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Sustainable Construction in Public and Private Works through IPP approach

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Report

Life Cycle Assessment of an Office Building

Leading Partner: NTUA

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Versioning and contribution history

Version	Description	Comments
1	Life Cycle Assessment study of an Office Building	1st Draft

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1 Introduction

As concern over the environmental impacts of construction grows, many researchers are beginning to use life cycle assessment as a means to quantify natural resources consumption, and emissions of global greenhouse gases. Historically, focus has been on understanding energy use during the operational period of the home (use phase). To understand overall environmental impacts of the building, all life cycle stages should be inventoried (material production, manufacturing, use, retirement). Assessing the environmental impact of a complex system, such as an office building, requires an understanding of the environmental impacts of all of its parts. As the production sequence is followed upstream, the material and energy input requires more effort to quantify. The procedures used in this study are standard life cycle assessment methods.

This report is part of Task 3 “Life Cycle Assessment in two construction activities” of the research project “Sustainable Construction in Public and Private Works through IPP approach – SUSCON” project. The object of this study was the environmental performance of an office building built in Athens, Greece. The report presents the Life Cycle Assessment study of the office building. The building consists of three basements, the groundfloor, three floors and the rooftop. The building was selected because it is close to the average size of new buildings built in Greece and uses standard construction materials and techniques. The mass of all building materials was determined. The modelling of the system and the impact assessment has been done with the use of the “GaBi 4” software. The software system GaBi is a tool for the modelling of life-cycle-balances.

The construction components and materials (e.g., gypsum boards, paint, concrete) consist of multiple materials. The inventory of the building system has been divided into eight systems: 3rd basement, 2nd basement, 1st basement, the groundfloor, 1st floor, 2nd floor, 3rd floor and the rooftop.

The life cycle of the building consists of three distinct phases; construction, use and end-of-life. The construction phase consists of the manufacturing and transportation of all building materials used, and the construction of the building. The use phase encompasses all activities related to the use of the building over an assumed life of 80 years. These activities includes all energy consumed within the building, including heating, cooling and lighting. The end-of-life phase deals with the eventual demolishing of the building, and includes the actual dismantling of it, and transportation of waste to recycling operations or landfills. The recycling, incineration, or other end-of-life management processes have not been included in this study.

The main responsibility for the implementation of this task lies on the Unit of Environmental Science and Technology (UEST) of the National Technical University of Athens (NTUA). The construction company EDRASIS C. PSALLIDAS S.A. that built the office building in Greece, has provided crucial input regarding the Life Cycle Inventory (LCI) of the system.

2 Life Cycle Assessment

2.1 About the methodology

Life Cycle Assessment (LCA) (or Analysis) is a method, which quantifies the environmental impacts associated with the delivery of a particular service or product. An accepted definition is:

'*LCA is a systematic way of evaluating the environmental impact of products or activities by following a 'cradle to grave' approach. This approach implies the identification and quantification of emissions and material consumption which affects the environment at all stages of the entire product of life cycle*'.

Thus the analysis includes all processes connected to the delivery of this service or product, from the extraction of raw materials to the disposal of wastes. This network of processes forms the life cycle of the product or service. Using this method ensures that all processes, which contribute to the environmental impacts of the delivery of a particular service or product are included in the final result. This produces an unambiguous picture of the overall impacts in certain environmental categories of a particular energy system, allowing the comparison of different energy systems to be made on a consistent basis.

The life cycles of production systems will therefore include processes such as raw material extraction, transportation, intermediate processing and delivery.

For each process within the life cycle, detailed inventories of the material and energy inputs and outputs are produced. In this way a life cycle inventory (LCI) is produced which accounts for the total inputs and outputs of all energy and material flows attributable to the provision of a particular service or product.

These inventories consist of a large number of inflows and outflows, which in them are difficult to relate to individual environmental problems. To make the results intelligible and relevant these material and energy flows have to be translated into environmental impacts. This is the final assessment of the LCA. This relates the overall life cycle inventory to the effect on the environment of providing a certain service or product (Figure 2.1).

The contribution of each input or output flow in the life cycle inventory to the each of the environmental impact categories is calculated by multiplying by a relevant factor. Thus an output of CO_2 contributes a certain amount to global warming potential, CFC emissions to both greenhouse gas emissions and ozone depletion potential, and SO_2 and NO_x emissions to acidification potential. In each case the impact described is equal to the maximum impact on the environment that could be caused by the particular emission or consumption of resource.

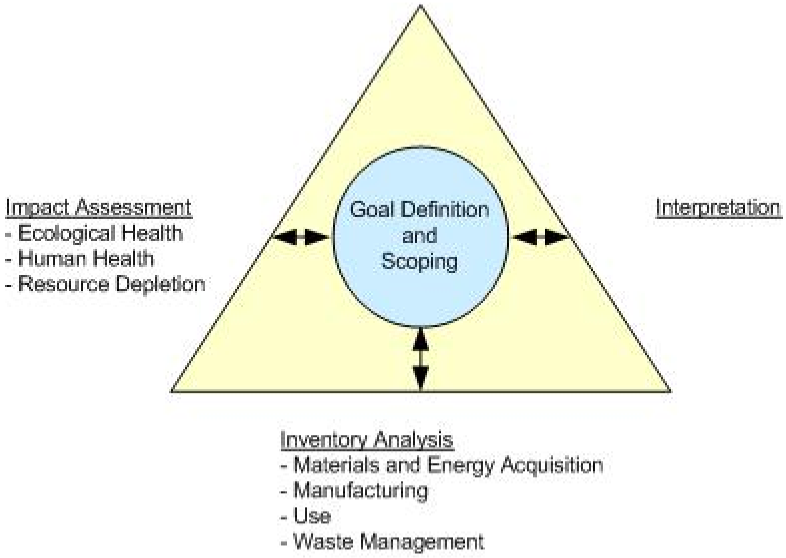

Figure 2.1: Technical framework for life cycle assessment studies

The end result of this procedure is to produce graphs of the environmental impacts in each category caused by the provision of the product or service. This information can be used in two ways. Firstly, when looking only at one life cycle, it can be used to assess which particular processes in the life cycle are responsible for the most significant environmental impacts. This allows improvements to the system to be targeted where they are likely to be most effective at reducing each category of environmental impact. Secondly, the results can be used to compare the environmental impacts of systems with the same functional units. This will provide answers to the questions of which energy system contributes most to each environmental category.

Thus LCA will give a clear and unambiguous account of the environmental impacts of the product under study and will allow the system to be analysed on a clear and consistent basis.

2.2 Goal definition and scoping

The goal of the LCA study is to analyse the environmental impacts of a widely used construction product, as an office building. The study will include the following components:

- Investigation of the production cycle of the materials including the construction phase of the building.
- Investigation of the impacts regarding the use phase of the building.
- Material and energy consumption, emissions to the environment and disposal problems will also be recorded.

The study will include all the material and components in the building from "cradle-to-grave". "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product, the use phase of the product (mainly energy consumption that is very much dependent on the design of the electronic device) and ends at the point when all materials are returned to the earth (end of life management). Based on the LCA study material, reduction opportunities, energy savings, recyclability, reusability and end of life management options will be determined.

2.3 The functional unit

The main purpose for a functional unit is to provide a reference to which the input and output data are normalised. This means that the data are transformed in units of an input or output flow per functional unit (ex. 2 g CO_2/kg cotton, 0.03 g CO/kg cotton etc.). The functional unit of this study is one (1) office building.

2.4 System boundaries

A system is a collection of operations that together perform some clearly defined function. A broad-based system begins with raw materials acquisition and continues through industrial or consumer use and final disposition.

In defining the system, the first step is to set the system boundaries (Figure 2.2). A complete life-cycle inventory will set the boundaries of the total system broadly to quantify resource and energy use and environmental releases throughout the entire life cycle of a product or process.

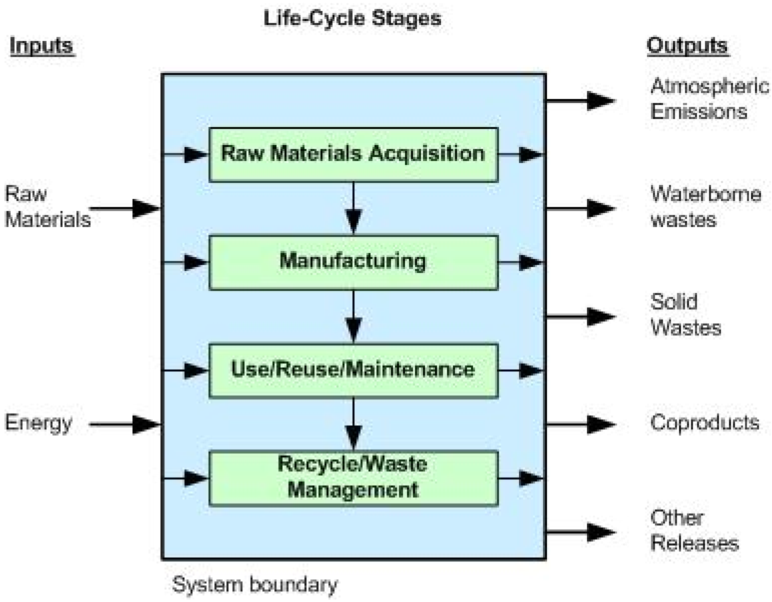

Figure 2.2: Defining system boundaries

The life cycle of the office building comprises of the following stages:

- **Raw material extraction:** The life cycle of the office building starts with the extraction of the raw materials. The building consists of various components, which are made of a large variety of materials and substances. This phase includes both the production of raw material and the use of these raw materials to produce other materials and substances. The environmental aspects and impacts from this phase arise from the mining operations, refining of ores, and manufacturing of materials and substances.
- **Components manufacture:** This phase covers the manufacturing of the components used in the office building as concrete, paint, bricks, gypsum fibre boards, aluminium windows etc. The components manufacture is characterised by several environmental aspects main among them being energy consumption and use of materials with hazardous properties. The role of component manufacturers is crucial to reduce the environmental impacts from this phase.
- **Components transportation:** Components are delivered to the construction site in Greece by road transport. The environmental impacts in this phase mainly arise from the energy consumption of the carriers.
- **Construction of the office building:** This phase covers the construction of the office building. The main process is components placement. The main

environmental aspect from this phase is the energy consumption and solid waste production of construction processes.

- **Use and Maintenance stage:** This stage includes the use phase of the building and all maintenance activities during its useful life. This stage deals mostly with energy that is consumed for cooling, heating and lighting purposes.
- **Demolition - Final Disposal/Recycle/Waste Management stage:** Begins after the building has served its intended purpose and includes the demolition process and the solid waste management system (recycling and final disposal of inert materials).

3 Life Cycle Inventory

3.1 About the LCI

The life cycle inventory (LCI) analysis component is a technical, data-based process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes and other releases for the entire life cycle of a product, package, process, material or activity.

Qualitative aspects are best captured in the impact analysis, although it is useful during the inventory to identify these issues. In the broadest sense, inventory analysis begins with raw material extraction and continues through final product consumption and disposal.

The LCI provides a quantitative catalogue of energy and other resource requirements, atmospheric emissions, waterborne emissions and solid wastes for a specific product, process, package, material or activity. Once the inventory has been performed and is deemed as accurate as possible within the defined scope and boundaries of the system, the results can be used directly to identify areas of greater or lesser environmental burden, to support a subsequent life-cycle impact analysis and as part of a preliminary improvement analysis. Life cycle impact assessment can be applied to quantify the human and ecological health consequences associated with specific pollutants identified by the inventory.

3.2 Data origin

The data used for the purpose of this study comes from the following sources:

- Raw data provided by the construction company EDRASIS C. PSALLIDAS S.A. This data included the mass of materials or construction components required for the construction of the office building.
- The GaBi software construction materials database that consists of life cycle data of generic construction materials and components.
- Literature data when it was necessary.

3.3 Data quality

Data quality is the degree of confidence in individual input data. The ISO standard sets some minimum standards for data quality: 'Data quality requirements shall be defined to enable the goals and scope of the Life Cycle Assessment study to be met. The data quality requirements address issues such as:

- the precision, completeness and representativeness of the data and the data sources;
- the consistency and reproducibility of the methods used throughout the LCA;
- the sources of the data;
- the variability and uncertainty of the information and methods.'

The quality of the data used for this study is considered to be adequate for the goal of the LCA of the office building.

3.4 Cut-off rules

During data collection, flows that are very small in the total mass of the product may have been disregarded. This rule does not apply where the flow, although below the cut-off level, cause significant environmental burdens, for example where the flow is classed as hazardous.

3.5 The LCI modelling

The modelling of the system has been done with the help of the GaBi Software. The software system GaBi is a tool for the build up of life-cycle-balances.

The modelling of the building life cycle included the construction phase and the use phase of the building (Figure 3.1). The demolition and disposal phase was not included due to lack of data.

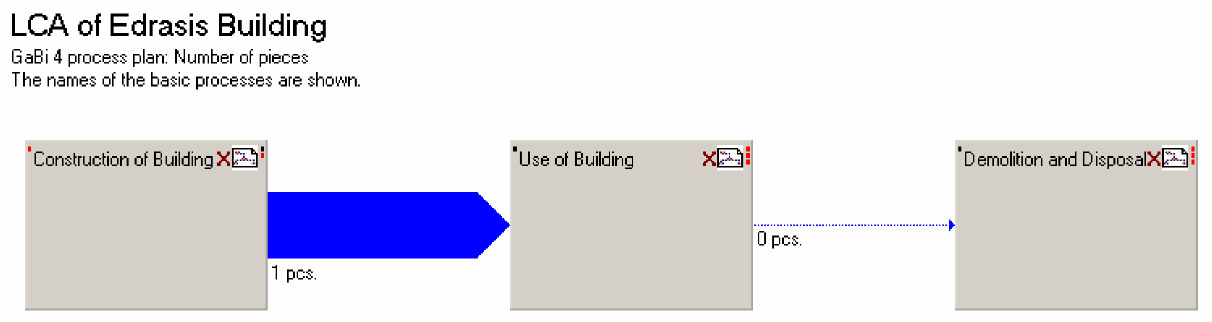

Figure 3.1: The office building life cycle model

The construction of the building was further divided to its components-levels (Figure 3.2) that are:

1. the 3rd basement
2. the 2nd basement
3. the 1st basement
4. the groundfloor
5. the 1st floor
6. the 2nd floor
7. the 3rd floor and
8. the rooftop

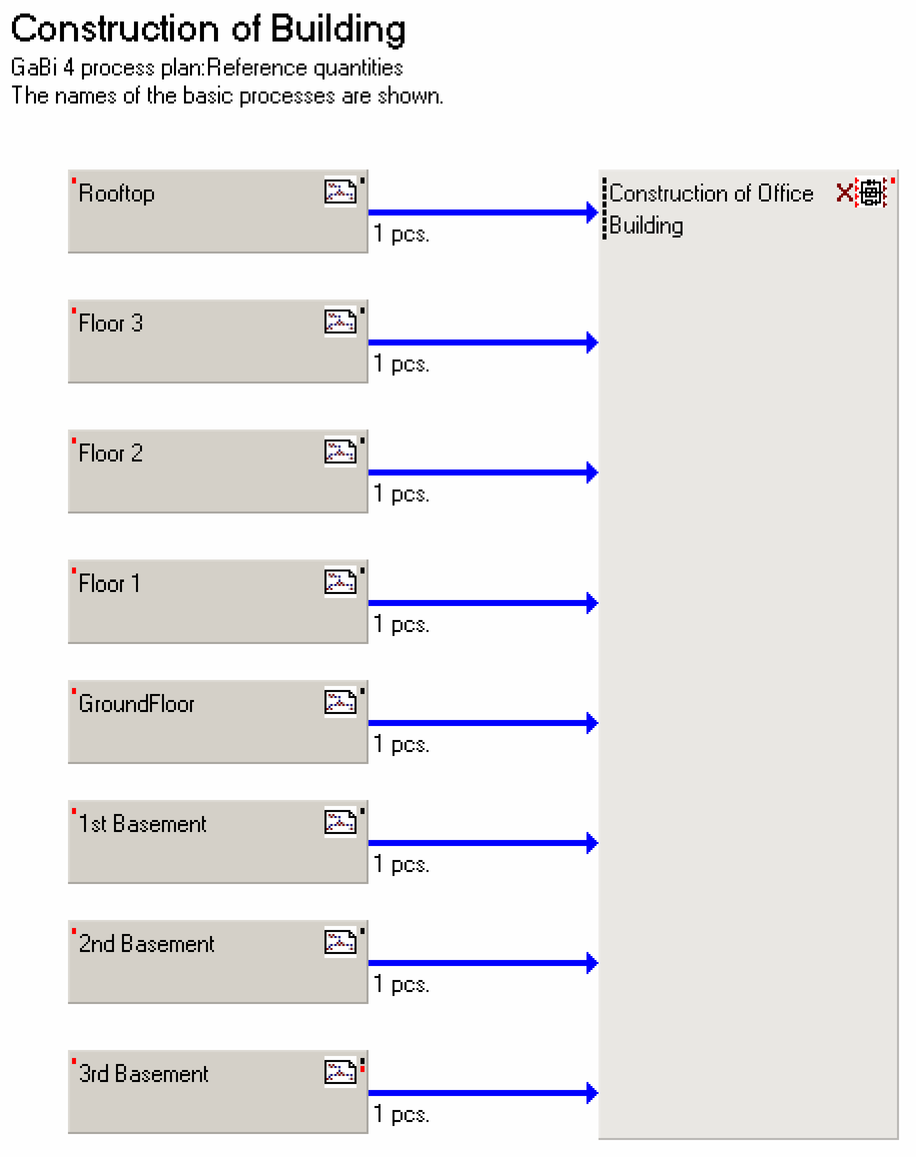

Figure 3.2: The construction phase modelling of the office building

The modelling of the construction phase of each building level is presented into Figures 3.3 to 3.10. The figures present the amount of the most important materials that were used for the construction of each level. The materials that were used for the construction of the building included the following:

- concrete
- steel
- bricks
- masonry mortar
- insulation materials
- aluminum
- glass
- marble
- gypsum fibre board
- paint

- PVC
- epoxy resin
- roof slabs
- ceramic tiles
- light weight concrete
- metals
- wood

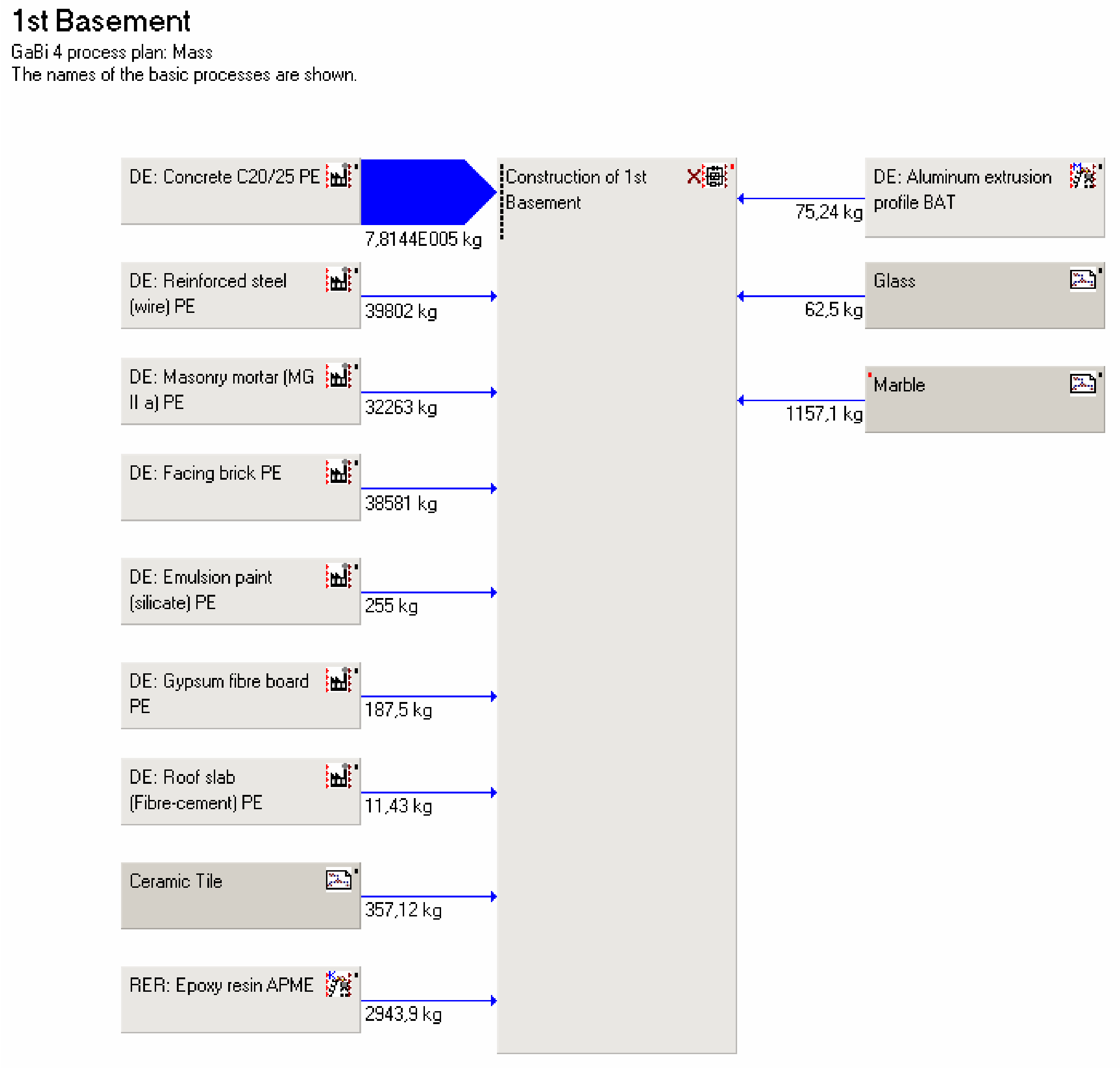

Figure 3.3: The modelling of the construction of the 1st basement

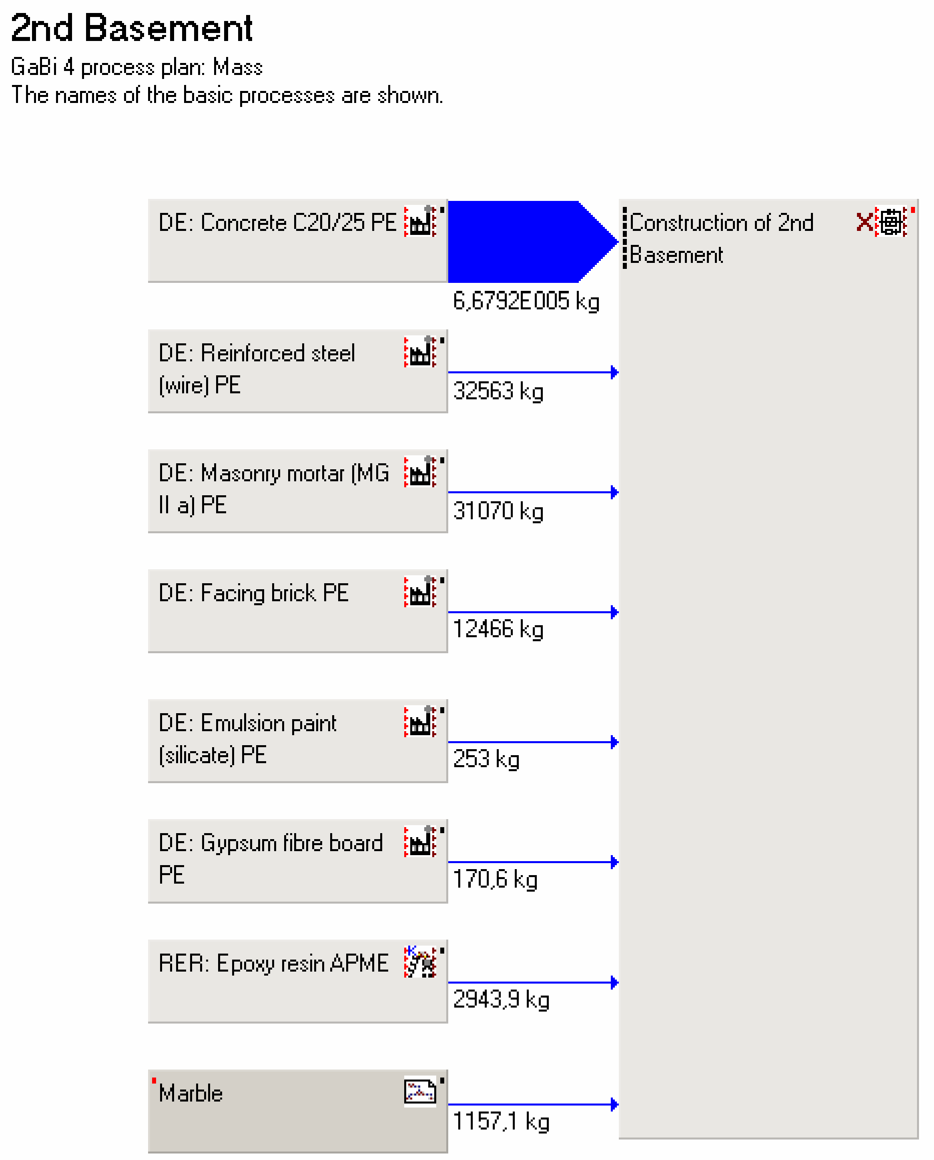

Figure 3.4: The modelling of the construction of the 2[nd] basement

3rd Basement

GaBi 4 process plan: Mass
The names of the basic processes are shown.

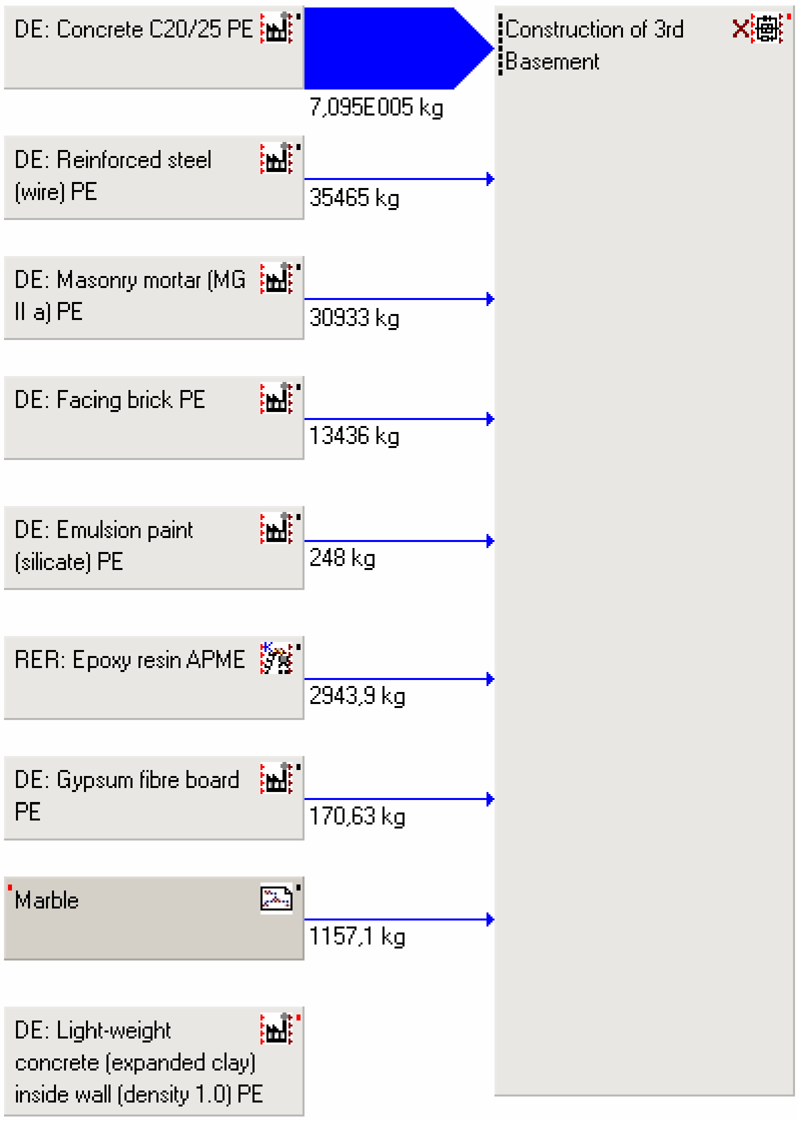

Figure 3.5: The modelling of the construction of the 3rd basement

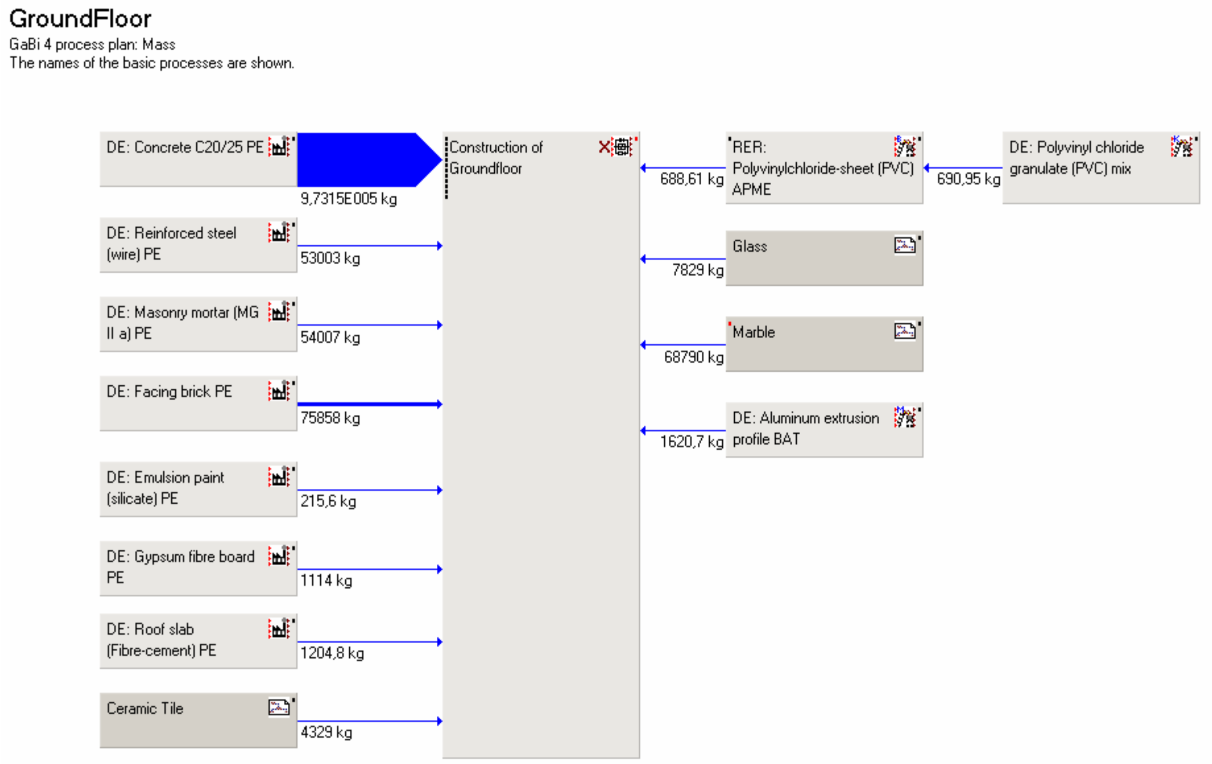

Figure 3.6: The modelling of the construction of the groundfloor of the office building

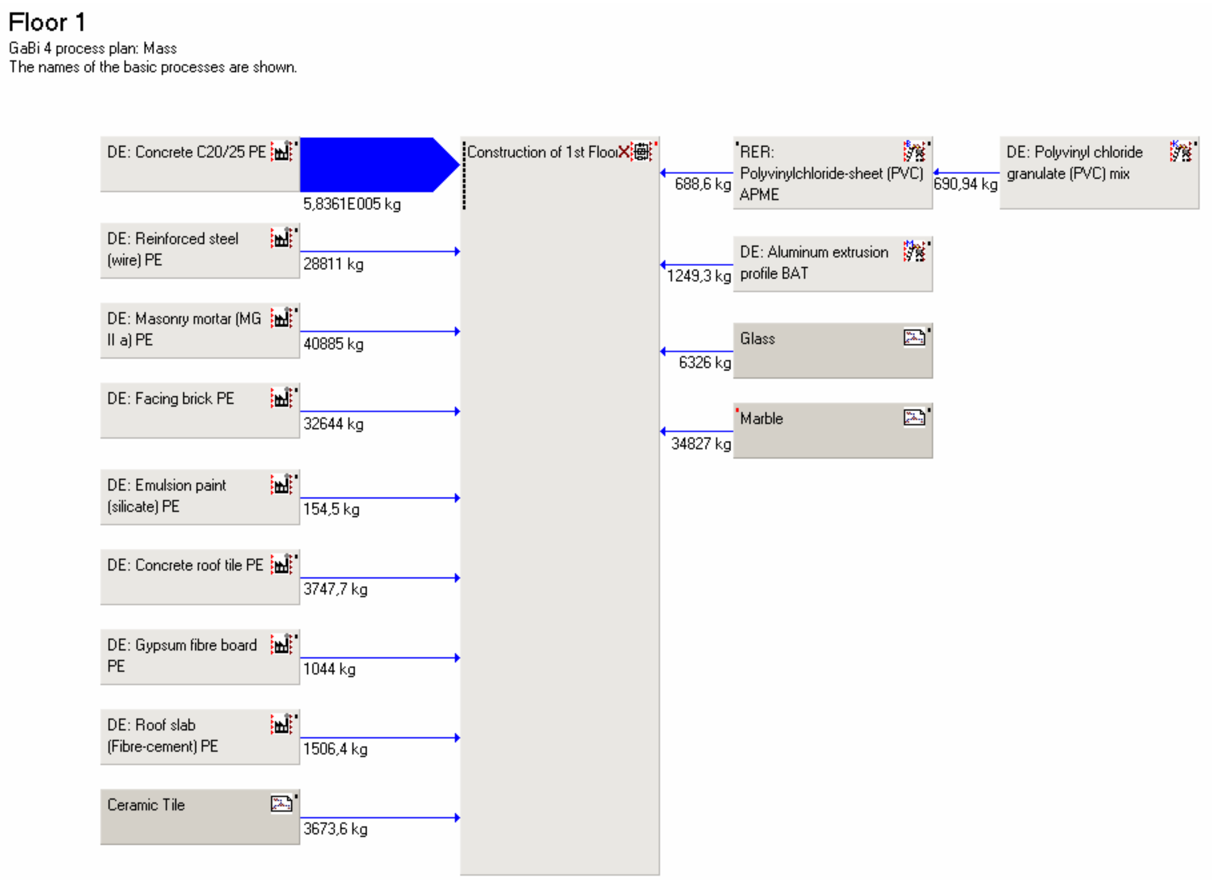

Figure 3.7: The modelling of the construction of the 1st floor of the office building

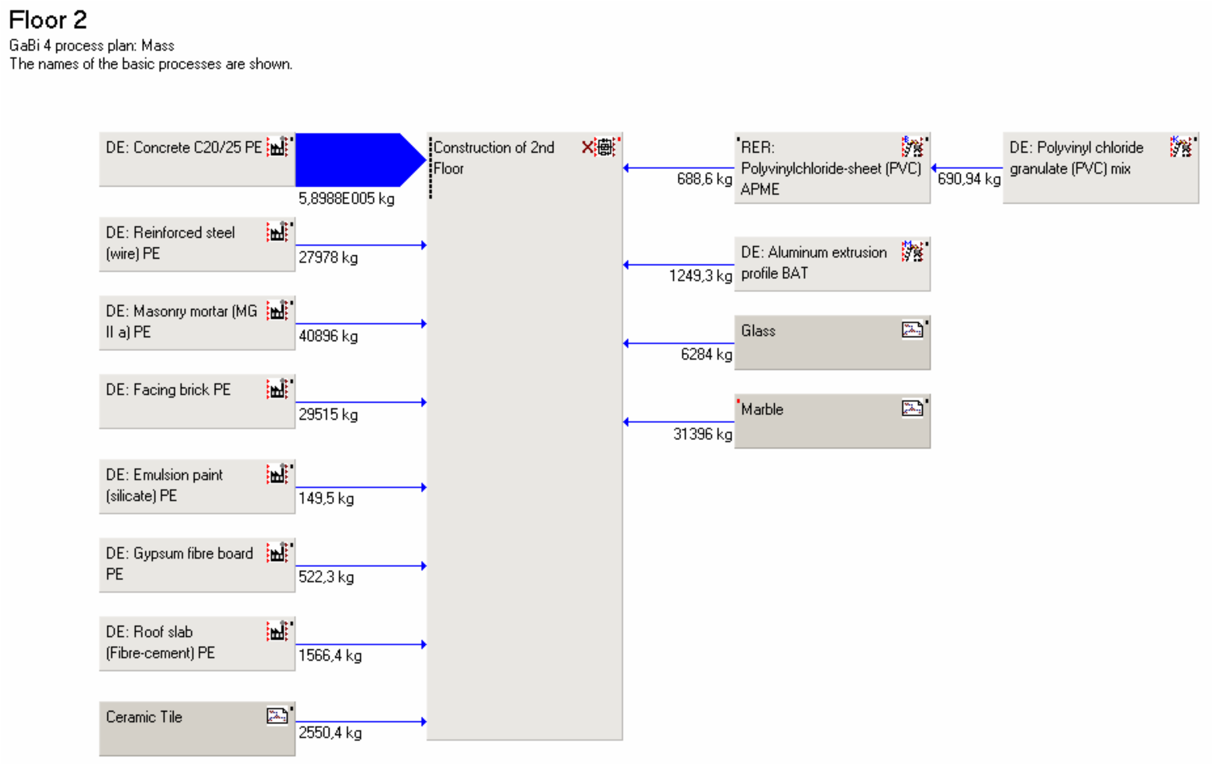

Figure 3.8: The modelling of the construction of the 2nd floor of the office building

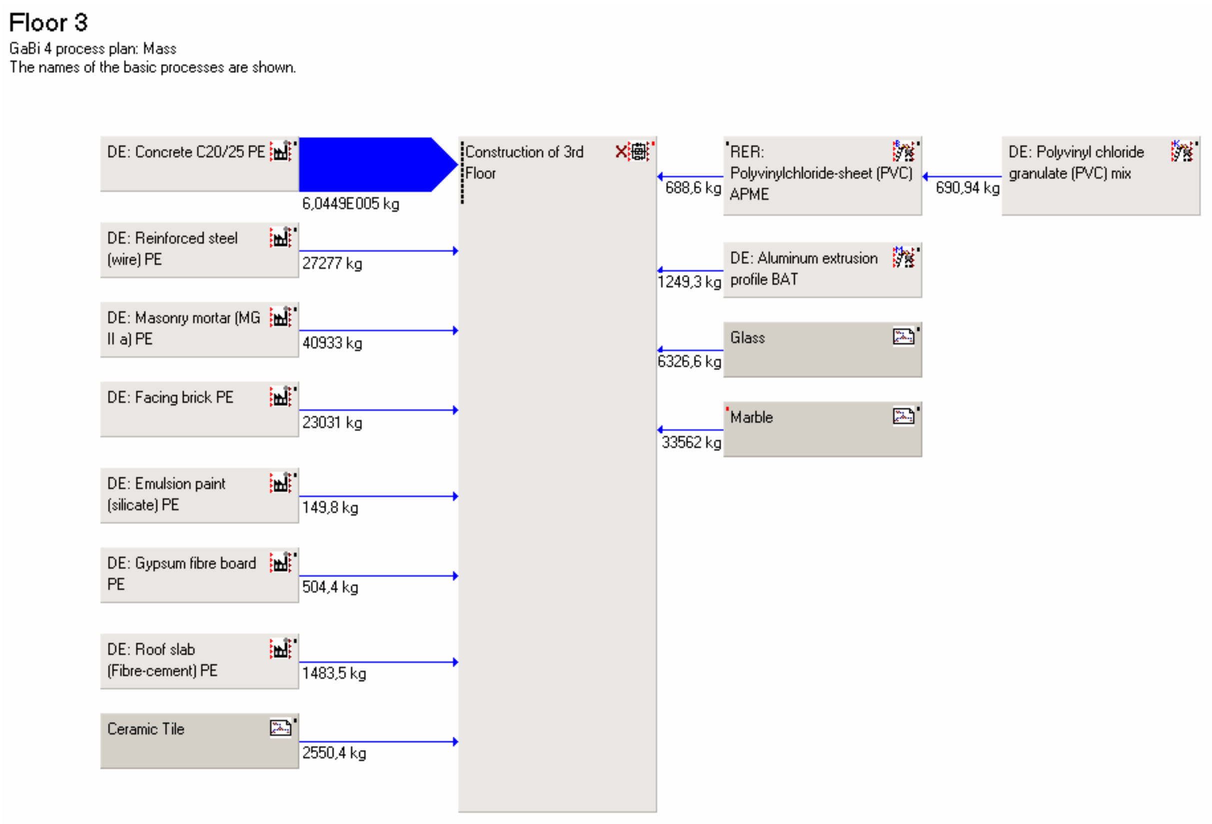

Figure 3.9: The modelling of the construction of the 3rd floor of the office building

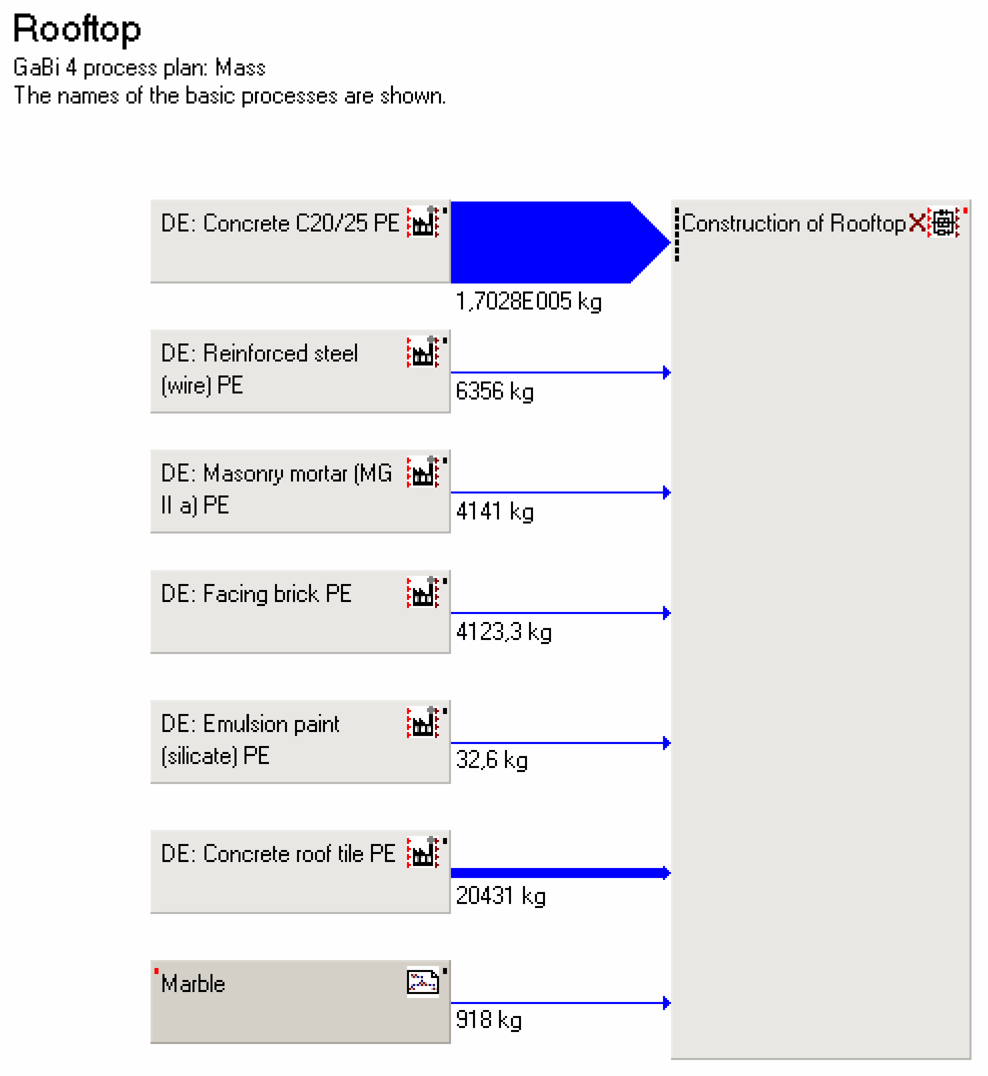

Figure 3.10: The modelling of the construction of the rooftop of the office building

The use phase of the building includes the energy consumption for heating, cooling and lighting purposes. The life span of the building is taken to be 80 years. The modelling of the phase has been done with the use of bibliographic data based on the Greek climatic conditions (Santamouris et al., 2005). The best scenario based on Greek conditions has been used for the energy consumption modelling. According to this both heating and cooling energy comes from natural gas. Lighting is provided from the Greek electricity grid (Figure 3.11).

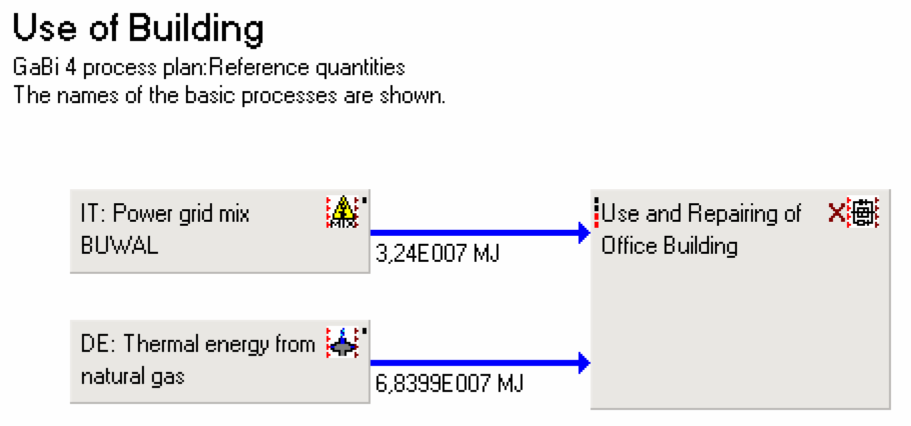

Figure 3.11: The modelling of the use phase of the office building

4 Impact Assessment

4.1 Procedure

The impact assessment step analyzes and evaluates the magnitude and significance of the potential environmental impacts of the life cycle of the office building. The results of the Inventory analysis are translated into contributions to relevant impact categories. Impact assessment consists of three steps:

- classification
- characterisation
- normalisation and
- evaluation

The classification assigns data identified in the inventory stage to various impact categories such as global warming, acidification, eutrophication, ozone layer depletion, photochemical oxidant formation, ecotoxicity and human toxicity.

The characterisation step aims at quantifying and aggregating the potential effects, normalized to the functional unit of the product system studied. In the characterisation step of Impact assessment the environmental interventions assigned qualitatively to a particular impact category in classification are quantified in terms of a common unit for that category, allowing aggregation into a single score: the indicator result. The resulting figure for one particular impact category is referred to as a category indicator result, and the complete set of category indicator results as the environmental profile. Equivalence factors are used for the different environmental effects.

Normalization is defined as an optional element relating all impact scores of a functional unit to the impact scores of a reference situation. This reference situation may be so-called actual flows of a certain region, but also variations in space or time of these. The main aim of normalization is therefore to relate the environmental burden of a product to the burden in its surroundings.

Normalization only reveals which effects are large, and which effects are small, in relative terms. It says nothing of the relative importance of these effects. Evaluation factors are used for this purpose. The evaluation step is the process where the impact scores of the different impact categories are compared and weighted for the comparison of the alternative products/processes. The relative importance of the impact scores is brought into perspective by normalization. In this way, impact scores are related to the total magnitude of the given impact category from all sources in a given area/period.

4.2 The CML2001 impact assessment weighting factors

Table 4.1 presents the normalization factors and Table 4.2 the evaluation factors used for the purpose of this study. The CML factors are used that were developed by the Institute of Environmental Sciences of the Leiden University[1].

Table 4.1: CML2001 Normalization factors (Europe)

Quantity	Unit	Weights
CML2001, Abiotic Depletion (ADP)	kg Sb-Equiv.	4,94E-11
CML2001, Acidification Potential (AP)	kg SO2-Equiv.	2,68E-11
CML2001, Eutrophication Potential (EP)	kg Phosphate-Equiv.	5,88E-11
CML2001, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	kg DCB-Equiv.	1,45E-12
CML2001, Global Warming Potential (GWP 100 years)	kg CO2-Equiv.	1,55E-13

[1] http://www.leidenuniv.nl/interfac/cml/ssp/index.html

CML2001, Human Toxicity Potential (HTP inf.)	kg DCB-Equiv.	9,69E-14
CML2001, Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	kg DCB-Equiv.	6,46E-15
CML2001, Ozone Layer Depletion Potential (ODP, steady state)	kg R11-Equiv.	8,83E-09
CML2001, Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	8,90E-11
CML2001, Radioactive Radiation (RAD)	DALY	1,51E-05
CML2001, Terrestric Ecotoxicity Potential (TETP inf.)	kg DCB-Equiv.	1,55E-11

Table 4.2: CML2001 Evaluation factors (Southern Europe)

Quantity	**Unit**	**Weights**
CML2001, Abiotic Depletion (ADP)	kg Sb-Equiv.	1,5
CML2001, Acidification Potential (AP)	kg SO2-Equiv.	1
CML2001, Eutrophication Potential (EP)	kg Phosphate-Equiv.	7
CML2001, Global Warming Potential (GWP 100 years)	kg CO2-Equiv.	10
CML2001, Ozone Layer Depletion Potential (ODP, steady state)	kg R11-Equiv.	2
CML2001, Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	3
CML2001, Radioactive Radiation (RAD)	DALY	0,5

The environmental score of each effect is calculated based on the simple formula:

Environmental Score = Characterized Value x Normalization factor x Weighting factor

4.3 Impact assessment of the office building

A division of environmental impacts on the life cycle stages can be seen from the Figures 4.1 and 4.2. Not surprisingly, the use and repairing stage is significantly high for the environmental impacts of the office building life cycle. The use phase contributes by 91,94% to the total of the life cycle. The construction phase contributes by 8,06% to the total environmental score.

The global warming potential is the environmental impact with the largest contribution to the overall score. GWP contributes by 83,53% to the construction phase and by 78,35% to the use phase of the building (Figure 4.3). The contribution of GWP to the total environmental score is 78,8% (Figure 4.4).

Photochemical ozone creation (POC) contributes by 8,4% to the total environmental score. POC contributes by 4,77% to the environmental impact of the construction phase of the building. At the same time it contributes 8,76% to the overall impact of the use phase due to impacts of energy production and consumption processes.

The acidification potential contributes by 7,24% to the total life cycle (production and use phase). Acidification contributes by 3,81% to the environmental impact of the construction phase of the building. At the same time it contributes 7,54% to the overall impact of the use phase.

The eutrophication potential contributes by 5,25% to the total life cycle (production and use phase). Eutrophication contributes by 7,27% to the environmental impact of the construction phase of the building. It also contributes 5,07% to the overall impact of the use phase.

The ozone layer depletion potential contributes by only 0.27% to the total impact. Radioactive radiation is also contributing by only 0.03% due to energy consumption for material production that is done in European countries where nuclear energy is part of the total electricity production.

The use phase is the larger contributor to most of the impacts of the building life cycle (Figure 4.5). Its contribution is at least 89% to the GWP, the acidification potential, the eutrophication potential and the ozone depletion potential. Abiotic depletion and radioactive radiation are mainly caused by the construction phase due to emissions regarding the material production stages.

The amount of material consumption is the main reason for the distribution of the environmental impact of each level of the office building construction phase. The groundfloor appears to be the level with the largest environmental impact during its construction phase (Figure 4.6) since it consumes the largest part of material. The three basements are the next largest contributors while the office floors have a little less contribution. The construction of the rooftop is the smallest contributor since it uses the smallest amount of materials. The global warming potential (Figure 4.7) is the environmental impact that corresponds to the largest portion (at least 82%) of the total impact of the construction phase of each level. The eutrophication potential corresponds to at least 6,5% to the impact of the construction of each level, the photochemical ozone creation potential around 4-4,5%, the acidification potential varies between 3,25-4,21% and the ozone layer depletion effect average contribution is 0,08%.

The environmental impact of the materials that is used for the construction of each building level is presented in Figures 4.8 to 4.15. Concrete production and placement is the largest contributor to the construction stage of each level of the office building. Steel is the material with the second largest contribution. Both materials are produced by energy intensive processes where air emissions are related with fossil fuel consumption. Epoxy resin that is used for the industrial floor placed in the three basements is also contributing significantly to the overall impact of the construction phase.

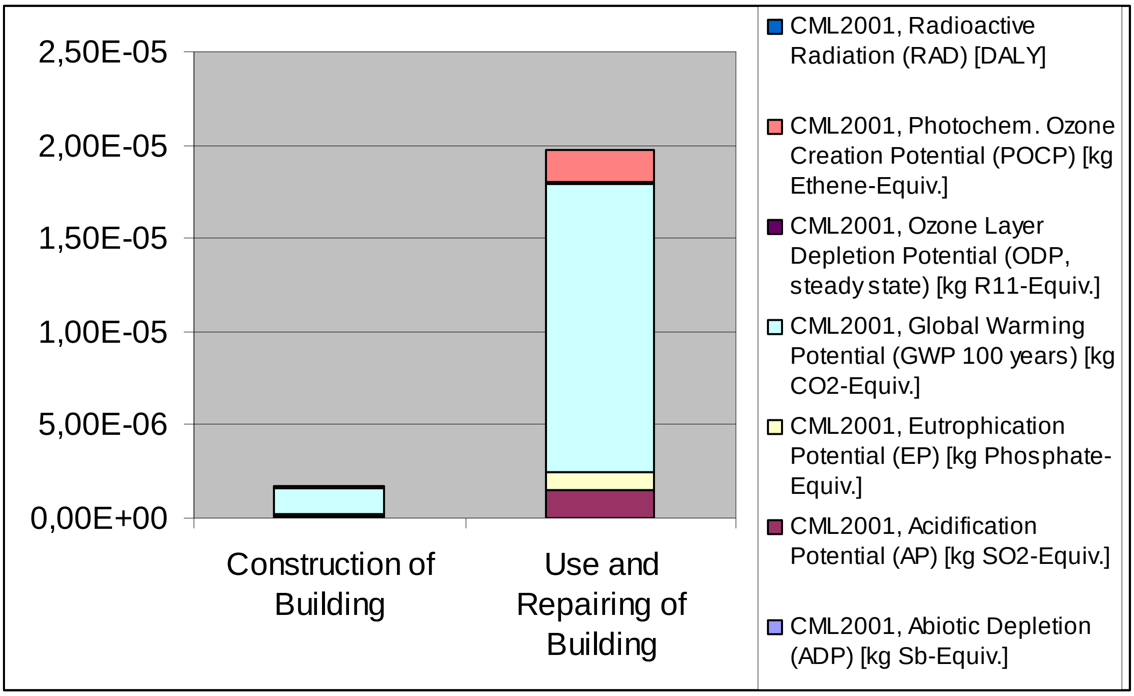

Figure 4.1: Total impact of the construction and use phase of the office building

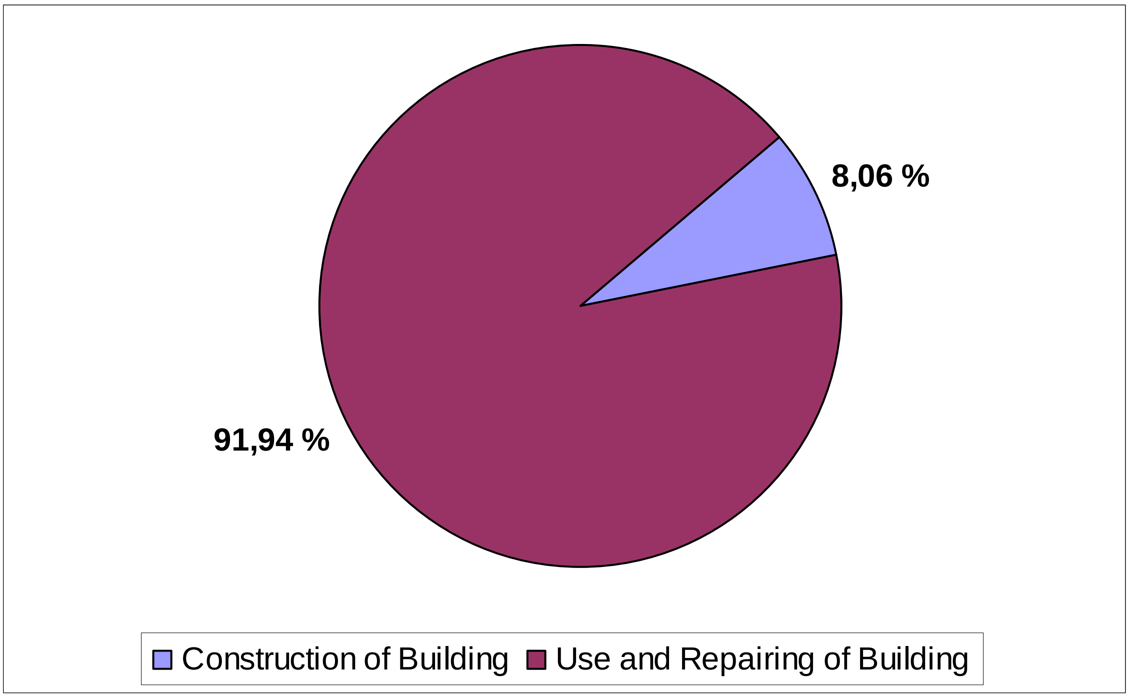

Figure 4.2: Percentage contribution to the total impact of the construction and use phase of the office building

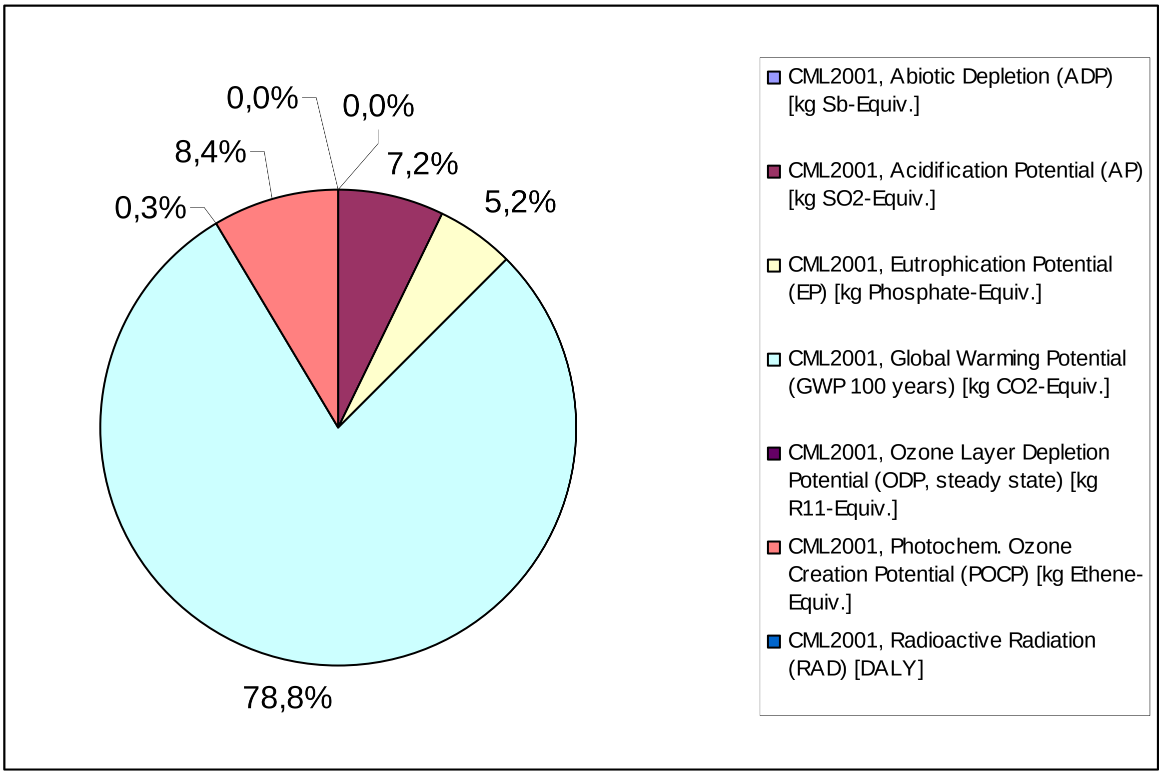

Figure 4.3: Percentage contribution of each impact category to the total impact of the office building

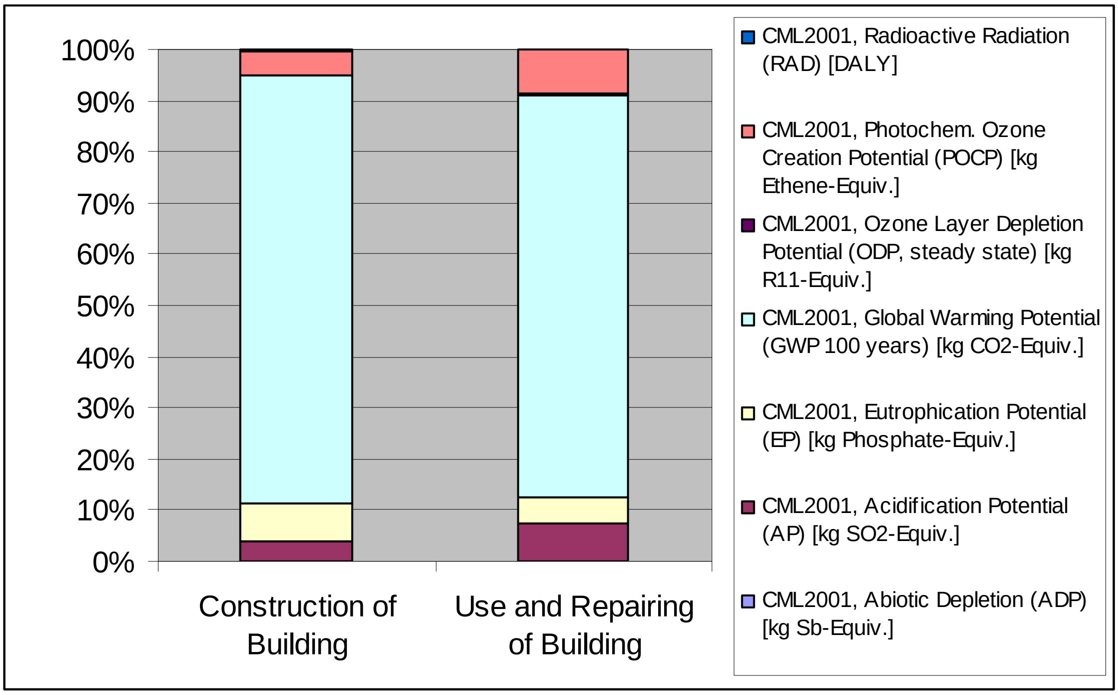

Figure 4.4: Percentage contribution of each impact category to the total impact of the construction and use phase of the office building

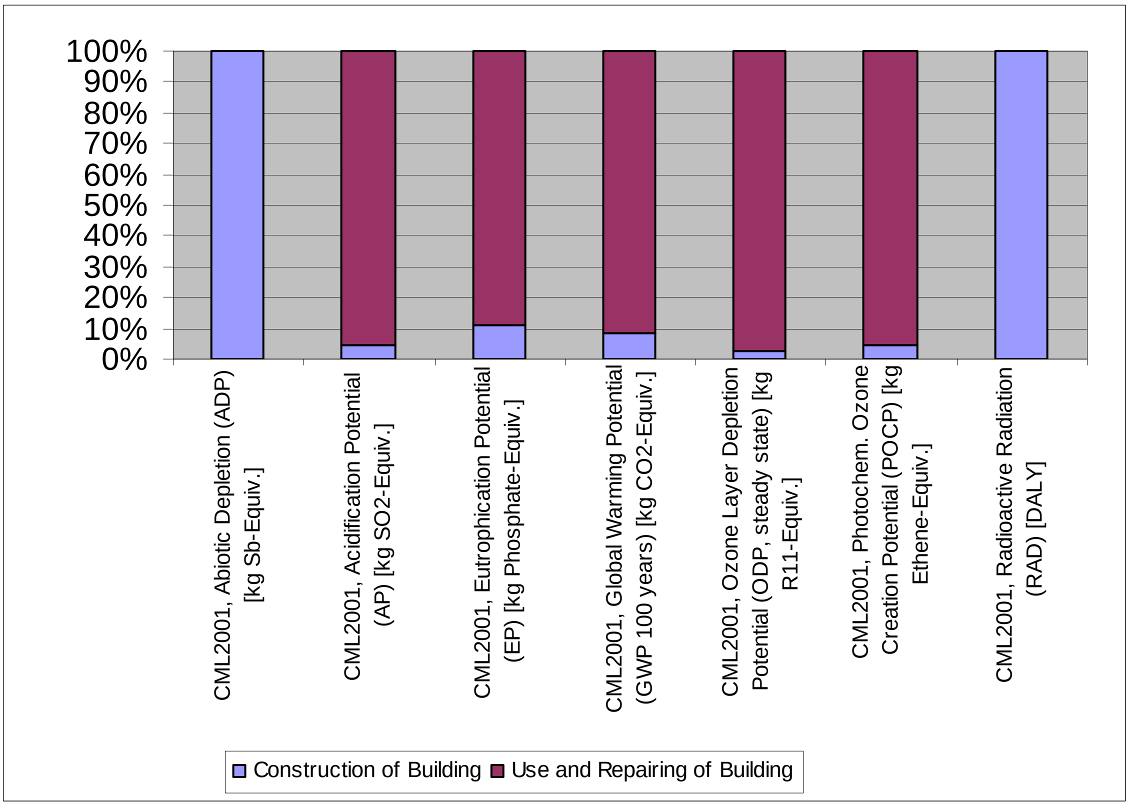

Figure 4.5: Percentage contribution of each life cycle phase to the total of each impact category

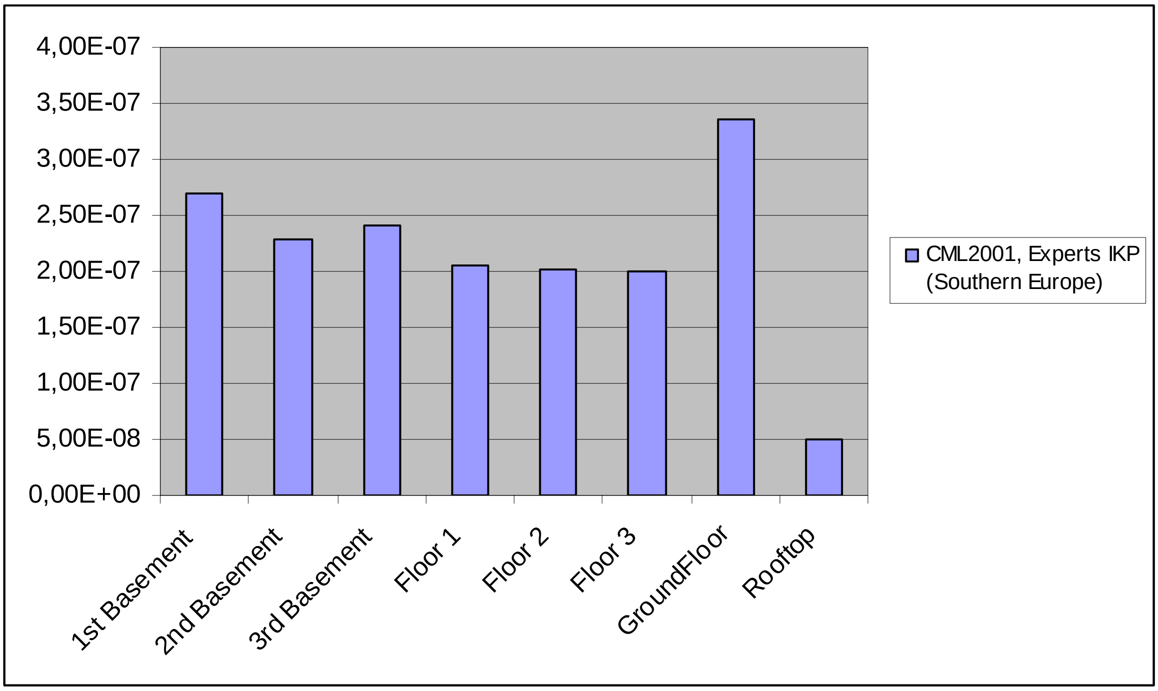

Figure 4.6: Total impact of each construction component of the office building

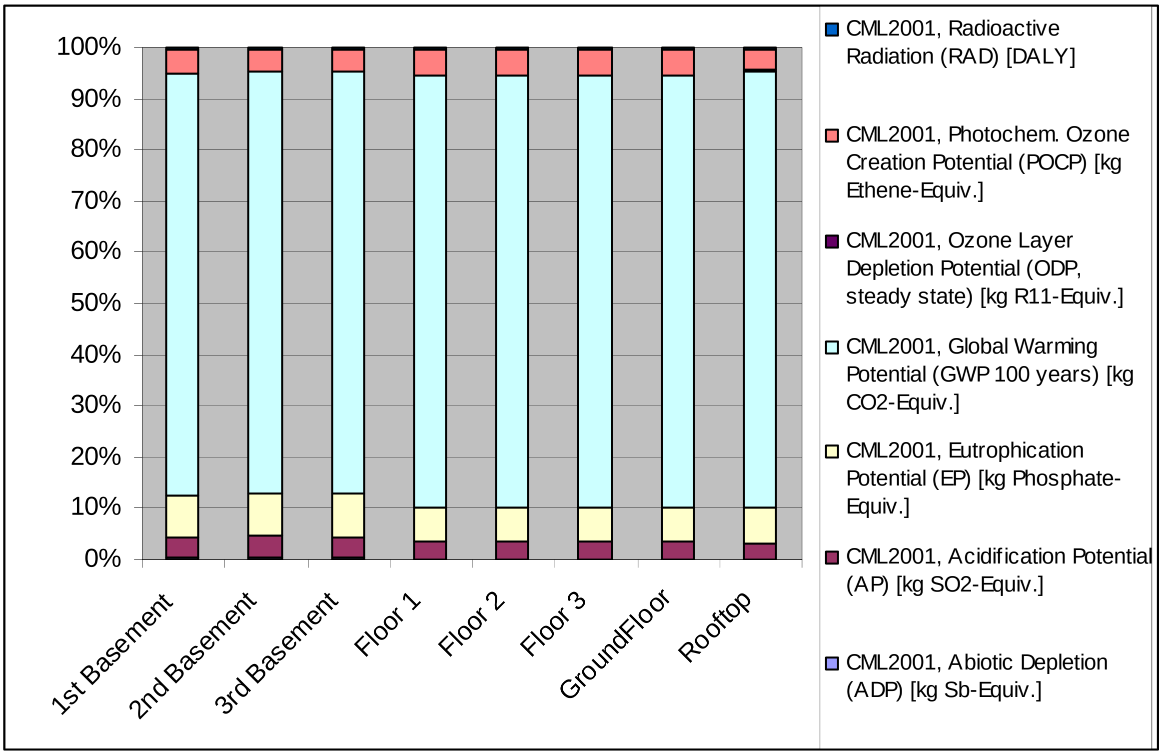

Figure 4.7: Percentage contribution of each impact category to the total impact of the construction components of the office building

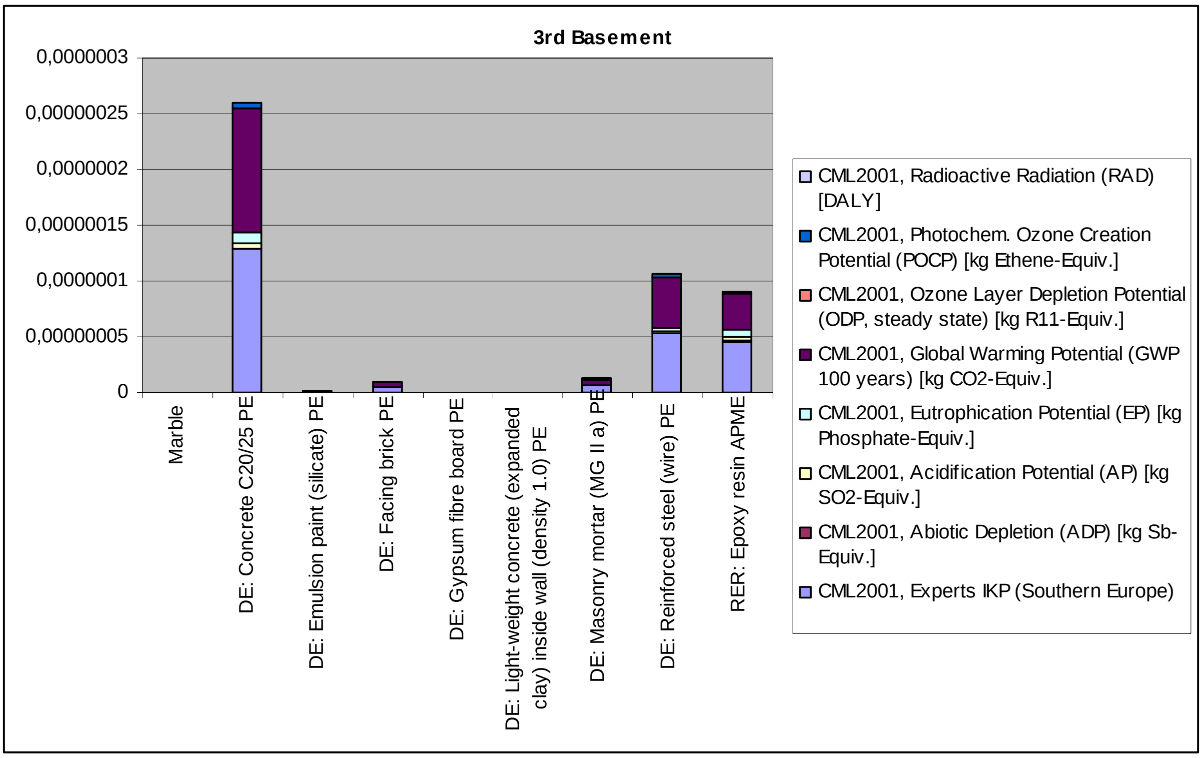

Figure 4.8: Contribution of each construction material - component to the total environmental impact of the construction phase of the 3rd basement of the building

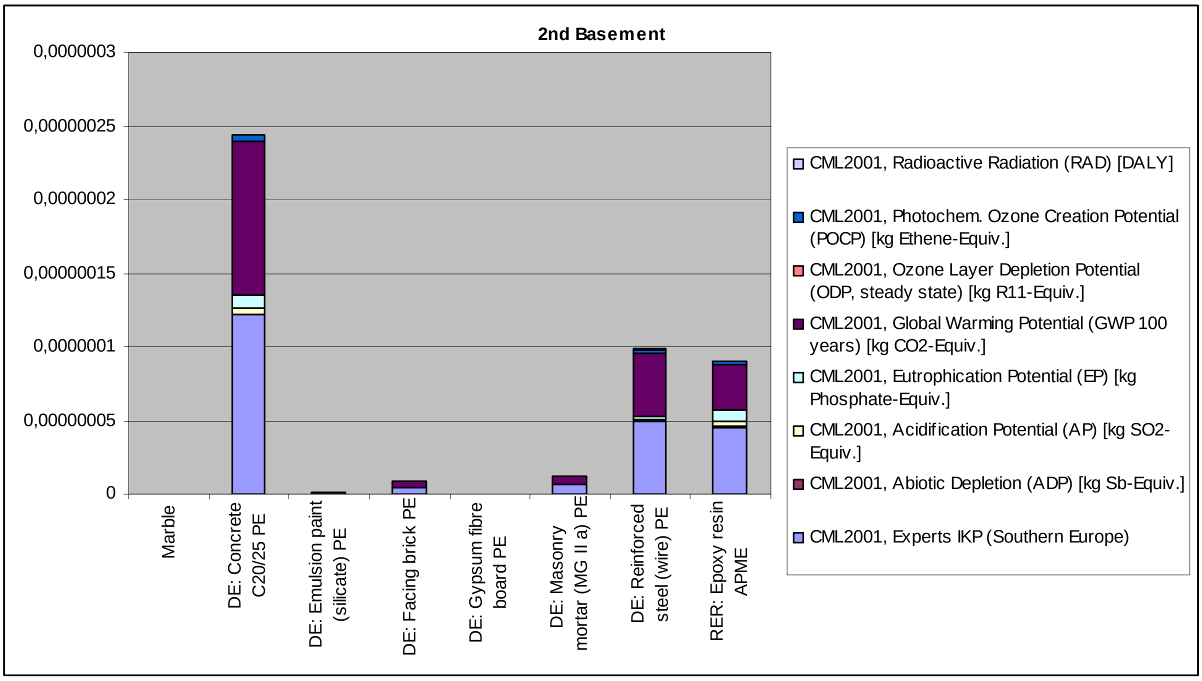

Figure 4.9: Contribution of each construction material - component to the total environmental impact of the construction phase of the 2nd basement of the building

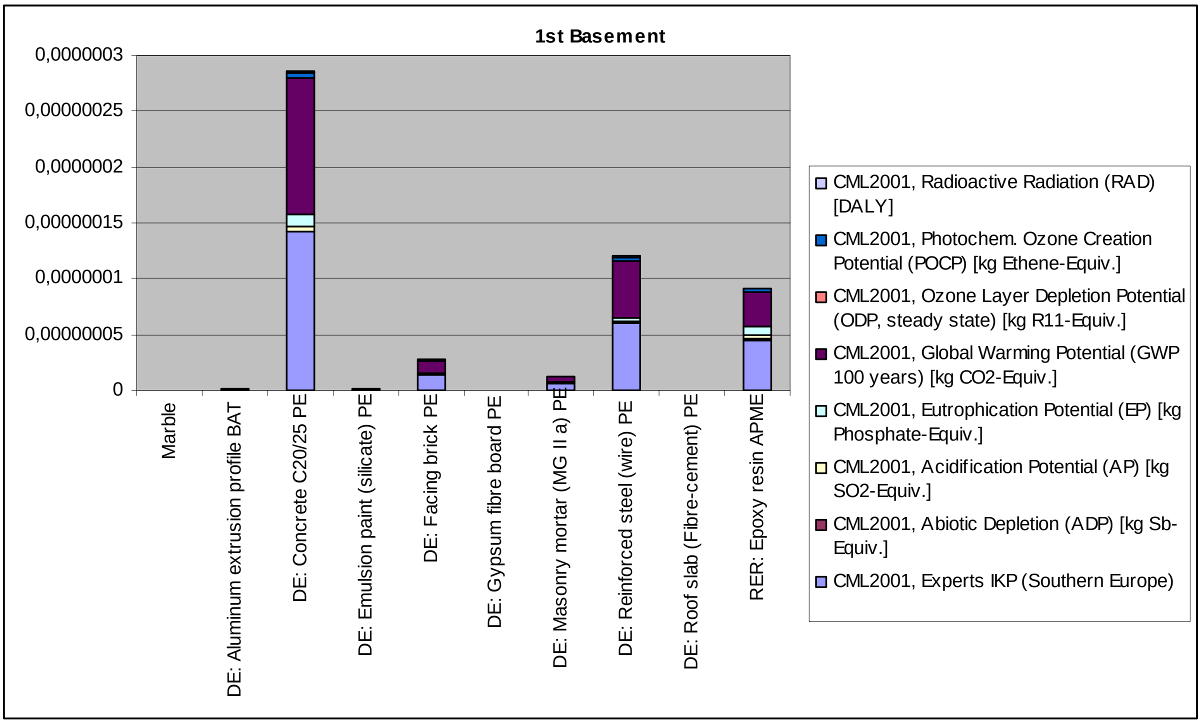

Figure 4.10: Contribution of each construction material - component to the total environmental impact of the construction phase of the 1st basement of the building

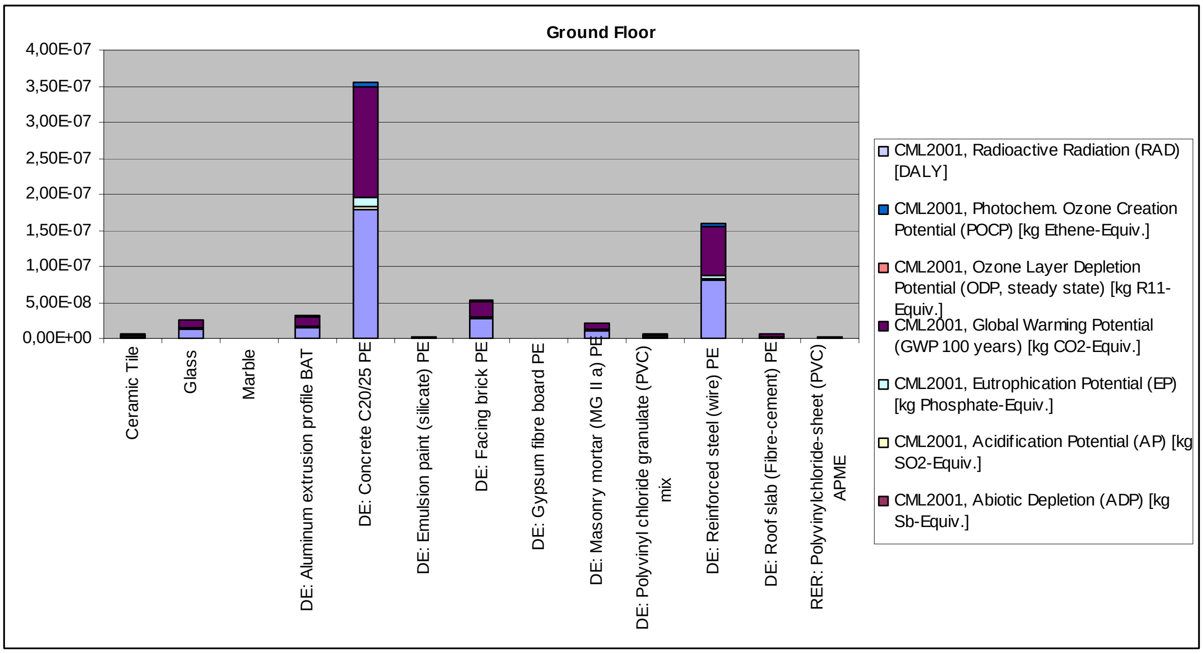

Figure 4.11: Contribution of each construction material - component to the total environmental impact of the construction phase of the ground floor of the building

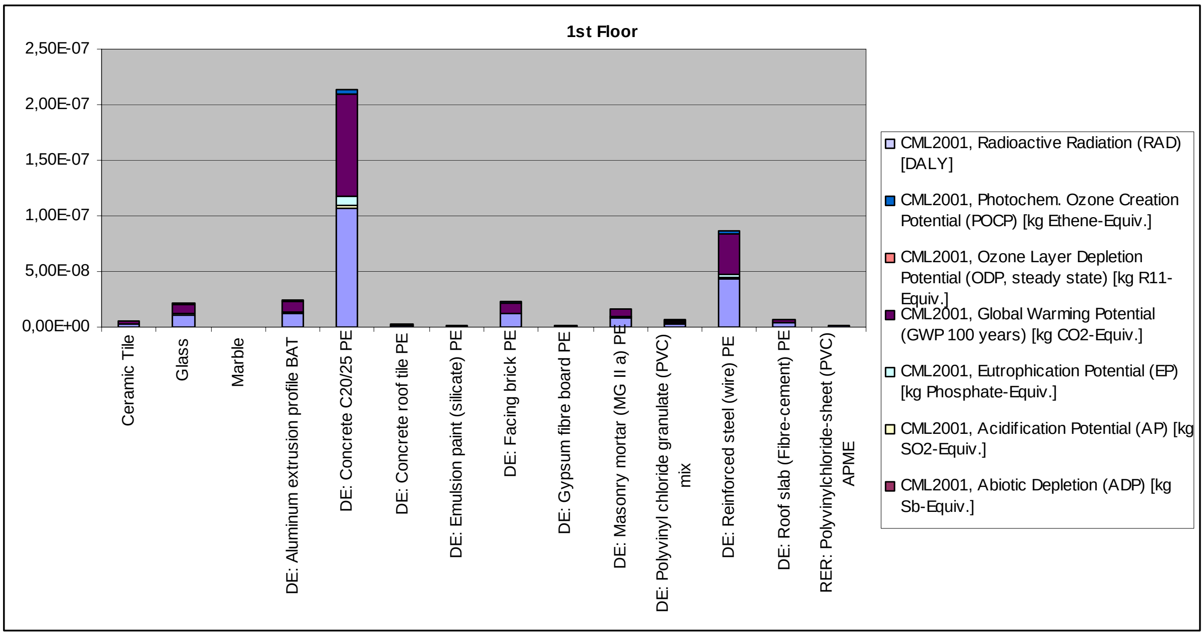

Figure 4.12: Contribution of each construction material - component to the total environmental impact of the construction phase of the 1st floor of the building

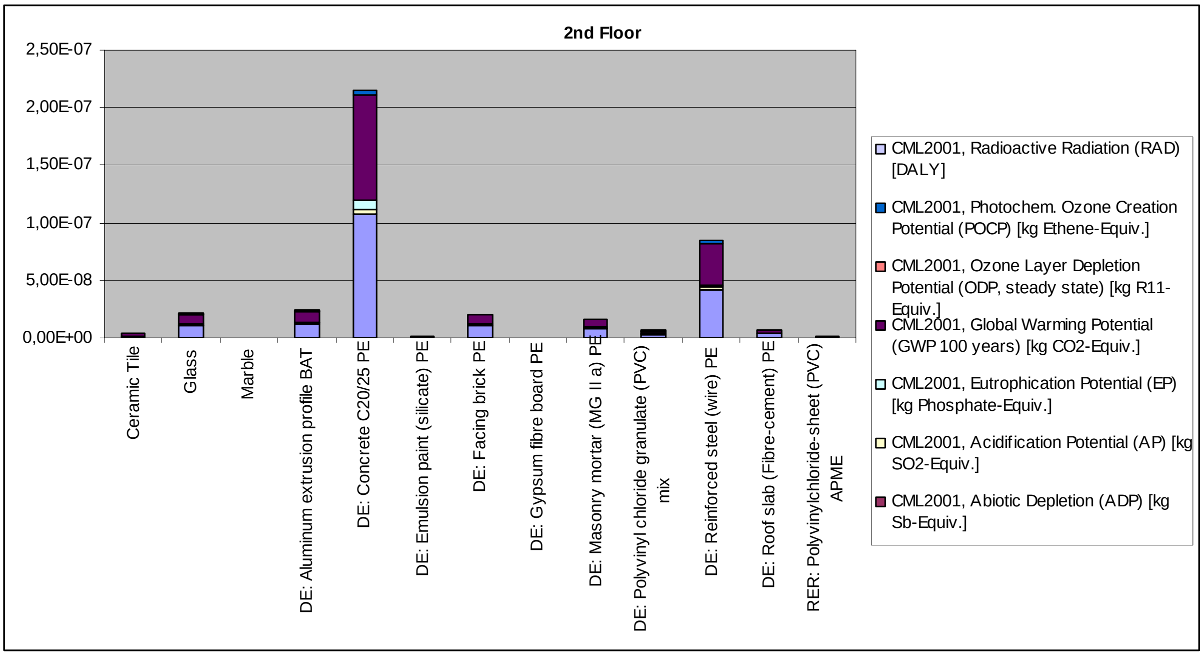

Figure 4.13: Contribution of each construction material - component to the total environmental impact of the construction phase of the 2nd floor of the building

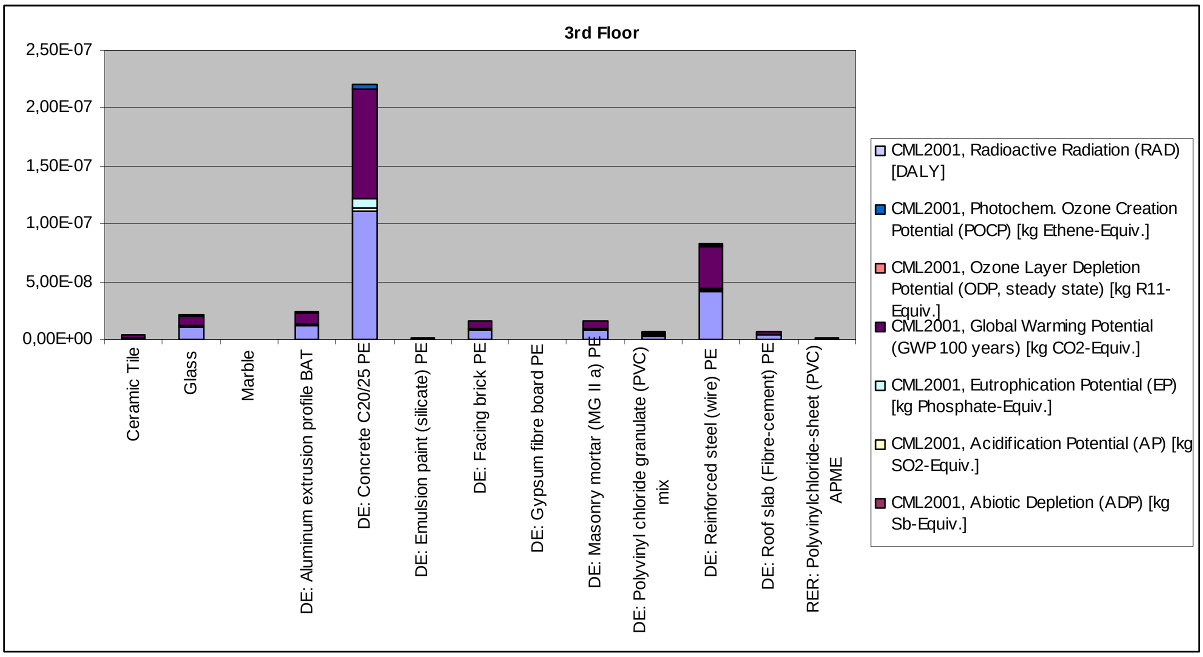

Figure 4.14: Contribution of each construction material - component to the total environmental impact of the construction phase of the 3rd floor of the building

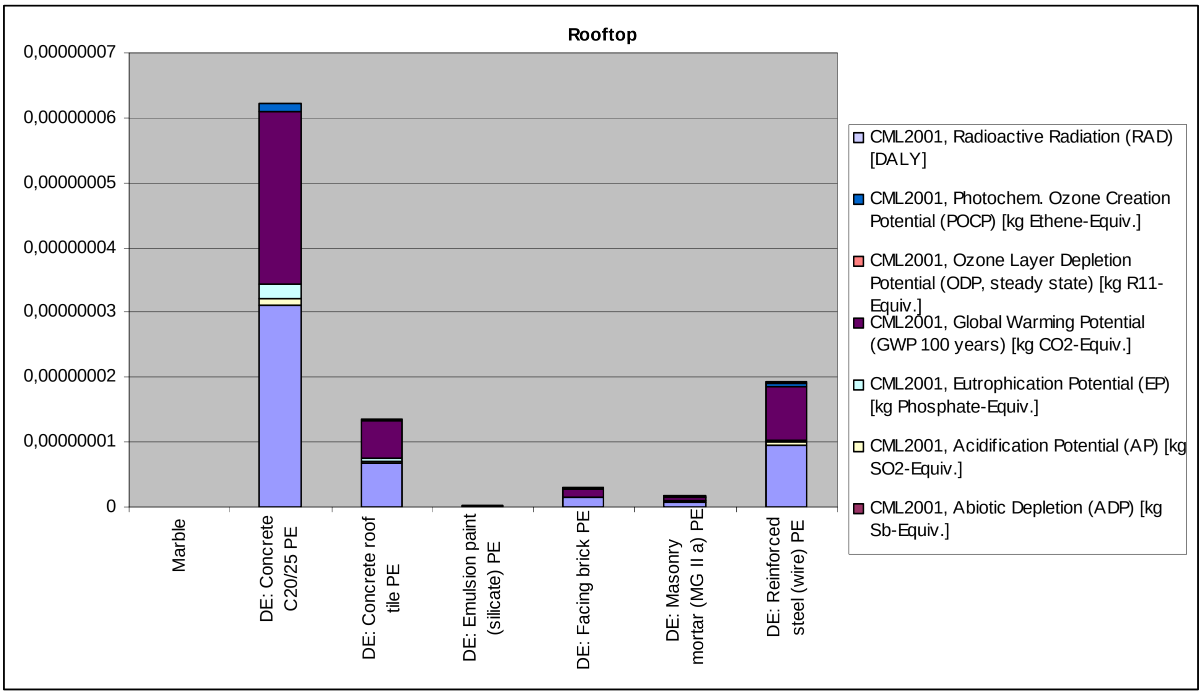

Figure 4.15: Contribution of each construction material - component to the total environmental impact of the construction phase of the rooftop of the building

5 Conclusions

Life cycle distribution of energy consumption and environmental impacts are concentrated in the use and renovation phase of the office building. Although results could change in the future with the use of more updated data, the overall conclusion is not expected to change. The results showed that the use phase environmental impacts accounted for more than 92% of the total inventoried environmental burdens. Global warming potential is the environmental impact with the larger contribution to the total environmental score of the life cycle. GWP contributes 78,77% to the total environmental score. The environmental impact of the use phase is attributed to the energy consumption that is related with fossil fuel use in energy production processes. Energy is used for the heating, cooling and lighting of the building during its life cycle.

The optimization of operations phase performance should be the primary emphasis for designing to minimise life cycle burdens. For example, design improvements related to the building energy losses can significantly reduce cumulative burdens even at the expense of greater material production and construction burdens. The use of renewable energy sources would also improve significantly the environmental profile of the life cycle.

Consequently, material selection can become a more critical factor as non-renewable resources become more scarce. However, this is still the exception rather than the rule, and for the time being the differential balance of burdens between the use phase and the construction phase shows that focus should be put onto the improvement of the use phase.

The initial design can minimise many environmental impacts and can influence opportunities for future improvements. While designers cannot control what happens after a building is completed (i.e. how it is renovated, or operated) the initial design of a building will determine in large part the baseline from which the building will begin its operational life.

Future improvements of the study should include a more detailed modelling of energy consumption during the use phase of the life cycle. Detailed calculation of energy consumption would reveal improvement opportunities to the design of the building. The energy consumption practices of the building users could also offer solutions for minimization of the energy consumption during the 80 year, use phase.

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