic the nature itself in the design of materials and buildings would make it a perfect criteria for the environmental aspect of the study. Even its slogan says “No waste, waste is food”, as it happens in the nature. Such an approach would assist us greatly in lowering considerably the amount of waste and damaging gas’s emissions into the environment.

The purpose of this assessment is to analyze the entire life cycle of the material, paying a very close attention to its “end of life” phase, in which 100% is expected to be either reused or recycled in order to not waste the energy used in its original manufacturing process nor to use additional energy or risk CO_2emissions for the manufacturing of the material from the very beginning.

Nonetheless such a rigid approach to the LCA marks almost an impossible criteria to achieve which not only completely ignores the economic aspect of the process, but even jeopardizes the economic efficiency of the final product. That said it offers a noble goal, worth pursuing. But the market is far from being ready to embrace this philosophy in day-to-day transactions.

Finally we opted for CES methodology as the most suited for our project. It does take a very thorough approach to the life cycle assessment of the materials used in the construction of the building, focusing on embodied energy and CO2 footprint parameters in each phase of the life cycle of the building. In the next point we will deepen further into the process it follows applied to out sample houses.

5. EXAMPLES OF APPLICATION

5.1. Methodology process.

In this part the sustainable assessment application "Eco Audit" will be explained based on two sample examples: Standard House (SH) and Energy Efficient House (EEH). The difference lies in the materials utilised, one of them will be built with traditional materials while the Energy Efficient House will be built with sustainable materials. Those examples will provide the opportunity to compare their relative efficiency in economic, ecological and energetic terms, through the results obtained by "Eco-audit" assessment.

The goal is to perform the assessment of the materials used in house construction, since the moment of its extraction until the "end of life", incorporating the recycling and re-use stages of the sustainable house's materials previously mentioned. In order to prove the energy efficiency of the sustainable house, in spite of the elevated cost relative to the traditional house. In order to achieve this goal, we will use Life Cycle Assessment technique based on calculating the embodied energy and CO2 footprint of the materials used in its construction, called Cambridge Engineering Selector (CES).

In order to obtain the necessary properties of the materials for the sustainable assessment, "Eco Audit", the assemblies will have to be developed by means of "CES" software, forming specific combinations of materials which will be formed for each construction phase and then, based on this assemblies, we will continue calculating in spreadsheets the embodied energy and CO2 footprint in "pre-use" and "end of life" phases in both examples to compare the eco audit of each house and point to the best solution. We will also add spreadsheets which reflect the economic cost of materials purchase.

To achieve an energy efficient house we will have to analyse and choose the most appropriate materials for our goal in order to make it more ecologically and energetically sustainable than the standard house, built with traditional materials. For this purpose we will use "CES" software as well as a gathering of information about sustainable and ecological materials on web sites dedicated to sustainable architecture products.

This selection of sustainable materials will be performed considering some ecologic and energetic criteria, such as embodied energy and CO2 footprint that the material generates in “pre-use” and “end of life” phases. Nonetheless, the economic cost will be also very much taken into account in order to achieve an ecologic and economic balance for customer’s benefit. To perform such a competent search of materials, a very thorough information gathering from manufacturers and providers of ecological and sustainable materials has been carried out, so the final assortment could achieve a market acceptance as well as efficiency for a single-detached dwelling sample we use for this study.

The procedures to perform in each example will be the following:

-To analyse the data and the properties of the materials to be used.

-To elaborate the assemblies through “CES” software.

-To calculate the embodied energy and the CO2 footprint of the assemblies formed with the “CES” software through Excel spreadsheets.

-To analyse and select the sustainable materials through an information gathering from the manufacturers and providers with a “CES” software support.

-To introduce the data into Excel spreadsheets.

-To calculate in Excel spreadsheets the ecological evaluation of both examples in different phases: “pre-use”, “use” and “end of life”.

-To calculate embodied energy and CO2 footprint of the transportation through Excel.

-To calculate the energy to be used during the active life of the building and the thermal transmittance of façades and covers.

-To compare and evaluate the results obtained throughout the assessment.

- The determination of the best option and a review of specific reasons behind the choice.

A dwelling which will be used as a practical example for this assessment will be a detached dwelling, with ground floor and first floor, located in the province of Madrid.

The ground floor consists of two bedrooms, a living room, kitchen, bathroom, terrace and a porch which can be accessed from the living room and kitchen. On the first floor there are two bedrooms, one double and one twin, a bathroom, a storage room and a lounge.

In the following points we will see with more detail the examples used for the evaluation.

Omissions for the assessment.

Processes and systems not modelled in this study include:

-The concrete foundation, which was assumed to remain in place in future demolition or rehabilitation.

- Energy and materials issues related to external house infrastructure.

- Furniture (except bathroom cabinets) and curtains.

- Household supplies including food, clothing, entertainment equipment, and cleaning materials.

- Municipal services including the production and disposal/treatment of potable water and collection and disposal of municipal solid waste.

-The maintenance during de “use” phase of the building.

-The CO_2 footprint that is generate for the labourer during the construction of building.

-Worker transportation to the manufacturing and construction house.

-CO2 generated during the construction stage of the building

EEH Strategies for the assessment.

Numerous primary strategies for lowering life-cycle energy consumption were investigated. These strategies mainly focused on methods to reduce utility-supplied energy. The reduction of embodied energy and CO_2 footprint of construction materials and increased product durability were also addressed. *Table1, shows the major strategies investigated.*

STRATEGIES FOR ENERGY EFFICIENT HOUSE

STANDARD HOUSE	ENERGY EFFICIENT HOUSE
Concrete (structural)	Aerated concrete (structural)
Facing brick+PS+brick common	Aerated concrete (blocks)
Brick common (partitions)	Aerated concrete (blocks)
Terrazzo (outdoor)	Bamboo extreme
Ceramic (floor)	Bamboo parquet
Aluminium windows	Wood pine windows
Ceramic tile (roof)	Plastic tile (roof)
PVC (building systems)	Polypropylene (building systems)
-	Thermal paint (facing)

Table 1

Now we will proceed to review the material choice that we have taken as major strategies for the sustainable house, and what major impact will they have on the comparison and EEH improvement.

Firstly, we used cellular concrete blocks, manufactured by Ytong. The cellular concrete cured in autoclave is a mineral material which is obtained from silica sand, cement, lime and an expansion agent, being this last one responsible for the typical micro alveolar structure that is generated during the manufacturing process.

The cellular concrete can be fabricated with various densities. These range between 350kg/m3 and 700kg/m3, which makes it a much lighter material in comparison to conventional concrete. *(Figure. 4)*

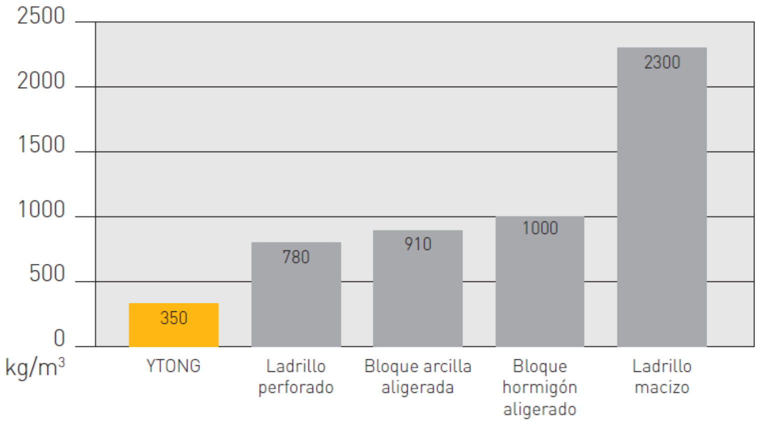


Figure. 4 Resistance and lightness

The manufacturing process of Ytong is simple and environment-friendly, since it requires a very small amount of raw material (1m3 of raw material transforms into 5m3 of product) and has a very low energy consumption rate. Ytong factories have ISO

9001 and ISO 14001 certificates and they manufacture the cellular concrete according to European Regulation EN 771-4 (Cellular concrete blocks cured in autoclave) *(Figure.5)*

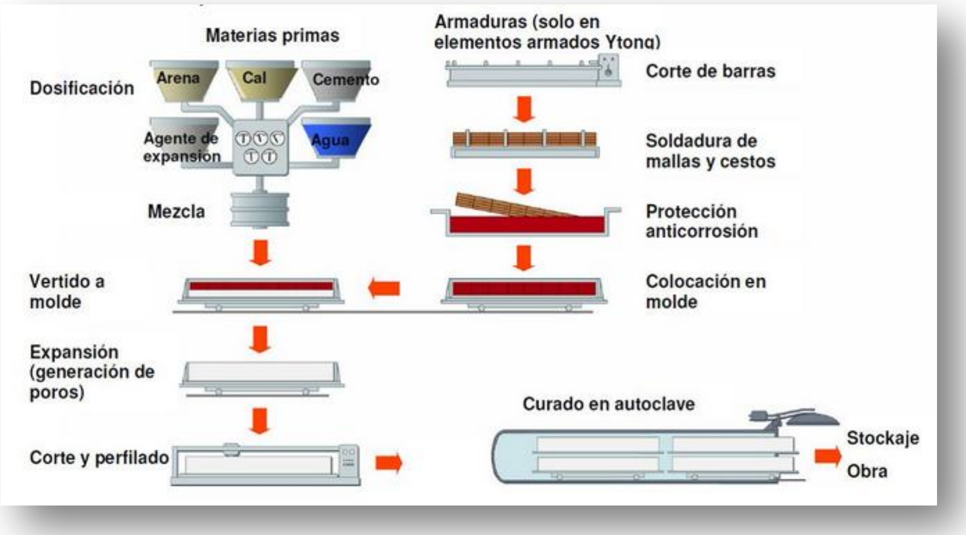


Figure.5. Process of production.

The cellular concrete Ytong is a 100% mineral material with no chemical components nor volatile organic components, making it totally recyclable.

The manufacturing process is very environment-friendly since it uses a nearly inexhaustible raw material and it requires relatively small amount of energy, comparing to standard materials.

The cellular concrete Ytong does not give off any smell or damaging dust, which protects the health of workers during the execution and the final users of the housing or building.

Hygrothermal characteristics of the material provide a high climatic comfort which translates directly into a well-being sensation inside of habitable environments. Moreover, an elevated thermal isolation reduces considerably the energetic and acclimatization consumptions.

The ecological nature of the concrete is accredited through the environmental declaration of the product (EPD according to ISO 14025 – ecolabel type III). This declaration gives all the information related to the life cycle of the cellular concrete Ytong and allows a comparison to other materials.

The ecologic qualities of the Ytong facilitate the securing of the sustainability certification for the buildings. [15]

The next material is a Bamboo, which has been used for the interior as well as for the exterior. The parquet flooring has been employed in the whole house, except for the kitchen and the bathrooms. On the exterior flooring we opted for floating pavements of bamboo tables over strips made of the same material.

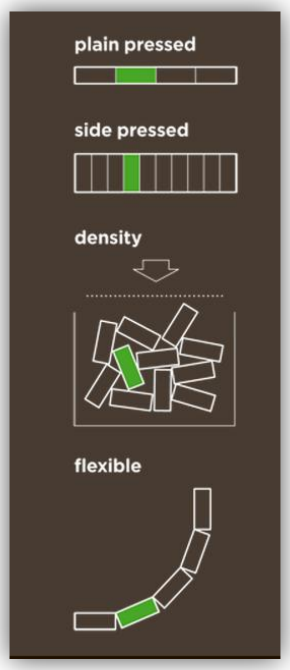
The official LCA shows that bamboo is an important CO2 'fixator'. This means that bamboo absorbs, during its growth and life until harvest, a relative large amount of CO2 from the air / atmosphere (and releases as subsequent large amount of CO2 in return through the photosynthesis process). Since the area of permanent MOSO bamboo plantations is growing steadily, an increasing amount of CO2 is permanently locked in the plantations plants. After the harvest this CO2 will remain locked in the material and will only be released when the material is discarded or burnt in the "end of life" phase, preferably in electrical power plants where it can substitute the use of carbon intensive fossil fuels and can thus be perceived as additional carbon credit following LCA methodology.

The growing speed of renewable materials in terms of annual yield in cubic meters per hectare is not included in a carbon footprint and can therefore be perceived as an additional environmental credential for renewable materials in general and in particular for the most rapidly growing materials such as MOSO bamboo.

The production processes are the following:

-Stem to strip: After harvesting the mature bamboo stems are split in longitudinal direction and the louter skin is removed. The strips naturally have a light yellow colour (natural), but can be steamed for a light brown colour (caramel) or thermally treated for a dark brown colour (chocolate).

-Strip to product: After treating and drying, the strips are ready to be connected in several ways to make the final product.



Plain pressed (PP)

Strips are placed horizontally and glued together to create a wide line pattern with the characteristic bamboo nodes clearly visible.

Side pressed (SP)

Strips are placed vertically and glued together to create a narrow line pattern with the bamboo nodes visible in a subtle way.

High density (HD)

Strips are compressed and glued under high pressure, creating an elegant random line pattern. The result is a floor that is even harder than the best tropical hardwood species.

Flexible (F)

There are 3 different looks: Tatamat (narrow strips connected with weaving thread), Panda (17mm wide strips) and Zen (50mm wide strips).[16]

Besides of the ecological benefits, the bamboo also offers a higher ease regarding its placing on the site, even though its price is higher than other, more traditional materials such as ceramics or stoneware, it reduces working time, which also decreases labour cost.

The painting used for the exterior of the façade is going to be a thermic painting or liquid ceramic which is a thermic isolation developed for the aerospace industry with multiple application options in the construction industry. The decision is justified by multiple advantages it has, comparing to traditional paintings. Also, since the façade is formed by a single sheet it allows it to give it a lesser thermal transmittance so it can work better with the façade as a whole.

It is formed by microspheres so small, with the naked eye it looks like a flour grain. This little "pearl" has a thickness of wall approximately 1/10 of its diameter, a large compression resistance, and a softening point at 1800 º C. The insulation ceramic has a thermic conductivity of 0,1W / m / ºC and is not combustible. The interior is empty and hollow. [18]

Regarding the choice of the windows, we searched for an environmental-friendly material, which could obtain better energy efficiency. So we chose wood because of being a completely renewable material and having positive energetic behaviour.

Moreover we will use an innovative window system in which we could economize on heating as well as on air conditioning. Below we explain the functioning of this system, which has been chosen as finalist of the “Urban Lab Challenge” contest.

It is a double window that gets to take advantage of the solar energy through a movable system and a translucent curtain, in order to make use of solar energy and climatic conditions to enhance comfort inside of the building and reduce from 20 to 25 % of energetic consumption in acclimatization and illumination. This system spares having to use blinds, which cause thermic bridge rather difficult to eliminate for a better energetic behaviour of the housing.

The double window is composed of a vertically sliding window facing the outside, a reclining window in the interior and a curtain between them to blur the light and accomplish a natural illumination.

Through various combinations, the double window manages solar energy according to the season and solar radiation. For example, during the winter the reclining window opens so the heat accumulated between them is transferred to the interior of the building, rising the temperature of atmosphere naturally. In summer, on the other hand, the translucent curtain allows for a good blurred lightning, extremely beneficial for ambient light, avoiding in this way any need for artificial lightning. Quite often people would lower the blinds to avoid a direct solar light, turning the lights on and also permitting cross ventilation of the building.

Such a system, based on a dynamic functioning of the windows, may be done in a manual as well as in automatic variation. “The automation of double window through automated systems of a building opens an opportunity to achieve a rather significant saving of energy in acclimatization and electrical lightning, since the windows respond adapting to aspects such as façade orientation, present solar radiation o current season. [19]

Next we shall proceed to present and analyse sample housings we used for the purpose of this project.

5.2. Comparing Standard House and Energy Efficient House examples.

All the data showed in the tables and graphs have been extracted from the Excel spreadsheets attached in the appendix of this project. They shall be consulted upon any doubt involving any piece of information discussed below in the comparison of both examples.

5.2.1. The life cycle mass assessment and results.

The life-cycle assessment evaluated the total mass of building materials required to construct the SH and EEH over estimated 50 year service life. The mass was assessed from construction drawings, project measurements and supplier data. Many home construction materials and appliances consist of a combination of multiple primary materials. Where possible, the mass of each component material was determinate by direct measurements or by multiplying measured dimensions by material density.

The greatest difficulty in determining the mass composition of individual components occurred with buildings systems. To this end we have made an estimation in kilograms based on the project blueprints.

The total mass of materials required to construct the standard house is been 291,60 tonnes and to construct the energy efficient house is been 126,90 tonnes. Table 2 provides a summary of the 26 materials with the greatest mass in the SH, and shows their percentage relative to total life cycle mass. And table 3 provides a summary of the 23 materials with the greatest mass in the EEH, and shows their percentage relative to total life cycle mass.

The greatest mass is contributed by reinforced concrete and bricks. These materials are associated with the building structure, façade and partitions, which are the greatest chapters in a house-building.

The changes of materials to the EEH altered the distribution and quantities of many materials. In this way the amount of the material mass has been significantly reduced in comparison to Standard House.

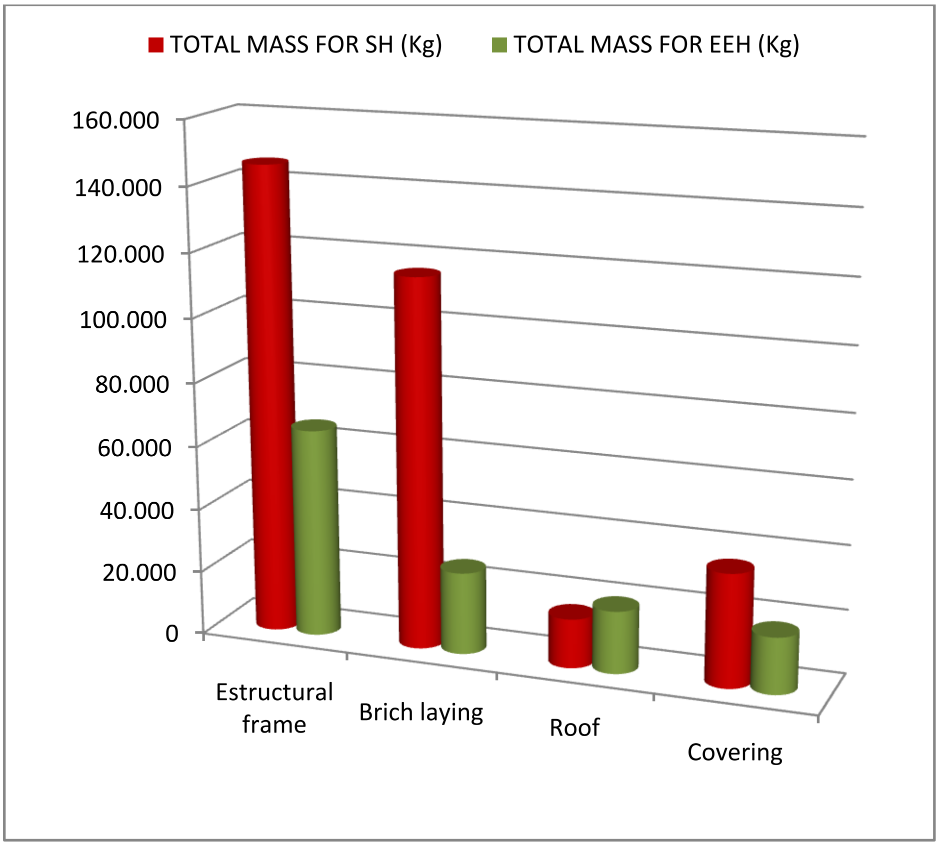
On the graphs below you can observe the mass of materials for every chapter of the project, in order to compare both examples. There we can appreciate the difference (if any) in mass reduction in both cases.*(Graphs 2 and 3)*

MATERIALS STANDARD HOUSE	FINAL MASS (kg)	%mass of total
Concrete	143.520,00	49,22%
Steel	2.511,60	0,86%
Facing brick	51.695,49	17,73%
Cement	33.066,75	11,34%
Brick common	29.607,42	10,15%
XPS	254,31	0,09%
Roofing tile	8.719,20	2,99%
Laminated glass	227,36	0,08%
Aluminium flake	324,80	0,11%
Extrusion aluminium	89,88	0,03%
Granite	3.043,20	1,04%
Adhesive	1.161,01	0,40%
Ceramic tile	2.028,00	0,70%
Gypsum	2.509,39	0,86%
Paint	3.534,77	1,21%
Porcelain	4.235,61	1,45%
Fine sand	1.421,20	0,49%
Sandstone	1.883,09	0,65%
Plaster	185,22	0,06%
Galvanized steel	97,01	0,03%
Wool	126,38	0,04%
PVC	988,10	0,34%
Polyethylene low density	7,59	0,00%
Stainless steel	49,50	0,02%
Copper	72,00	0,02%
PS	245,20	0,08%
TOTAL	291.604,06	
	291,60	Tonnes

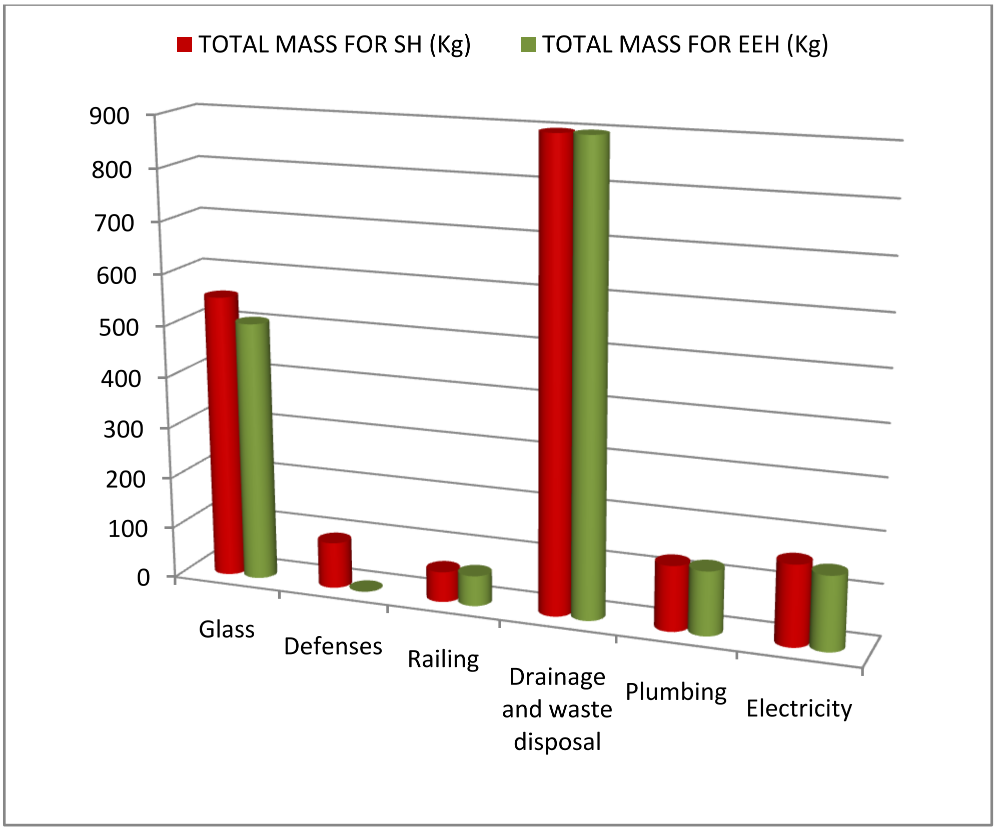
Table2.

MATERIALS ENERGY EFFICIENT HOUSE	FINAL MASS (kg)	%mass of total
Concrete	16.560,00	13,05%
Steel	2.326,00	1,83%
Aerated concrete (slab)	47.160,00	37,16%
Aerated concrete (facing blocks)	17.878,88	14,09%
Polystyrene extruded (Ps high)	166,60	0,13%
Plastic tile (LDPE)	928,20	0,73%
Aerated concrete (roof)	17.850,00	14,07%
Aerated concrete (partition blocks)	7.805,00	6,15%
Laminated glass	227,36	0,18%
Wood	278,40	0,22%
Bamboo	1.809,78	1,43%
Gypsum	1.406,65	1,11%
Porcelain	2.109,40	1,66%
Bamboo extreme	852,72	0,67%
Plaster	185,22	0,15%
Paint	3.534,77	2,79%
Facing paint	3.473,61	2,74%
Galvanized steel	97,01	0,08%
Wool	1.150,51	0,91%
Polypropylene	974,43	0,77%
Polyethylene low density	6,00	0,00%
Stainless steel	49,50	0,04%
Copper	72,00	0,06%
TOTAL	126.902,03	
	126,90	Tonnes

Table 3.



Graph 2. Total mass of materials of each chapter.



Graph3. Total mass of materials of each chapter.

As we can verify, the chapters where the saving in EEH are most noticeable in comparison to SH are: “structural frame”, “facing brick”, “covering” and “defences”. In the “defences” chapter the blinds have not been used in EEH. In “roof” chapter is the only case where EEH has exceeded SH in mass, since the usage of cellular concrete block is much larger than reinforced concrete in a “in-situ” beam and pot floor.

Finally the change in the installations has not been substantial enough to alter the mass of the materials used in either one of the houses.

5.2.2. The life cycle energy assessment and results.

Pre-use Phase Energy.

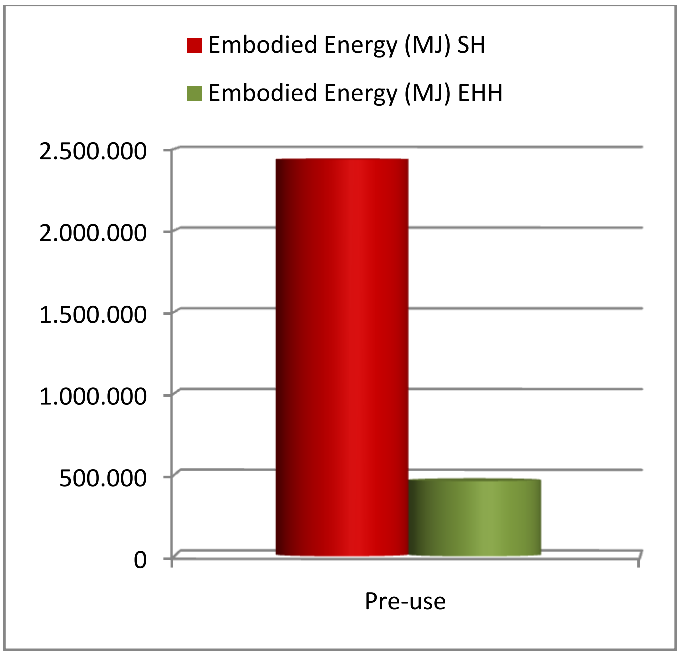
Energy is measured as the primary energy associated with the consumption of energy sources such as coal, natural gas, fuel oil, and gasoline. The primary energy is calculated from the energy content of these resources, expressed as a higher heating value (HHV). In addition to the energy for extraction and processes.

MATERIALS STANDARD HOUSE	Total Embodied energy (MJ/kg)	%embodied energy of total
Concrete	186.576,00	7,66%
Steel	76.101,48	3,13%
Facing brick	1.168.318,07	47,99%
Cement	198.400,49	8,15%
Brick common	148.037,09	6,08%
XPS	25.939,62	1,07%
Roofing tile	109.861,92	4,51%
Laminated glass	6.957,22	0,29%
Aluminium flake	49.694,40	2,04%
Extrusion aluminium	19.234,32	0,79%
Granite	19.476,48	0,80%
Adhesive	104.026,25	4,27%
Ceramic tile	25.552,80	1,05%
Gypsum	4.516,90	0,19%
Paint	4.511,34	0,19%
Porcelain	178.319,27	7,33%
Fine sand	142,12	0,01%
Sandstone	1.129,85	0,05%
Plaster	427,85	0,02%
Galvanized steel	1.086,90	0,04%
Wool	7.115,31	0,29%
PVC	70.155,10	2,88%
Polyethylene low density	664,13	0,03%
Stainless steel	3.648,15	0,15%
Copper	3.960,00	0,16%
PS	20.473,87	0,84%
TOTAL	**2.434.326,90**	

MATERIALS ENERGY EFFICIENT HOUSE	Total Embodied energy (MJ/kg)	%embodied energy of total
Concrete	21.528,00	4,67%
Steel	70.477,80	15,28%
Aerated concrete (slab)	1.461,96	0,32%
Aerated concrete (facing blocks)	822,43	0,18%
Polystyrene extruded (Ps high)	16.993,20	3,68%
Plastic tile (LDPE)	72.492,42	15,71%
Aerated concrete (roof)	660,45	0,14%
Aerated concrete (partition blocks)	265,37	0,06%
Laminated glass	6.957,22	1,51%
Wood	2.700,48	0,59%
Bamboo	10.858,68	2,35%
Gypsum	2.531,97	0,55%
Porcelain	88.805,74	19,25%
Bamboo extreme	5.969,04	1,29%
Plaster	427,85	0,09%
Paint	4.511,34	0,98%
Facing paint	4.446,22	0,96%
Galvanized steel	2.784,10	0,60%
Wool	64.773,83	14,04%
Polypropylene	73.764,35	15,99%
Polyethylene low density	525,00	0,11%
Stainless steel	3.648,15	0,79%
Copper	3.960,00	0,86%
TOTAL	**461.365,59**	

Table 4 and 5.

In the tables 4 and 5 show the embodied energy of each material in both sample houses. These results have been obtained multiplying the embodied energy per kilogram of material per the whole of mass of the material.

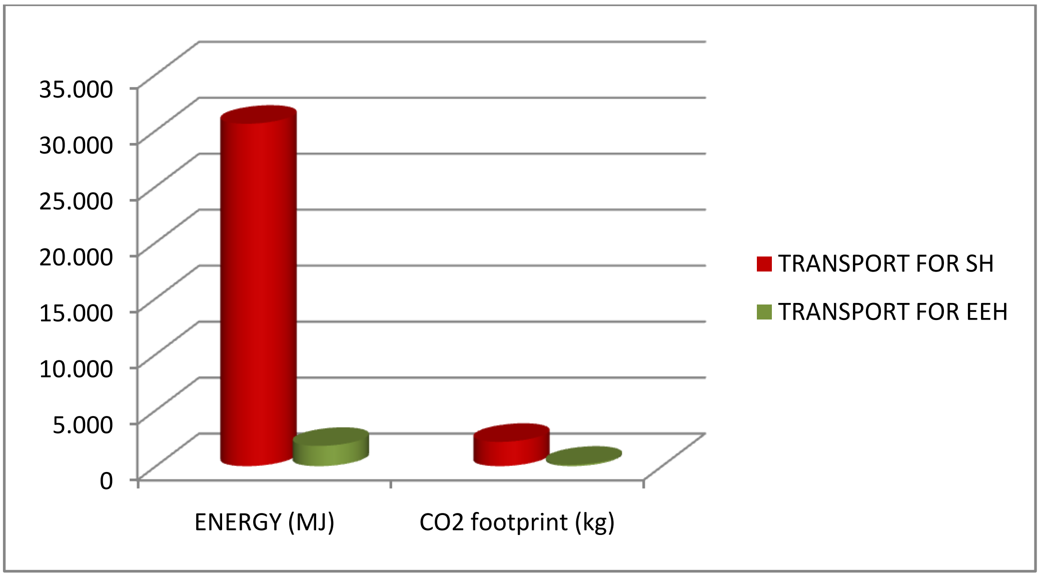


Graph 4. Shows the embodied energy comparative of both examples in the "pre-use" phase.

On the graph above we can confirm the embodied energy generated in the manufacturing phase of the materials of the SH surpasses greatly the one generated in EEH, what makes obvious the huge benefit for the environment from a plane material selection carried out carefully to this goal.

	ENERGY (MJ)	**CO2 footprint (kg)**
TRANSPORT FOR SH	30.595,87	2.172,31
TRANSPORT FOR EEH	1.810,52	128,55

In the "pre-use" phase it is also included the embodied energy and CO2 footprint of the transportation of all materials from factories and warehouses to the site. From the calculations in the appendix we extract the most interesting data for the comparison of energy and CO2 footprint generated by the transportation.*(Graph5)*



Graph 5. Comparing transport.

On this graph it is shown the direct relationship between the amount of kilograms of the materials and the increase of the transportation it entails, consequently increasing energy and CO2 consumption. EEH keeps coming as the best option, mostly due to the energy consumed during the transportation, phase where the impact is most noticeable.

Use Phase Energy.

The “use” phase of a building comes to be the most expensive energy-wise since its useful life is at least of 50 years. Electrical appliances energy consumption, lightning, heating and air conditioning all builds up over those years. The strategy is to build a halting thermal envelope using the best insulation possible, in order to get the least thermal losses. This method ensures a minimum environmental impact.

For such analysis we have calculated thermal transmittance (U) of the façade and roof in both examples, according to CTE, to learn the losses the house would have through the enveloping. We have also done an estimation of the consumption of every house during the “use” phase.

STANDARD HOUSE

THERMAL TRANSMITTANCE:

Climatic zone D3

U_{Mlimax}= 0,66 W/m²K

U_{Calc}= 0,559 W/m²K

FAICING	e	λ	R
outdoor			0,04
parging	0,01	1,3	0,0077
LCH 11	0,11		0,2300
parging	0,01	1,3	0,0077
EPS	0,04	0,034	1,1765
LCH 7	0,07		0,1600
gypsum	0,015	0,4	0,0375
indoor			0,13

R_T= 1,789

U= 0,559 ≤ 0,66 W/m²K

Climatic zone D3

U_{Clim}= 0,38 W/m²K

U_{Calc}= 0,448 W/m²K

ROOF	e	λ	R
outdoor			0,04
ceramic tile	0,02	0,230	0,133
cement	0,02	1,300	0,018
XPS	0,05	0,029	1,724
Damp-proofing	0,003	0,230	0,013
cement	0,02	1,300	0,018
Vapour barrier			0,000
slab	0,3		0,210
gypsum	0,01	0,400	0,025
indoor			0,1000

R_T= 2,645

U= 0,378 ≤ 0,38 W/m²K

No cumple

ENERGY CONSUMPTION:

LIGHTING AND ELECTRIC APPLIANCES CONSUMPTION STANDARD HOUSE	POWER (W)	USE DAILY HOURS	ENERGY CONSUMED	
Kitchen lighting (fluorescent)	40	6	240	
restroom lighting (fluorescent)	40	6	240	
4rooms and 2bathrooms lighting (fluorescent)	70	4	280	
outdoor (fluorescent)	40	3	120	
kitchen	7000	1,5	10.500	
heating and water heater	2300	4	9.200	
A/C central unit	2100	4	8.400	
electric furnace	3800	0,5	1.900	
Microwave oven	1100	1	1.100	
Fridge	150	12	1.800	
Clothes washer	2200	1	2.200	
TV	100	6	600	
Computer	300	3	900	
TOTAL ENERGY PER DAY			37.480	
			37,48	KWh/day

ENERGY EFFICIENT HOUSE

THERMAL TRANSMITTANCE:

Climaticzone D3
$U_{Mlimax}=$ 0,66 W/m^{2}K
$U_{Calc}=$ 0,339 W/m^{2}K

FAICING	e	λ	R
outdoor			0,04
paint	0,01	0,1	0,1000
Block Ytong	0,25	0,1	2,5000
gypsum	0,003	0,4	0,0075
paint	0,005	0,029	0,1724
indoor			0,13
		$R_{T}=$	2,950

U= 0,339 ≤ 0,66 W/m^{2}K

ClimaticzoneD3

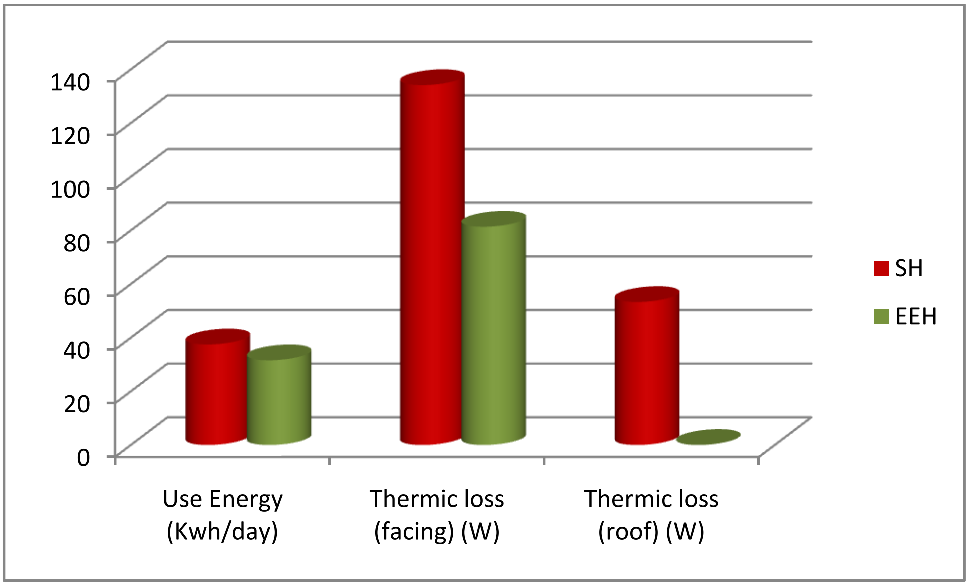
U_{Clim}= 0,38 W/m²K
U_{Calc}= 0,271 W/m²K

ROOF	e	λ	R
outdoor			0,04
plastic tile	0,005	0,210	0,024
XPS	0,04	0,029	1,379
Vapour barrier			0,000
Block Ytong	0,3	0,140	2,143
gypsum	0,003	0,400	0,008
indoor			0,1000
		R_T=	3,693

U= 0,271 ≤ 0,38 W/m²K

ENERGY CONSUMPTION:

LIGHTING AND ELECTRIC APPLIANCES CONSUMPTION ENERGY EFFICIENT HOUSE	**POWER (W)**	**USE DAILY HOURS**	**ENERGY CONSUMED**	
kitchen lighting (saver)	20	6	120	
restroom lighting (saver)	20	6	120	
4rooms and 2bathrooms lighting (saver)	35	4	140	
outdoor (saver)	20	3	60	
kitchen	3700	1,5	5.550	
heating and water heater	2300	4	9.200	
A/C central unit	2100	4	8.400	
electric furnace	3680	0,5	1.840	
Microwave oven	800	1	800	
Fridge	150	12	1.800	
Clothes washer	2200	1	2.200	
TV	100	6	600	
Computer	250	3	750	
TOTAL ENERGY PER DAY			31.580	
			31,58	KWh/day



Graph6. Comparing energy consumption and thermic loss in each example.

As we can see the daily energy consumption on both examples does not show a significant difference, since renewable energies have been avoided in both cases. But it is in thermic losses through the covering where we see an important difference. The façade and roof of the EEH have almost just a half of heat loss rate, what translates into an energy saving in heating and air conditioning of 20-25% at very least. If we add to that the window system, the saving through the useful life becomes significantly more important. [19] [20]

End of life: Energy and CO_2 footprint.

The energy and CO2 footprint associated with a product's "end of life" are split into two distinct contributions: "Disposal" and "End of life (EoL) Potential".

"Disposal" includes the cost of:

1) Collection of the material/component at "end of life" and, where applicable, disposal in landfill, and

2) Separation and sorting of the collected material, ready for reprocessing by the proposed "end of life" route.

"EoL Potential" represents the "end of life" savings or "credits" that can be realized in future life cycles by using the recovered material or components.

As the ”credit” associated with the recovery and reuse of material/components lies outside the standard system boundaries for a product's life cycle, the “EoL Potential” is displayed as a separate life phase.

This enables:

1. Determination of the environmental footprint of a product over its entire lifecycle (achieved by ignoring the “EoL Potential” phase).
2. Evaluation of the benefits of the various “end of life” options (achieved by considering just the “EoL Potential” phase).

In calculating this “end of life” “credit”, the following assumptions are made:

- The recovered material is used to replace material of the same grade (i.e. credit is only given for recovering the virgin content of the component).
- In versions of the tool where there is no option to specify a recovery ratio at “end of life”, it is assumed to be 100% (i.e. r = 100). This leads to a “best case scenario” as, in practice, not all material will be collected and most recovery processes are not 100% efficient.

The calculations used to determine the credit for each “end of life” option are detailed below:

Landfill

Landfill is seen as the end of a product's life. As a result, no future energy benefits or costs are associated with this option.

Downcycle

In downcycling a material is processed into a material of lower quality. The environmental benefits of downcycling are dependent on both the downcycling technique and the relative reduction in material quality.

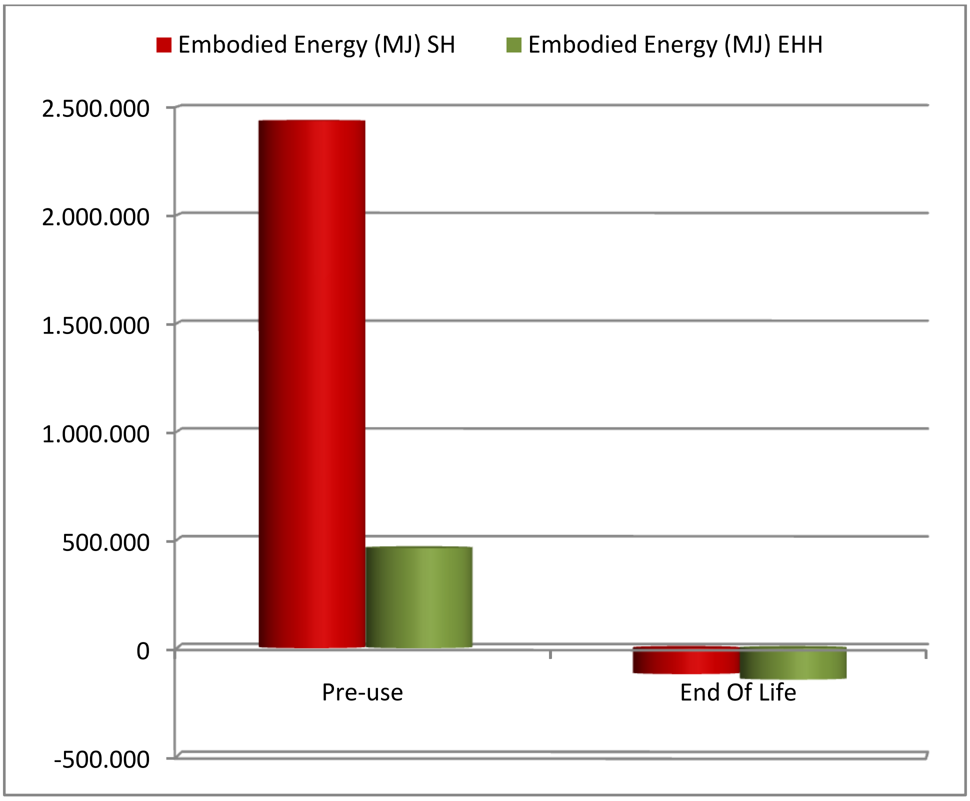
Recycle

In recycling, material is reprocessed into a material of similar quality. This leads to a saving of the energy and CO_2 footprint associated with the production of virgin material, minus the energy and CO_2 associated with the recycling process

Reuse

Reuse is essentially the extension of a product's life.

All the calculations related to "EoLPotencial" can be found in the appendix of this project. In this section we will take a look at the graph, which compares the embodied energy of the materials in "pre-use" and end-of-life phases *(Graph 7).*



Graph 7. Comparing embodied energy in "pre-use" phase and "end of life" in each example.

On the previous graph we can see how, despite of "end-of-life" phase being relatively equal in embodies energy recuperated, in "pre-use" phase the difference is over 20.000 MJ. Moreover, if we add this to the "pre-use" phase difference the "pre-use" data it gets significantly larger.

5.2.3. The life cycle global warming potential assessment and results.

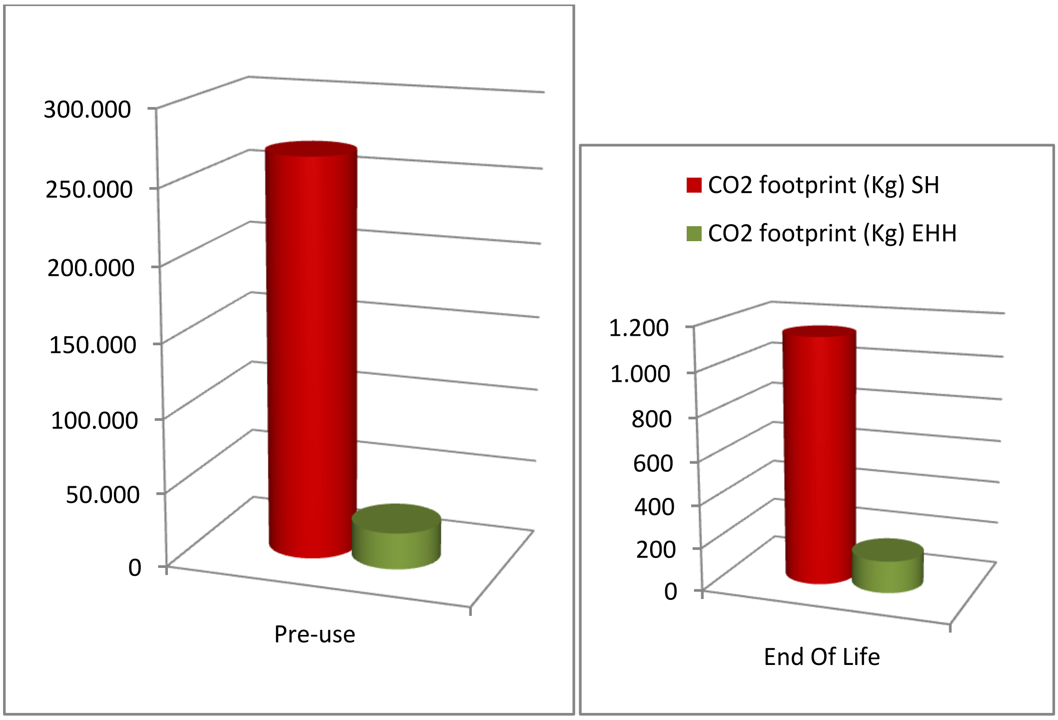
Determining life cycle global warming potential was similar to the assessment of life cycle energy. Greenhouse gas emissions associated with materials production and fabrication stages were determined by multiplying the emission factors in kg of CO_2 equivalents per kg of construction materials by the life cycle mass inputs of each material. Greenhouse gas emissions associated with transportation fuels were also inventoried.

On the tables below we notice how the manufacturing of the bricks for the facade and partitions add a huge number to CO2 emissions, followed by more reasonable numbers in cement and concrete. Nonetheless on the EEH table shows much lesser numbers, quite equivalent between them. However, the materials possible to highlight would be: porcelain, steel, mineral wool, polypropylene. Even though it never gets as high as a Standard House. *(Tables 6 and 7)*

MATERIALS STANDARD HOUSE	**Total CO2 footprint (kg/kg)**	**%CO2 footprint of total**
Concrete	14.323,30	5,36%
Steel	5.173,90	1,93%
Facing brick	163.357,75	61,09 %
Cement	33.066,75	12,37 %
Brick common	6.720,88	2,51%
XPS	1.014,70	0,38%
Roofing tile	15.345,79	5,74%
Laminated glass	418,34	0,16%
Aluminium flake	2.640,62	0,99%
Extrusion aluminium	1.006,66	0,38%
Granite	1.019,47	0,38%
Adhesive	4.435,05	1,66%
Ceramic tile	3.569,28	1,33%
Gypsum	301,13	0,11%
Paint	234,41	0,09%
Porcelain	9.614,84	3,60%
Fine sand	7,11	0,00%
Sandstone	55,93	0,02%
Plaster	38,15	0,01%
Galvanized steel	74,61	0,03%
Wool	444,86	0,17%
PVC	3.181,68	1,19%
Polyethylene low density	27,63	0,01%
Stainless steel	223,25	0,08%
Copper	282,96	0,11%
PS	836,12	0,31%
TOTAL	267.415,15	

MATERIALS ENERGY EFFICIENT HOUSE	**Total CO2 footprint (kg/kg)**	**%CO2 footprint of total**
Concrete	1.652,69	6,72%
Steel	4.791,56	19,47 %
Aerated concrete (slab)	136,76	0,56%
Aerated concrete (facing blocks)	77,95	0,32%
Polystyrene extruded (Ps high)	664,73	2,70%
Plastic tile (LDPE)	1.577,94	6,41%
Aerated concrete (roof)	62,48	0,25%
Aerated concrete (partition blocks)	24,98	0,10%
Laminated glass	418,34	1,70%
Wood	110,25	0,45%
Bamboo	542,93	2,21%
Gypsum	168,80	0,69%
Porcelain	4.788,34	19,46 %
Bamboo extreme	1.424,04	5,79%
Plaster	38,15	0,16%
Paint	234,41	0,95%
Facing paint	243,15	0,99%
Galvanized steel	191,10	0,78%
Wool	4.049,80	16,46 %
Polypropylene	2.884,31	11,72 %
Polyethylene low density	21,84	0,09%
Stainless steel	223,25	0,91%
Copper	282,96	1,15%
TOTAL	24.610,77	

Tables 6 and 7. Shows the CO_2 footprint for each materials.



Graphs 8 and 9. Shows the CO_2 footprint comparing for the SH and EEH in the “pre-use” phase and “end of life” phase.

In the previous comparative it displays the big difference in CO2 emissions in “pre-use” phase, as well as in end-of-life phase of the materials. SH emits an approximate amount of 240.000 kg more CO2 then EEH in just the “pre-use” phase, while the materials are just being manufactured. Once again we can see how much more environmentally-friendly EEH is, facing SH.

The comparative of the “lifecycle GWP” referring to the transportation of the materials has been made in 5.2.2. (The life cycle energy assessment and results) in the part related to the “pre-use” phase, in order to achieve a comparative of the energy consumed by the transportation in combination with CO2 emissions, so we could see better the transportation impact on the environment as a group.

6. ECONOMICAL IMPACT OF THE ASSESSMENT

6.1. The life cycle cost assessment and results.

In this point we will deepen the analysis to further comprehend the economical repercussion of the material choices taken earlier. For this purpose we have multiplied the €/kg price for the total mass of a material, summing the afterwards to obtain the global price of the housing. However, in this budget we have not accounted for the labor cost, nor the demolition and subsequent recycling/re-use or transportation to the landfill.

While budgeting by materials, it can be observed that those materials with major presence on the site are those most expensive regarding to others and will take the biggest chunk of the budget; in case of standard house these are: Concrete, since the whole building structure is made of this material; Facing brick, since the formation of the building envelope is done with two leaves; and the paint, granite, adhesive, and PVC not only because of a rather large repercussion on the weight of the housing, but also due to its high unit price.

In energy efficient house, there's a material that stands out above everything else, even above any material used in the standard house sample. Aerated concrete blocks of the slab, it being prefabricated blocks of a big stretcher face and therefore more expensive than the prefabricated materials of the conventional slabs.

The second material with most weight on the final cost of the Energy Efficient House would be the Aerated concrete blocks for the façade, although with a much lower price. Regarding the Standard House, you can spare the isolation and building a two leaves façade, which implies a lighter use of materials and an execution of one leave only, which has a highly efficient isolation function, as we have confirmed earlier in the heat loss calculations of the enveloping.

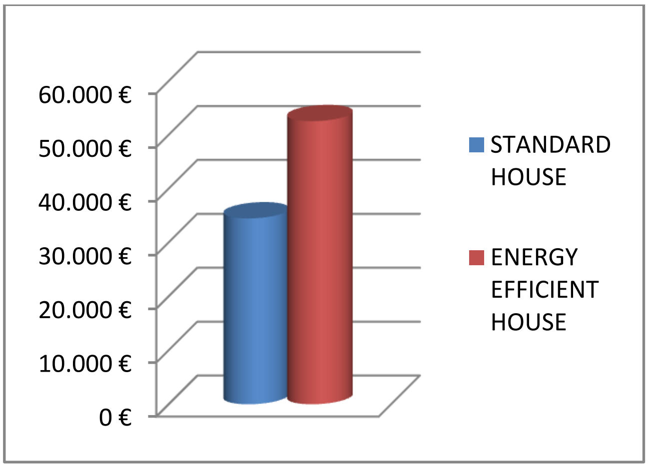
Other materials of the Energy Efficient House that would stand out would be the interior and the façade paints, which are more expensive because they are special paints, improving the isolation capacity of the building envelope.

There's a difference of 18.000€ between the final prices of both houses which it's not a very alarming quantity referring to the final price of the house adding to it the execution of the building.

Furthermore, as we have been able to confirm along the study, the Energy Efficient House is a very good choice, both, as for the environmental awareness, and for the efficiency of the thermic covering, which achieves an economization for the user of at least25-30% per year in the heating and air-condition usage. And saving this amount of money every year, in less than 10 years we could recover the whole investment in materials and in more ecologic and energy efficient systems, besides the fact that the user is made aware of the environmental-friendly nature of the Energy Efficient House choice.

Besides, In the EEH we could also economize on the building execution, considering that the building's envelope and the slabs are entirely prefabricated, with large size blocks but still light, reducing the time of building execution process and consequently the price of the construction.

The plastic tile placement on the roof reduces the cost of roof construction, because despite having the same size as traditional tiles they are lighter, and also because of the fastening system, we save up to 70% of time in the building execution.



Graph 10. Comparing cost of SH and EEH.

After observing everything shown up until now, we shall conclude the EEH is the best choice, as it has achieved the desirable ecological and economic balance outperforming Standard House in every way. Therefore we must consider such a product may have relatively good acceptance on the competitive market.

STANDARD HOUSE	Final Mass (Kg)	Price (EUR/kg)	Total Price (EUR)	ENERGY EFFICIENT HOUSE	Final Mass (Kg)	Price (EUR/kg)	Total Price (EUR)
Concrete	143.520,00	0,03 €	4.305,60 €	Aerated concrete	16.560,00	0,07 €	1.126,08 €
Steel	1.623,30	0,18 €	292,19 €	Steel	2.326,00	0,18 €	418,68 €
Facing brick	51.695,49	0,09 €	4.652,59 €	Aerated concrete (slab)	47.160,00	0,50 €	23.580,00 €
Cement	33.066,75	0,08 €	2.645,34 €	Aerated concrete (facing blocks)	17.878,88	0,24 €	4.290,93 €
Brick common	29.607,42	0,02 €	503,33 €	Polystyrene extruded (Ps high)	166,60	1,95 €	324,87 €
XPS	254,31	1,95 €	495,90 €	Plastic tile (LDPE)	928,20	1,42 €	1.318,04 €
Roofing tile	8.719,20	0,21 €	1.831,03 €	Aerated concrete (roof)	8.925,00	0,18 €	1.606,50 €
Laminated glass	227,36	4,49 €	1.020,85 €	Aerated concrete (partition blocks)	7.805,00	0,07 €	546,35 €
Aluminium flake	324,80	2,86 €	928,93 €	Laminated glass	227,36	4,49 €	1.020,85 €
Extrusion aluminium	89,88	3,14 €	282,22 €	Wood	278,40	1,09 €	303,46 €
Granite	3.043,20	0,83 €	2.519,77 €	Bamboo	399,42	2,00 €	798,84 €
Adhesive	1.161,01	1,74 €	2.020,15 €	Gypsum	1.406,65	0,17 €	239,13 €
Ceramic tile	2.028,00	0,41 €	831,48 €	Porcelain	2.109,40	0,36 €	759,38 €
Gypsum	2.509,39	0,17 €	426,60 €	Bamboo extreme	852,72	1,80 €	1.534,90 €
Paint	3.534,77	1,62 €	5.726,32 €	Paint	3.534,77	1,62 €	5.726,32 €
Porcelain	4.235,61	0,36 €	1.524,82 €	Facing paint	3.473,61	1,70 €	5.905,14 €
Fine sand	1.421,20	0,30 €	426,36 €	Plaster	185,22	1,15 €	213,00 €
Sandstone	1.883,09	0,33 €	613,89 €	Galvanized steel	37,87	0,57 €	21,59 €
Plaster	185,22	1,15 €	213,00 €	Wool	1.150,51	0,50 €	575,26 €
Galvanized steel	97,01	0,57 €	55,30 €	Polypropylene	974,43	1,53	1.490,88 €
Wool	126,38	0,50 €	63,19 €	Polyethylene low density	7,59	1,58 €	11,99 €
PVC	988,10	2,13 €	2.104,65 €	Stainless steel	49,5	3,24 €	160,38 €
Polyethylene low density	7,59	1,58 €	11,99 €	Copper	72	7,72 €	555,84 €
Stainless steel	49,50	3,24 €	160,38 €			TOTAL	52.528,40 €
Copper	72,00	7,72 €	555,84 €				
PS	245,20	1,10 €	269,72 €				
		TOTAL	34.481,45 €				

Table 8. Final cost of materials for the both buildings.

7. CONCLUSIONS

This project of life cycle assessment for buildings shows us some opportunities for achieving a dramatic reduction in embodied energy, CO_2 footprint, and energy consumption by residential construction sector with as little as only incremental energy-efficiency measures, and a proper selection of sustainable materials.

The design of the sample EEH used in this assessment is focused primarily on techniques of reduction of life cycle energy consumption and life cycle global warming potential as much as possible using equipment and materials easily obtainable in Spanish market. With an increment of life cycle cost of materials obtain and transportation not very large, to be an interesting product in its market sector.

The results obtained in this project are very promising for the environmental awareness of construction customers to have its place on the competitive market

In the EEH detached dwelling sample the mass of materials have been reduced by 57%, which is closely linked to energy and CO2 emission reduction in "pre-use" phase and transportation from the factories to the building site. In comparison to the SH the economization in transport impact have been of almost 90%.

In regard to the pre-use phase, the changes made to the most relevant materials (regarding its weight in the construction) and a good selection of them, making them as environmental-friendly as possible, it has been achieved a reduction in embodied energy of 80% and 90% in CO_2 footprint. Moreover because of choosing sustainable materials, they can be recycled and re-used, which may recover some of the embodied energy generated in pre-use phase, and saves even more in energy consumption and CO_2 emissions in future life cycles of materials.

The life cycle energy profiles for both the SH and the EEH indicated that most of the energy consumption and CO2 emission happen in the use phase, considering the useful life of a building is estimated at 50 years. And the energy consumption per year is usually quite high in economic terms. So in addition to pursuing EEH to prevent environmental damage and secure a healthier life-style in the future, we also look for economization on bills, in order to dwelling buyers or users to be involved in the purchase of a more sustainable and efficient housing.

The EEH indicated significant energy consumption savings relative to the SH, through the use of prefabricated parts of aerated concrete for the building's envelope, which offers a great energy efficiency, by reducing heat loss as much as 35% in the façade and the roof. This has a direct impact on the cooling and heating consumption.

Also thanks to the system of ecological windows used in the EEH the energy consumption is further reduced by, at the very least, 20%.

So even though the previously calculated daily energy consumptions in each example are very similar, having achieved such a large consumption saving in heating and cooling in the EEH, the receipts will be seriously affected as a direct consequence of it. After around ten years, the initial extra investment will be recuperated, offering pure benefit from that point on for the user in form of drastically reduced acclimatization costs.

The desirable goal have been achieved through this project, it being to find a balanced relationship between ecological and economical efficiency in a detached dwelling to make it a competitive product on the current construction market. People are getting gradually more and more aware of environmental situation thanks to direct and indirect information consumption they have been exposed to in the latest decades.

Cities are beginning to embrace those ideals of creating healthy urban landscapes, incrementing well-being in order to attract more residents, and businesses – factors which both have very positive effect on the economic situation of the geographic zone.

Not only the customers are benefited nonetheless, even though the project focused exclusively on a single family housing representing the lowest scale of the market; taken to a bigger extent, where local governments as well as large companies from private sector get involved into sustainable architecture, this phenomenon has the potential to gradually increase general well-being and the planet's also along the way.

The human being should be addressing all his efforts into understanding the nature's design and trying to mimic it to perfection, since it is but the only design system proven to be absolutely sustainable. And only after achieving a complete comprehension of it shall we try to look for new horizons.

"Cradle to Cradle" philosophy, which we explained previously to an average extent, means to be the mimicking nature ideology, therefore being the closest thing we had up until now to any effort in that direction.

On the other hand "LEED" certification, which the most respected and accepted on the current market, in spite of taking into account the material selection, energy efficiency, enhancement of interior environment quality, alternative energy use, etc. and having a rather global perspective on everything construction related, is not being consistent with sustainability and environmental awareness criteria it claims to defend. As, for example in case of solar panels, positively rated in this certification, the damage may very well exceed the benefit, if any. Also, simply making them profitable takes much more time than some of sever alternative solutions.

We should but pursue a completely sustainable, self-sufficient, as environmental-friendly as possible in each and every phase of life cycle, all of this while still being worthwhile economically.

As Gaudi said on an occasion, the architect of the future shall be guided by the imitation of the nature itself, because it is the most rational, long-lasting and economic method of them all.

8. REFERENCES

1. AIA Guide to Life Cycle Assessment in Practice. Published 2010 by The American Institute of Architects.

2. Article of Journal of Industrial Ecology. *Life-Cycle Energy, Costs, and Strategies for Improving a Single-Family House*. 2001.Gregory A. Keoleian Center for Sustainable Systems
University of MichiganAnn Arbor, MI, USA ; Steven Blanchard*Clean Air CampaignColorado Springs, CO, USA;* Peter Reppe*Center for Sustainable SystemsUniversity of MichiganAnn Arbor, MI, USA.*

3. *Material Architecture. Emergent materials for innovative buildings and ecological construction.* 2006. John Fernandez.

4. Software CES Selector 2013.

5. The International Organization for Standardization ISO 14000. Environmental Management .2009

6. The International Organization for Standardization ISO 14040. Environmental Management: Life cycle assessment. 2006

7. American Center for Life Cycle Assessment. Available from: http://www.lcacenter.org/about-lca.aspx

8. Life Cycle assessment: Past, Present and Future. Heijungs, Reinout; Huppes, Gjalt; Zamagni, Alessandra; Masoni, Paolo. 2011

9.The Encyclopedia of Earth.

http://www.eoearth.org/article/Life_cycle_assessment_of_farming_systems

10. Life Cycle Assessment. A guide to approaches, experiences and information sources. European Environment Agency. *Hoffman, Leif*
Schmidt, Anders. UK 1997.

11. What does “Cradle to Cradle” mean?

http://www.wisegeek.com/what-does-cradle-to-cradle-mean.htm

12. Wikipedia

http://en.wikipedia.org/wiki/Cradle_to_cradle

13. U.S. Green building council. (USGBC) LEED.

http://www.usgbc.org/leed/why-leed

14. Energy-related Environmental Impact of Buildings. Annex 31. November 2001.

15.Hormigón celular: eficiencia, sostenibilidad y ecología.

http://www.ytong.es/#_sub1544

16. Moso: bamboo flooring and panels.

http://www.moso-bamboo.com/company

17. Roof eco smart system: Plastic tile.

http://www.roofecosystem.com/

18. Thermal paint.

http://www.pinturatermica.org/

19. Ecological system for windows.

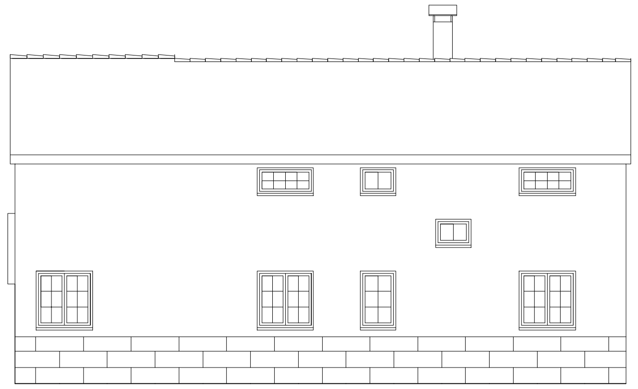
http://certificadoeficienciaenergeticamalaga.wordpress.com/category/ventanas-ecologicas/

20. Ecological Appliances.

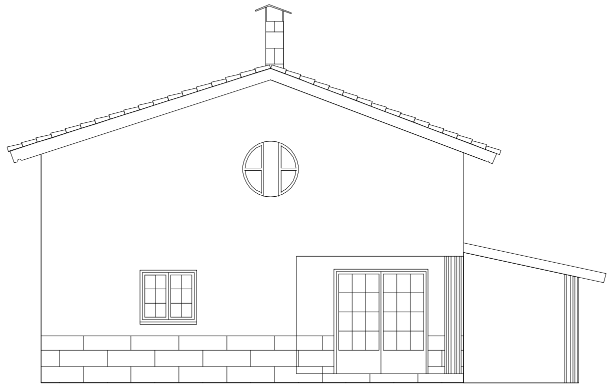
http://www.electrolux.es/Products/Cocina/Encimeras/Modulares/EQL4520BOG

9. APPENDIX A

9.1. HOUSE'S CONSTRUCTION DRAWINGS

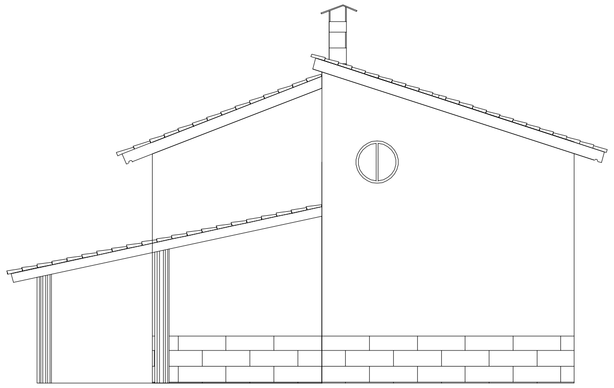


FACHADA NORTE



FACHADA OESTE

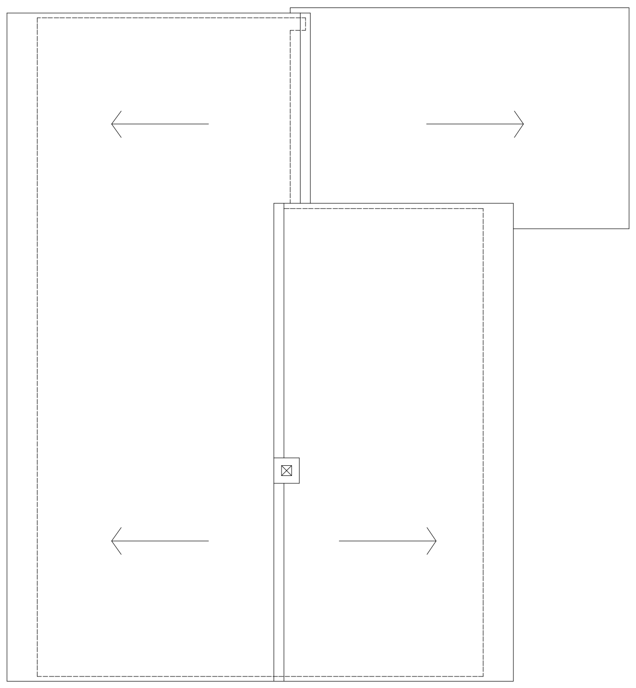
FACHADA SUR



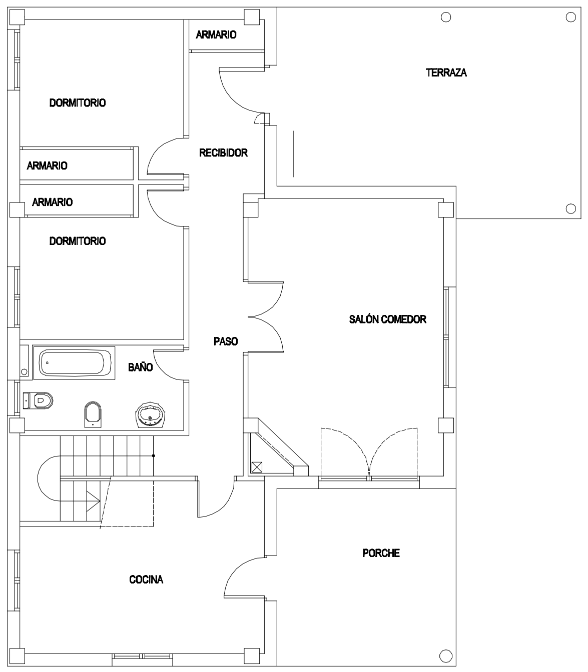
FACHADA ESTE

9. APPENDIX A: HOUSE'S CONSTRUCTION DRAWINGS

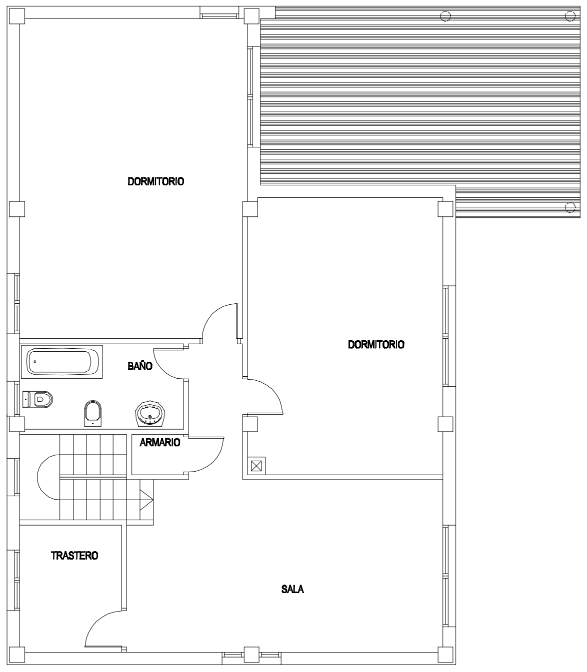
E: 1/150



CUBIERTA



DISTRIBUCIÓN PB



DISTRIBUCIÓN P1

9. APPENDIX A: HOUSE'S CONSTRUCTION DRAWINGS

E: 1/150

10. APPENDIX B

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

CALCULATING ASSEMBLIES	MATERIALS	kg/m3	ESPESOR (m)	kg/m2	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)	Assemblie mass Kg/m2	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)
Reinforced concrete	Concrete	2.400	1	2400	1,3	0,0998	14,4	2442	22,4	1,52	14,4
	Steel	42	1	42	30,3	2,06	44				
Faicing brick,PS,galvanize steel,gypsum	Facing brick	2.300	0,11	253	22,6	3,16	0,1	421,1	21,2	2,41	0,1
	Cement	2.200	0,01	22	6	1	1,26				
	PS	30	0,04	1,2	83,5	3,41	0,1				
	Brick (common,hard)	2.070	0,07	144,9	5	0,227	18,2				
Brickwork	Cement	2.200	0,01	22	6	1	1,26	188,9	3,84	0,378	1,26
	Brick (common,hard)	2.070	0,07	144,9	5	0,227	18,2				
	Cement	2.200	0,01	22	6	1	1,26				
Cement,PS high, ceramic tile	Cement	2.200	0,02	44	6	1	1,26	105,75	40,4	2,23	0,1
	Polystyrene extruded (Pshigh)	35	0,05	1,75	102	3,99	6,3				
	Roofing tile	2.400	0,025	60	12,6	1,76	0,1				
Double glass	Laminated Glass	2.450	0,005	12,25	30,6	1,84	0,1	59,5	95,4	5,15	0,1
	Aluminum flake	1.610	0,02	35	153	8,13	0,1				
	Laminated Glass	2.450	0,005	12,25	30,6	1,84	0,1				
Blinds	Extrusion Aluminum (ABS)	800	0,015	12	214	11,2	0,1	12	214	11,2	0,1
Stone veneer	Granite	3.200	0,025	80	6,4	0,335	1,48	113	5,86	0,503	1,26
	Cement	2.200	0,015	33	6	1	1,26				
Parging	Cement	2.200	0,013	28,6	6	1	1,26	28,6	6	1	1,26
Wall ceramic covering	Cement	2.200	0,015	33	6	1	1,26	61,52	14,5	1,45	0,1
	Adhesive	904	0,005	4,52	89,6	3,82	0,1				
	Ceramic tile	2.400	0,01	24	12,6	1,76	0,1				
Lining	Gypsum (general)	1.300	0,01	13	1,8	0,12	1,48	13	1,8	0,12	1,48
Paint	Dounle coat	1.600	0,003	4,8	1,28	0,07	0	4,8	1,28	0,07	0
Porcellanite	Cement	2.200	0,015	33	6	1	1,26	61,72	25,8	1,65	0,1
	Adhesive	904	0,005	4,52	89,6	3,82	0,1				
	Porcelain	2.420	0,01	24,2	42,1	2,27	0,1				
Terrazzo	Cement	2.200	0,01	22	6	1	1,26	115	1,37	0,185	1,26
	Fine sand	2.000	0,02	40	0,1	0,005	1,48				
	Sandstone	2.650	0,02	53	0,6	0,0297	1,48				
False ceiling	Plaster	1.700	0,005	8,5	2,31	0,206	0,1	16,04	46,6	2,93	0,1
	Galvanized steel	7.900	0,00022	1,74	28,7	1,97	57,8				
	Wool	145	0,04	5,8	56,3	3,52	0,1				

ASSEMBLIES	MATERIALS	kg/m3		kg/m	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)	Assemblie mass Kg/m	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)
Railing	Galvanized steel	7.900		22,4	28,7	1,97	57,8	22,4	28,7	1,97	57,8
Drainage and waste disposal	PVC (downpipes, drains)	1460		-	71	3,22	1,58	-	71	3,22	1,58
Plumbing	Polyethylene low density	932		0,506	87,5	3,64	8,86	0,506	87,5	3,64	8,86
	Stainless steel	8100		-	73,7	4,51	57,8	-	73,7	4,51	57,8
	PVC	1460		1,69	71	3,22	1,58	1,69	71	3,22	1,58
	Porcelain	2420		-	42,1	2,27	0,1	-	42,1	2,27	0,1
Electricity	Copper	8900		0,45	55	3,93	45	0,45	55	3,83	45
	PVC	1460		0,53	71	3,22	1,58	0,53	71	3,22	1,58

MEASURING

	CHAPTER/SUBJECT	MATERIALS	DENSITY (kg/m3)	Kg/m2	Q (m3)	FINAL MASS (kg)	
Estructural frame	Slab	Reinforced concrete	2.642	2442	34,25	90.488,50	
	Edge beam	Reinforced concrete	2.642	2442	3,89	10.277,38	
	Beams	Reinforced concrete	2.642	2442	11,11	29.352,62	
	Pillars	Reinforced concrete	2.642	2442	10,55	27.873,10	
	CHAPTER/SUBJECT	**MATERIALS**	**DENSITY (kg/m3)**	**Kg/m2**	**Q (m2)**	**FINAL MASS (kg)**	
Brick laying	Facing	Facing brick,PS,Brick common	2.040	421,10	204,33	86.043,36	
	Partition	Brickwork	2.020	188,90	156,10	29.487,29	
Roof	Roof	Cement,PS high, ceramic tile	1.550	105,75	145,32	15.367,59	
Glass	Glass	Double glass	1.850	59,50	9,28	552,16	
Defences	Blinds	Extrusion Aluminum (ABS)	1.610	12,00	7,49	89,88	
Covering	Wall Surface	Stone veneer	2.560	113,00	38,04	4.298,52	
		Parging	2.200	28,60	167,68	4.795,65	
		Wall ceramic covering	1.880	61,52	84,50	5.198,44	
		Lining	1.300	13,00	193,03	2.509,39	
		Paint	1.600	4,80	736,41	3.534,77	
	Flooring	Porcellanite	1.920	61,72	172,36	10.638,06	
		Terrazzo	2.350	115,00	35,53	4.085,95	
	Roofing	False ceiling	1.310	16,04	21,79	349,47	
	CHAPTER/SUBJECT	**MATERIALS**	**DENSITY (kg/m3)**	**Kg/m**	**Q (m)**	**FINAL MASS (kg)**	
Railing	Railing	Galvanized steel	7.900	22,40	2,64	59,14	
Drainage and waste disposal	PVC (downpipes, drains)	PVC	1.460	-	-	898,23	
Plumbing	Polyethylene low density	Polyethylene	932	0,51	15,00	7,59	
	Stainless steel	Stainless steel	7.900	-	-	49,50	
	PVC	PVC	1.460	1,69	3,00	5,07	
	Porcelain	Porcelain	2.420	-	-	64,50	
Electricity	Copper	Copper	8.900	0,45	160,00	72,00	
	PVC	PVC	1.460	0,53	160,00	84,80	
					TOTAL	326.182,95	Kg
						326,18	Tonnes

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

ASSEMBLIES	MATERIALS	Kg/m3	Q (m3)	FINAL MASS (kg)	Total Embodied energy (MJ/kg)	Total CO2 footprint (kg/kg)	%mass of total
Reinforced concrete	Concrete	2.400	59,80	143.520,00	186.576,00	14.323,30	45,67%
	Steel	42	59,80	2.511,60	76.101,48	5.173,90	0,80%
		Kg/m2	Q (m2)				
Faicing brick,PS,brick work	Facing brick	253	204,33	51.695,49	1.168.318,07	163.357,75	16,45%
	Cement	22	204,33	4.495,26	26.971,56	4.495,26	1,43%
	PS	1,2	204,33	245,20	20.473,87	836,12	0,08%
	Brick common	144,9	204,33	29.607,42	148.037,09	6.720,88	9,42%
Brickwork	Cement	22	156,10	3.434,20	20.605,20	3.434,20	1,09%
	Brick common	144,9	156,10	22.618,89	113.094,45	5.134,49	7,20%
	Cement	22	156,10	3.434,20	20.605,20	3.434,20	1,09%
Cement,PS high, ceramic tile	Cement	44	145,32	6.394,08	38.364,48	6.394,08	2,03%
	Polystyrene extruded (Pshigh)	1,75	145,32	254,31	25.939,62	1.014,70	0,08%
	Roofing tile	60	145,32	8.719,20	109.861,92	15.345,79	2,77%
Double glazing	Laminated Glass	12,25	9,28	113,68	3.478,61	209,17	0,04%
	Aluminum flake	35	9,28	324,80	49.694,40	2.640,62	0,10%
	Laminated Glass	12,25	9,28	113,68	3.478,61	209,17	0,04%
Blinds	Extrusion Aluminum (ABS)	12	7,49	89,88	19.234,32	1.006,66	0,03%
Stone veneer	Granite	80	38,04	3.043,20	19.476,48	1.019,47	0,97%
	Cement	33	38,04	1.255,32	7.531,92	1.255,32	0,40%
Parging	Cement	28,6	167,68	4.795,65	28.773,89	4.795,65	1,53%
Wall ceramic covering	Cement	33	84,50	2.788,50	16.731,00	2.788,50	0,89%
	Adhesive	4,52	84,50	381,94	34.221,82	1.459,01	0,12%
	Ceramic tile	24	84,50	2.028,00	25.552,80	3.569,28	0,65%
Lining	Gypsum (general)	13	193,03	2.509,39	4.516,90	301,13	0,80%
Paint	Dounle coat	4,8	736,41	3.534,77	4.511,34	234,41	1,12%
Porcellanite	Cement	33	172,36	5.687,88	34.127,28	5.687,88	1,81%
	Adhesive	4,52	172,36	779,07	69.804,42	2.976,04	0,25%
	Porcelain	24,2	172,36	4.171,11	175.603,82	9.468,42	1,33%
Terrazzo	Cement	22	35,53	781,66	4.689,96	781,66	0,25%
	Fine sand	40	35,53	1.421,20	142,12	7,11	0,45%
	Sandstone	53	35,53	1.883,09	1.129,85	55,93	0,60%
False ceiling	Plaster	8,5	21,79	185,22	427,85	38,15	0,06%
	Galvanized steel	1,74	21,79	37,87	1.086,90	74,61	0,01%
	Wool	5,8	21,79	126,38	7.115,31	444,86	0,04%
ASSEMBLIES	**MATERIALS**	Kg/m	Q (m)	**FINAL MASS (kg)**			
Railing	Galvanized steel	22,4	2,64	59,14	1.697,20	116,50	0,02%
Drainage and waste disposal	PVC (downpipes, drains)	-	-	898,23	63.774,33	2.892,30	0,29%
Plumbing	Polyethylene low density	0,506	15	7,59	664,13	27,63	0,00%
	Stainless steel	-	-	49,50	3.648,15	223,25	0,02%
	PVC	1,69	3	5,07	359,97	16,33	0,00%
	Porcelain	-	-	64,50	2.715,45	146,42	0,02%
Electricity	Copper	0,45	160	72	3.960,00	282,96	0,02%
	PVC	0,53	160	84,8	6.020,80	273,06	0,03%

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

CALCULATING TRANSPORT

MATERIALS	TRANSPORT TYPE	COMPONENT MASS (tonnes)	DISTANCE (Km)	ENERGY (MJ)	CO2 footprint (kg)
Concrete	100 tonne truck	143,52	200	24.398,40	1.732,29
Steel	14 tonne truck	2,51	52	60,08	4,27
Facing brick	100 tonne truck	51,70	180	2.805,89	199,22
Brick common		29,61			
Brick common		22,62			
PS	14 tonne truck	0,25	40	8,34	0,59
Cement	32 tonne truck	4,50	30	245,06	17,40
Cement		3,43			
Cement		3,43			
Cement		6,39			
Polystyrene extruded (Pshigh)	14 tonne truck	0,25	40	8,65	0,61
Roofing tile	14 tonne truck	8,72	90	667,02	47,36
Double glass	14 tonne truck	0,55	60	35,76	2,54
Extrusion Aluminum (ABS)		0,09			
Galvanized steel		0,06			
Granite	14 tonne truck	3,04	142	1.342,84	95,34
Sandstone		1,88			
Ceramic		2,03			
Porcelain		4,17			
Cement	32 tonne truck	1,26	30	230,88	16,39
Cement		4,80			
Cement		2,79			
Cement		5,69			
Fine sand		1,42			
Cement		0,78			
Adhesive	14 tonne truck	0,38	140	558,80	39,67
Adhesive		0,78			
Dounle coat(paint)		3,53			
Gypsum	14 tonne truck	2,51	66	160,38	11,39
Plaster		0,19			
Galvanized steel		0,04			
Wool		0,13			
PVC (downpipes, drains)	14 tonne truck	0,90	74	56,98	4,05
Polyethylene low density		0,01			
Stainless steel	14 tonne truck	0,05	74	7,49	0,53
PVC		0,01			
Porcelain		0,06			
Cupper	14 tonne truck	0,07	70	9,33	0,66
PVC		0,08			
			TOTAL	30.595,87	2.172,31

TOTAL EMBODIED ENERGY AND C0$_2$ FOOTPRINT

ASSEMBLIES	FINAL MASS (kg)	Total Embodied energy (MJ/kg)	Total CO2 footprint (kg/kg)
Reinforced concrete	157.991,60	3.539.011,84	240.147,23
Facing brick,PS,Brick common	86.043,36	1.824.119,30	207.364,50
Brickwork	29.487,29	113.231,19	11.146,20
Cement,PS high, ceramic tile	15.367,59	620.850,64	34.269,73
Double glass	552,16	52.676,06	2.843,62
Extrusion Aluminum (ABS)	89,88	19.234,32	1.006,66
Stone veneer	4.298,52	25.189,33	2.162,16
Parging	4.795,65	28.773,89	4.795,65
Wall ceramic covering	5.198,44	75.377,38	7.537,74
Lining	2.509,39	4.516,90	301,13
Paint	3.534,77	4.511,34	234,41
Porcellanite	10.638,06	274.461,93	17.552,80
Terrazzo	4.085,95	5.597,75	755,90
False ceiling	349,47	16.285,21	1.023,94
Galvanized steel	59,14	1.697,20	116,50
PVC (downpipes, drains)	898,23	63.774,33	2892,3006
Polyethylene low density	7,59	664,13	27,6276
Stainless steel	49,5	3.648,15	4,51
PVC	5,07	359,97	16,3254
Porcelain	64,5	2.715,45	146,415
Copper	72	3.960,00	3960
PVC	84,8	6.020,80	273,056

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

ASSEMBLIES	MATERIALS	END OF LIFE OPTION	% RECOVERED	ENERGY (MJ)	CO2 footprint (kg)
Reinforced concrete	Concrete	Recycle	14,40	-26.866,94	521,13
	Steel	Recycle	44,00	-33.484,65	9,81
Facing brick,PS,galvanize steel,gypsum	Facing brick	Landfill	0	0	187,19
	Cement	Downcycle	1,26	-339,84	16,28
	PS	Downcycle	0,10	-20,47	0,89
	Brick (common,hard)	Downcycle	18,20	-26.942,75	107,21
Brickwork	Cement	Downcycle	1,26	-259,63	12,44
	Brick (common,hard)	Downcycle	18,20	-20.583,19	81,90
	Cement	Downcycle	1,26	-259,63	12,44
Cement,PS high, ceramic tile	Cement	Downcycle	1,26	-483,39	23,15
	Polystyrene extruded (Pshigh)	Recycle	6,30	-1.634,20	0,94
	Roofing tile	Landfill	0	0	31,57
Double glass	Laminated Glass	Landfill	0	0	0,41
	Aluminum flake	Landfill	0	0	1,18
	Laminated Glass	Landfill	0	0	0,41
Blinds	Extrusion Aluminum (ABS)	Landfill	0	0	0,33
Stone veneer	Granite	Downcycle	1,48	-288,25	11,02
	Cement	Downcycle	1,26	-94,90	4,55
Parging	Cement	Downcycle	1,26	-362,55	17,37
Wall ceramic covering	Cement	Downcycle	1,26	-210,81	10,10
	Adhesive	Landfill	0	0	1,38
	Ceramic tile	Downcycle	0,1	-25,55	7,34
Lining	Gypsum (general)	Downcycle	0,1	-4,52	9,09
Paint	Dounle coat	Landfill	0	0	12,80
Porcellanite	Cement	Downcycle	1,26	-430,00	20,60
	Adhesive	Landfill	0	0	2,82
	Porcelain	Landfill	0	0	15,10
Terrazzo	Cement	Downcycle	1,26	-59,09	2,83
	Fine sand	Downcycle	1,48	-2,10	5,15
	Sandstone	Downcycle	1,48	-16,72	6,82
False ceiling	Plaster	Landfill	0	0	0,67
	Galvanized steel	Recycle	57,8	-628,23	0,15
	Wool	Recycle	0	0,00	0,46
Railing	Galvanized steel	Recycle	57,8	-980,98	0,24
Drainage and waste disposal	PVC (downpipes, drains)	Recycle	1,58	-1.007,63	3,27
Plumbing	Polyethylene low density	Recycle	8,86	-58,84	0,03
	Stainless steel	Recycle	57,8	-2.108,63	0,22
	PVC	Recycle	1,58	-5,69	0,02
	Porcelain	Landfill	0	0,00	0,23
Electricity	Copper	Recycle	45	-1.782,00	0,29
	PVC	Recycle	1,58	-95,13	0,31
			TOTAL	-119.036,33	1.140,11

CALCULATING END OF LIFE OF THE MATERIALS

ENERGY TRANSPORT (MJ)	MATERIALS	CO2 footprint recycle (kg)	Final mass (tonnes)	Final mass (kg)	Transport type	Transport energy (MJ/tonne/km)	CO2 footprint source (Kg/MJ)
7.319,52	Concrete	0,0698	143,52	143.520,00	32 tonne truck	0,46	0,071
128,09	Steel	0,646	2,51	2.511,60	14 tonne truck	0,85	0,071
2.636,47	Facing brick	-	51,70	51.695,49			
229,26	Cement	-	4,50	4.495,26			
12,50	PS	2,77	0,25	245,20			
1.509,98	Brick (common,hard)		29,61	29.607,42			
175,14	Cement	-	3,43	3.434,20			
1.153,56	Brick (common,hard)		22,62	22.618,89			
175,14	Cement	-	3,43	3.434,20			
326,10	Cement	-	6,39	6.394,08			
12,97	Polystyrene extruded (Pshigh)	1,35	0,25	254,31			
444,68	Roofing tile	-	8,72	8.719,20			
5,80	Laminated Glass	-	0,11	113,68			
16,56	Aluminum flake	-	0,32	324,80			
5,80	Laminated Glass	-	0,11	113,68			
4,58	Extrusion Aluminum (ABS)	-	0,09	89,88			
155,20	Granite	-	3,04	3.043,20			
64,02	Cement	-	1,26	1.255,32			
244,58	Cement	-	4,80	4.795,65			
142,21	Cement	-	2,79	2.788,50			
19,48	Adhesive	1,3	0,38	381,94			
103,43	Ceramic tile	-	2,03	2.028,00			
127,98	Gypsum (general)	1,82	2,51	2.509,39			
180,27	Dounle coat		3,53	3.534,77			
290,08	Cement	-	5,69	5.687,88			
39,73	Adhesive	1,3	0,78	779,07			
212,73	Porcelain	-	4,17	4.171,11			
39,86	Cement	-	0,78	781,66			
72,48	Fine sand	-	1,42	1.421,20			
96,04	Sandstone	-	1,88	1.883,09			
9,45	Plaster	-	0,19	185,22			
1,93	Galvanized steel	0,62	0,04	37,87			
6,45	Wool	1,46	0,13	126,38			
3,02	Galvanized steel	0,62	0,06	59,14			
45,81	PVC (downpipes, drains)	1,09	0,90	898,23			
0,39	Polyethylene low density	1,24	0,01	7,59			
2,52	Stainless steel	1,27	0,05	49,50			
0,26	PVC	1,09	0,01	5,07			
3,29	Porcelain	-	0,06	64,50			
3,67	Copper	1,04	0,07	72,00			
4,32	PVC	1,09	0,08	84,80			

	Distancia (km)
Vertedero	50
Planta de Reciclaje	60

10.1. INVENTORY ANALYSIS RESULTS STANDARD HOUSE

10. APPENDIX B

10.2. INVENTORY ANALYSIS RESULTS ENERGY EFFICIENT HOUSE

10.2. INVENTORY ANALYSIS RESULTS ENERGY EFFICIENT HOUSE

CALCULATING ASSEMBLIES	MATERIALS	kg/m3	ESPESOR (m)	kg/m2	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)	Assemblie mass Kg/m2	Embodied energy (MJ/kg)	CO2 footprint (kg/kg)	Recycle fraction (%)
Reinforced concrete	Aerated concrete (structural)	900	1	900	1,3	0,0998	14,4	930	22,4	1,52	14,4
	Steel	30	1	30	30,3	2,06	44				
Slab	Steel	20	-	36	30,3	2,06	44	180	5,18	0,35	44
	Aerated concrete (placas)	600	0,24	144	0,031	0,0029	100				
Faicing	Aerated concrete (blocks)	350	0,25	87,5	0,046	0,00436	100	87,5	0,046	0,00436	100
Partitions	Aerated concrete (blocks)	500	0,1	50	0,034	0,0032	100	50	0,034	0,0032	100
Roof	Aerated concrete (placas)	500	0,15	75	0,037	0,0035	100	89,2	25,27	1,08	6,3
	Steel	30	-	5	30,3	2,06	44				
	Polystyrene extruded (Pshigh)	35	0,04	1,4	102	3,99	6,3				
	Plastic tile (LDPE)	1.560	0,005	7,8	78,1	1,7	100				
Double glass	Laminated Glass	2.450	0,005	12,25	30,6	1,84	0,1	54,5	19,04	1,04	0,1
	Wood	530	0,06	30	9,7	0,396	100				
	Laminated Glass	2.450	0,005	12,25	30,6	1,84	0,1				
Bamboo parquet	Bamboo (sist.click)	700	0,015	10,5	6	0,3	1,48	10,5	6	0,3	1,48
Lining	Gypsum (general)	1.300	0,003	3,9	1,8	0,12	1,48	3,9	1,8	0,12	1,48
Faicing paint	Faicing paint	1.700	0,01	17	1,28	0,07	0,1	17	1,28	0,07	0,1
Paint	Dounle coat	1.600	0,003	4,8	1,28	0,07	0,1	4,8	1,28	0,07	0,1
Porcellanite	Cement	2.200	0,015	33	6	1	1,26	61,72	25,8	1,65	0,1
	Adhesive	904	0,005	4,52	89,6	3,82	0,1				
	Porcelain	2.420	0,01	24,2	42,1	2,27	0,1				
Bamboo exterior	Bamboo extreme	1.200	0,02	24	7	1,67	1,48	24	7	1,67	1,26
False ceiling	Plaster	1.700	0,005	8,5	2,31	0,206	0,1	63,04	46,6	2,93	0,1
	Galvanized steel	7.900	0,00022	1,74	28,7	1,97	57,8				
	Wool	1.320	0,04	52,8	56,3	3,52	0,1				
ASSEMBLIES	**MATERIALS**	**kg/m3**		**kg/m**	**Embodied energy (MJ/kg)**	**CO2 footprint (kg/kg)**	**Recycle fraction (%)**	**Assemblie mass Kg/m**	**Embodied energy (MJ/kg)**	**CO2 footprint (kg/kg)**	**Recycle fraction (%)**
Railing	Galvanized steel	7.900		22,4	28,7	1,97	57,8	22,4	28,7	1,97	57,8
Drainage and waste disposal	Polypropylene (downpipes, drains)	946		-	75,7	2,96	6	-	75,7	2,96	6
Plumbing	Polyethylene low density	932		0,4	87,5	3,64	8,86	0,4	87,5	3,64	8,86
	Stainless steel	8100		-	73,7	4,51	57,8	-	73,7	4,51	57,8
	Polypropylene	946		1,4	75,7	2,96	6	1,4	75,7	2,96	6
	Porcelain	2420		-	42,1	2,27	0,1	-	42,1	2,27	0,1
Electricity	Copper	8900		0,45	55	3,93	45	0,45	55	3,83	45
	Polypropylene	946		0,45	75,7	2,96	6	0,45	75,7	2,96	6

10.2. INVENTORY ANALYSIS RESULTS ENERGY EFFICIENT HOUSE

MEASURING

	CHAPTER/SUBJECT	MATERIALS	DENSITY (kg/m3)	Kg/m2	Q (m3)	FINAL MASS (kg)
Estructural frame	Slab	Aerated concrete (placas),steel	720	216	78,60	56.592,00
	Edge beam	Reinforced concrete	930	930	2,70	2.511,00
	Beams	Reinforced concrete	930	930	8,15	7.579,50
	Pillars	Reinforced concrete	930	930	7,55	7.021,50
	CHAPTER/SUBJECT	**MATERIALS**	**DENSITY (kg/m3)**	**Kg/m2**	**Q (m2)**	**FINAL MASS (kg)**
Brick laying	Facing	Aerated concreteconcrete (blocks)	350	87,50	204,33	17.878,88
	Partition	Aerated concrete concrete (blocks)	550	50,00	156,10	7.805,00
Roof	Roof	Aerated concrete (placas) ,PS high, plastic tile	620	89,20	119,00	10.614,80
Glass	Glass	Double glass	1.850	54,50	9,28	505,76
Revestimientos	Flooring	Bamboo parquet	700	10,50	172,36	1.809,78
	Wall Surface	Lining	1.300	3,90	360,68	1.406,65
		Faicing paint	1.700	17,00	204,33	3.473,61
		Paint	1.600	4,80	736,41	3.534,77
	Flooring	Porcellanite	1.920	61,72	84,50	5.215,34
		Bamboo extreme	1.200	24,00	35,53	852,72
	Roofing	False ceiling	1.310	63,04	21,79	1.373,60
	CHAPTER/SUBJECT	**MATERIALS**	**DENSITY (kg/m3)**	**Kg/m**	**Q (m)**	**FINAL MASS (kg)**
Railing	Railing	Galvanized steel	7.900	22,40	2,64	59,14
Drainage and waste disposal	Polypropylene (downpipes, drains)	Polypropylene	946	-	-	898,23
Plumbing	Polyethylene low density	Polyethylene	932	0,40	15,00	6,00
	Stainless steel	Stainless steel	7.900	-	-	49,50
	Polypropylene	Polypropylene	946	1,40	3,00	4,20
	Porcelain	Porcelain	2.420	-	-	64,50
Electricity	Copper	Copper	8.900	0,45	160,00	72,00
	Polypropylene	Polypropylene	946	0,45	160,00	72,00

ASSEMBLIES	**MATERIALS**	**Kg/m3**	**Q (m3)**	**FINAL MASS (kg)**	**Total Embodied energy (MJ/kg)**	**Total CO2 footprint (kg/kg)**
Reinforced concrete	Aerated concrete	900	18,40	16.560,00	21528	1652,688
	Steel	30	18,40	552,00	16725,6	1137,12
Slab	Steel	15	78,60	1.179,00	35723,7	2428,74
	Aerated concrete (placas)	600	78,60	47.160,00	1461,96	136,764
		Kg/m2	**Q (m2)**			
Faicing	Aerated concrete (blocks)	88	204,33	17.878,88	822,43	77,95
Partitions	Aerated concrete (blocks)	50	156,10	7.805,00	265,37	24,98
Roof	Aerated concrete (placas)	75	119,00	8.925,00	330,23	31,24
	Steel	5	119,00	595,00	18.028,50	1.225,70
	Polystyrene extruded (Pshigh)	1,4	119,00	166,60	16.993,20	664,73
	Plastic tile (LDPE)	7,8	119,00	928,20	72.492,42	1.577,94
Double glazing	Laminated Glass	12,25	9,28	113,68	3.478,61	209,17
	Wood (pine)	30	9,28	278,40	2.700,48	110,25
	Laminated Glass	12,25	9,28	113,68	3.478,61	209,17
Bamboo parquet	Bamboo (sist.click)	10,5	172,36	1.809,78	10.858,68	542,93
Lining	Gypsum (general)	3,9	360,68	1.406,65	2.531,97	168,80
Faicing paint	Faicing paint	17,00	204,33	3.473,61	4.446,22	243,15
Paint	Dounle coat	4,8	736,41	3.534,77	4.511,34	234,41
Porcellanite	Cement	33	84,50	2.788,50	16.731,00	2.788,50
	Adhesive	4,52	84,50	381,94	34.221,82	1.459,01
	Porcelain	24,2	84,50	2.044,90	86.090,29	4.641,92
Bamboo extreme	Bamboo	24	35,53	852,72	5.969,04	1.424,04
False ceiling	Plaster	8,5	21,79	185,22	427,85	38,15
	Galvanized steel	1,74	21,79	37,87	1.086,90	74,61
	Wool	52,8	21,79	1.150,51	64.773,83	4.049,80
ASSEMBLIES	**MATERIALS**	Kg/m	Q (m)	**FINAL MASS (kg)**		
Railing	Galvanized steel	22,4	2,64	59,14	1.697,20	116,50
Drainage and waste disposal	Polypropylene (downpipes, drains)	-	-	898,23	67.996,01	2.658,76
Plumbing	Polyethylene low density	0,4	15	6,00	525,00	21,84
	Stainless steel	-	-	49,50	3.648,15	223,25
	Polypropylene	1,4	3	4,20	317,94	12,43
	Porcelain	-	-	64,50	2.715,45	146,42
Electricity	Copper	0,45	160	72,00	3.960,00	282,96
	Polypropylene	0,45	160	72,00	5.450,40	213,12

10.2. INVENTORY ANALYSIS RESULTS ENERGY EFFICIENT HOUSE

CALCULATING TRANSPORT

MATERIALS	TRANSPORT TYPE	COMPONENT MASS (tonnes)	DISTANCE (Km)	ENERGY (MJ)	CO2 footprint (kg)
Aerated concrete	14 tonne truck	1,65	100	140,48	9,97
Steel	14 tonne truck	1,14	50	203,64	14,46
Steel		2,43			
Steel		1,23			
Aerated concrete (placas)	14 tonne truck	0,14	60	15,41	1,09
Aerated concrete (blocks)		0,08			
Aerated concrete (blocks)		0,02			
Aerated concrete (placas)		0,06			
Polystyrene extruded (Pshigh)	14 tonne truck	0,66	40	76,25	5,41
Plastic tile (LDPE)		1,58			
Wood	14 tonne truck	0,28	60	25,79	1,83
Laminated Glass		0,23			
Bamboo extreme	14 tonne truck	1,42	250	328,07	23,29
Bamboo (sist.click)		0,12			
Gypsum (general)	14 tonne truck	0,17	30	243,90	17,32
Faicing paint		3,47			
Dounle coat		0,23			
Cement		5,69			
Adhesive	14 tonne truck	2,98	30	317,33	22,53
Porcelain		9,47			
Plaster	14 tonne truck	0,04	66	233,52	16,58
Galvanized steel		0,07			
Wool		4,05			
Galvanized steel	14 tonne truck	0,12	40	3,96	0,28
Polypropylene (downpipes, drains)	14 tonne truck	2,66	74	168,61	11,97
Polyethylene low density		0,02			
Stainless steel	14 tonne truck	0,22	74	24,03	1,71
Polypropylene		0,01			
Porcelain		0,15			
Copper	14 tonne truck	0,28	70	29,52	2,10
Polypropylene		0,21			
			TOTAL	1.810,52	128,55

TOTAL EMBODIED ENERGY AND C0$_2$ FOOTPRINT

MATERIALS	FINAL MASS (kg)	Total Embodied energy (MJ/kg)	Total CO2 footprint (kg/kg)
Reinforced concrete	17.112,00	383.308,80	26.010,24
Slab	56.592,00	292.961,50	19.954,74
Faicing	17.878,88	822,43	77,95
Partitions	7.805,00	265,37	24,98
Roof	10.614,80	268.249,90	11.468,28
Double glass	505,76	9.631,59	527,06
Bamboo parquet	1.809,78	10.858,68	542,93
Lining	1.406,65	2.531,97	168,80
Faicing paint	3.473,61	4.446,22	243,15
Paint	3.534,77	4.511,34	234,41
Porcellanite	5.215,34	134.555,77	8.605,31
Bamboo exterior	852,72	5.969,04	1.424,04
False ceiling	1.373,60	64.009,67	4.024,64
Railing	59,14	1697,2032	116,50
Drainage and waste disposal	898,23	67996,011	2.658,76
Polyethylene low density	6,00	525	21,84
Stainless steel	49,50	3648,15	223,25
Polypropylene	4,20	317,94	12,43
Porcelain	64,50	2715,45	146,42
Copper	72,00	3960	275,76
Polypropylene	72,00	5450,4	213,12

10.2. INVENTORY ANALYSIS RESULTS ENERGY EFFICIENT HOUSE

CALCULATING END OF LIFE OF THE MATERIALS

ASSEMBLIES	**MATERIALS**	**END OF LIFE OPTION**	**% RECOVERED**	**ENERGY (MJ)**	**CO2 footprint (kg)**
Reinforced concrete	Aerated concrete	Recycle	14,40	-3.100,03	6,00
	Steel	Recycle	44,00	-7.359,26	4,44
Slab	Steel	Recycle	44,00	-15.718,43	9,49
	Aerated concrete (placas)	Recycle	100,00	-1.461,96	0,50
Faicing	Aerated concrete (blocks)	Recycle	100,00	-822,43	0,29
Partitions	Aerated concrete (blocks)	Recycle	100,00	-265,37	0,09
Roof	Aerated concrete (placas)	Recycle	100,00	-330,23	0,23
	Steel	Recycle	44,00	-7.932,54	4,79
	Polystyrene extruded (Pshigh)	Recycle	6,30	-1.070,57	2,46
	Plastic tile (LDPE)	Recycle	10,00	-7.249,24	5,91
Double glass	Wood	Renowable	100,00	-2.700,48	1,01
	Laminated Glass	Re-use	60,00	-4.174,33	1,00
Bamboo parquet	Bamboo (sist.click)	Renowable	100,00	-10.858,68	0,31
Lining	Gypsum (general)	Downcycle	0,1	-2,53	0,61
Faicing paint	Faicing paint	Landfill	0	0,00	12,58
Paint	Dounle coat	Landfill	0	0,00	0,85
Porcellanite	Cement	Downcycle	1,26	-210,81	20,60
	Adhesive	Landfill	0	0,00	10,78
	Porcelain	Landfill	0	0,00	34,29
Bamboo exterior	Bamboo extreme	Renowable	100,00	-5.969,04	3,64
False ceiling	Plaster	Landfill	0	0,00	0,14
	Galvanized steel	Recycle	57,80	-628,23	0,30
	Wool	Renowable	100,00	-64.773,83	14,66
Railing	Galvanized steel	Recycle	57,80	-980,98	0,46
Drainage and waste disposal	Polypropylene (downpipes, drains)	Recycle	6,00	-4.079,76	9,80
Plumbing	Polyethylene low density	Recycle	8,86	-46,52	0,08
	Stainless steel	Recycle	57,80	-2.108,63	0,97
	Polypropylene	Recycle	6,00	-19,08	0,05
	Porcelain	Landfill	0,00	0,00	0,53
Electricity	Copper	Recycle	45,00	-1.782,00	1,16
	Polypropylene	Recycle	6,00	-327,02	0,79
			TOTAL	-143.971,98	148,80

ENERGY TRANSPORT (MJ)	**MATERIALS**	**CO2 footprint recycle (kg)**	**Final mass (tonnes)**	**Final mass (kg)**
84,29	Aerated concrete	0,07	1,65	1.652,69
57,99	Steel	0,65	1,14	1.137,12
123,87	Steel	0,65	2,43	2.428,74
6,97	Aerated concrete (placas)	0,07	0,14	136,76
3,98	Aerated concrete (blocks)	0,07	0,08	77,95
1,27	Aerated concrete (blocks)	0,07	0,02	24,98
3,19	Aerated concrete (placas)	0,07	0,06	62,48
62,51	Steel	0,65	1,23	1.225,70
33,90	Polystyrene extruded (Pshigh)	1,35	0,66	664,73
80,47	Plastic tile (LDPE)	1,24	1,58	1.577,94
14,20	Wood	-	0,28	278,40
11,60	Laminated Glass	1,29	0,23	227,36
6,11	Bamboo (sist.click)	-1,06	0,12	119,83
8,61	Gypsum (general)	1,82	0,17	168,80
177,15	Faicing paint	-	3,47	3.473,61
11,96	Dounle coat	-	0,23	234,41
290,08	Cement	-	5,69	5.687,88
151,78	Adhesive	1,30	2,98	2.976,04
482,89	Porcelain	-	9,47	9.468,42
72,63	Bamboo extreme	-1,06	1,42	1.424,04
1,95	Plaster	-	0,04	38,15
3,80	Galvanized steel	0,62	0,07	74,61
206,54	Wool	-	4,05	4.049,80
5,94	Galvanized steel	0,62	0,12	116,50
135,60	Polypropylene (downpipes, drains)	1,11	2,66	2.658,76
1,11	Polyethylene low density	1,24	0,02	21,84
11,39	Stainless steel	1,27	0,22	223,25
0,63	Polypropylene	1,11	0,01	12,43
7,47	Porcelain	-	0,15	146,42
14,43	Copper	1,04	0,28	282,96
10,87	Polypropylene	1,11	0,21	213,12

Transport type	**Transport energy (MJ/tonne/km)**	**CO2 footprint source (Kg/MJ)**
32 tonne truck	0,46	0,071
14 tonne truck	0,85	0,071
100 tonne truck	0,15	0,071

	Distancia (km)
Vertedero	50
Planta de Reciclaje	60