Development of a Method for Building Life Cycle Analysis at an Early Design Phase

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Implementation in a Tool

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Sensitivity and Uncertainty of Such a Method in Comparison to Detailed LCA Software

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Julie Chouquet

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Dipl.-Ing. Julie Noémie Chouquet
aus Champigny-sur-Marne

Referent: Prof. Dr. ès. sc. tech. Niklaus Kohler
Korreferent: Dr. habil. Bruno Peuportier

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Summary

The thesis presents in detail the various steps in the development of an early design phase method for the life cycle analysis of buildings. After a brief introduction concerning life cycle analysis and building life cycle analysis, particular emphasis is put on the realisation of the geometrical model and the analysis of construction elements, both implemented in the method and in the developed tool Stilcab (Simplified Tool for Integrated Life Cycle Analysis of Buildings). Moreover, the results of the sensitivity analysis for the different building categories are explained, as well as the implementation of the sensitivity analysis in the tool. In the final section, the method is validated with the help, amongst others, of Stilcab's uncertainty analysis as well as the uncertainty analysis of another life cycle analysis tool.

Abstract

During the last few decades, life cycle analysis (LCA) in general has been of great value as a tool to judge, qualify or rank products according to environmental impacts generated during their life span. However, when applied to buildings, LCA appears to be an elaborated process, mainly due to the complexity and the diversity of buildings which all have their own particularities. In fact, the building itself is a conglomerate of a large number of materials which can be present in specified quantities, and a multiplicity of factors which intervene and influence the building‘s lifetime. Several tools can be found on the market, each making it possible to calculate, describe, model and/or classify buildings. All of these require a detailed description of the building with the use of a well developed building construction element database and they all claim to attain a high degree of quality and accuracy in the results when a high degree of precision is reached in the description of the building.
However, the complexity and the variety of data which have an influence on the LCA of buildings require many assumptions and hypotheses to be made and simplifications to be carried out. Those assumptions, hypotheses and simplifications introduce uncertainties into the results of a building's LCA. The main objective of the future building LCA tool is to allow for identification of improvement potentials in terms of costs and environmental impacts. Unfortunately, this objective has often been replaced by a race to the «best and most precise description of buildings, and the integration of such tools to CAD program».

With the development of a simplified tool for integrated life cycle analysis of buildings (Stilcab), the aim of the thesis is to demonstrate that a simple description of buildings allows almost the same conclusions to be made about a building's LCA with a lot less effort required to describe the building as with «conventional» integrated LCA (ILCA) tools. Results are achieved with the little input data available at early design phases. Furthermore, such an easy to use tool also allows for the calculation of building stocks and the assessment of several buildings at the same time, as well as for building sensitivity analysis in order to identify, in general, where the improvement potentials are for a specified category of building use or a particular building. Indications and instructions regarding the quality of the ILCA results are given and in particular it is assessed when two buildings can indeed be considered different.

The thesis was greatly supported with fundings from the European Institute for Energy Research (EIfER), for the research project called «STILCAB». The work took place at the Institut für Industrielle Bauproduktion (ifib).

Aperçu

Pendant les dernières décennies, l'analyse du cycle de vie (ACV) a été considéré comme un outil idéal pour juger, qualifier ou encore classer des produits selon les impacts environnementaux générés pendant leur cycle de vie. Cependant, appliqué au cas des bâtiments, cet outil se révèle être un processus élaboré, principalement en raison de la complexité et de la diversité des bâtiments qui ont tous leurs propres particularités.
En fait, le bâtiment en lui-même est une accumulation d'un grand nombre de matériaux qui rentrent dans sa composition dans des quantités spécifiques, et d'une multitude de facteurs qui interviennent et influencent sa durée de vie.
Plusieurs outils existent sur le marché, chacun permettant de calculer, de décrire, de modéliser et / ou de classer les bâtiments. Tous requièrent une description détaillée du bâti grâce à l'utilisation d'une base de données d'éléments de construction. Ils revendiquent tous l'obtention d'un haut degré de qualité et d'exactitude des résultats à condition qu'un haut degré de précision soit atteint dans la description initiale du bâtiment.
Cependant, la complexité et la variété des données ayant une influence sur l'ACV de bâtiments nécessitent la réalisation de suppositions, d'hypothèses et de simplifications. Celles-ci introduisent nécessairement des incertitudes sur les résultats de l'ACV. L'objectif principal des futurs outils d'ACV bâtiments est de permettre l'identification des potentiels d'amélioration en termes de coûts et d'impacts environnementaux. Malheureusement, cet objectif majeur a souvent été remplacé par une course à « la meilleure et la plus précise description du bâtiment et l'intégration de l'ACV aux programmes de CAO ».

Avec le développement d'un outil simplifié pour la réalisation de l'ACV de bâtiment, le but de la thèse est de démontrer qu'une description simple des bâtiments permet de tirer les mêmes conclusions sur les résultats d'ACV que les programmes dits « conventionnels» avec beaucoup moins d'effort nécessaire pour la description du bâtiment. Les premiers résultats peuvent être obtenus avec aussi peu de données que celles à disposition pendant les premières phases de la conception du bâtiment. En outre, cet outil si pratique à utiliser, permet également l'évaluation de plusieurs bâtiments en même temps, ainsi qu'une analyse de sensibilité pour identifier, où se situent, en général, les potentiels d'amélioration pour une catégorie d'utilisation de bâtiments spécifique ou pour un bâtiment en particulier. Des indications et des instructions quant à la qualité des résultats d'ACV sont données et en particulier il est évalué quand deux bâtiments peuvent être considérés différents. La flexibilité d'utilisation et l'adaptation de l'outil à la phase de conception du bâtiment considérée, sont en particulier mises en avant dans la thèse.

La thèse a recu le soutien financier de l'European Institute for Energy Research (EIfER), pour le projet de recherches nommé «STILCAB». Le travail a eu lieu au sein de l'Institut für Industrielle Bauproduktion (ifib).

Überblick

Während der letzten Jahrzehnte hat die Lebenzyklusanalyse an Bedeutung gewonnen. Sie dient als Werkzeug zur Evaluation und Klassifizierung von Produkten gemäß ihrer Umwelteinflüsse während ihrer Lebensdauer. Auf Gebäude bezogen stellt sich die Lebenszyklusanalyse hingegen als ein sehr schwierige Methode dar. Dies liegt an der hohen Komplexität und Diversität von Gebäuden mit jeweils unterschiedlichen Besonderheiten. Im Grunde besteht ein Gebäude aus einer Ansammlung unterschiedlicher Materialien in unterschiedlicher Menge mit jeweils einer Vielzahl von Faktoren, die ihre Lebensdauer beeinflussen.
Es existieren mehrere Werkzeuge auf dem Markt. Jedes ermöglicht eine Berechnung, Beschreibung, Modellierung und/oder Klassifizierung von Gebäuden. Jedes benötigt dafür eine detailierte Beschreibung des jeweiligen Gebäudes über eine tabellarische Aufführung der verbauten Materialien. Unter der Voraussetzung einer sehr prezisen Beschreibung des Gebäudes bei der Eingabe nehmen diese Werkzeuge alle für sich in Anspruch, besonders hochwertige und exakte Resultate zu erzielen.
Dennoch verlangt die Komplexität und Unterschiedlichkeit der Faktoren, die den Lebenzyklus von Gebäuden beeinflussen, nach Annahmen und Vereinfachungen. Diese Annahmen und Vereinfachungen führen zwangsläufig zu einer gewissen Unsicherheit bezüglich der Ergebnisse der Lebenszyklusanalyse. Das Ziel zukünftiger Werkzeuge sollte daher sein, die Möglichkeiten einer Optimierung hinsichtlich Kosten und Umwelteinflüsse klar darzustellen. Bedauerlicherweise rückte dieses Ziel in der Vergangenheit zugunsten einer möglichst genauen Beschreibung des Gebäudes und deren Integration in CAD-Systeme in der Hintergrund.

Mit der Entwicklung eines vereinfachten Werkzeuges zur Lebenszyklusanalyse von Gebäuden solte dargelegt werden, dass eine vereinfachte Beschreibung von Gebäuden mit wesentlich weniger Aufwand ermöglicht, die gleichen Rückschlüsse auf den Lebenszyklus zu ziehen, wie es die herkömmlichen Programme ermöglichen. Ersten Ergebnisse können hierbei sogar bereits bei einem sehr kleinen Informationenstand erzielt werden, so wie es zum Beispiel in einer frühen Planungsphase eines Gebäudes der Fall ist. Darüber hinaus ermöglicht dieses Werkzeug trotz seiner einfachen Handhabung mehrere Gebäude parallel zu betrachten, sowie eine Sensitvitätsanalyse, um klarzustellen, wo sich -im allgemeinen- Optimisierungsspielräume in Abhängikeit einer speziellen Gebäudenutzung oder eines speziellen Gebäudes befinden. Angaben und Anweisungen bezüglich Qualität der Ergebnisse der Lebenszyklusanalyse werden dargestellt und insbesondere wird darauf hingewiesen, wenn zwei Gebäude tatsächlich unterschiedlich sind. Die flexible Einsetzbarkeit und Anpassbarkeit des Werkzeuges an den jeweiligen Planungsstand des betrachteten Gebäudes wurden in dieser Arbeit in der Vordergrund gestellt.

Die Doktorarbeit hat die finanzielle Unterstützung der European Institute for Energy Research (EIfER) gehalten, für das «STILCAB» genannte Forschungsprojekt. Die Arbeit hat innerhalb des Institutes für Industrielle Bauproduktion (ifib) stattgefunden.

Context	Method	Tool	Example
I. Objectives			
II. Context II.1. Life cycle analysis II.2. Particularities of building LCA			
II.3. The necessity for simplifications of the building's representation model			
	III. Building representation model and statistical interpretation		
	III.1. Description of the building's representation model III.2. Geometrical building analysis III.3. Construction elements and their characteristics		
	III.4. Perspectives for the use of the building representation model		
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		IV. Development of a method for integrated building LCA in early design phases	
			V. Running the tool
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	X. Uncertainty analysis of building LCA tool		
Discussion - Conclusions - Perspectives			

Framework

INTRODUCTION

The necessity and the objectives of the method are briefly presented. An introduction is given about life cycle analysis in general, and then specifically for buildings.
Software for building life cycle analysis is briefly described in order to justify the requirements of a building model.

I. Objectives

The Institut für Industrielle Bauproduktion (ifib) at the University of Karlsruhe took part in the development of a tool for the Integrated Life Cycle Analysis (ILCA) of buildings. This tool is called Legep.
This software requires information from the user such as the description of the construction with supplied construction elements, details concerning the lifetime of the building, its use, and it provides results such as the investment costs, the life cycle costs, the environmental impacts, and energy and water requirements.
Very detailed data such as the ecological profile of material and data which is difficult to assess, such as the inventory of material and hours of work necessary to complete a part of a building, are included in the construction element database. Due to the degree of complexity of those basic data and their aggregation to allow for building life cycle calculations, uncertainties are induced which are carried throughout the use of Legep.
Furthermore, the use of such a software is time consuming as it requires a large amount of information from the user, information which is not usually at the user's disposal (or not completely in the early stages of design). However, this kind of tool was developed with the prospect of allowing a link to be made with CAD[i] systems, which might no longer be possible with a simplified method.

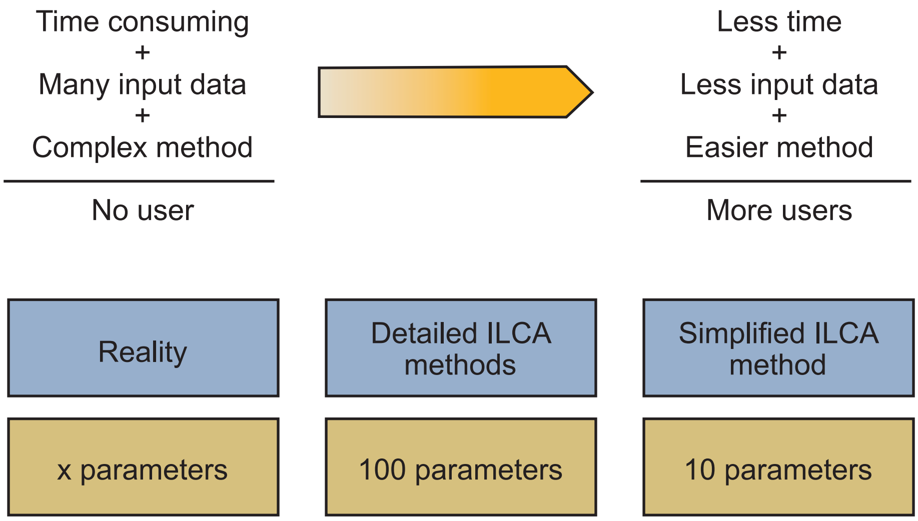


Figure 1

Basic idea for the development of a simplified tool for ILCA of buildings

The underlying aim of the development of the present method is to take advantage of these two undesireable occurrences (uncertainty and time consumption) in order to **design equivalent software** that will be able to give reliable results with as little input as possible and which will not be time consuming (cf. Figure 1).
In fact, while reality might be described with an infinite number of parameters (just like buildings), the detailed ILCA methods are doing calculations for buildings with about 100 parameters. Those are required from the user, which is extremely time consuming, and are then used in a complex calculation algorithm.
The purpose of developing a simplified calculation method is therefore to reduce the number of requested input data (leading to a reduction in time

i CAD: Computer assisted design

spent) - and in this way obtaining more users - without compromising the accuracy of the results.
Thus, the objectives can be summarized as follows:

- to set a simple building description model which adapts itself to the planning phase considered (i.e. to the amount and quality of information available at a given time). The representation model should allow the realisation of a small and easy tool able to calculate missing values for the geometrical description of buildings: **flexibility and scalability**;
- to use the tool to calculate a large amount of buildings and allow for the analysis of neighbourhoods or cities, as well as single buildings: **application**;
- to run sensitivity analysis for a specified building or building's use category in order to identify its improvement potential, by assessing to which parameters the building LCA model is more sensitive: **sensitivity**;
- to demonstrate that the results provided by the simplified tool are not less precise or of lower quality than the results given by a conventional ILCA tool: **accuracy and reliability**;
- and to determine the uncertainties in integrated LCA: **uncertainty**.

Furthermore, the developed method is adaptable to both French and German contexts as it considers the main construction techniques, materials, and costs of both countries. It could be adapted to other national contexts in the future.
It provides environmental impacts, construction costs, use costs as well as energy consumption associated impacts over the total lifetime of the building. It is a so-called «Integrated Life Cycle Analysis» tool, named Stilcab (Simplified Tool for Integrated Life Cycle Analysis of Buildings).

Stilcab is not a «starting from scratch» ILCA tool. It integrates the ecological data of the sirAdos[i] database as well as its elements of construction; but a new model of building description is developed, used and referred to. For the assessment of the energy requirement of buildings, an additional module was developed which allows for the implementation of the EBPD[ii] as well as of the simplified EnEV[iii],which is in application in Germany and is the direct translation of the EN832 [ENE] at the European level.
From the detailed analysis of a building database (1050 buildings), ratios between the use surfaces and the element surfaces of buildings are assessed; a geometrical model of buildings (according to classification into several buildings categories) is developed.
From the geometrical model on one hand, and the elements analysis (from the sirAdos database) on the other hand, a sensitivity analysis is carried out and integrated into the tool (cf. Figure 2). It allows for the identification of improvement potentials in buildings. Moreover, the geometrical model is further developed into a calculation tool for building stocks and groups of buildings.
An uncertainty analysis of both methods (Stilcab as the simplified one and Legep as the most complete software available) indicates to what extent it is relevant to use a simplified method, especially in the early planning phases. The validation of the simplified method compares the quality and the accuracy of results of the two methods.

i sirAdos: www.sirados.de
ii EPBD: European Building's Performance Directive
iii EnEV: Energieeinsparverordnung

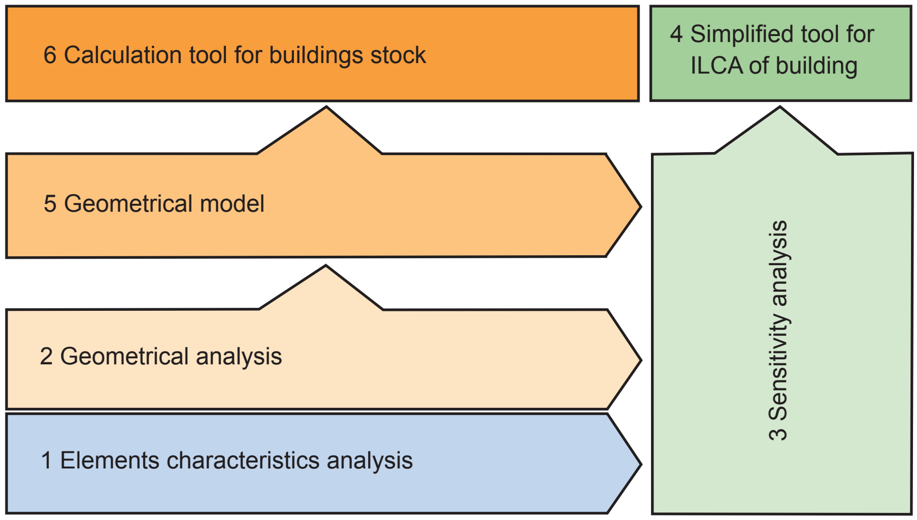


Figure 2

Development of Stilcab

II. Context

II.1. Life Cycle Analysis (LCA)

II.1.1. General idea behind Life Cycle Analysis

LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.
The life cycle analysis was developed in the United States in the 70's and has been evolving in Europe since the 80's.
«The first LCA study is a study for Coca-Cola conducted in 1969-1970 by the Midwest Research Institute in the United States concerning the environmental consequences of packaging manufacture, alternative to beverage cans», states [BAU]. The 1970's are known for the oil crisis and the energy debate, and therefore could be the reasons that the first LCA was conducted at that time. However, at the same time, the issue of packaging and waste was another environmental debate. Indeed, the first LCAs conducted between 1969 and 1972 were all studies on packaging and waste management. Later on, due to the energy crisis, there was intense interest in the energy aspects of the analysis. In the mid 80's, environmental issues became a focus of public interest more then ever before. This was spurred by environmental disasters such as the chemical accident in Bhopal, India in 1984, the nuclear reactor explosion in Chernobyl in 1986, and the oil spill from the tanker Exxon Valdez in 1989. Some countries began to carry out large studies and published their data each time, therefore allowing a spread of data and information. However, in comparison, the many packaging studies showed diverging results and somewhat different methodologies. This sparked a debate and started a new era of methodological discussion and development. A sign of increasing research activity is the number of articles about LCA in academic journals. The field also developed its own journals, amongst others the International Journal of Life Cycle Assessment. In the 1990's, LCA application became more diverse, extending beyond packaging into food products, building materials and construction, chemicals, automobiles and their components

and electronics.
The methodology of life cycle assessment has been developed by scientific associations like SETAC[i] and has been widely accepted by industry and standardization boards like ISO[ii]. Having defined the scope of the study, which allows the definition of system limits and function, the method consists of accounting for the resources taken from and the substances emitted to the environment, resulting in an inventory. The inventory is then aggregated into indicators corresponding to various environmental themes (e.g.: global warming, etc.) [PEU].

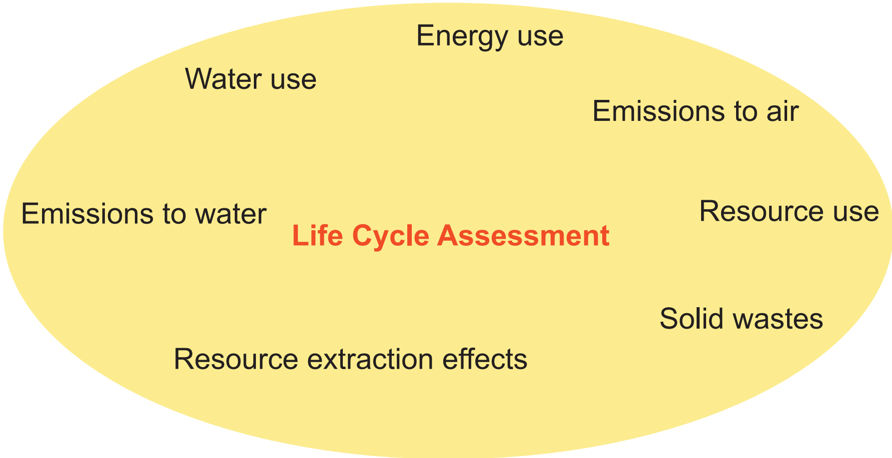


Figure 3

Integration of different themes in LCA

II.1.2. Standards for Life Cycle Analysis

In today's global economy, organizations are increasingly called upon to demonstrate sound management of economic, social and environmental issues. Evidence suggests that a focus on this «triple bottom line» results in advantages in financing, insurance, marketing, regulatory treatment, and other areas.
An environmental management system (EMS) is a structured approach to address the environmental bottom line. ISO 14001 is the world's most recognized EMS framework that helps organizations both to better manage the impact of their activities on the environment and to demonstrate sound environmental management.
In 1997, an international standard [ISO] for life cycle assessment, the EN ISO 14040 « Principles and framework » was published by the CEN[i]. This standard was subsequently supplemented by EN ISO 14041 to 14043, which describes the basic principles and elements of a LCA study [NEU].
The ISO 14040 standards give guidelines regarding the principles and conduct of LCA studies that provide an organization with information on how to reduce the overall environmental impact of its products and services.
The ISO 14041 provides guidance in determining the goal and scope of an LCA study, and for conducting a life cycle inventory.
The ISO 14042 provides guidance for conducting the life cycle impact assessment phase of an LCA study.
The ISO 14043 provides guidance for the interpretation of results from an LCA study.
The ISO 14048 provides information regarding the formatting of data to support life cycle assessment.
Finally, the ISO 14049 provides examples that illustrate how to apply the guidance done in ISO 14041 and ISO 14042.

i SETAC: Society of Environmental Toxicology and Chemistry; www.setac.org
ii ISO: International Organization for Standardization; www.iso.org
iii CEN: European Committee for Normalization

In the introduction of the norm ISO 14040, the following is specified: «Life cycle analysis is an evaluation technique of environmental aspects and of potential environmental impacts associated to a product by:

- Elaboration of an inventory of relevant inputs and outputs of a product system;
- Evaluation of the potential environmental impacts associated with those inputs and outputs;
- Interpretation of the results of the two previous phases in relation to the objectives of the study.

The life cycle analysis assesses the environmental aspects and the potential impacts during the life time of a product (from cradle to grave), from the acquisition of the primary resources to its production, its use and its destruction. The major categories of environmental impacts which should be considered include the use of resources, the human health and the ecological consequences.»

II.1.3. Evolution of building Life Cycle Analysis

In Europe, the European Commission is extending the description and assessment of buildings to an integrated environmental performance assessment. The Commission has recently issued a mandate to CEN to develop methods for an «assessment of the integrated environmental performance of buildings» [LÜT].
Within the scope of international standardization activities at ISO, intense efforts are currently being undertaken to standardise the description and assessment of the environmental performances of buildings. Amongst other reasons, these standardisation activities are due to an extremely inconsistent use of assessment criteria and indicators in existing tools and methods. As a result of the work of ISO TC59 SC 17 «Sustainability in building construction» a standard will soon be available (ISO 21931) that offers the methodical basics for the further development and harmonisation of environmental planning and assessment tools.
In order to improve the informational basis of environmental assessments, current efforts (e.g. within the scope of ISO TC 59 SC 17 but also in the scope of national activities) are bringing data requirements concerning construction products and materials in line with the forms of provision and preparation of information on these products and materials. In particular this applies to the adjustment and fine-tuning of assessment indicators. A trend towards the development of national databases for building product information can be observed. This leads to the necessity of existing environmental planning and assessment tools to adjust or modify data structures and to allow for the transfer of data among these national databases.

II.1.4. The different steps of Life Cycle Analysis

The process of LCA is composed of the following steps, according to the ISO standard.

Each of the four steps is succinctly described below.

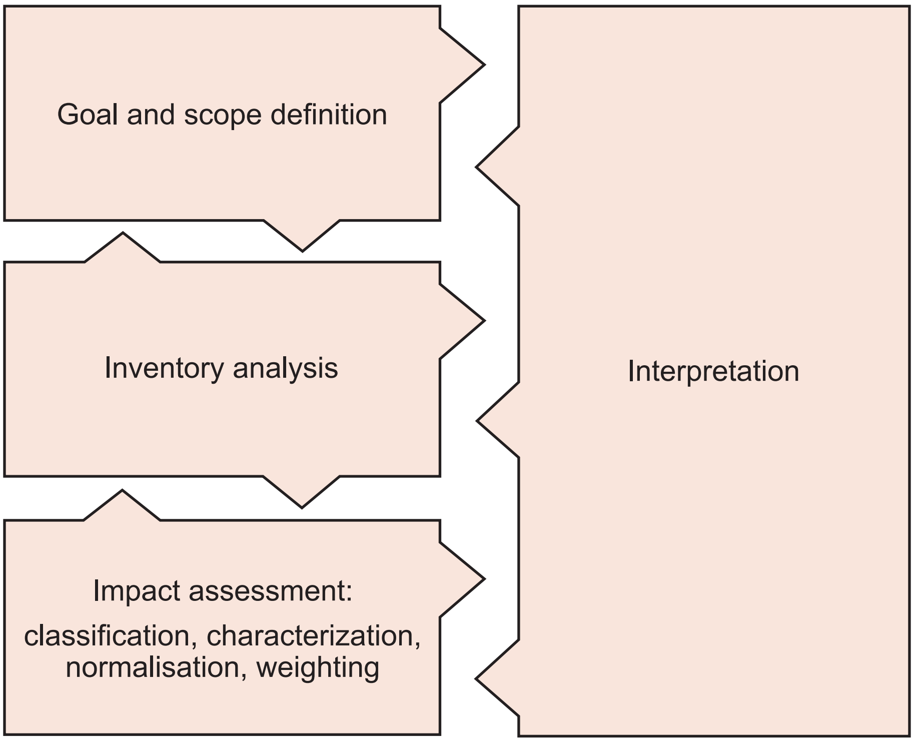


Figure 4

Overview of the LCA process according to ISO 14041

II.1.4.a. Goal and scope definition

In the first step of an LCA, the goal and the scope of the study have to be clearly defined and agreed upon with reference to the applications intended. Therefore the goal of an LCA shall include motivations for the study, intended applications and audiences, initial data quality requirements and a type of critical review.

Furthermore, it is important to define the system in term of its functional service and its boundaries. This is the subject of the scope phase, which should also include the method of impact assessment and subsequent interpretation, the data requirements, all assumptions made and their limitations. All these parameters are defined according to the stated goal of the study and should be clearly stated, comprehensible and transparent. They should also indicate the representativeness of the system in terms of technology, geography, time, market, data and data sources. In comparative studies, the equivalence of the systems being compared shall be evaluated before interpreting the results [BÜL].

II.1.4.b. Inventory analysis

The inventory analysis phase provides a comprehensive view of the flow of materials, energy, water and pollutants in and out of the system boundaries. This phase is fundamental, since its reliability will affect the complete study. The issue is not a trivial one, since many product life cycles imply both complex systems and subsystems and complex energy and material flows. However, there are precise guidelines and ISO standard 14041 for LCA practitioners on how to make key decisions related to the definition of the systems and their

boundaries, the definition of the functional unit and the data collection and calculation procedures, particularly as far as energy accounting and allocation rules are concerned [BÜL].
Indeed, the construction of the flowchart is realised according to the system boundaries decided on in the goal and scope definition phase. Inventory data is to be related to reference flows for each unit process in order to quantify and normalise input and output to the studied functional unit. Data will then be aggregated in order to create an input-output table for the studied product.
Finally, a calculation of the environmental loads (resource use and pollutant emissions) of the system in relation to the functional unit is realised.

II.1.4.c. Impact assessment

The impact assessment phase is composed of several activities: category definition, classification, characterization and weighting, as represented in the following figure (cf. Figure 5).

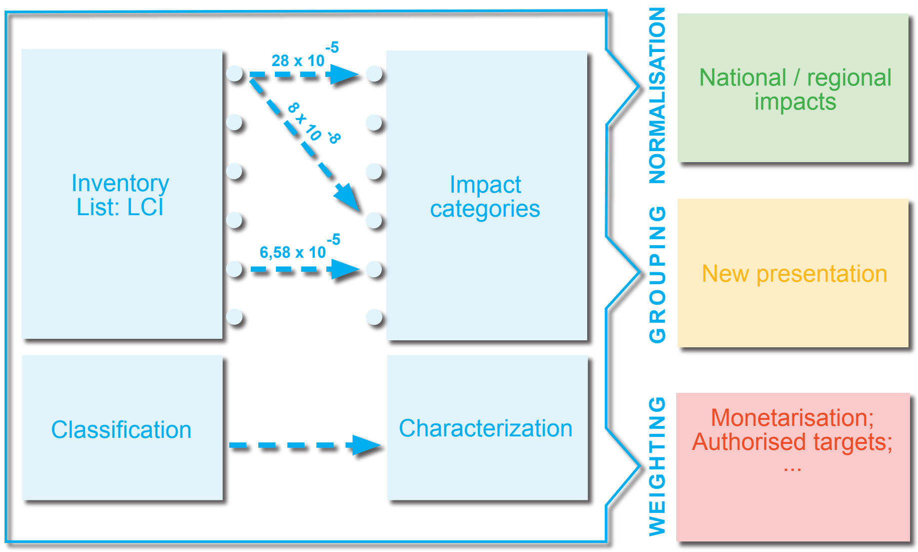


Figure 5

Description of life cycle impact assessment

II.1.4.c.i. Impact category definition

Impact category definition consists of [BAU] drawing the list of all inputs and outputs (activity of the life cycle inventory LCI[i]) and choosing which impact category will be considered (activity of the «Impact category definition»).
In practice this can be a specification of environmental impacts considered relevant in the goal and scope definition. Such a specification is sometimes based on what information was collected during the inventory analysis.
Several things should be considered when deciding which impact categories to include:

<u>Completeness:</u> the list of impact categories should cover all relevant environmental problems, i.e. problems that are generally regarded as major environmental problems and also problems that may be of specific interest for the particular LCA study.

<u>Practicality:</u> the list should not contain too many categories.

i LCI: Life Cycle Inventory

Independence: the categories should be mutually independent in order to avoid double-counting.

Possibility to be integrated in the LCA calculations: this implies that it should be possible to link the LCI result parameters to chosen impact categories and characterisation methods.

Environmental relevance: indicators derived from characterisation methods should be environmentally relevant to the impact category and safeguard subjects.

Scientific method: characterisation methods should have scientific validity.

CML[i] and SETAC describe a general approach for the calculation of environmental effects. There are three steps: classification and characterisation, normalization and evaluation

II.1.4.c.ii. Classification

In the classification step, all substances are sorted into classes according to the effect they have on the environment.
The results of the inventory (= the list) are sorted out and assigned to the various impact categories selected in the impact category definition phase. Certain substances are included in more than one class. For example, NO_x is found to be toxic, acidifying and causes eutrophication. The substances are aggregated within each class to produce an effect score. It is not sufficient just to add up the quantities of substances involved without weighting. Some substances may have a more intense effect than others. This problem is dealt with by applying weighting factors to the different substances. This step is the characterisation.

Example:

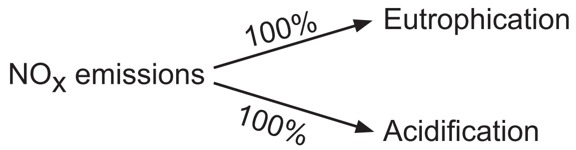


Figure 6

Example of classification into impact categories

II.1.4.c.iii. Characterisation (CML / SETAC)

This is the quantitative step based on physical-chemical mechanisms regarding how different substances contribute to the different impact categories.

Example:

Global warming potential:	$CH_4 \leftrightarrow 56kg\ (CO_2)_{eq}/kg$
Depletion of abiotic resources:	$Al \leftrightarrow 1.10^{-8}\ kg\ (Sb)_{eq}/kg$
	$Si \leftrightarrow 2{,}99.10^{-11}\ kg\ (Sb)_{eq}/kg$

II.1.4.c.iv. Normalisation

The aim of this phase is to gain a better understanding of the magnitude of the environmental impacts caused by the system under study. Therefore, the

i CML: Leiden University Institute of Environmental Sciences; www.leidenuniv.nl/cml/

characterisation results are related to (= divided by) the actual or predicted magnitude for each impact category. For example, the Eco-indicator method normalises with effects caused by the average European during a year. But other bases are available for normalisation.

II.1.4.d. Interpretation of Life Cycle Analysis results

Up to this step, non final judgements can be made as all effects are considered to be of equal importance. In the evaluation phase the normalised effect scores are multiplied by a weighting factor representing the relative importance of the effect.
The characterisation results are sorted out into one or more sets. It is useful for the analysis and the presentation of results.
This includes an identification of significant environmental issues, an evaluation of the underlying study and the generated information. From the interpretation, conclusions and recommendations will be made. Therefore, the interpretation should be evaluated with sensitivity, consistency and completeness.

II.1.4.e. Weighting

Weighting can be defined as the qualitative or quantitative procedure where the relative importance of an environmental impact is weighted against all the others. Methods of weighting are based on social sciences and on several different principles (monetarisation, authorised targets, authoritative panels, proxies, technology abatement). In the weighting phase, ideological and ethical values are involved.
Since ethical and ideological values are involved in the weighting element in LCIA[i], there will never be a consensus on these values. Many engineers therefore have an awkward relationship to weighting and its use. Factors often lead to discussion about whether they are «scientifically correct» or not, whether the values are representative or not, etc. This awkwardness also leads to discussions of what is objective and what is subjective. Although our values concerning the environment are subjective, the methods for describing them as weighting factors are objective in the sense that the resulting weighting factors should, in principle, be empirically verifiable. In order not to trample on anyone's feelings, the ISO 14042 standard (2000) recommends that it may be… «desirable to use several different weighting factors and weighting methods and to conduct sensitivity analyses to assess the consequences on the LCIA results of different value choices and weighting methods. All weighting methods and operations used shall be documented to provide transparency».

II.1.4.f. Data quality analysis

To assess the quality of data, several methods are commonly used. They are briefly presented here:

- The most polluting activities in the life cycle (dominance analysis, also called «gravity analysis» in the ISO standard);

i LCIA: Life Cycle Impact Assessment

- The most crucial inventory data. That is, the data describing the activities in the life cycle for which slight changes in value change the ranking between compared alternatives. This is called sensitivity analysis;
- The most crucial impact assessment data. That is, the data describing impact categories for which slight changes in value change the ranking between compared alternatives. This is called sensitivity analysis;
- The significance of alternative methodological choices (different types of allocation for example). This is also a sensitivity analysis;
- The degree of uncertainty in the results (uncertainty analysis). Note that uncertainty is introduced to the calculations when input data are estimates, intervals or probabilities.

Eco-indicator 99 distinguished two types of uncertainties: data uncertainty and uncertainties about the correctness of the models used. They specified data uncertainties for most damage factors as squared geometric standard deviation. On the other hand, they consider uncertainties about the model to be related to subjective choice made in the model. In order to deal with these, they developed three different perspectives of the methodology, using the archetypes specified in Thompson's Cultural Theory. The hierarchical, individualist and egalitarian perspectives were considered [PRE].

II.1.5. Life Cycle Impact Assessment methods

According to [BAU] and [NEU].

II.1.5.a. EPS: Environmental Priorities Strategies

The environmental priority strategies system is material intensive. For each material an environmental load index (ELI) is evaluated. This index assigns values to emissions and resources consumptions based on 5 criteria (biodiversity, human health, ecological health, resources and aesthetics). The indices are then multiplied by the material loadings to give the ELU (environmental load unit), which are later added up to quantify the total environmental load. Indices are not transparent and country specific. Each index is accompanied by an uncertainty factor.

II.1.5.b. Environmental themes - CML

The CML method was developed in 1992 by the Centre of Environmental Science at the Dutch University Leiden. It summarises the set of results from the inventory analysis in impact categories. A classification of the environmental interventions has to be conducted to qualitatively assign the interventions to a particular impact category (cf. Figure 6). Then, during the characterisation step, these interventions are quantified in terms of a common unit for that category (cf. II.1.4.c.iii.), allowing aggregation into a single score. These scores together describe the environmental profile of the analysed product or process. In a later step, normalisation serves to indicate the percent of the results in a worldwide or regional total. Moreover, the CML contains additional characterisation methods such as Eco-indicator 99 and EPS.

II.1.5.c. Eco-indicator 95 and 99

This method was developed in the Netherlands. It is mainly based on the CML method but it includes fewer impact categories. Furthermore, a weighting step is introduced to convert and aggregate the indicator results across impact categories.
In the Eco-indicator 99, weighting is realised according to several cultural values; it is possible to consider three different views: the individualist, the hierarchical and the egalitarian perspectives.

II.1.5.d. EDIP

EDIP[i] was developed for use in product development processes. Its main differences from environmental themes are the assessment of toxic substances and the focus on the work environment.
The method is largely based on Danish political targets (environmental impacts and weighting for the work environment are also based on Danish statistics).

II.1.5.e. Others

Other methods do exist, such as the “ecological footprint”. This method is a one parameter method, for example “area”.
The UBP (Umwelt Belastungs Punkte - Switzerland) method (also known as ecopoint) is based on the principle of ecological scarcity.
MIPS is another proxy method in which the amount of material is the proxy parameter, as MIPS stands for «material intensity per service unit». All materials, irrespective of the type, are added up on a weight basis. Analysis is greatly simplified with this method since it is sufficient to concentrate on the mass flow in the life cycle without inventorying all emissions.
Energy consumption reduction is a proxy method which is based on energy. The energy parameter includes the energy consumption in the life cycle as well as the energy needed by, for example, end-of-pipe technology for reducing environmental impacts.

KEA stands for Kumulierter Energie Aufwand, the cumulative energy expenditure. It is a number used to define the whole expenditure of energy resources (primary energy) necessary for the supply of a product or a service.
The KEA also contains the energy linked with the production of materials, e.g., from wood as a building material or paper, even if the energy is still available as a heat value in the product.
Similarly the KEA also encloses the whole expenditure of energy in crude oil or natural gas with the synthetic material production. The KEA is methodically described with the directive VDI 4600.
GEMIS stands for «Globales Emissions-Modell Integrierter Systeme», Global Emissions-Model of Integrated Systems. It is an ecobalance and mass flow analysis tool with a public database from the Öko-Institut in Darmstadt. GEMIS is free to use. Its model and database can be easily accessed from the web.
The KEA is partitioned into renewable, non-renewable and «recycled» primary energies. In GEMIS 4.0 implemented arithmetic methods of the KEA shows two important changes in the methodology of VDI 4600directive:

- Certainly, the KEA contains the primary energy expenditure for the

i EDIP: www.mst.dk

supply of required materials; however the energy content (heat value) of these materials is not considered if they are not used as source of energy (e.g. wood as a building material, oil in synthetic materials, natural gas in nitrogenous fertilizer).

- For the primary energy production - and only there - all sources of energy are counted for on a fixed level of use of 100% - all production losses are attributed to the stock.

In Gemis, this methodology can be switched off and the “old“ methodology of the VDI 4600 directive can be switched on.
The KEA is an important judgement number for energy systems and is also recognized as a «coarse check» in eco balance applications.

II.1.5.f. Mid point categories – Damage categories

LCIA methods aim to connect, as much as possible and desired, each type of LCI results to the environmental damages caused by it, on the basis of impact pathways (impact pathways are composed of environmental processes like a product system consists of economic processes). To achieve this, it has been proven useful to group types of LCI results with similar impact pathways (e.g. all substance flows influencing stratospheric ozone concentrations) into impact categories at midpoint levels, also called midpoint categories.
In the following section of the report, the author limits his assessment to the midpoint categories.
One midpoint indicator per midpoint category is defined in view of comparing and characterizing the substance flows and/or physical changes tabled as LCI results, which contribute to the same midpoint category. The term «midpoint» expresses the idea that this point lies somewhere on the impact pathway as an intermediate point between the LCI results and the damage or end of the pathway. Consequentially, a further step may allocate these midpoint categories to one or several damage categories, the latter representing quality changes to the environment as being the ultimate objects of concern to human society [JOL].
Figure 1 in the glossary shows the overall scheme of the proposed framework, linking all types of LCI results to the damage categories via the midpoint categories. An arrow means that a relevant impact pathway is known or supposed to exist between the two corresponding elements.
It would be desirable to draw reliable quantitative impact pathways connecting each «relevant» type of LCI results to midpoint indicators and eventually to the corresponding damage indicator. This ambitious task can not be completed for the time being for all types of impacts, mainly due to current limits on scientific knowledge. It appears that currently available information on the last sections of certain impact pathways, between midpoint and damage levels, is sometimes particularly uncertain (dotted arrows). This causes a dilemma between the certainty and the completeness of LCIA. An answer to this dilemma is to model quantitative impact pathways only where reasonably reliable information is available (full arrows).

II.1.5.g. Comparison of Life Cycle Impact Assessment methods

The comparison [BAU] in the following table (Figure 7) shows that the environmental damage from a pollutant or resource is different in the different LCIA methods. The reason for this is that the different LCIA methods convey different types of information, be it society’s priorities through political systems or captured through panels, through its individuals’ economic priorities or be it

the «priorities» of nature (expressed by critical loads). As these LCIA methods reflect different prioritisation principles, it is not possible to say that any one of them is more correct than the others.
Comparisons such as those in the following table are useful in identifying where different methods and values lead to large differences in LCA results. Although each LCIA methods has its weighting principle, the diffculties the constructors of the methods have in finding enough and adequate data have sometimes led them to use default parameters in calculating their indices. The use of the ranking principle in product comparisons then becomes less consistent.

	Eco indicator ‘99	Environmental themes - short	EPS
CO_2	0,00019 (/g)	0,011 (/g)	0,0702 ELU/kg
CO_2	1	1	1
NO_x	416	356	2,32
SO_2	737	218	0,524
HC	63	293	-
PAH	4842195	177477	6952
Hg (air)	484211	4252253	2521
Hg (water)	4842105	2837378	-
N-tot	289	647	0,142
BOD	-	36	0,004

ELU: Environmental Load Unit
HC: Hydrocarbons
PAH: Polycyclic Aromatic Hydrocarbons
BOD: Biological Oxygen Demand

Figure 7

Comparison of the relative harm of selected environmental loads (relative to CO_2) in three LCIA methods [BAU]

II.2. Particularities of building Life Cycle Analysis

II.2.1. Statistics concerning the construction industry

In the Kyoto Protocol, negotiated in 1997, the participating industrialised countries committed themselves to a 5% reduction in emissions of climate-damaging gases - such as carbon dioxide - by the period 2008-2012 as compared with 1990. The European Union has agreed to cut its emissions by 8% during the years 2008-2012 as compared to the level of 1990. To meet this target, the EU Member States have set national climate protection goals. Germany has pledged to reduce greenhouse gas emissions by 21% during the same period (based on 1990 levels). In the context of the implementation of the Kyoto Protocol, the European Union launched its emissions trading scheme on the 1st of January 2005. On the basis of the Emissions Trading Directive which came into effect in October 2003, EU Member States are obliged to adopt National Allocation Plans for the implementation of emissions trading. The Federal Government notified the European Commission in Brussels of its National Allocation Plan on schedule on the 31st of March 2004.
The emissions trading system provides an economic basis for lowering emissions of climate-damaging CO_2 where such a reduction is most cost-efficient. This means that ecologically effective action is implemented economically. Specific reduction targets are set for each branch of industry and the individual installations concerned, which received this quantity of free emissions allowances as of 30 September 2004 for the first trading period. The certificates are tradable and therefore serve as a kind of currency. If the company meets the targets by means of its own cost-saving CO_2 reduction measures, it can sell unused certificates on the market. Alternatively, it has to buy additional certificates on the market if its own reduction measures become more expensive. If a company does not meet the reduction requirements, sanctions are due, which amount to 40 euros per ton of carbon dioxide (as in 2004). The failed reduction requirement has to be fulfilled in the following year. In Germany, operators of about 2400 installations have been able to participate in emissions trading since 2005. In particular, this

applies to all large combustion plants (thermal output higher than 20 MW) as well as larger installations in the energy-intensive sectors [BMU].
As the heating, air-conditioning and hot water production sectors are responsible for 30% of the total energy demand in Germany, it is reasonable to predict that the same emissions trading process used for industries might go into effect for domestic consumers, for households. The building sector might therefore be directly concerned with future emissions trading systems.
Furthermore, according to the German government [NEU], more than 300 million tons of waste per year result from construction activities, representing about 60% of all waste weight in Germany.
The construction industry plays a major role in a country's economy and environment protection policy. It is a large source of employment, but at the same time, it represents an important consumption of materials (generates mass flows) and leads to energy consumption both during the process of building and during the lifetime of each building. The Kyoto Protocol aims to reduce CO_2 emissions, which goes hand in hand with the reduction of overall energy consumption which is intimately linked to the reduction of building energy consumption.

II.2.2. Specificities of buildings

The LCA of buildings has different characteristics than the LCA of other industrially produced products, mainly because it does not concern a serial product but a unique one, and because the user has a main role to play during the lifetime of the building (cf. Figure 8).

The differences are stated below:

- The life span of a building is long and uncertain. The results of the ILCA of a building depend widely on the user and on the life expectancy of the construction and of each building's construction elements.
- Buildings are one of a kind products, which makes comparison more difficult.
- Construction depends on the site and the impacts are local; the geographic distribution and the accounting of environmental impacts are limits, otherwise they are a real problem of definition of LCA methods.
- Contrary to most serial products, a building consists of several diverse products. That is why the description of a building requires a multitude of construction elements. These elements are themselves the results of a multitude of manufacturing processes which differ from one element to another. Furthermore, from one construction to another, the elements used to describe the construction differ.
- The life cycle of a building includes, amongst other factors, a long period of use during which the user has a large influence according to his lifestyle, for example, contrary to other consumer goods for which the user has no influence during the use phase of the product (cf. Figure 8).
- Buildings are multi functional in space and in time dimensions; it is difficult to choose a functional unit to compare one building with another. Indeed, the LCA data are established on the basis of typical references multiplied by a functional unit. In the case of buildings, the choice a priori of a functional unit to draw hypothesis of the life cycle impacts is tricky as the function of the building can change during its life (office into house, day-care centre into gymnasium, warehouse into factory, for example).
- The urban infrastructure can be integrated or not in the LCA. Due to this fact, the establishment of precise borders of study for the LCA of building is highly recommended. The integration of the results of building LCA - even only a share thereof - in the corresponding infrastructure would

considerably disadvantage the building with regard to other case studies for whom the infrastructure would not be considered.
- The internal living environment is bound to the outside environment, etc., which is obviously not the case for others consumer goods.

II.2.3. The importance of the use phase of the building

In this simplified scheme representing the various stages of any product's life cycle (here a ballpoint pen) and of a building (cf. Figure 8), it can be seen that the user of the pen does not affects its life cycle at all, which is not the case for the building. Indeed, the user has a large influence during the building's lifetime. He can be responsible for a large share of the environmental impacts and energy used in the building.

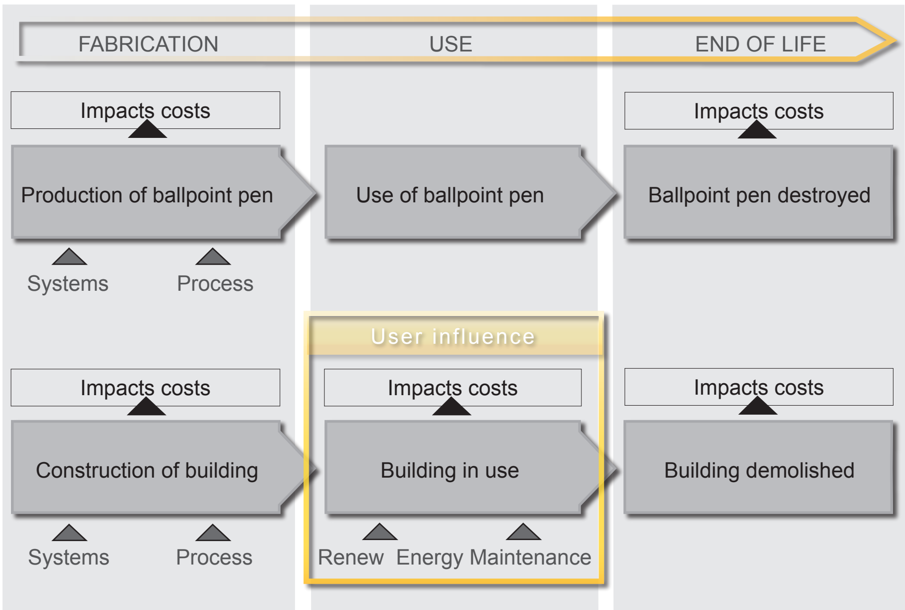


Figure 8

Comparison between buildings and serial product life cycles

Naturally the construction of a building, like the production of some other products, depends on several serial products gathered together (cf. Figure 9).

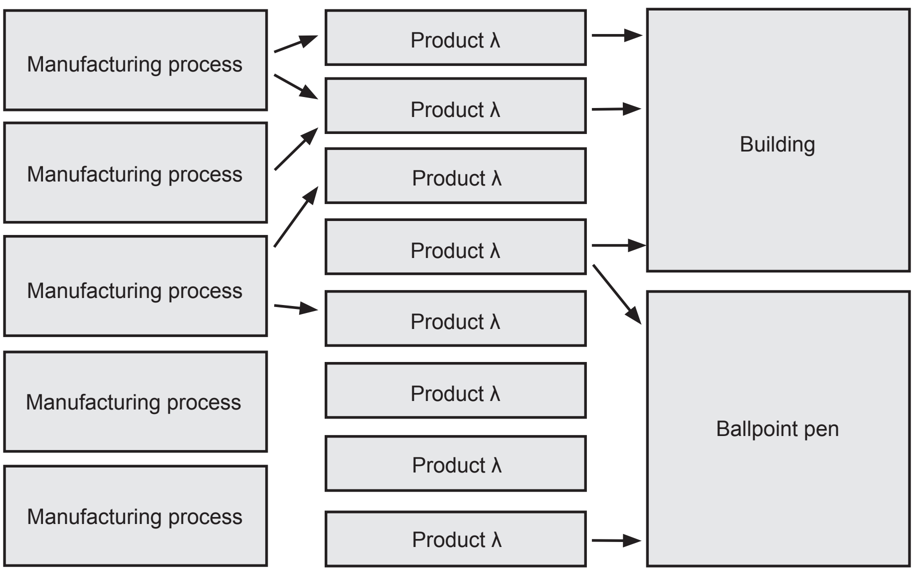


Figure 9

Building and ballpoint pen manufacturing processes from raw products

Thus the difference in the life cycle of a product λ and a building lies only in the use phase.
In particular, the energy consumption during the use phase of the building is far from being insignificant for the calculations of costs and impacts (cf. Figure 54), as it will be discussed later on.

By taking back the four stages of a product's ILCA realization as mentioned in the previous chapter as well as the specificities of the case «building», the differences which can exist between the LCA of a product λ and the LCA of a building are highlighted. This facilitates the understanding of the necessity of realizing uncertainties and sensitivity analyses.
The aim of this exercise is to illustrate to the reader the fact that buildings are unique and that their lifetimes are rich in events (user's influence) which can drastically change the outcomes of the building's LCA (renovation cycles, cleaning intensity among others).

II.2.4. Main parameters for building Life Cycle Analysis

The important parameters for a building's ILCA are summed up below and in Figure 10.
It is common sense to distinguish the lifetime of the building from its construction and to consider them as two different phases. One is short but well known and has a large influence on the other (construction phase), whereas the second one is long and uncertain, mostly unknown or difficult to simulate as it requires forecasting of the coming years (lifetime).
However, both phases induce environmental impacts as well as costs and mass flows. The impacts and costs generated by the construction phase of the building mainly depend on the construction elements selected and the geometry of the building (that is to say, the quantity of each of those elements).
For the second phase, the impacts, mass flows and costs generated are mainly caused by the use of the building considered and the renovation and maintenance cycles. However, the choice of elements made in the construction phase greatly influences the energy consumption during the lifetime of the building. Likewise, the choice of material (i.e. construction elements) also influences the renovation cycles which occur during the lifetime.

<u>Parameters for the building's construction:</u>

- Choice of the appropriate building construction element to describe each part of the building;
- Quantity of this element (usually expressed in m² or m³).

<u>Parameters for the life cycle of the building:</u>

- Lifespan of the building (years);

<u>Buildings construction element's internal characteristics:</u>

- Cost / unit of element;
- Environmental impacts / unit of element;
- Mass flow / unit of element;
- Cycles of renovation[i], maintenance, cleaning of each building construction element.

i The service life of the building and components are defined in ISO15686 [ISO15686]

Figure 10

Important parameters for building LCA

II.2.5. Buildings detailed Life Cycle Analysis with Legep software

Legep is a tool for integrated building life cycle analysis resulting from research in Germany. The goal of the research project was to integrate LCA (based strictly on energy and mass flow) into the professional work environment of architects, engineers, quantity surveyors and contractors.
Legep supports the planning teams in the design, construction, quantity surveying and evaluation of new or existing buildings and buildings products. It works hand in hand with the sirAdos database of construction elements.
Legep establishes simultaneously and for the whole life cycle:

- the energy needs for heating, hot water, electricity (following the German standard EnEV 2002 and EN832);
- the construction, operation, maintenance, refurbishment and demolition costs;
- the environmental impacts (based on ISO 14040 to 14043) and resource consumption.

The method is based on cost planning by «elements». The database is hierarchically organised, starting with the LCI data at the bottom, building material data, work process description, simple elements for material layers, composed elements like windows, and ends with macro-elements like building objects. Each construction element triggers its own life cycle following elements (operation, maintenance, with their periodicity and intensity) [KOH].

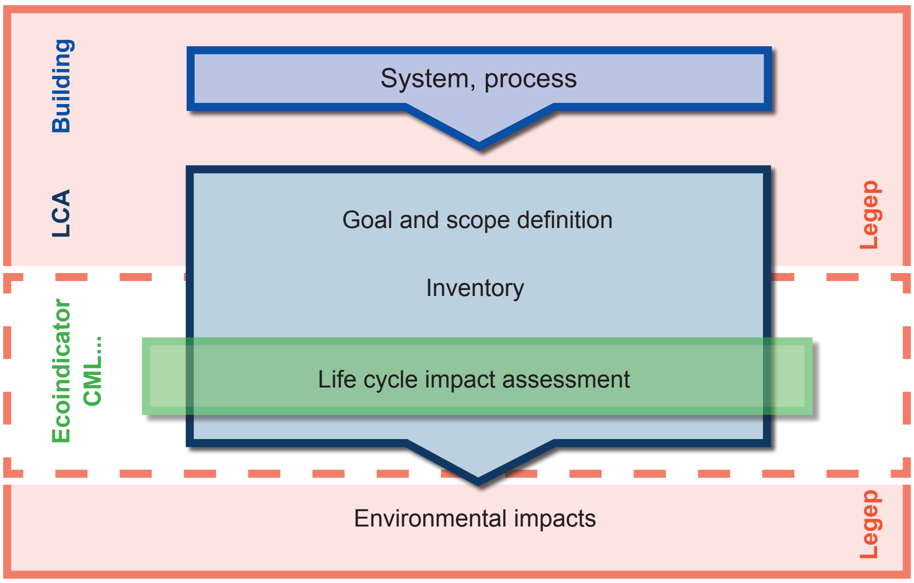


Figure 11

How Legep is made, what the inputs and outputs of the program are.

II.2.5.a. Building description in Legep

The description of buildings in Legep is realised with construction elements. The element selection can be realised (depending upon the necessary degree of detail) by means of:

- the macro elements, during the pre-planning phase;
- the elements, when realising the draft;
- or the detailed elements, during the execution phase.

New elements can be created and equipped freely with materials and layer sequence.
The following figure (cf. Figure 12) shows the display of Legep with 14 construction elements (8 detailed elements and 6 elements) and their cost.

KG	Name	Nr	Menge	Einheit	KG Alt	Einzelpreis	Gesamtpreis	benszyklus Kosten
	Neuer Ordner						**762 930,88**	**16 738,88**
310	BGK-Aushub Bkl. 3-5, m. Oberbodenabtrag, seitl. lagern,Hinterfüllen	131013111	700,000	m³		17,03	11 921,00	
320	GRK Fdm-Pl. C 20/25, Abd.Bodenf., Estrich, Beschichtung	132011111	700,000	m²		120,44	84 308,00	2 568,37
330	AWK KS, WDVS PS, Dispersion., I-Putz, Dispersion	133014335	574,150	m²		164,02	94 172,08	2 304,74
336	Trockenputz mit Dämmung, GK 12,5 + PS 20	133642135	90,650	m²		27,50	2 492,88	
336	AW Bekleidung GK m.Lattung, innen, d=12,5 mm	133646112	20,630	m²		24,00	495,12	18,54
340	IWK KSL 20 cm, Gipsputz, Dispersion	134013334	50,670	m²		98,85	5 008,73	47,08
342	Innenwand Mz 12/1,8, d= 17,5 cm	134211715	562,500	m²		67,22	37 811,25	
350	DEK Beton C 20/25, 20 cm glatt, ZE+TSD PS 120, Linoleum, Putz, Dispersion	135022341	1,000	m²		157,89	157,89	8,85
351	Decke B25, rauhe Schalung, d=25 cm	135125215	1 065,000	m²		94,68	100 834,20	
350	DEK Beton C 20/25, glatt, ü. unbeh.DE, schw.Estr.,TSD u.WD 120 mm,Textil, Disp.	135021221	1 125,000	m²		120,52	135 585,00	5 356,13
360	DAK Holz, flach, Bitumendeckung, MF 160 mm, Bekleidung	136041124	945,000	m²		149,27	141 060,15	4 328,05
344	IW Holztür+STZ, WC, KS-Beschichtung, 625x2000x145 mm	134411171	20,000	St		382,12	7 642,40	278,59
334	AW Fenster Fi,Ug=0,9, 2-flügelig,2,0-3,0m², o.Sprossen	133451119	79,550	m²		391,44	31 139,05	1 041,22
334	AW Fenster Fi, 2-flügelig, 1625x1250 mm, aufgekl. Sprossen, Ug 1,1	133451122	25,680	St		835,62	21 458,72	787,31
361	DA Ziegelelemente flach, 21 cm	136111111	1 035,000	m²		85,84	88 844,40	
	Summe Projekt (Netto)						**762 930,88**	**16 738,88**
	Umsatzsteuer 16%						**122 068,94**	**2 678,22**
	Summe Projekt (Brutto)						**884 999,80**	**19 417,10**

Figure 12

Display of the construction elements and related costs in Legep (see "Traduction" for the traduction of the key terms)

II.2.5.b. Costs calculation in Legep

If the building is completely described by means of the elements from the database, the new construction costs can be computed automatically. On each working stage, the cost calculation is done according to DIN 276[i], allowing the following to be accomplished:

- the cost estimation,
- the cost calculation,
- the preliminary real cost estimate.

With the element method, the selected building is always referred to and no statistic linkages of surface to cost are made, contrary to others cost estimation procedures which already exist on the market.
The sirAdos element database is based on the sirAdos tendering, which is developed according to the arrangement of the standard performance specification (Standardleistungsbuches). The element classification according to DIN 276 can therefore be completely dissolved into a trade (activity) arrangement. Thus all building data are available for the complete tender.

The building costs for the tendering of positions, which represent the basis for the element prices, are completely revised once a year and adapted to the growth in construction costs. Over 150 architect offices in Germany make the tender documents and the price of realized and planned building projects available. These are evaluated by and assigned to the sirAdos positions for activity.

i DIN: Deutsches Institut für Normung e.V. The DIN 276 regulates the cost calculation in the building construction. The DIN 277 describes the surface areas and volumes of building constructions, DIN 276: cf. Annex 14

Working in «from - average – to» - prices allows consideration of regional characteristics (density - rural area), building type and size (single family houses, multi-story buildings, multi-story residential buildings - administration buildings), construction period or technical standard. The planner must select the applicable price level according to his mandate and on the basis of reference prices.
Each price can be adapted project-specifically to the planning situation.

II.2.5.c. Heating and energy requirements in Legep

The heating and energy module computes values regarding the energy consumption of the building. It differs from other building physics programs because not only is the verification of the energy consumption for the heating of the building realised, but the description of all technical equipment which is necessary during the use of a building is also done.
The warming and energy documents are:

- the heat flow of a building regarding heat gain and heat losses according to the «calculation basis of thermal insulation» regulations of 1995 (WSVO[i]) and the energy saving regulation 2002 (EnEV);
- the construction units relevant for the energy balance of the building, which represent the basis for WSVO/EnEV calculations;
- the information about the occurrence of condensation and about each layers of the construction parts will also be included in a future version;
- additional consumption of energy (specified electricity) according to the use category and occupation scheme;
- the water consumption according to the use category and occupation scheme;
- the possibilities for the saving of external energy supplies with the use of solar energy (solar collectors) or photo voltaic energy;
- the replacement of external water supplies with the use of rain water collection;
- the building-specific operating cost per year by linking with the specific cost of the different sources of energy;
- the possibilities of national subvention are considered when delivery to the network is realised.

All these computations are reported to the life cycle cost program so that corresponding costs are taken into consideration.

The «comparison module» allows comparison between as many projects or variants of a project as desired. The results can be extensively documented.
The module «ecology» can compute the environmental impacts resulting from energy consumption.
The physical values of the materials are taken either from the known standards (DIN 4108[ii]) or the basis literature accessible on material physics.
The sirAdos elements are fully equipped with the necessary arithmetic procedures and can be used immediately for the calculation of the energy requirement of the building. The building-technical equipment is linked to necessary performance characteristics to make them freely combinable (such as is required by the EnEV).

The arithmetic rules of the WSVO and/or the EnEV correspond to the respective regulation. Likewise, the documents provided by Legep conform to regulations. The «energy pass» of the Institute for Living and Environment (IWU[iii]) corresponds to the arithmetic rules developed there.

i WSVO: Wärme Schutz Verordnung
ii DIN 4108: Wärmeschutz und Energie-Einsparung in Gebäuden - Thermal protection and energy conservation in buildings
iii IWU: Institut für Wohnen und Umwelt, www.iwu.de

The needs of the different media (fresh water, hot water, electricity) for the different uses (living building, administration) were taken from different literature sources. The computation is based on this statistical data.
The range of the data collected in the literature allows the Legep user to set the consumption level either to low, normal, or high.
The selection of the energy and water consumption level (low / normal / high) has no influence on the element selection and vice-versa.

With the selection of environmentally friendly building services components (e.g. solar heat collector, rain water collector device, etc.) the user can dramatically affect the energy consumption. If those elements are used in a project description, they are recognized for their specific function and the renewable energy will automatically replace the sources of energy otherwise used. This is appropriately considered by the costs and ecology parts of Legep.

II.2.5.d. Life Cycle Costs in Legep

The life cycle costs part is an extension of the costs for new building parts (cf. II.2.5.b.). It concerns the subsequent costs: those occurring during the use of a building.
Parallel to the construction costs of the building (realised according to DIN 276), the subsequent costs - also referred to as life cycle costs - are computed and indicated. The duration of the use phase considered can be specified at will, although a lifetime of 80 years is recommended for new building calculations.

The module life cycle costs documents:

- the cleaning costs,
- the maintenance costs,
- the renovation costs,
- in a future version, the costs of the demolition or deconstruction of the building[i].

Figure 13 displays two construction elements. For the second one, the renovation and cleaning phases are shown («RE» and «INS»).
The activity prices for the subsequent activities during the use phase of the building (concerning cleaning and maintenance) are determined by specialized enterprises (cleaning firms, building services and maintenance companies). The renovation prices result from the current manufacturing prices plus the demolition costs. No further rates of construction cost growth are considered over the period of the building's use.

The cleaning cycle is subject to large variations regarding execution quality, type of use and hygiene standards. For this reason one or more scenarios are indicated in Legep depending on the element. For several scenarios (e.g. for the floor area) a standard variant is activated. Alternative scenarios can be activated by the Legep user if desired.
The maintenance cycles correspond either to the recommendations of the manufacturers or to regulations (e.g. heating systems maintenance).
To a large extent, the renovation cycles refer to the data in the "manual for lasting building" of the German Federal Ministry for traffic, building and living, published in 2001 [BUW]. The data in the manual were extended for some construction units, if it became necessary due to specific execution variants. Furthermore, some cycles were changed in particularly justified cases. Each cycle can be changed project-specifically.

i Legep - life cycle definition: In Legep, the "life cycle" considers the construction, the energy and water consumed during the life time as well as the renovation, the cleaning and the maintenance of the building. In the work, the same assumptions are made, and in particular in Stilcab, the limits of the life cycle analysis are the same as those considered in Legep.

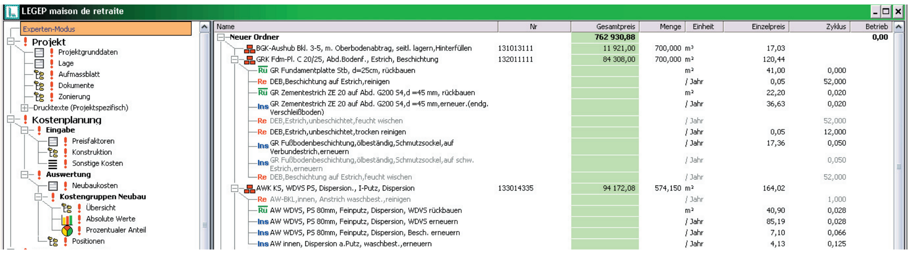


Figure 13

Legep's Life Cycle Costs display (see "Traduction" for the traduction of the key terms)

II.2.5.e. Environmental impacts in Legep

With the «environmental impacts» module, computations can be made in order to assess the ecological consequences, which occur both during the production of the building and during all cleaning, maintenance and renovation cycles of the building during its use phase.
The duration of the use phase can be specified at will by the user of Legep.

Since, so far, no program exists in Germany which computes and documents resulting environmental impacts of building elements and thus subsequent elements, a building planner enters an area for which no experience or orientation values exist. This means that the information collected must be interpreted carefully. Evaluating statements about building quality should be formulated and presented with necessary caution.

The ecology module documents (as shown in Figure 14 and Figure 15):

- the entire material flow for the production of the building,
- the entire material flow for the various life cycle phases,
- the impact assessment for the life cycle phases.

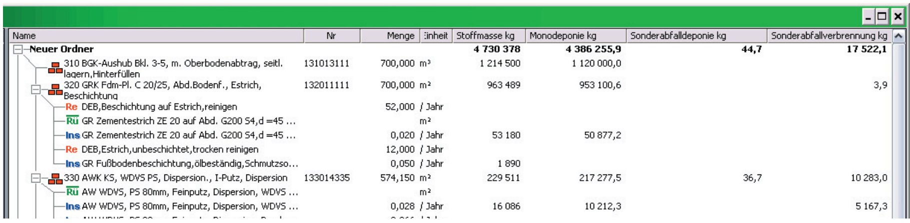


Figure 14

Display of mass flow in Legep (see "Traduction" for the traduction of the key terms)

The represented criteria are:

- Greenhouse potential in kg CO_2 equivalent.
- Acidification potential in kg SO_2 equivalent
- Renewable primary energy (PER) in MJ
- Non-renewable primary energy (PENR) in MJ
- Ozone depletion potential (ODP) in kg CFC_{11} equivalent
- Summer smog potential in kg Ethen equivalent
- Abiotic resources consumption in kg Sb equivalent
- Nutrification potential in kg P equivalent.

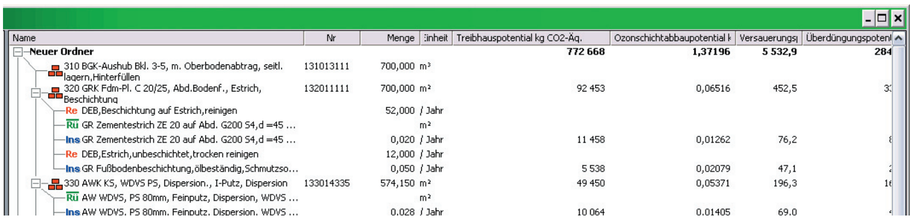


Figure 15

Display of environmental impacts in Legep (see "Traduction" for the traduction of the key terms)

The life cycle analysis with its three steps (goal and scope definition, inventory, life cycle impact assessment) is included in Legep. The life cycle impact assessment was realised with several methods (CML, Ecoinvent, Eco indicator, UBP[i]), as shown in the following figure.

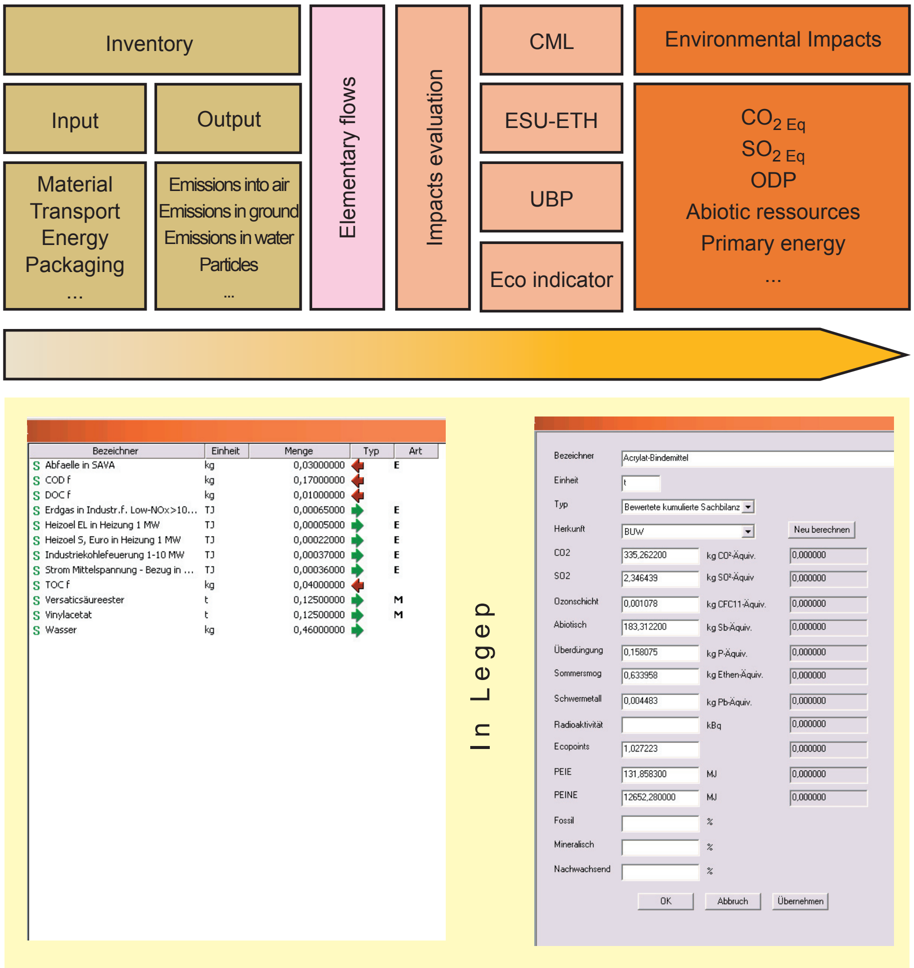


Figure 16

From inventory to environmental impacts in Legep (see "Traduction" for the traduction of the key terms)

II.2.5.f. Advantages and drawbacks of Legep

The principal advantages of Legep in comparison with the other building LCA software are:

- The use of a detailed cost of construction elements database which is actualised every year;
- The energy consumption calculations from the description of the building envelope;
- The supply of tender and other official documents required by legal authorities;
- The use of statistical renovation cycles, of cleaning intensity requirements and their associated costs and impacts;
- The limited time required to enter the necessary input.

It is also possible to describe buildings both in a very rough way with a few macro-elements or describe them later on in the design and detailing stages

i UBP: Umwelt Belastungs Punkte

in a very precise manner without losing information and without changing the systematics. After commissioning the same data can be used for facility management and refurbishment. Even if the first description is cumbersome, the advantages of using it during the whole life cycle make it worth the effort.

If the use of integrated LCA tools like LEGEP is appropriated in the German context where architects are in charge of the design, detailing, construction management and commissioning process and where detailed commercial cost databases exist, this is not the case in other countries where the architects work mainly in the design phase and do not use detailed databases of cost elements [KOC]. It is however important to create common tools which can be used in different national contexts and which give both reliable specific cost results and comparable environmental impact indications.
Therefore, Legep presents the following drawbacks:

- The lack of information in early design phases when the architect does not have more than a design brief in the form of a program and performance targets and constraints.
- The lack of national element data in many countries.
- The performance orientation implicit in new EU standards and in several international projects is lacking at the beginning of the design process.

II.2.6. Other software for building Life Cycle Analysis

In a sustainability assessment of the built environment several method families coexist. One family is the rating methods which has the advantage of encompassing a large number of very different criteria, but they lack an explicit quantitative framework which limits the validity of the results to the specific national context and the views of its authors [KOC].
Another family of methods can be considered life cycle assessment oriented.

According to [RMI], building LCA tools are categorised as:

- Detailed LCA tools focusing on materials, components and processes (e.g.: Simapro, Gabi);
- Design tools, which use LCA as a basis but are simplified to single indicator points or to an aggregation of impacts on building component levels (e.g.: LISA, EcoQuantum, Ecoscan);
- LCA CAD Tools, integrated tools that can read material and component information from CAD drawings (also called hybrid tools, e.g.: LCADesign, Legep, OGIP);
- Green product guides and checklists, which are mainly qualitative;
- Buildings assessment schemes, used to assess whether a building is performing adequately, sometimes allocating star ratings;
- Embodied energy tools.

However, the last three mentioned are not LCA tools.
Improving the environmental performance of buildings and building stocks is best accomplished using tools as decision-making aids. Many countries now have a variety of tools that have been tailored for use by specific users and to fill particular analytical needs.
The reader is asked to refer to [IEA] for a detailed list of tools to realise building LCA, classified by type and country. Moreover, in Annex 11, the list of tools which were looked at can be found.

II.2.6.a. Equer – Paris, Ecole des Mines de Paris – Centre d'énergétique

EQUER (Evaluation de la qualité environnementale des bâtiments) was mainly developed by Ecole des mines de Paris.
EQUER is a life cycle simulation tool providing quantitative indicators of environmental quality for various actors. The tool is primarily intended to work at the whole building level, in order to capture the trade-offs between different systems. For example, a concrete slab may store the heat collected by a window and thus increase the environmental benefit of this window (and vice-versa).The system limits can be chosen according to the purpose of the study. For instance, work-at-home transportation can be included in the analysis when choosing the building site, but it may be excluded in the design steps. Finally, the tool allows for a comparison with a reference building, providing an evaluation of the improvement of environmental performance compared to a present construction standard.

II.2.6.b. OGIP - Switzerland

OGIP is a LCA CAD tool. It is a software based on the NPK[i] (building element catalogue of CRB[ii]) which enables the user to compare building projects regarding costs, external costs, Umwelt Belastungs Punkte (UBP) and energy. It can be used in the early stages of the design phase, when construction and dimension characteristics are known. However, one or two weeks are necessary to complete the inputs.

II.2.6.c. LCADesign - Australia

LCADesign [SEO] is an application which enables building design professionals to make informed and quick decisions about a building or its products, utilizing extensive high quality data. Computer aided design (CAD) models of buildings are linked with LCI data to produce LCIA on environmental aspects of building materials.
The tool is fully automated from the completion of the 3D CAD drawing of a building to the viewing of calculated environmental impacts resulting from building construction. The automated take-off provides quantities of all building components made of products such as concrete, steel and timber. This construction information is combined with the life cycle inventory to estimate key internationally recognized environmental indicators. It also considers the components which are replaced in part or in whole over the life of a building. LCADesign is a good compromise between traditional CAD programs and LCA software.

II.2.6.d. LISA

LISA (LCA in sustainable architecture) is a streamlined LCA decision support tool for construction. It was developed in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design [LIS].

i NPK: Normpositionen- Katalogs
ii CRB: Centre Suisse d'études pour la Rationalisation du Bâtiment; The catalogue of standard positions NPK is the standardized basis of the Swiss building industry for the production of uniform and clear bills of quantity ranges from above ground construction, foundation engineering and building engineering; www.crb.ch

II.2.6.e. Japan's tool for renovation assessment

There are limits on the effective reduction of carbon dioxide emissions through measures related to new buildings alone. Energy-saving renovations are also needed for existing buildings, which constitute an enormous stock. However, although they use an environmental assessment technique (LCA) for new building construction, there is still no assessment technique for renovation projects. To rectify this situation, a tool has been developed in Japan [KAW] which can be used in the renovation stage to assess both life cycle carbon dioxide emissions (LCCO2) and life cycle cost (LCC).

The present list of tools is limited to a few examples. One can find many more software and calculation programs which are dedicated to the LCA of buildings in the Internet. A more complete list can be found in Annex 11.

II.3. The necessity for simplifications of the building's representation model

The developers of ILCA software for buildings have drawn a list of all possible building construction elements which they thought were necessary. Those elements are then selected by the user of the software to compile a list of elements and used to describe the building of study in the software.
However, thinking it would be the best, the developer does not only describe one or ten elements for each part of the building but a large quantity of them. He assumes all elements are different, all have different characteristics, some contain more or less material, different material, have different lifetimes, and so on. Therefore the end effect is that the developer provides the user with a list of several elements, all which have the same function in the building but very different characteristics. Usually, those elements are very exactly described with as much information as possible (i.e. as much as the developer has).
On the other hand, the user of the software seldom has such a level of precision when he wants to describe a building in the ILCA software. Therefore, he opens the list of elements corresponding to the function in the building (e.g.: exterior walls) and tries to select the most appropriated element (i.e. the element which best corresponds to the construction of study).
Because all elements and all buildings are different, due to geographical location or climatic condition, due to different internal element function (e.g. carrying beam), the user never finds the element he is actually looking for in the element's database, there is always a detail in the element's description which does not fit with what he is looking for. As he naturally needs an element for this particular function, he picks an element which is not really the one he is searching for but which fits best.
There is a communication problem between the developer and the user of the software. Both think they are doing the best by providing as much information about the element as possible (and respectively by selecting the best element available), but in reality, both are making mistakes, which may greatly influence the end-results of the ILCA:

- The developer thinks that all elements are fundamentally different (different material, costs, environmental impacts…). He aims to provide a more complete database of elements which does not yet exist.
- The user of the software, who is helpless in front of such a range of possible elements, selects a "default element" which does not necessarily correspond to reality (i.e. to the information he has at this

particular planning stage) and gives in an approximate quantity of this element although the planning phase does not allow for such a precise idea of this quantity at the moment.

The combination of those two mistakes can be eradicated by proving that:

- Element characteristics are not fundamentally different when the element's lifetime is looked at;
- The quantity of building construction elements mainly depends on one characteristic of the building and can be therefore determined with as little information as BGF[i] (Gross Floor Area).

This is what is done in the next section (cf. III.) by suggesting a building description model, assessing the geometrical analysis of a large quantity of buildings and analysing building construction element characteristics.

i BGF: Brutto Grund Flache, is almost the equivalent to Surface Hors d'Oeuvre Brute in France. It is the gross floor area (m²)

A METHOD FOR BUILDING LIFE CYCLE ANALYSIS

A building's description model is suggested and defined before being developed and implemented in a geometrical model. The model considers both construction elements on one hand, and building use and element surfaces on the other hand.
A gross life cycle evaluation tool is developed for groups of buildings.
Finally, the various modules of the early design phase tool for building ILCA are presented and implemented.

III. Building representation model and statistical interpretation

After having described the building model and its origin, each part of the model is defined and analysed in this paragraph:

- The geometrical building characteristics;
- Construction elements.

How the analysis of both of these factors was carried out is explained, as well what outcomes were reached.
Then the last part presents some of the perspectives for such a model.

III.1. Description of the building's representation model

LCA programmes need a very detailed estimation of all the materials in a building. To simplify and to allow for the rapid choice of alternatives, a building is generally divided into elements. These (functional) elements have a specific surface (or volume). A quantity of materials that corresponds to the amount of a specific element in a building is assigned to each of these elements. The building description model considered consists of a list of construction elements (with their specific material quantities) on one hand and the corresponding element surfaces on the other hand. This vision of buildings is extremely simplified, but it is sufficient for the costs, energy and environmental impact calculations of all integrated LCA methods.
In the following, buildings will be considered as a superposition of elements of construction and their associated quantity which comes from the analysis of typical building geometry in a specified building use category (cf. Figure 17).

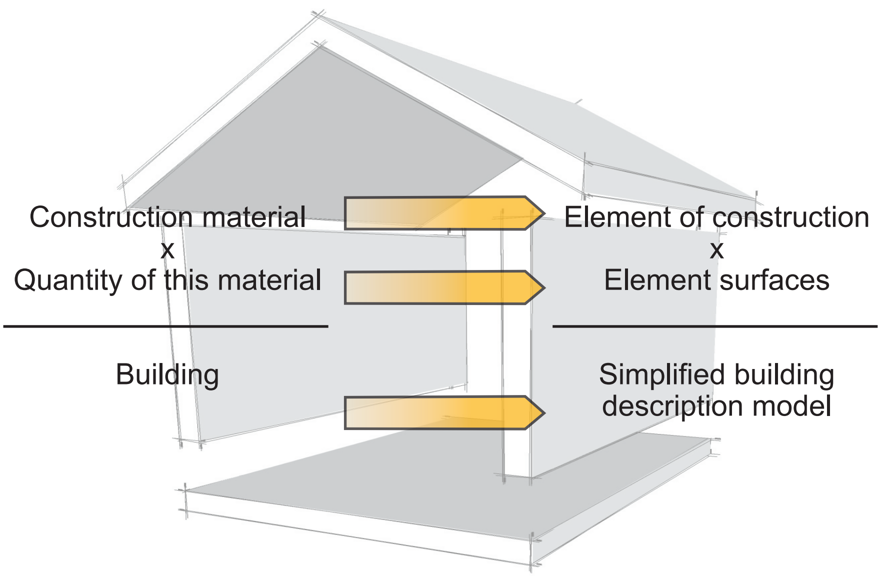


Figure 17

Building description model

In order to simplify building descriptions, it is necessary to have a list of construction elements on one hand and the element surfaces on the other hand.

III.1.1. Construction elements

As already mentioned, the building is broken down into functional units (or cost elements like 1m² of exterior wall), which are the result of all building processes proportionally necessary to realise the element.
This process-oriented specification contains the necessary quantities of materials (including all auxiliary materials and waste) as well as the type and working time of machines used (including their energy and material consumption as well as their capital and maintenance costs). Material and building process quantities can be linked to the basic inventory data and evaluation sets (mass flow, primary energy consumption, effect-oriented impact categories, aggregate indicators etc.). In order to reflect the life cycle of a building element, additional information about the life expectancy, maintenance and cleaning cycles, energy consumption during use, recycling behaviour and possible downstream paths must be provided. Element data also contain information about the succession and fixation of the different layers (and materials), which allows for the calculation of heat flow. Other performances can theoretically also be calculated like vapour diffusion, outgazing, toxicity risks, construction time and deconstruction possibilities.
Furthermore, when using such elements in a scaleable way, a complete list of elements and specifications is created by the end of the design process. These specifications can be reorganised along trade divisions or contractor rules as a basis for tender without the loss of the initial information.
In this case, the database sirAdos [SIR] is considered as the source for construction elements. The following figure (Figure 18) presents the display of this database as it appears in Legep, detailed here for exterior wooden walls.

However, the database offers several possibilities (i.e. elements) to fulfil the same function in the building. The necessity of distinguishing all elements from each other has been assessed (cf. III.3.). Furthermore, according to the planning phase considered, the choice of the appropriate element may be impossible as the building‘s developer may not yet know which material will be used for construction.

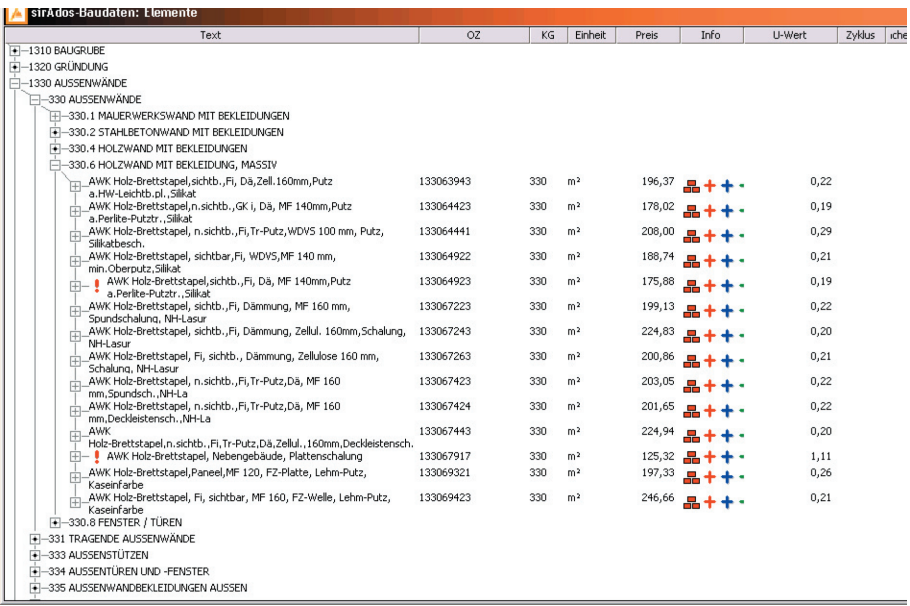


Figure 18

Screenshot of an extract of the sirAdos database as presented in Legep

III.1.2. SirAdos: a database for construction elements

The sirAdos database has existed for about 20 years. It allows for costs planning. SirAdos allows tenders to be drawn, with building costs, elements and technical conditions as per contract. One goal is to save expensive project operating time and thus to increase profit when creating the description of the building to be built.

It offers authorities, large-scale enterprises and administrations a good basis for the building management of cleaning and maintenance with the tendering and evaluation of costs which occur during the lifetime.
A constant structure from the position to the construction unit has been chosen in the database sirAdos. Construction elements are a summary of individual specifications for the cost planning. Thus constant passing on of information from the cost estimation to the tender is achieved.
SirAdos offers current, investigated market prices. Its tendering text and elements contain additional important information, like current values, detailed sketches and cost elements according to DIN 276, and references [SIR].
Furthermore, the structure of sirAdos database is taken from DIN 276, the German standard for describing buildings. The norm sorts out the construction in several topics such as “foundation”, “excavation”, etc. (cf. Annex 14 for the norm). The norm is usually used for cost estimation. Its use is extended in sirAdos to building description.
The purpose of III.3. is the analysis of the database and its construction elements.

III.1.3. Construction element surfaces

According to the planning phase considered, the quantity of construction elements is more or less known. However, the tool to be developed should be flexible and adaptable enough for the planning phase considered (i.e. for the quality of information available about the building at a particular time). To do so, the “default quantity” (= default element surfaces) will be assessed, derived from the analysis of a large quantity of buildings (cf. III.2.4.). Those “default values” can then be selected by the user of the tool when not enough is known about the building to be analyzed. However, the user will still have the chance to enter his own value, if known.
This analysis is the purpose of III.2.

III.2. Geometrical building analysis

One step in developing the simplified method is the geometrical analysis of buildings.
Buildings are seen as a superposition of geometrical description on one hand and of construction on the other hand. The geometrical description of buildings is considered in this paragraph.
There are different ways of considering the question. First the typology of buildings can be examined (cf. Figure 19 and III.2.1.). Otherwise relations between use surfaces and element surfaces in buildings can be considered (cf. III.2.4.).
The goal of the process is to reduce the complexity of the building geometry down to a couple of mathematical relations between use surfaces and element surfaces so that from the knowledge of one specific surface, all others can be calculated.

III.2.1. Analysis of buildings typology: geometry

Buildings are described with geometrical characteristics (area, length, width, height, etc.). When the user has identified which typical typology best suits the building in consideration, he simply uses the mathematical relations to calculate the other characteristics of the building. This is the elementary geometrical representation of reality.
An extract of [BRA] follows (cf. Figure 19). It shows some typical building typologies which can be considered.

Nevertheless, it is difficult to assess a particular typology of one building. The selection of the appropriate typical typology is user dependent and can not be achieved scientifically. Therefore, the second possibility is looked at, which is the assessment of building quantities, in order to establish mathematical relations between use surfaces and element surfaces.

III.2.2. Building information database

For the purpose of the analysis of element surfaces, a building database was constituted.
The database gives more than 220 pieces of information for each building. Information ranges from geometrical information (surface of exterior walls, gross floor area, etc.) to the location in Germany, from the use of the building to the number of rooms.

The database gives information about buildings covering:

- A large range of building categories (9 use categories (Figure 21), 900 buildings);
- A geographical repartition of the buildings in Germany, avoiding any regional differences (cf. Figure 20);
- Buildings with small and large gross floor areas (i.e.: ranging from 150 to 25000 m² of gross floor area for office buildings).

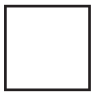
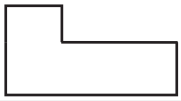
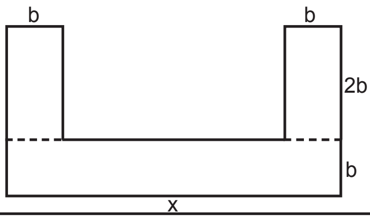
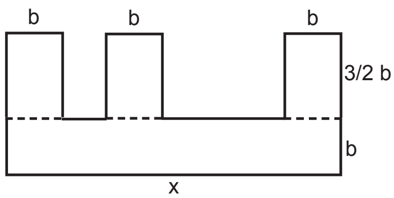
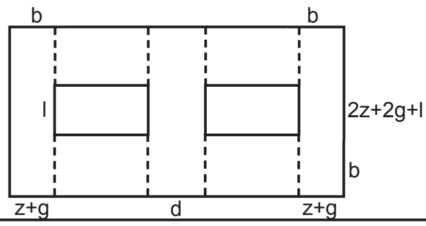
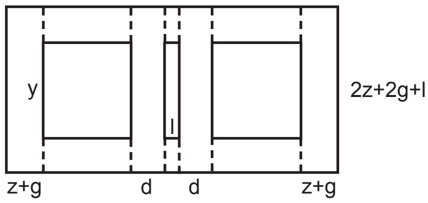
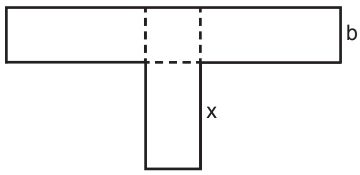
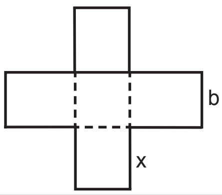
Square	
Rectangle	
L-shaped office buildings are approximated by rectangular buildings of the same area.	
U Form	
The **comb** has a similar shape to the U-form, but is defined to have at least three wings, each of them having a length of l = 3/2*b which gives an area of A = $3/2*b^2$.	
For the typology **(m, n)-atrium** the first parameter m denotes the number of inner courtyards and the second, n, the number of light wells. A distance of d = 10m is assumed between inner courtyards or light wells.	
The existence of inner **courtyards** gives an arrangement of light wells differing from the case without inner courtyards.	
A regular **T-shaped** typology is assumed as in the picture.	
Cross-shape	

Figure 19

Different building typologies, according to Patrick Erik Bradley

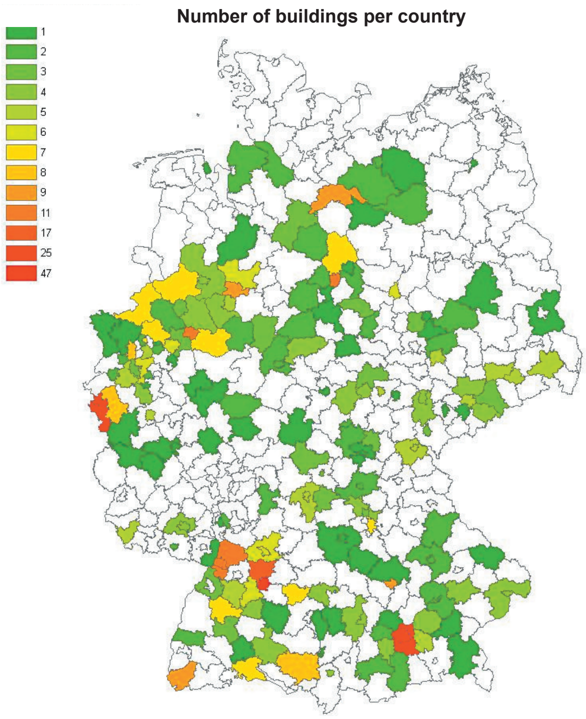


Figure 20

Geographical repartition of the buildings in the BKI database – courtesy of Martin Behnisch

Following from various discussions, according to the StaBu[i] building classification and the classification of buildings in the concerned building database, the following categories were defined:

Category	Example of buildings concerned	Number of buildings
Hostel, student habitations	Boarding school, hotel…	20
Houses, double houses	One and two family houses…	181
Factories	Factory plant, warehouses, storehouses, halls…	88
Industry and trade buildings	Restaurants, stores…	51
Hospitals	Hospital, clinics, infirmary …	38
Fire stations	Emergency services, fire stations	34
Multiple family housing	Multiple family housing, apartments…	172
Office buildings	Office buildings, banks, administration offices…	106
Educational buildings	Kindergartens, schools, research institutes, educational buildings ….	212
Others: Churches, stadiums, libraries, cemetery, gymnasiums, parking, streets and places, museums, swimming pools…	These cases were not taken into consideration, as there are either only a few case-studies (and also few of those buildings would be constructed), or they are unique building types (churches, museums, stadiums…)	

Figure 21

Building categories

III.2.3. Building elements surfaces and use surfaces

The “quantities” taken into consideration are those used to describe buildings in Germany, according to the DIN 276 and DIN 277[ii]. Figure 22 and Figure 23 allow a visualization of the meaning of all cost types[iii] (KG, group of costs description) and of the German norm DIN 277.

i StaBu: Statistiches Bundesamt. Statistical institute. The French equivalent is INSEE (National Institute for Statistics and Economic Studies)
ii DIN 277: cf. Annex 14
iii KG: Kosten Gruppe. In Germany, architects have to provide a document which describes the construction and allows cost calculation at the same time. This document is drawn up according to the German norm DIN 276. Costs are distributed among groups of costs (KG). A group of costs represents a part of the construction: exterior wall, foundation…

The selection of the quantities which should be analysed is carried out according to the following facts:

- DIN 276 and DIN 277 are widely used in Germany (cf. Figure 22 and Figure 23) and legally compulsory; they provide a description of the building at several points, each point representing a specific function in the building.
- Among those two standards, the cost types which will be taken into consideration are only those related to construction. The other cost types are related to parcel, decoration, etc., and are therefore not relevant for a building analysis.
- Moreover, it is necessary to keep in mind that the aim of this analysis is to allow for a complete building description with as little information as possible. In other words: with one parameter, assumptions about all the other parameters are possible (in some cases, two parameters are necessary, or two parameters allow a more accurate definition of the other parameters).
- The last but not the least important consideration is that the chosen "initial parameter" must be an "easy to get" parameter. It means that this parameter must either be compulsory for the owner of the building when requiring construction allowances, or an easily calculable parameter.

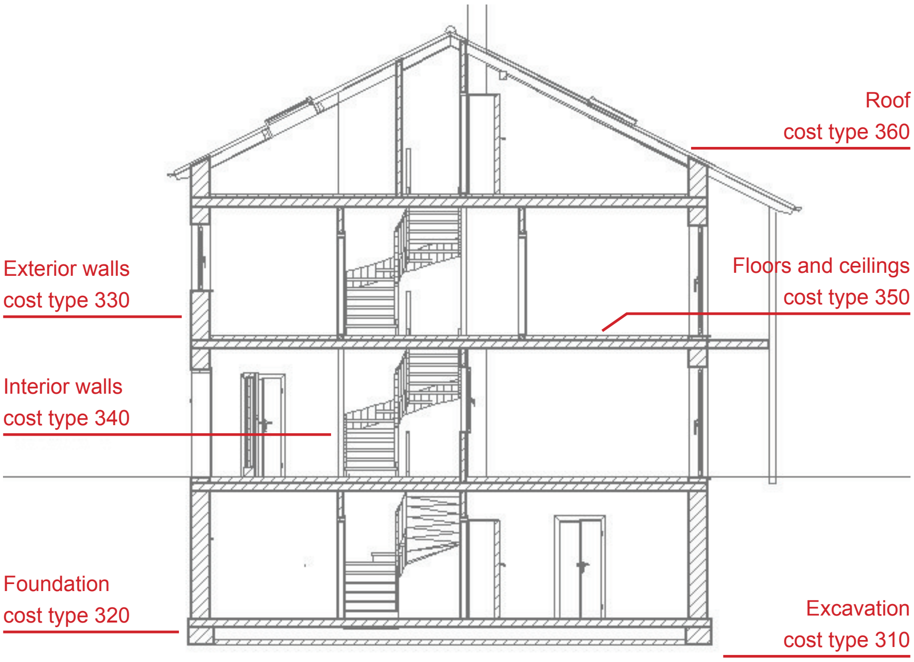


Figure 22

Structure of the German norm DIN 276 with KG - Definition of the various cost types

The figure below (cf. Figure 23) sums up the quantity which will be considered in the rest of the project. The right column refers to element surfaces, according to DIN 276 whereas the left one mentions the use surfaces, classified according to DIN 277.

The standards (DIN 276 and DIN 277) arrange the use surfaces and element surfaces of all buildings in a specific way. Those norms are commonly used and are frequently referred to when dealing with construction projects. Moreover, when assessing the construction costs of a building project, the applicant must specify the quantity of each cost type which occurs in the building. Therefore, databases exist where many buildings are saved in the form of plans and of lists of cost types with their associated quantities and costs. Such a database is used to run the geometrical building analysis (cf. III.2.4.).

BGF	Gross floor area
NF	Net floor area
KGF	Construction area
FBG	Parcel area
HNF	Main function area
BRI	Volume
FF	Function area
VF	Traffic area
NNF	Secondary function area
BF	Constructed area
OG	Number of floors
NGF	Gross net floor area

Cost type 310	Excavation
Cost type 320	Foundation
Cost type 330	Exterior wall
Cost type 340	Interior wall
Cost type 350	Floors and ceilings
Cost type 360	Roof
Cost type 200	Viabilisation (not considered)
Cost type 500	Exterior amenities (not considered)

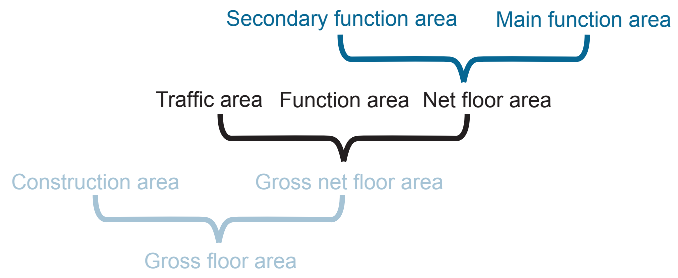


Figure 23

Parameters used in order to process descriptive statistics of building data (top) and structure of the German norm DIN 277 (bottom)

III.2.4. Statistical analysis of building use surfaces and element surfaces

The analysis is carried on on the basis of buildings found in a building database (cf III.2.2.).
First of all, the buildings were sorted out into 9 categories (cf. Figure 21). Each category represents a specific building use, a housing or non-housing use.
The database provides information about each use surface (according to DIN 277) and each element surface (according to DIN 276).
From this information and of basis of statistical analysis, typical mathematical equations are established between use and element surfaces for each of the 9 building use categories.
The process is described in Figure 24 and Figure 25.

The same process was used in [LDK] in order to establish a simplified method for the calculations of building energy consumption in Germany. In this study they looked at the relation between the gross floor area and the heated used area in housing buildings. The established relation was $(0,75)^{-1}$. The thermal transmission losses of around 4000 buildings determined with this relation and one calculated with the real building surfaces revealed a standard deviation of around 15%, which is more than reasonable. It reinforces the validity of the geometrical analysis done here. The same study determined relations between windows areas and gross floor areas, with the intermediary of used area. They established that one family houses take up about 20% of their use area for windows, and 18% for multiple family housing. They also proved that the geometrical relations found are independent from the construction year of the buildings concerned. Furthermore, they consider that the height of floors does not have to be considered as a representative parameter as high floors concern only 15% of the actual building stock (and much less for the new buildings), and because the consideration of the floor height only influences the determination of thermal losses by about 5%.

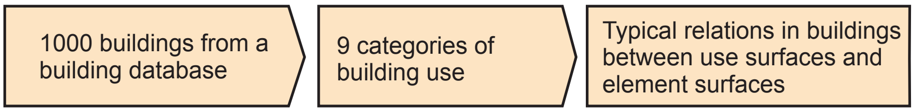


Figure 24

Geometrical analysis

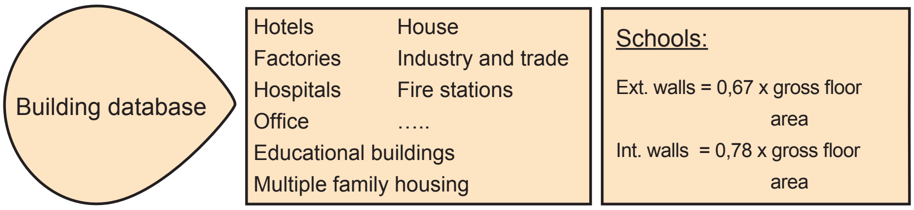


Figure 25

Details of the geometrical analysis

The established linear relations between the use surfaces and the element surfaces in a building category are of the type shown in Figure 25 (exterior walls (m²) = 0,67 * gross floor area (m²) for the category "educational buildings"). They allow for the calculation of a building's characteristics when only one parameter is known, i.e. the gross floor area.
The known variable required in order to calculate the relation is always the gross floor area. This parameter is always known by the architect as it is compulsory to provide it in order to get the building permit.
The realisation of this process fulfils all conditions mentioned in III.2.3.

When using several of those relations, it is possible to calculate a building which will then have "typical characteristics" for the use category of the considered building. That is the process which will be used later in the "Geometrical Model" (cf. III.4. and IV.).
Furthermore, the analysis of geometrical building characteristics will be used later in the "gross life cycle evaluation" of neighbourhoods, cities, etc., when only a little information about buildings is known (cf. Figure 26).

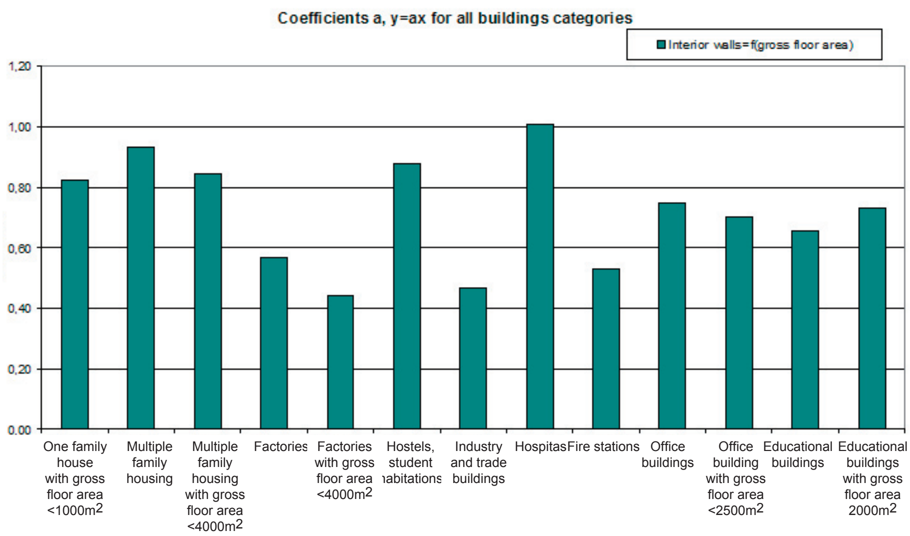


Figure 26

The different equations found for the determination of interior walls surfaces as a function of the gross floor area, for all building categories

	Constructed Area [m^2]	Gross floor area [m^2]	Volume [m^2]	Main function area [m^2]	Construction area [m^2]	Excavation [m^3]	Foundation [m^2]	Exterior wall [m^2]	Interior wall [m^2]	Floors and ceilings [m^2]	Roof [m^2]
Minimum	218	218	1114	166	7	20	218	226	90	13	233
Maximum	21302	27358	193018	19739	2311	16268	21431	6981	19081	7921	21432
Standard deviation	2851	3886	25894	2817	343	3385	2948	1609	2779	1745	3016
Average	2463	3498	20329	2534	238	3522	2526	2022	2217	1609	2646
Variation coefficient	1,16	1,11	1,27	1,11	1,44	0,96	1,17	0,80	1,25	1,08	1,14

Figure 27

Minimum, maximum, average, standard deviation and variation coefficient of several characteristics for the building category "Factories"

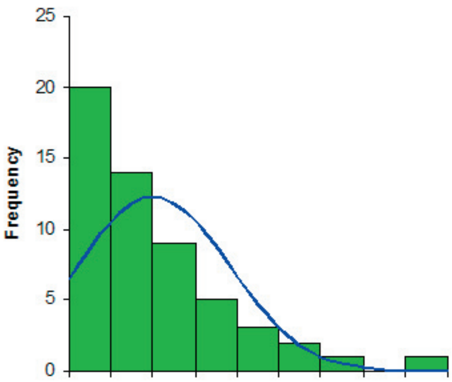


Figure 28

Probability distribution and normal distribution of the characteristics KG 320 for factories

III.2.5. Statistically representative buildings and missing values

It is now possible to create representative buildings with the help of the mathematical relations established between use surfaces and element surfaces for a given gross floor area.
The buildings created do not represent real buildings but they are "statistically representative" of a category and a gross floor area. Therefore, they can be referred to as "typical buildings".
Moreover, each time values are missing in the description of a building, it is now possible to substitute a calculated value. This is referred to as the "retrieved value".

III.3. Construction elements and their characteristics

III.3.1. Classification of construction elements

The construction elements considered in this paragraph are the elements from the sirAdos database. There are approximately 2500 construction elements. For each of them, a certain amount of information is available (cf. Figure 29 and Figure 30) concerning environmental impacts, costs and cycles of renovation and maintenance.
The elements are classified according to DIN 277; thus, according to their function in the construction (cf. Figure 23), there are 6 classes of elements (excavation, foundations, exterior walls, interior walls, floors and ceilings, roofs).
Moreover, four new categories have been created for the simplified method (e.g.: the category "windows" has been created for the energy calculations), corresponding to windows, exterior doors, interior doors and stairs (cf. Figure 33).

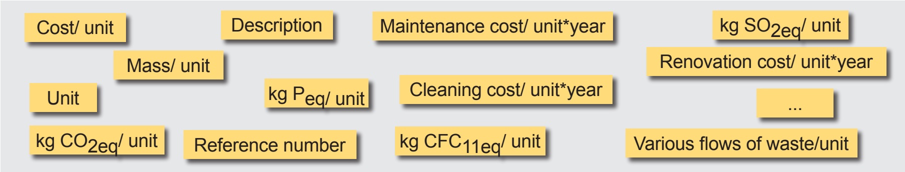


Figure 29

Information available in the database concerning one construction element

GWP	Global warming potential	kg CO_2 eq.
ODP	Ozone depletion potential	kg CFC_{11} eq.
AP	Acidification potential	kg SO_2 eq.
NP	Nutrification potential	kg P eq.
Abiotic	Abiotic resources consumption	kg Sb eq.
POCP	Photochemical ozone creation potential	kg Ethen eq.
PER	Primary energy renewable	MJ
PENR	Primary energy non-renewable	MJ
HMW	Domestic waste incineration	kg
SAV	Hazardous waste incineration	kg
MOD	Mono-landfill	kg
SAD	Hazardous waste landfill	kg
ECO	Ecopoints	points
STM	Mass flow	kg
HMD	Domestic waste landfill	kg
KOM	Compost	kg
UTD	Underground landfill	kg
Radio	Radioactivity	kBq
Kosten	Costs	€

Figure 30

Element characteristic analysis

III.3.2. Database for construction elements

In the following figure, an example of information which can be collected for one element can be seen.
First, the description of the element with its name can be read, then the unit in which it is expressed, the cost for cleaning, maintenance, renovation, and the total cost over the lifetime. The cycles for renovation and maintenance are also given.
Then, in the second part of the figure, the mass of the elements and which waste treatment options can be considered can be seen.
In the third part, the environmental impacts associated with the elements and its life phases (construction, renovation, maintenance, etc.) are displayed.

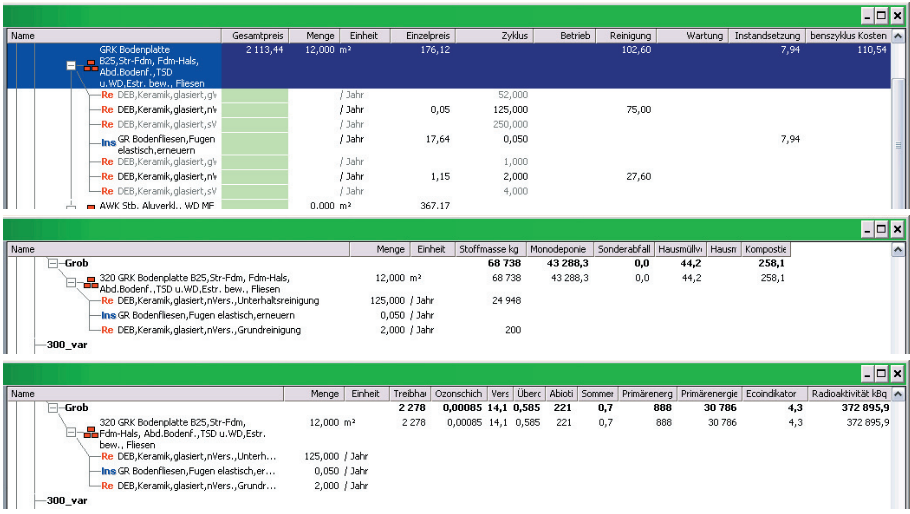


Figure 31

Information concerning one element in the sirAdos database (see "Traduction" for the traduction of the key terms)

The sirAdos elements database is used. This leads to at least two problems:

- Some construction descriptions are not possible because the database can not provide all the possible elements. One partial solution for this problem is to create your own elements. However, when doing so, the created element has no information connected to it: no cost, no eco data, no life cycle information, etc.
- The database is made of elements, renovation cycles and maintenance cycles. For the lifetime of the building considered, it is supposed that one element is replaced by the same element. However, the window in the year 2025 will be completely different from the window in year 2005. Therefore, the information contained in sirAdos does not take technical improvement, safety decision, and health restrictions which will surely appear in the coming years into consideration, such as changing the characteristics of the construction elements, forbidding one material or another, etc.

III.3.3. Element characteristic analysis

Each element has particular characteristics, as shown in Figure 29 and Figure 30. That information can be sorted into three classes:

- Information concerning the construction phase,
- Information concerning maintenance and cleaning,
- Information concerning renovation.

The first type of information (related to the construction) is “one time” information. The event “construction” happens only once in the lifetime of a building. Therefore, this information is a singleton.
The two other types of information (maintenance and cleaning and renovation) are “cyclic information”. The events “maintenance and cleaning” and “renovation” occur several times during the lifetime of a building. In fact, this information must be accompanied by the corresponding cycle (e.g.: three times per year, one time every 25 years, etc.).
All elements are documented in the database, with characteristic information as well as with the associated cycles, when required.
In order to analyse the elements, the set of five pieces of information is too complex to compute (concerning construction, maintenance and cleaning, cycles of maintenance and cleaning, renovation, cycles of renovation). Therefore, the information was transformed into “meta-information” for each element and each characteristic according to the following equation:

where:

$$P_{element\_N} = C_{element\_N} + (REWA_{element\_N} * Trewa_{element\_N} * t) + (INS_{element\_N} * Tins_{element\_N} * t)$$

Eq. 1

Variable	Unit	Description
$C_{element\_N}$	for example €	value of the characteristic for the construction of element N
$REWA_{element\_N}$	for example €	value of the characteristic for the cleaning and maintenance of element N
$Trewa_{element\_N}$	time/year	time cycle for the happening of the event “cleaning and maintenance” of element N
$INS_{element\_N}$	for example €	value of the characteristic for the renovation of element N
$Tins_{element\_N}$	time/year	time cycle for the occurence of the event “renovation” of element N
t	80 years	lifetime for the analysis of a building

Figure 32

Meta information

The information in the database concerning one construction element is divided into information concerning the associated secondary element and the information associated with the detailed element. This information is not available as a sum for the considered element (cf. Figure 31).
Therefore, all this information will be computed together first for a lifetime of 80 years. The characteristics for one element and all its associated secondary elements and detailed elements are added.
Then the information for one element for a lifetime of 80 years is obtained.
However, the elements will not always be used for a time period of 80 years. Therefore, the characteristics calculated for 80 years will then be divided by 80 in order to get information for one year.
This process introduces errors as the arbitrary choice of 80 years or the choice of another time length will change the outcome.

As already mentioned, the elements are classified into 6 main official categories, each representing a different function in the building, plus the four new categories.
Furthermore, a sub-classification is carried out, which distributes the elements from one category into several sub-categories, according to the material used.

Categories and Sub-categories	
Cost type 310 Excavation	
Cost type 320 Foundations	
Mat foundation with lining - cave	Base plate with lining
Mat foundation with lining	Base plate with lining
Timber construction resoles with lining	Timber construction massif, resoles with lining
Other establishment surfaces	
Cost type 330 Exterior walls	
Brick-work wall with clothing	Reinforced concrete wall with clothing
Wood wound with clothing	Wood wound with clothing, massif
Cost type 340 Interior walls	
Brick-work wall with clothing	Reinforced concrete wall with clothing
Wood stand wall with clothing	Metal stand wall with clothing
Wood board pile wall with clothing	
Cost type 350 Ceilings and floors	
Brick floor with lining and clothing	Finished unit cover with lining and clothing
Ferro concrete covers with lining and clothing	Timber ceiling with lining and clothing
Cost type 360 Roofs	
Brick flat roof with lining and clothing	Prefabricated flat roof with lining and clothing
Ferro concrete, flat roof with lining and clothing	Flat timber roof with lining and clothing
Ferro concrete, sloping roof, with covering and clothing	Wood sloping roof, with covering and clothing
Wood sloping roof, substantial, with covering and clothing	
New categories:	Exterior doors Interior doors Windows Staircases

Figure 33

Categories and sub-categories of building construction elements

Following the process described in Figure 34 and Figure 35, the characteristics of all elements were analysed and values which are typical for a characteristic and an element category (respectively sub-category) were assessed. Figure 36 shows the typical values assessed for 7 sub-categories of cost type 330 (exterior walls) and cost type 340 (interior walls), concerning the characteristics of GWP, ODP, etc., costs.

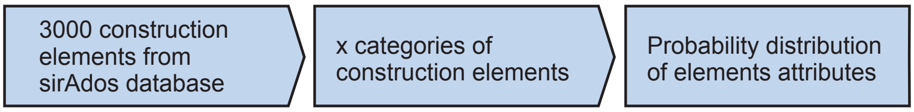
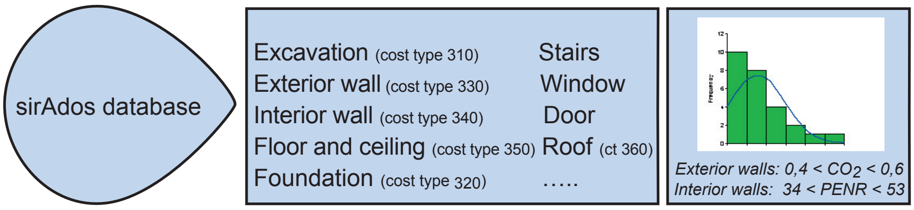


Figure 34
Element characteristics analysis



(PENR: Primary energy non-renewable)

Figure 35
Details of the element characteristics analysis

	Global warming potential [kg $CO_{2\ eq}$.]	Ozon depletion potential [kg $CFC_{11\ eq}$.]	Acidification potential [kg $SO_{2\ eq}$.]	Nutrification potential [kg P_{eq}.]	Mass flow [kg]	Radioactivity [kBq]	Costs [€]
Cost type 3306	6,65E-01	8,11E-07	4,39E-03	3,26E-04	2,47E+00	1,58E+02	5,95E+00
Cost type 3308	3,55E+00	3,40E-06	2,40E-02	1,52E-03	5,51E+00	5,08E+02	1,01E+02
Cost type 3401	7,60E-01	6,67E-07	2,62E-03	2,42E-04	3,93E+00	8,54E+01	2,47E+00
Cost type 3402	1,23E+00	4,70E-07	5,20E-03	3,41E-04	1,09E+01	2,44E+02	4,00E+00
Cost type 3404	3,11E-01	6,28E-07	2,37E-03	2,41E-04	1,43E+00	9,77E+01	3,82E+00
Cost type 3405	5,83E-01	9,46E-07	3,74E-03	3,41E-04	1,33E+00	1,34E+02	4,13E+00
Cost type 3406	3,17E-01	6,38E-07	2,17E-03	2,22E-04	1,87E+00	7,72E+01	4,04E+00

Figure 36

Average of the different characteristics for all elements in the sirAdos database - Value determined for a life time of 80 years, and reported for one year - Cf. Annex 6

The analysis of element characteristics will be used later in the "gross life cycle evaluation" of neighbourhoods, cities, etc., when only a little information is known about the buildings (cf. Figure 42) and in the tool for early design phase building LCA.
The results of the statistical analysis of construction elements are partially shown in Figure 37.

	Global Warming Potential [kg $CO_{2\ eq}$-]	Ozone Depletion Potential [kg CFC11 $_{eq}$-]	Acidification Potential [kg $SO_{2\ eq}$-]	Nutrification potential [kg P $_{eq}$-]	Abiotic resources consumption [kg Sb $_{eq}$-]	Photochemical Ozone Creation Potential [kg Ethen $_{eq}$-]	Primary energy renewable [MJ]	Primary energy non-renewable [MJ]	Eco-points [-]	Mass flow [kg]	Radioactivity [kBq]	Costs [€]
Cost type 310 Average	4,29E-03	0,00E+00	3,10E-05	1,11E-06	3,58E-04	9,92E-07	6,15E-03	9,30E-02	8,65E-06	3,06E+01	3,61E+00	6,81E-01
Cost type 3201 Average	1,96E+00	1,17E-06	9,91E-03	6,21E-04	2,62E-01	8,48E-04	1,15E+00	2,99E+01	2,97E-03	2,96E+01	4,02E+02	8,94E+00
Cost type 3202 Average	1,48E+00	1,06E-06	8,64E-03	4,99E-04	2,06E-01	7,47E-04	9,88E-01	2,25E+01	2,66E-03	3,03E+01	2,56E+02	1,03E+01
Cost type 3204 Average	1,53E+00	9,92E-07	9,52E-03	4,83E-04	2,27E-01	8,57E-04	7,14E-01	2,47E+01	2,64E-03	2,02E+01	3,29E+02	8,43E+00
Cost type 3205 Average	2,41E+00	9,36E-07	1,54E-02	6,72E-04	2,36E-01	1,12E-03	1,47E+00	3,28E+01	4,02E-03	5,64E+01	4,34E+02	1,32E+01
Cost type 3206 Average	1,58E+00	8,08E-07	8,67E-03	5,44E-04	2,12E-01	1,28E-03	2,15E+00	2,52E+01	2,99E-03	4,38E+01	3,58E+02	1,24E+01
Cost type 3207 Average	1,58E+00	8,64E-07	9,18E-03	6,18E-04	2,07E-01	6,68E-04	1,58E+00	2,24E+01	2,64E-03	3,80E+01	3,16E+02	1,33E+01
Cost type 3209 Average	8,63E-01	1,11E-06	5,61E-03	3,37E-04	3,02E-01	7,91E-04	6,02E-01	2,36E+01	1,78E-03	9,19E+00	2,67E+02	5,52E+00
Cost type 3301 Average	1,68E+00	1,24E-06	6,04E-03	4,83E-04	2,25E-01	1,64E-03	1,09E+00	1,86E+01	3,26E-03	6,69E+00	1,88E+02	4,70E+00
Cost type 3302 Average	1,52E+00	7,35E-07	1,05E-02	4,49E-04	1,97E-01	5,60E-04	1,31E+00	2,31E+01	3,09E-03	1,03E+01	2,93E+02	4,52E+00
Cost type 3304 Average	1,08E+00	1,10E-06	7,23E-03	4,60E-04	2,39E-01	7,71E-03	3,83E+00	2,19E+01	6,27E-03	1,75E+00	3,01E+02	1,15E+01
Cost type 3306 Average	6,65E-01	8,11E-07	4,39E-03	3,26E-04	1,48E-01	6,77E-03	2,04E+00	1,24E+01	3,14E-03	2,47E+00	1,58E+02	5,95E+00
Cost type 3308 Average	3,55E+00	3,40E-06	2,40E-02	1,52E-03	7,04E-01	5,86E-03	6,62E+00	5,90E+01	1,39E-02	5,51E+00	5,08E+02	1,01E+02
Cost type 3401 Average	7,60E-01	6,67E-07	2,62E-03	2,42E-04	1,21E-01	4,59E-04	7,72E-01	9,07E+00	1,05E-03	3,93E+00	8,54E+01	2,47E+00
Cost type 3402 Average	1,23E+00	4,70E-07	5,20E-03	3,41E-04	1,13E-01	3,55E-04	1,34E+00	1,70E+01	1,53E-03	1,09E+01	2,44E+02	4,00E+00
Cost type 3404 Average	3,11E-01	6,28E-07	2,37E-03	2,41E-04	1,11E-01	2,56E-03	1,04E+00	8,24E+00	1,26E-03	1,43E+00	9,77E+01	3,82E+00
Cost type 3405 Average	5,83E-01	9,46E-07	3,74E-03	3,41E-04	1,80E-01	8,62E-04	1,03E+00	1,36E+01	2,62E-03	1,33E+00	1,34E+02	4,13E+00
Cost type 3406 Average	3,17E-01	6,38E-07	2,17E-03	2,22E-04	9,69E-02	3,15E-03	1,29E+00	7,01E+00	1,14E-03	1,87E+00	7,72E+01	4,04E+00
Cost type 3407 Average	2,41E+00	1,18E-06	1,07E-02	8,79E-04	3,24E-01	1,06E-03	1,99E+00	2,97E+01	6,39E-03	6,34E+00	3,33E+02	2,26E+01
Cost type 3408 Average	3,41E+00	2,96E-06	2,33E-02	1,26E-03	5,68E-01	2,14E-03	1,26E+01	6,32E+01	2,32E-02	3,00E+00	9,90E+02	5,09E+01
Cost type 3501 Average	1,53E+00	1,10E-06	6,90E-03	4,81E-04	2,22E-01	2,40E-03	1,17E+00	1,96E+01	2,40E-03	1,62E+01	2,16E+02	1,04E+01
Cost type 3502 Average	1,13E+00	9,95E-07	7,36E-03	4,17E-04	1,88E-01	1,25E-03	2,05E+00	1,94E+01	2,43E-03	2,00E+01	2,38E+02	1,07E+01
Cost type 3503 Average	1,52E+00	1,59E-06	1,23E-02	5,71E-04	2,92E-01	1,74E-03	2,15E+00	2,75E+01	3,76E-03	2,16E+01	2,85E+02	1,43E+01
Cost type 3504 Average	5,24E-01	7,26E-07	4,04E-03	3,17E-04	1,31E-01	2,78E-03	2,43E+00	1,23E+01	1,95E-03	1,39E+01	1,32E+02	1,07E+01
Cost type 3506 Average	1,17E+01	7,51E-06	2,94E-01	3,60E-03	1,53E+00	5,62E-03	1,14E+01	2,02E+02	7,58E-02	4,03E+02	2,91E+03	8,34E+01
Cost type 3508 Average	6,41E-01	3,19E-07	3,44E-03	3,01E-04	9,37E-02	2,66E-03	1,32E+00	1,02E+01	1,39E-03	3,10E+01	1,19E+02	1,28E+01
Cost type 3601 Average	4,29E+00	8,27E-06	3,95E-02	1,80E-03	1,41E+00	8,43E-03	2,96E+00	9,90E+01	1,45E-02	9,07E+00	8,73E+02	8,49E+00
Cost type 3602 Average	1,84E+00	3,05E-06	1,69E-02	6,56E-04	5,11E-01	3,18E-03	1,50E+00	3,96E+01	5,89E-03	8,67E+00	3,48E+02	3,01E+00
Cost type 3603 Average	3,49E+00	7,59E-06	4,10E-02	1,38E-03	1,23E+00	7,64E-03	3,08E+00	8,49E+01	1,35E-02	1,05E+01	6,30E+02	8,18E+00
Cost type 3604 Average	1,97E+00	5,76E-06	2,69E-02	1,06E-03	9,18E-01	7,32E-03	5,43E+00	6,26E+01	1,02E-02	5,03E+00	5,21E+02	8,48E+00
Cost type 3607 Average	1,32E+00	1,04E-06	7,25E-03	4,23E-04	1,84E-01	8,20E-04	1,01E+00	2,37E+01	9,74E-03	5,85E+00	2,26E+02	5,60E+00
Cost type 3608 Average	1,01E+00	1,46E-06	1,01E-02	4,47E-04	2,76E-01	1,68E-03	2,25E+00	2,32E+01	6,27E-03	2,10E+00	2,07E+02	5,41E+00
Cost type 3609 Average	8,98E-01	1,00E-06	9,15E-03	3,10E-04	1,83E-01	3,18E-03	1,50E+00	1,74E+01	7,78E-03	2,63E+00	1,81E+02	5,29E+00
Cost type 3701 Average	2,36E-01	2,37E-06	1,58E-02	1,24E-03	3,81E-01	2,93E-03	1,53E+01	3,44E+01	9,07E-03	8,45E+00	4,91E+02	1,47E+02
Total Average	1,73E+00	1,63E-06	1,93E-02	6,25E-04	3,12E-01	2,48E-03	2,40E+00	3,03E+01	6,62E-03	2,62E+01	3,55E+02	1,41E+01

Figure 37

Average of the different characteristics for all elements in the sirAdos database
– Value determined for a life time of 80 years, and reported to one year

III.4. Perspectives for the use of the building representation model

The knowledge of the relations established in III.2.4. allows for the calculation of missing geometrical information about buildings. For example, when considering the beginning of the planning phase, the architect first has a rough idea of how large and long the building will be but can not provide more information about the exterior walls or the interior wall surfaces (at this time). Therefore, no more details about the building are known and no assumption can be made concerning, amongst other things, the global warming potential which this building will induce.
The two previous steps of the project development (III.2. and III.3.) provide a solution to this problem.

III.4.1. Geometrical building model

Typical geometrical relationships in buildings allow for the determination of all unknown geometrical characteristics of a building from the knowledge of its gross floor area and its use, as shown in Figure 38. This is called the "geometrical model".
It can also be used to create "retrieved buildings", that is to say buildings which do not exist but if they did exist, there would be a high probability that the building would have the calculated geometrical description.
These retrieved buildings can be used to model cities, neighbourhoods and to achieve a large variety of calculations.

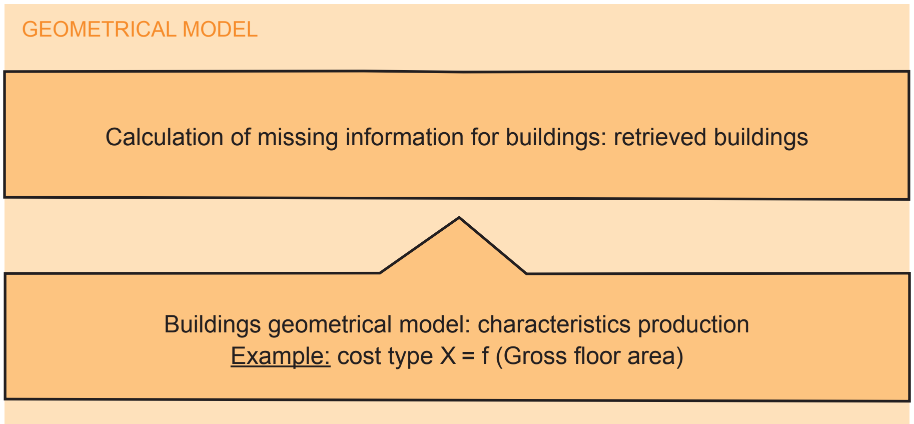


Figure 38

Details of realizing the geometrical model

III.4.1.a. Development of the geometrical model

Derived from the statistical analysis of around 1000 buildings, the geometrical model is developed (cf. III.2.3.). It consists of a matrix with the following characteristics (cf. Figure 39 – the values shown are not the values found, they are only examples).

Y = a * Gross floor area	One and two family houses Gross floor area < 1000m²	Multiple family houses	Multiple family houses Gross floor area < 4000m²	Factory buildings	Factory buildings Gross floor area < 4000m²	Hotel and students habitation	Industry and trade buildings	Hospital	Fire station	Office buildings	Office buildings Gross floor area < 2500m²	Educational buildings	Educational buildings Gross floor area < 2000m²
Excavation	0,39	0,24	0,28	0,37	0,45	0,57	0,46	0,50	0,55	0,55	0,52	0,40	0,52
Foundation	0,17	0,08	0,10	0,21	0,29	0,10	0,15	0,09	0,19	0,10	0,12	0,14	0,22
Exterior wall	0,33	0,27	0,25	0,20	0,26	0,26	0,21	0,19	0,26	0,22	0,27	0,23	0,29
Interior wall	0,33	0,37	0,34	0,23	0,18	0,35	0,19	0,40	0,21	0,30	0,28	0,26	0,29
Floors and ceilings	0,24	0,30	0,30	0,19	0,12	0,26	0,27	0,28	0,20	0,29	0,27	0,21	0,18
Roof	-	-	-	-	0,30	0,12	0,16	0,10	0,22	0,10	-	-	0,28
Net floor area	0,27	0,28	0,28	0,30	0,34	0,27	0,28	0,24	0,30	0,25	0,27	0,24	0,27
Gross net floor area	0,33	0,35	0,33	0,37	0,37	0,34	0,36	0,35	0,35	0,35	0,34	0,34	0,34
Main function area	0,20	0,23	0,21	0,27	0,31	0,22	0,24	0,19	0,19	0,19	0,22	0,20	0,22
Traffic area	0,04	0,06	0,05	-	0,03	0,06	-	0,09	0,04	0,07	0,06	0,08	0,07
Function area	0,01	0,01	0,01	0,02	-	0,01	0,01	0,02	0,01	0,02	0,01	0,01	0,01
Construction area	0,07	0,06	0,07	0,02	0,03	0,06	0,04	0,05	0,05	0,05	0,06	0,05	0,06
Volume	1,17	1,15	1,17	2,21	2,29	1,29	1,48	1,29	1,57	1,43	1,39	1,55	1,51

Figure 39

Geometrical matrix – Typical relations (values shown are only indicative, no real values are displayed and "-" means that no typical value was found)

For each building category, coefficients are available to calculate any of the geometrical characteristics (on the vertical axis in Figure 39) of a building when the gross floor area is known.
Therefore, it is easy to calculate all the missing geometrical information of a building. The validity of the results provided by this process is discussed in the next paragraph.
The geometrical matrix is available in Annex 7.

III.4.1.b. Validity of the geometrical model

In order to validate the geometrical model, the factors found regarding use surfaces and element surfaces in buildings (specific for each building category, cf. matrix in Figure 39) can be compared either:

- With the "real" relations of some buildings,
- or compared with literature dealing with this topic.

In the literature, some "typical characteristic relations" between some of the parameters from the geometrical matrix were found. In particular, the relations which are shown in the following chart (cf. Figure 40).

	Literature [AGE]	Building database	
		All office buildings	Office buildings with Gross floor area < 2500m²
Gross net floor area = **A** * Gross floor area	A=0,87	A=0,85	A=0,88
Net floor area = **C** * Gross floor area	C=0,61	C=0,67	C=0,64
Main function area = **D** * Gross floor area	D=0,48	D=0,56	D=0,48

Figure 40

Comparison of some of the geometrical relations established with the geometrical model and factors found in literature

The figures shown demonstrate the reliability of establishing such relations between use surfaces and element surfaces. Indeed, the factors established and indicated in the geometrical matrix are almost the same as the ones found in relevant literature. Even if the factors are slightly different, they all are in the same order of magnitude.
This literature source has only looked at some of the dimensions of the building, only regarding the use of the gross floor area.

In the second step, the factors of the geometrical matrix with 28 real buildings, 5 buildings in six use categories each time (except for one family housing with 3 items considered) for which all the geometrical characteristics are known, can be compared.
The following chart (Figure 41) shows the percentage of success when comparing the real geometrical characteristics with the one found when the geometrical matrix factor was used to calculate the geometrical characteristics with the gross floor area value only. The geometrical characteristics considered are the six element categories described in the DIN 276 (an extract of the norm is available in Annex 14).
The comparison is assessed as being successful when the difference between the calculated parameter and the real value is less than 40 %. The percentages shown in the chart (cf. Figure 41) are the overall success percentages determined for the whole category of buildings (five buildings were considered each time per category, apart from the one family house where only three buildings were considered).

	Excavation	Foundations	Exterior walls	Interior walls	Floors and ceilings	Roofs
One family house	100%	67%	100%	67%	100%	100%
Multiple family housing	60%	80%	60%	80%	80%	100%
Hostels, student habitations	60%	100%	100%	100%	100%	60%
Educational buildings	40%	60%	100%	100%	40%	60%
Hospitals	40%	60%	100%	60%	80%	60%
Factories	-	60%	80%	80%	-	60%

Figure 41

Comparison of the geometrical matrix calculations results with the real values for 28 buildings in 6 categories

The full analysis can be found in Annex 12. It concerns all categories of buildings use and a total of 50 buildings.

For all building categories and for each of the elements concerned (excavation, foundation, etc.), the success rate is high. A weakness has to be pointed out for excavation, for which the rate is lower. This is due to the complexity of estimating the volume to be excavated as this largely depends on the soil considered and the height of the building. Otherwise, the comparison of characteristics calculated with the geometrical matrix with the real values (given in the buildings database) is satisfactory; the geometrical matrix is validated.

III.4.2. Geometrical model for a rough life cycle evaluation tool

The geometrical model can be further developed into a calculating tool. With the combination of the geometrical model and the outcomes of the analysis of building construction element characteristics, it is possible to create a model for the life cycle evaluations of buildings and groups of buildings. This model does not provide precise values as results but provides a rough estimate in order to place a building (respectively, a group of buildings) and, eventually to compare it with another building (respectively, a group of buildings).

The "rough life cycle evaluation" model can be executed either:

- with a range of values (as shown in Figure 42, when using the information "minimum and maximum" values for the geometrical analysis as well as for the element analysis);
- or with determinate values.

Typical results of the building group gross life cycle evaluation could be:

- mass flow of material which will leave the building stock in X years;
- global warming potential which is induced by the construction, the renovation and the maintenance of a particular neighbourhood;
- household energy planning for a neighbourhood;
- costs which will occur in the next X years in order to maintain and renovate a company's building stock.

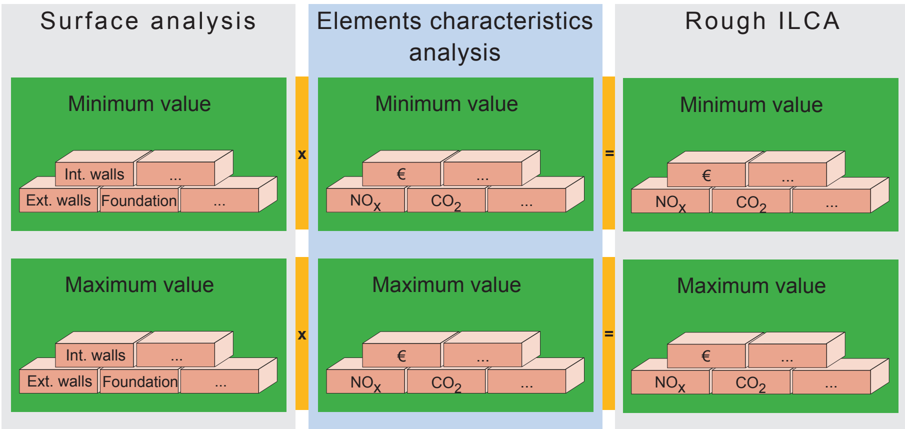


Figure 42

Rough life cycle evaluation

An application allowing for the assessment of environmental impacts, costs and mass flows of up to 15 buildings at the same time was developed, called: "the rough life cycle evaluation tool".
For each building, basic information is required such as the gross floor area, the use of the building and the supposed life duration for each one (cf. Figure 43).
The results are displayed in a second screen (cf. Figure 44).
Included in the results are materials necessary for the construction phase and the renovation and maintenance cycles for the given lifetime. Technical equipment as well as energy consumed during the lifetime of the building are not considered at the present time. There is no estimation of water requirements and no environmental impacts associated with energy consumption. This could be quickly added in the tool if necessary, using average values per m² of gross floor area.
When the user wants more information in the results for the life cycle analysis of a particular building, he is asked to use the early design phase tool Stilcab (read further in the report).

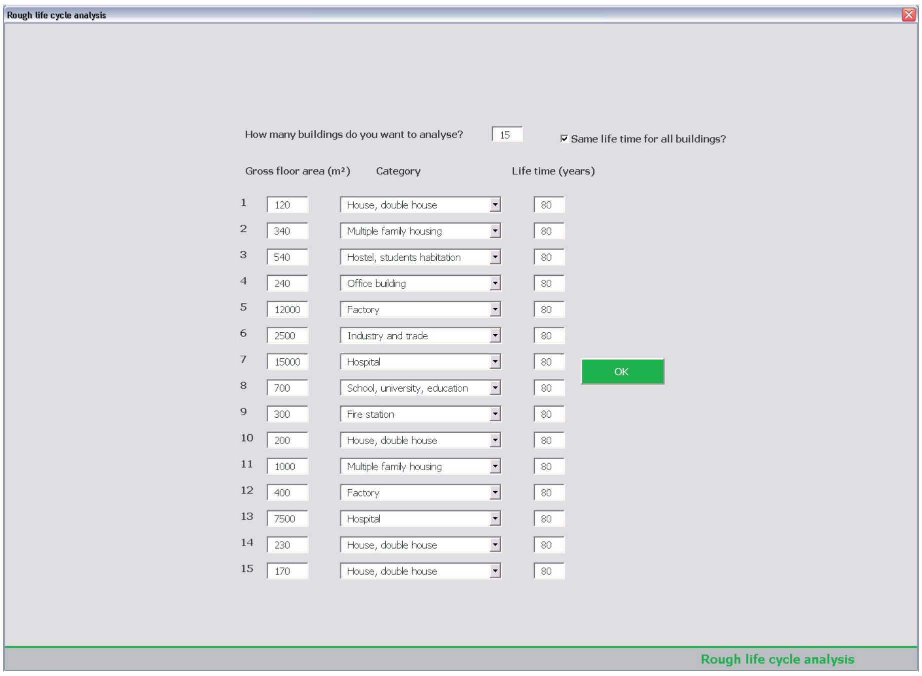
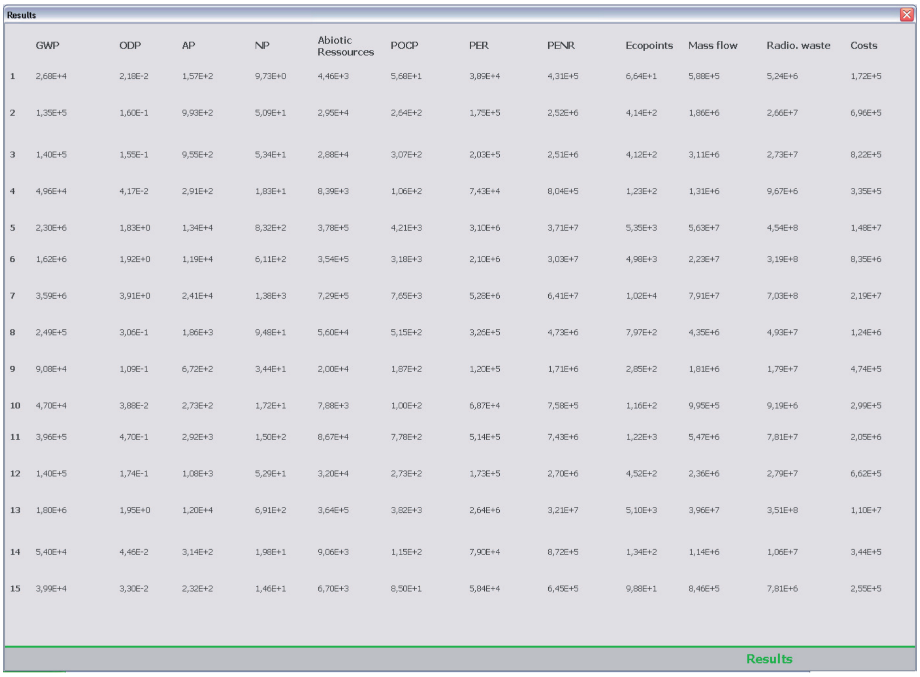


Figure 43

Data input in the rough life cycle evaluation tool



Results

	GWP	ODP	AP	NP	Abiotic Ressources	POCP	PER	PENR	Ecopoints	Mass flow	Radio. waste	Costs
1	2,68E+4	2,18E-2	1,57E+2	9,73E+0	4,46E+3	5,68E+1	3,89E+4	4,31E+5	6,64E+1	5,88E+5	5,24E+6	1,72E+5
2	1,35E+5	1,60E-1	9,93E+2	5,09E+1	2,95E+4	2,64E+2	1,75E+5	2,52E+6	4,14E+2	1,86E+6	2,66E+7	6,96E+5
3	1,40E+5	1,55E-1	9,55E+2	5,34E+1	2,88E+4	3,07E+2	2,03E+5	2,51E+6	4,12E+2	3,11E+6	2,73E+7	8,22E+5
4	4,96E+4	4,17E-2	2,91E+2	1,83E+1	8,39E+3	1,06E+2	7,43E+4	8,04E+5	1,23E+2	1,31E+6	9,67E+6	3,35E+5
5	2,30E+6	1,83E+0	1,34E+4	8,32E+2	3,78E+5	4,21E+3	3,10E+6	3,71E+7	5,35E+3	5,63E+7	4,54E+8	1,48E+7
6	1,62E+6	1,92E+0	1,19E+4	6,11E+2	3,54E+5	3,18E+3	2,10E+6	3,03E+7	4,98E+3	2,23E+7	3,19E+8	8,35E+6
7	3,59E+6	3,91E+0	2,41E+4	1,38E+3	7,29E+5	7,65E+3	5,28E+6	6,41E+7	1,02E+4	7,91E+7	7,03E+8	2,19E+7
8	2,49E+5	3,06E-1	1,86E+3	9,48E+1	5,60E+4	5,15E+2	3,26E+5	4,73E+6	7,97E+2	4,35E+6	4,93E+7	1,24E+6
9	9,08E+4	1,09E-1	6,72E+2	3,44E+1	2,00E+4	1,87E+2	1,20E+5	1,71E+6	2,85E+2	1,81E+6	1,79E+7	4,74E+5
10	4,70E+4	3,88E-2	2,73E+2	1,72E+1	7,88E+3	1,00E+2	6,87E+4	7,58E+5	1,16E+2	9,95E+5	9,19E+6	2,99E+5
11	3,96E+5	4,70E-1	2,92E+3	1,50E+2	8,67E+4	7,78E+2	5,14E+5	7,43E+6	1,22E+3	5,47E+6	7,81E+7	2,05E+6
12	1,40E+5	1,74E-1	1,08E+3	5,29E+1	3,20E+4	2,73E+2	1,73E+5	2,70E+6	4,52E+2	2,36E+6	2,79E+7	6,62E+5
13	1,80E+6	1,95E+0	1,20E+4	6,91E+2	3,64E+5	3,82E+3	2,64E+6	3,21E+7	5,10E+3	3,96E+7	3,51E+8	1,10E+7
14	5,40E+4	4,46E-2	3,14E+2	1,98E+1	9,06E+3	1,15E+2	7,90E+4	8,72E+5	1,34E+2	1,14E+6	1,06E+7	3,44E+5
15	3,99E+4	3,30E-2	2,32E+2	1,46E+1	6,70E+3	8,50E+1	5,84E+4	6,45E+5	9,88E+1	8,46E+5	7,81E+6	2,55E+5

Results

Figure 44

Results of the rough life cycle evaluation tool

This application allows for a quick evaluation of costs and impacts arising in one building or in a neighbourhood when very little information about the building (or the neighbourhood) is available (gross floor area and its main use). Therefore, a comparison of several alternatives of one given building is not possible with this tool.
Cf. Annex 13 for screenshots of the rough life cycle analysis tool.

III.4.3. Geometrical model for early design phase tool for building ILCA

With the help of the geometrical analysis, it is possible to determine the geometrical characteristics of a building as soon as its use and its gross floor area are known.
On the other hand, the analysis of the element characteristics has shown that the elements are not necessarily different one from another when the whole life cycle is considered. Average characteristics for each element (cost type) are already assessed (cf. Figure 36).
Therefore, a direct application of this hypothesis for building life cycle analysis is the lack of necessity in choosing a specific element in a database to get information as to the environmental impacts and the costs generated by this element (respectively for a building) during its whole lifetime.
These two facts are combined to create a simplified tool for the integrated life cycle analysis of buildings (cf. Figure 45 and IV.): Stilcab

The different steps in developing the simplified method are summed up in the following chart (cf. Figure 45) and developed in the next paragraphs:

- Building geometric analysis;
- Construction analysis (= element analysis);
- And sensitivity analysis to determine relevant parameters.

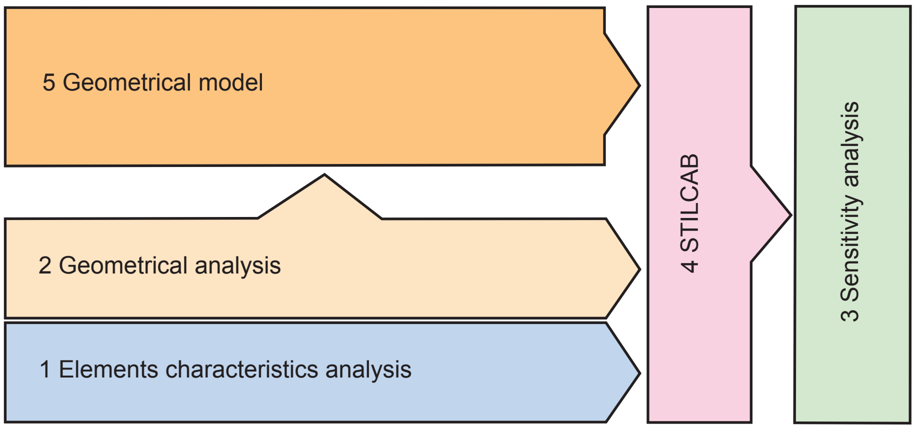


Figure 45
Development of Stilcab

In Stilcab, the geometrical model is used each time a default value is required by the user when he is not certain about the corresponding value. This may be the case during the planning phase, or when the user of the method only knows a little information about the building.
The geometrical model provides indications of several parameters: excavation, foundations, exterior walls, interior walls, floors and ceilings and roofs. For each of these, a "quantity" is calculated with the geometrical model, depending on the buildings use category and its gross floor area.
Other studies [LDK] already use this process to calculate building surfaces when the gross floor area is known. It refers to this procedure as safer than data inputs and surface statements realised according to plans or architects.
In Stilcab, the user can either give in the "correct values" (read from the plans, or determined) or select the option "default value" when Stilcab asks for the building description.

IV. Development of a method for integrated building life cycle analysis in early design phases

Below is a list of questions one should answer when doing a building life cycle analysis.

Step 1: What is the goal of doing a LCA? What are the aims and objectives? Who is the audience? Who will be using the results and what are the motivations?

Step 2: Define the building and how long its lifetime will be. What type of building is assessed? What are its functions? What are the boundaries? What is the functional unit? To what extent will data be collected? To what extent will the results be analysed?

Step 3: To what extent will the issues be analyzed? Do the issues involve materials, energy, water, waste, indoor air quality?

Step 4: How will the results be presented (e.g. all emissions or only embodied energy)?

Step 5: Using the results in the building design process, will operational performance and material selection be looked at?

Step 6: Reporting: is it for a comparative assertion (in which case it must ensure that the functional unit and the data are comparable)? Is it for a publication?

The aim of using the developed method is to get a rough idea of the environmental impacts and costs generated by a building for its construction and lifetime as early as the first planning phase of the building so that improvement measures can be undertaken later. The LCA helps the user to compare several variants of a building in terms of environmental impacts and costs; it provides cost planning information as well as possibilities for energy optimisation.
The building is defined by its main use, gross floor area and other geometrical characteristics when available (otherwise they will be assessed). For the development of the method, as well as for the sensitivity and uncertainty analysis, a lifetime of 80 years is assumed. All building use categories can be analysed (cf. Figure 21). However, the LCA is limited to the building itself. There is no consideration of urban networks, traffic connections, etc. The building is limited by the exterior facades in all directions (360°), starting from its centre.
In order to compare one building with another, the gross floor area seems to be the most appropriate functional unit. However, in some particular cases, other units such as beds, rooms, students, etc. can be referred to.
In terms of outputs costs, environmental impacts expressed as potential effects (GWP, ODP, etc.) and the quantity (kg) of material used are considered. Indoor air quality, risks assessment, acoustics, aesthetics and health care are not considered in the method.
The results of the LCA are presented as total results (for the whole life duration) and as phase dependent results (separate for renovation / construction, etc.). Although 11 environmental impacts are present as outputs of the method, as well as costs and energy consumption, the sensitivity and uncertainty analysis

are restricted to costs, GWP, ODP, PENR, ecopoints, compost and massflow. Other environmental impacts could have been implemented in the method as well. However, for the succinty requirement of the program, only the above mentioned parameters were implemented.
The use phase of the building is considered: energy consumption is addressed as well as cleaning, maintenance and renovation cycles occurring in the 80 years following the construction of the building.

IV.1. A tool for early design phases: Stilcab

Using the building description model described in III.1., with, on one hand a restricted geometrical description of the building and, on the other hand, a limited choice of elements, a simplified tool for integrated building life cycle analysis was developed, named Stilcab.
The tool is able to calculate the environmental impacts as well as the costs generated by a building during its entire lifetime.
When the beginning of the planning phase is considered, the user of the tool does not need to know much about the building to get the first results, as the tool suggests “default values”. However, the more the user knows about the building, the more accurate the results provided by the tool will be.

The Figure 44 shows (from top to bottom) the several paths which can be followed by the user in Stilcab. The clouds represent the inputs of the user whereas the triangles represent the influence of those inputs in the calculation procedure.

IV.2. Tool module

The several steps which the user must go through to realize the building LCA in Stilcab are represented in the following figure (cf. Figure 46).
After entering basic information concerning the building, such as its use and its gross floor area, the user must select the energy module he wants to use.
When the energy module is selected (the simplified EnEV or the independent energy calculations), the building’s description must be completed in order to realise the sensitivity analysis afterwards, and to provide ILCA results.
Throughout the use of the tool, every time the user is supposed to enter a value, a “default value” is suggested, in case the user does not yet know the required characteristics, in order that Stilcab will nevertheless provide the desired results.

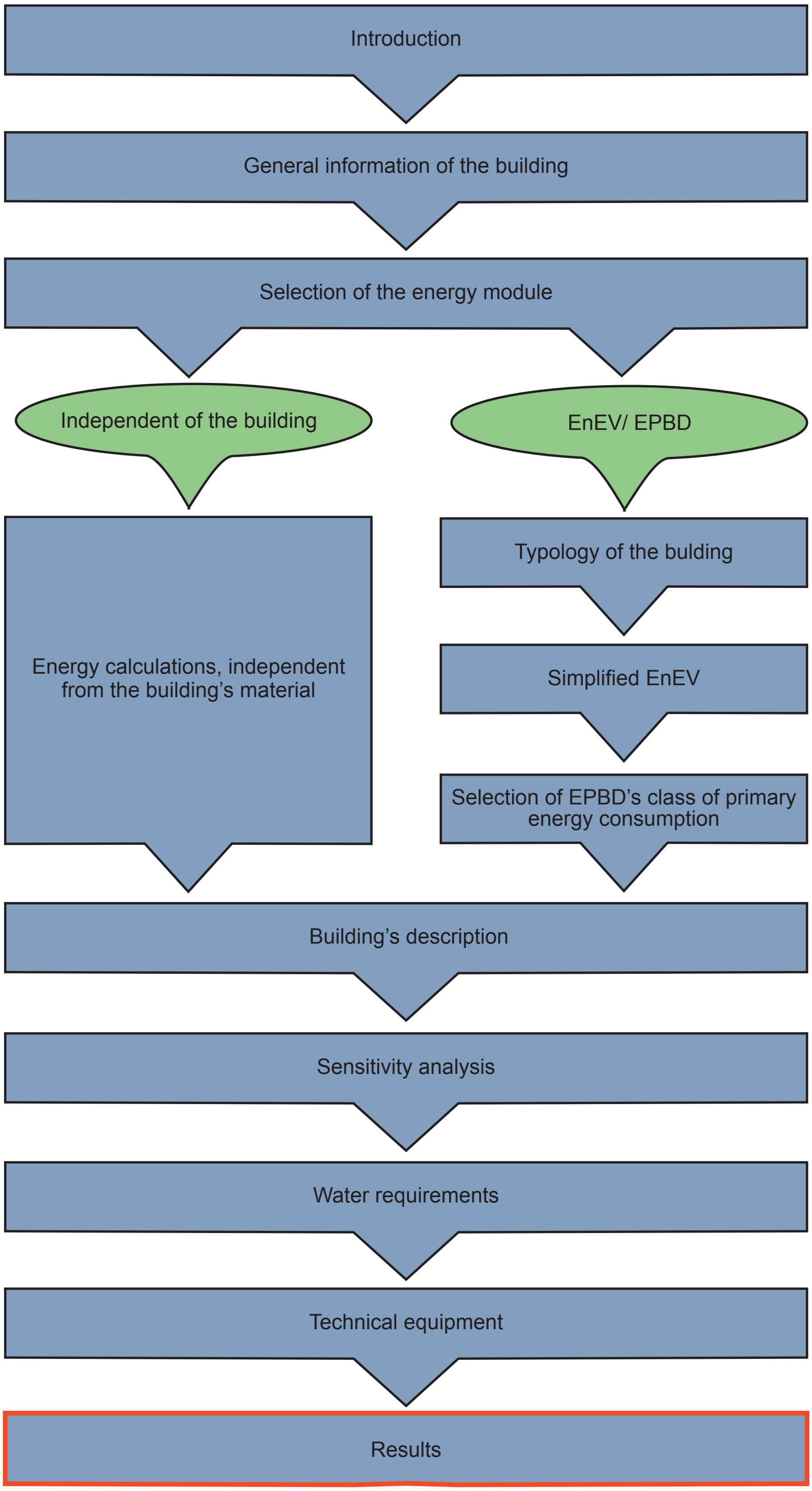


Figure 46

Stilcab steps

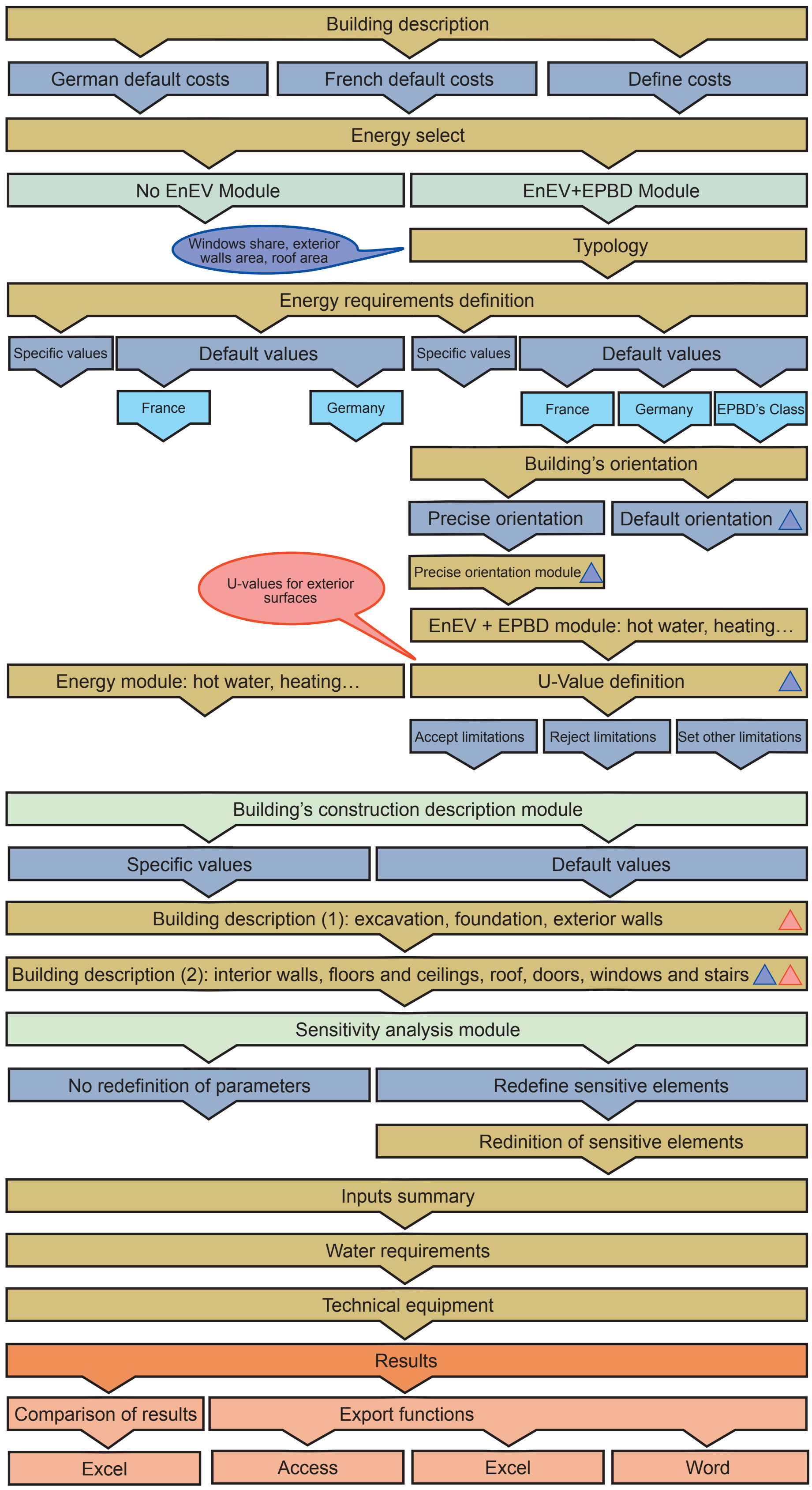


Figure 47

Stilcab paths

IV.2.1. Description of the building in Stilcab

The building representation model presented in III.1. is implemented in Stilcab. Buildings are therefore described by 8 parameters ("quantities") and their associated elements. Combinations of these creates eight "mega-parameters" (cf. Figure 72), for which the user must provide information if known, or else default values are selected. For each "mega-parameter", there are three levels of definition:

- Level 1 - Default value: this is the case when the user does not know anything about the building. A value will be automatically calculated (with the help of the statistical analysis of 1000 buildings done in III.2.) according to several parameters:
    - gross floor area;
    - constructed area (BF[i]);
    - the building's use.
- Level 2 - Enter a value: the user must give only one value for each mega-parameter. This is the case when he does not know with which material the building will be built, but he already knows the form and the quantity of each construction part.
- Level 3 - Detailed value: the user can describe the building and give appropriate input in m² corresponding to different construction materials; therefore the user selects a particular kind of mega-parameter. He does not say "200m² of roof" as in Level 2, but instead: "200m² of brick flat roof".

In addition to the eight mega-parameters, the user must also give indications concerning the quantity of interior doors and staircases. However, according to the building analysis, those two building parts are not as relevant as the other eight parameters regarding their influence on the output.

IV.2.2. Transferability of German construction costs

SirAdos is the database from which the construction elements come. The database suggests costs for each construction element, as already mentioned in II.2.5.b. However, those costs are representative for the German market only. Using them for another country would provide only a rough estimate of the costs.
Therefore, when using Stilcab in France, the costs of the French construction materials have to be assessed.
Several databases also exist in France which provide the construction material costs (batitel[ii], batiprix[iii]). However, it was not possible to find:

- the same classification of elements as the one present in sirAdos (which follows the DIN 276);
- the same description of elements as in sirAdos (the detail of the description);
- the same content as in sirAdos (work costs, material costs, etc.).

Nevertheless the French database Batiprix [BAT] was considered and the costs of more than 80 elements were compared. Those elements were chosen as being "representative" for constructions and covering the whole range of possibilities (from concrete to wood elements, from roof to drain).
A typical conclusion of this analysis is, for example, that the cost of windows

i BF: Bebaute Flache – Constructed area
ii www.batitel.com
iii www.batiprix.com

is 50% higher in France than in Germany, in average.
The analysis can take into consideration neither every type of frames nor every type of glass, nor several different physical characteristics. The whole process of comparing costs between France and Germany is based on punctual comparisons which are extrapolated afterwards.
It is indeed difficult to assess such an analysis of two items which are very different and poorly documented. The material costs seem to be lower in France than in Germany, but on the other hand, "we estimate that the overall labour costs in France are 1,5 time more expensive than in Germany" [FDS].
In the end, an overall cost difference of 10% is considered between the two countries, France being the more expensive of the two.

The following price differences are considered in Stilcab when selecting the option "French costs":

Figure 48

Comparison of costs for construction elements, in France and Germany – Assumptions made in Stilcab

	France	Germany
Excavation	89	100
Foundation	110	100
Exterior walls	100	100
Interior walls	117	100
Floors and ceilings	131	100
Roofs	87	100
Windows	151	100
Exterior doors	100	100

Furthermore, Stilcab enables the user to set his own costs, if necessary, in a separate input table. It is open for analysis in other countries, as far as cost data for elements are available in other national contexts.

IV.2.3. German and French buildings and construction types

The buildings which were considered in the analysis (1000 buildings) were all German. Even if it is assumed that they are representative for Germany, they might not be representative for France. Materials used may be different, as well as construction methods; insulation modes are different (related to heating systems which are electric or gas in France whereas no electrical heating systems are used in Germany, etc.).
The conclusions of the comparison are presented in Annex 10.
The following was stated when looking at construction materials at the macro-economic level (cf. Figure 49): the only remarkable differences concern the entryways. Indeed, whereas 60% of French interior doors are wooden, only 40% of interior doors are wooden in Germany (this might be connected with the after war reconstruction of Germany). Moreover, less double glazing is used in France than in Germany (due to climatic conditions), and the German windows are almost all bottom hang windows.
Concerning the insulation techniques, in Germany exterior insulation is used whereas in France interior insulation is predominant.

Some studies even consider regional construction types as specific and relevant enough to be assessed separately. However, to make distinctions between regional / local / international construction types is tricky and difficult to assess and quantify. Moreover, Stilcab is already a simplified method, therefore taking aesthetics and construction habits into account as quantitative parameters is irrelevant and contrary to the aims of the simplified method.
In Annex 10, the study [INV] assessed the different materials used in European countries for the construction industry. Like in this study, no differences in construction material and practices between France and Germany will be assessed. This is only given as information for the reader.

	Construction part	France	Germany
Construction material	Reinforced concrete	Frequently employed for all type of construction in various forms, run on the building site or precast. Especially common for the construction of large buildings	
			In former East Germany, large prefabricated concrete blocks were often used
	Wood	About 9% of material used by the building industry	About 10% of material used by the building industry
	Plastic	Yearly consumption for the construction industry : 891 000 tons (about 18% of European consumption)	Yearly consumption for the construction industry : 1 299 000 tons (about 27% of European consumption)
	Glass	Existing windows : Simple glazing: 170,40 Mm^2 (44%) Double glazing: 213 Mm^2 (56%)	Existing windows : Simple glazing: 207,40 Mm^2 (32%) Double glazing: 429,80 Mm^2 (68%)
Openings	Doors	Exterior doors: metallic doors are often used, in particular for high buildings and garages. PVC is becoming more common.	
		60 % of interior doors are made of wood	41 % of interior doors are made of wood and 11% of PVC
	Windows	-Plastic- PVC 54% -Wood 24%	-Plastic- PVC 50 % -Wood 20%
		-20% bottom hang windows	-80% bottom hang windows
Construction techniques	Insulation	Interior insulation	Exterior insulation
		Common thickness : -walls : 110mm -roof : 240mm	Common thickness : -walls : 100mm -roof : 180mm

Sources: [EQU], [HOM], [INT], [FAO], [APM], [SEN]

Figure 49

Remarks concerning construction materials in Germany and in France regarding several building construction parts

IV.2.4. Technical equipment in buildings

The German DIN 276 is composed of several groups of construction elements. One group concerns technical equipment (Cost type 400). It gathers equipment for hot water production, sanitary equipment, electro-installation, heating systems and ventilation systems, following this classification:

400.1	Sanitary installations
400.2	Heating systems
400.3	Ventilation systems
400.4	Electro-installations

Figure 50

Technical equipment classification

Technical equipment is, like other construction elements in a building, responsible for mass flows, costs, and environmental impacts which occurs when installed, maintained and renovated. However, those consequences are relatively negligible when compared to the influence the selection of those equipment might have on the energy consumption (heating and ventilation systems). For example, the choice of a hot water production system with an optimised efficiency might lead to savings in primary energy consumption for

the production of hot water of up to 40 % (the difference between an electrical boiler with a 30 to 80 litre capacity and a low temperature gas boiler).
Therefore, the technical equipment must be taken into consideration not only for their contribution to overall mass flows, costs and environmental impacts, but primarily for the efficiencies of heating systems (space and water heating).

Indeed, many studies show that the influence of technical equipment on overall mass flows and costs is not so drastic [AMS]. Nevertheless, they will be considered in Stilcab, in which the user can select the type of equipment he wants (low temperature / constant temperature), the distribution type (centralised / decentralised) and the production type (combustible, energy) in the first step. This is done in Stilcab in the display called “Energy requirement” (cf. Annex 5). In the second step, the display “Technical Equipment” allows for the selection of the desired technical equipment according to the specified classification (cf. Figure 50).
In this second step, the Stilcab user has access to the whole list of technical equipment, which is presented in the sirAdos database of “macro-elements”, only a further distinction is made between space heating systems and hot water production systems.
Behind the selection of the required equipment, information concerning costs, mass flows and environmental impacts occurring during the lifetime of the building is added to the rest of the construction element information.
Data concerning the efficiencies of the different technical equipment available (distribution efficiencies as well as production efficiencies) was either found in literature or in equipment distributor documentation ([LOG], [SIA]) (cf. Figure 57).

IV.2.5. Water requirements during a building’s lifetime

Fresh water consumption is taken into consideration in Stilcab in the display “Water requirements” (cf. Annex 5). Both costs and flows generated by water consumption are considered in the final results of Stilcab.
The user must enter the quantity of fresh water required and the price of 1m³ of fresh water. A default price for France and another one for Germany are suggested and can be selected by the user. However, the cost of 1m³ of fresh water is geographically dependent and can be different from one place to another by up to a factor of 10. The price entered by the user should include sewage water costs.
Data concerning water consumption per person and price of fresh water per m³ was found in literature ([COS], [GAB], [STA], [OEC]).

Category	Water consumption (m³/day.person)
Hostel, students habitation	0,13
Houses, double houses	0,134
Factories	0,05
Industry and trade	0,05
Hospitals	0,13
Multiple family housing	0,13
Educational building	0,015
Office buildings	0,015

Figure 51

Default values for water consumption in the program [IWU]

IV.2.6. Energy consumption

IV.2.6.a. Embodied energy vs. operational energy

Embodied energy is the energy used to produce the materials which are used in the building. Minimizing embodied energy means minimizing the impact on the environment from the construction materials as well as of the renovation and maintenance cycles which occur during the building's lifetime.
Operational energy is the energy consumed during the building's lifetime once it has been constructed. This energy is consumed by heating and cooling, lighting and appliances.

IV.2.6.b. Electricity mix considered

The electricity mix used for material production and transport is the UCPTE[i] mix, whereas for the energy consumption during the use of the building, it is possible to build up its own electricity mix. Therefore, it is possible to adapt the electricity mix to different countries and also to a specific local context.
However, two energy mixes are implemented in Stilcab as the program was mainly developed for France and Germany. The user has the option to select the electricity mix he wishes.
Indeed, the building's material market is considered to be European-wide (i.e. produced with the UCPTE mix) whereas the consumption of energy directly in buildings and households is considered locally.

IV.2.6.c. Differences between construction and energy in Stilcab

The graph illustrates the distinction which can be made between "construction" and "energy", between fixed parameters and parameters which are left up to the user's choice.
The "fixed parameters" are the life duration (which is estimated) and the size of the building. The building has heating, hot water and ventilation requirements, amongst others things.
The user of the tool can intervene in the analysis process by choosing the appropriate construction elements as well as the technical equipment. In the same way, he can also select the several systems which will produce the required energy (e.g.: selection of the hot water boiler). However, the requirements for the energy consumption of the building are determined by a specific module: the energy module, which is independent from the rest of the construction simulation.
In the first step, according to the energy module of the tool, the energy requirements of the building are determined, and the costs and the environmental impacts specific to energy consumption are calculated. In the second step, energy-specific costs and impacts are added to the construction-specific factors, in order to ensure that the results of the tool are integrated.
The differentiation between "energy" and "construction" also makes sense when one considers the share of impacts and costs produced by "energy" and the share produced by "construction" (cf. Figure 54).

i UCPTE : Union pour la coordination de la production et du transport de l'électricité). It was transformed in 1990 into Union for the Coordination of Transmission of Electricity (UCTE - http://www.ucte.org/). According to the half-yearly report (http://www.ucte.org/pdf/Publications/2005/Report_1_2005_2.pdf), the production of electricity for this period was about 33% thermal nuclear – 54% thermal conventional – 10% hydro power – 2% others)

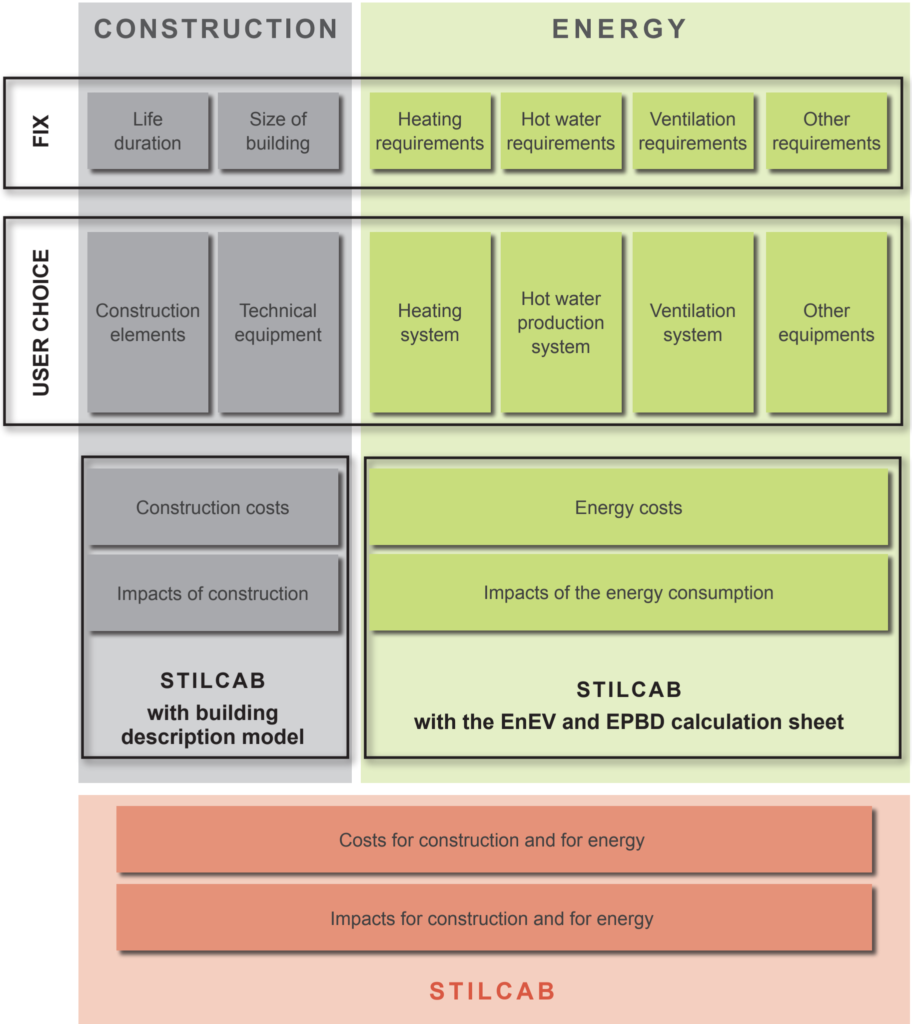


Figure 52

Energy and construction, what is given and fixed, and what is not

IV.2.6.d. Importance of the used energy

The energy consumed by buildings can be subdivided into three categories:

1. Energy for construction (included in the material – embodied energy);
2. Energy for building use;
3. Energy for building maintenance and renovation.

The embodied energy for the construction phase is relatively small when compared to the energy requirement for the use stage of the building. Moreover, reducing the energy for construction requires a lot of effort for a small amount of gain. It is much more profitable to attempt to reduce the used-energy of the building. This could mean, for example, renovating the building in order to make it more energy efficient.

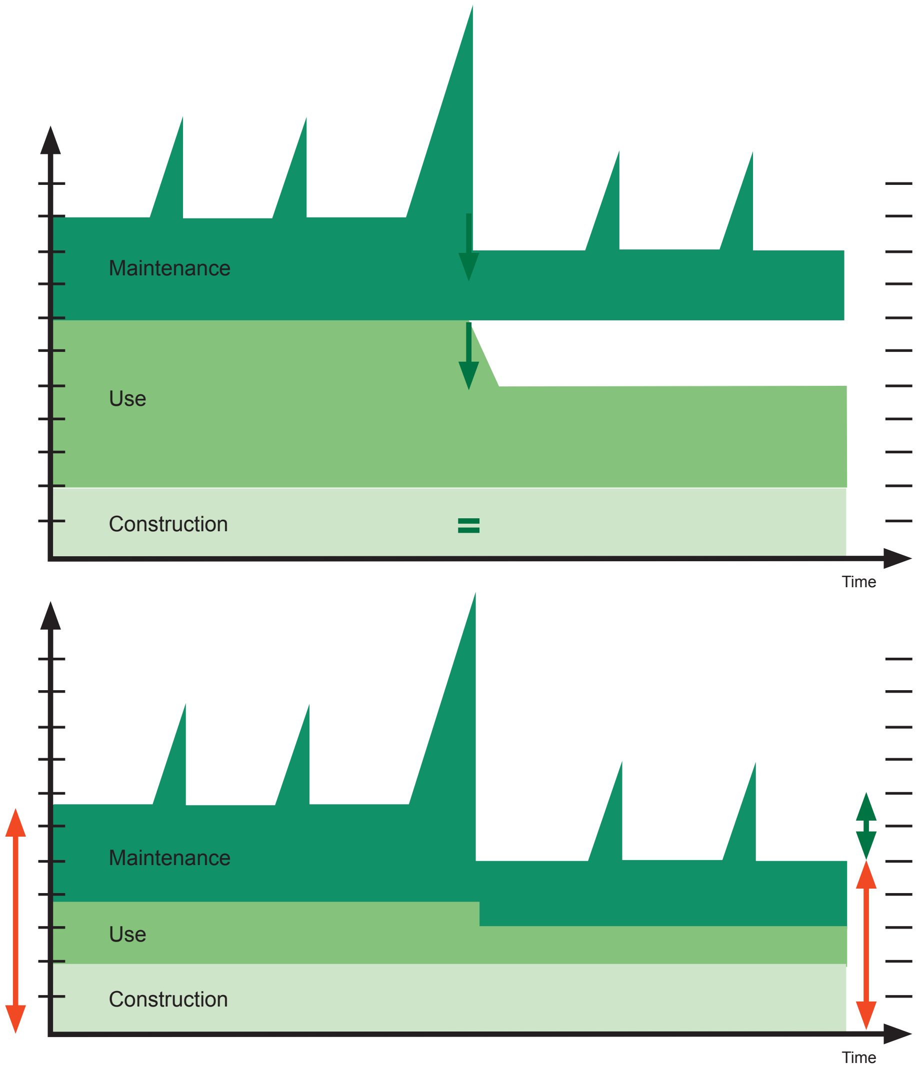


Figure 53

Energy consumption in a building and energy consumption after improvement of the energy efficiency of the building (during renovation)

NB: in Figure 53, the graphic scales have no meaning; there are only an indication of relative efforts and gains which can be achieved.

The following figure shows examples of buildings. Only non-renewable energy needs are represented (the share of renewable energy is not considered in the graphic, but nevertheless taken into consideration in the ILCA tool). The lifetime of the building is assumed to be 80 years.

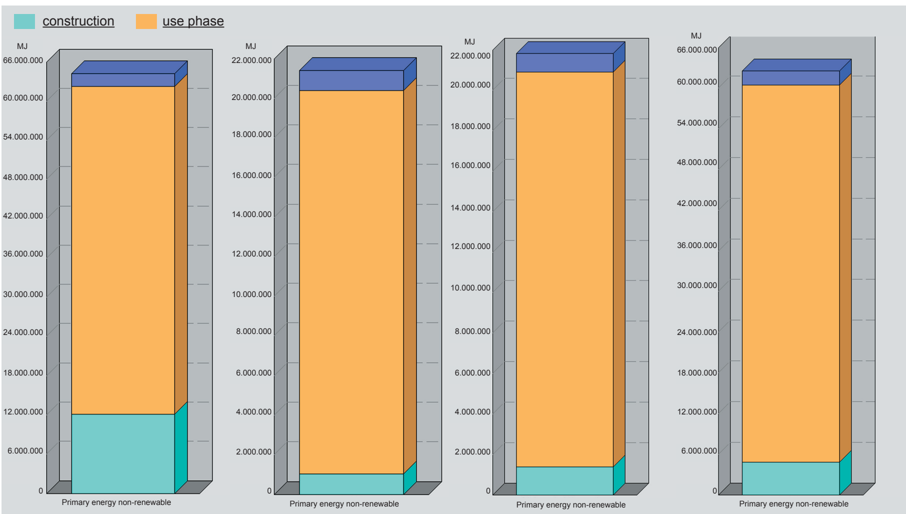


Figure 54

Comparison of shares of energy for construction (clear blue), the building energy for use (orange) and energy for maintenance of the building (blue), for four different (randomly selected) conventional buildings

The share for construction is low when compared to the energy used during the lifetime of the building. That is one of the reasons why it is necessary to integrate the best available norms and regulations for the calculations of energy consumptions during the building's lifetime in the tool.
So called "low energy buildings" have a ratio "embodied energy / used energy" larger than conventional buildings. Indeed, the embodied energy is almost the same for those buildings as for conventional ones. Only the used-energy is greatly reduced in low energy buildings.

There are two different options for energy calculations in Stilcab.

IV.2.6.e. Energy calculations independent of the building

The objective of the part of the tool responsible for energy is to allow a cost and environmental impact estimation related to energy consumption of the building during its lifetime.
The estimation must satisfy two points:

- The effort required for data delivery and calculations must be reduced;
- A level of precision must be reached for the results.

With as little information as required, the part of the tool responsible for energy is able to calculate the cost and the environmental impacts due to energy consumption of the building determined regarding the DIN V 4108-6 and DIN 4701-10 to 12.
In order to do so, surfaces of the building must be collected or calculated, efficiencies of the technical energy equipment must be determined, and heat transfers in the building must be estimated.

The first approach of the program is to consider "Energy" as a separate module. The user is asked to allocate each energy consumption position (heating, hot water production, lighting, etc.) a requirement value. For example, for heating: 80 kWh/(m^2.year) of primary energy. If the user does not know what to enter, a typical default value is suggested, determined by taking the use and the gross floor area of the building into consideration.

This approach presents the following drawbacks:

- The prices and environmental impacts calculated are not related to the building energy performances selected: there is no relation between the level of energy performance of the building and the choice of the building's material.
- It is then impossible to compare "two energetically different versions" of the same building as the energy consumption level has no influence at all on the building itself and vice-versa when this module is selected. In both cases, the costs and environmental impacts associated with the construction are the same. In the end results, there will be no differences for the building, only differences due to different energy-related costs and impacts.

Nevertheless, this method gives a rough estimation of the "energy-related" impacts of the building during its lifetime, and allows a primary calculation of those impacts, independent of the material choice.
This energy module does not claim to be a thermal calculation tool. However, it is not the aim of Stilcab to be a "calculation code for building energy consumption".

Indeed, thermal codes require a lot more information concerning the building itself, in addition to the solar gain, the geographical location, the occupants' behaviour, - information which is not required to make the ILCA.
Moreover, the aim of Stilcab is not to assess building energy consumption. Its role is to draw a list of costs and environmental impacts which arise during the building's lifetime. Of course, energy is one of the main factors concerning the environmental impacts and the costs (indeed, one of the more influencial); it is the reason why "energy" is considered here.

IV.2.6.f. Simplified EnEV and the new European Performance of Buildings Directive - Implementation in the method

- Regarding the European Directive of the 16th of December, 2002 (2002/91 CE), replaced in January 2006 by the EPBD "Energy Performance of Buildings Directive" which both suggest the introduction of a buildings energy certificate at the beginning of 2006 for all buildings which are sold and in the middle of 2007 for all buildings which are rented;
- Regarding the previous points mentioned about the first module of the tool concerning energy;
- Regarding the current energy regulations, laws, standards, calculation methods and simulation tools;

a second energy module is implemented in Stilcab.

It allows the user to respect the simplified EnEV criterion and also to select an energy class for the new EPBD.
This Directive of the European Commission concerns the primary energy consumption of buildings. It sets classes of consumption, like those which already exist for household appliances such as refrigerators [CEN], according to the use category of buildings.

Procedure:

<u>Class selection</u>
The user selects the class of energy corresponding to the targeted primary energy consumption (cf. Figure 55).

Class	Value
Class A	< 30 $kWh.m^{-2}.y^{-1}$
Class B	60 $kWh.m^{-2}.y^{-1}$
Class C	90 $kWh.m^{-2}.y^{-1}$
Class D	120 $kWh.m^{-2}.y^{-1}$
….	
Class H	> 200 $kWh.m^{-2}.y^{-1}$

Figure 55

Example of classes – Maximal primary energy consumption for a building, per m², per year for heating and cooling, for ventilation, for hot water, for lighting and for energy and heat produced on site - suggested values

Use of the building	School
Gross floor area of the building	600 m²
Energy class of the building	Class D: primary energy consumption < 120 kWh m-2y-1

$$P_{Max} = P_{HC}+P_V+P_{HW}+P_L-P_P$$
$$P_{HC} = P_{Max}-P_V-P_{HW}-P_L+P_P$$

P_{HC}: primary energy consumption for heating and cooling of the building
P_V: primary energy consumption for the ventilation of the building
P_{HW}: primary energy consumption for preparation of hot water for the building
P_L: primary energy consumption for lighting of the building
P_P: primary energy consumption from the site energy production
P_{Max}: primary energy consumption maximal for the building

Default values are suggested for P_{HW}, P_V, P_L and P_P or the user enters other values	P_{HW} = 30 kWh m-2 y-1 P_V = 6 kWh m-2 y-1 P_L = 4 kWh m-2 y-1 P_P = 10 kWh m-2 y-1
P_{HC} is determined	P_{HC} = 100 - 30 - 6 - 4 + 10 P_{HC} = 70 kWh m-2 y-1

According to the EnEV - Simplified version:

(P_{HC}* Gross floor area) * (ratio end / primary energy) = Q_H = 66 * (H_T+H_V) - 0,95 * (Q_I+Q_S)

with:
- H_T: transmission losts
- H_V: ventilation losts
- Q_I: internal gains
- Q_S: solar gains

With developed expression of H_V, Q_I and Q_S:

$$\sum(U_i*A_i*F_{xi}) = (P_{HC}*\text{Gross floor area})+8{,}1225*V+0{,}95\,(\sum I_{s,j} \sum(0{,}597*g_i*A_{wi}))-0{,}05*A$$

with:
- Gross floor area, P_{HC} given
- V = net volume of the building
- A = area of the exterior surface
- $I_{s,j}$ = sun radiation (see tables)
- A_{wi} = area irradiated
- g_i = energy transparency degree for perpendicular raditation according to DIN EN 410
- A_i = area of the exterior part considered
- U_i = U_value of the material for the exterior part considered
- F_{xi} = temperature correction factor, according to tables

Assuming a geometry, which can be a default value or can be selected by the user, V, A, $A_{w,l}$, A_i and F_{xi} are also known.
Therefore: $\sum(U_i*A_i*F_{xi})$ ist detemined
And a value for the average U_i is also calculated

All the exterior walls, roofs and windows which do not respect the criteria on the U-value are no longer taken into consideration for the calculation of costs and environmental impacts of the building.

Figure 56
Calculations of energy requirements

This amount of primary energy (P_{MAX}) corresponds to the sum of several positions (according to the EPB Directive):

$$P_{MAX} = P_{HC} + P_v + P_{HW} + P_L - P_P \quad \text{Eq. 2}$$

They represent the primary energy respectively:

- for heating and cooling (P_{HC}),
- for ventilation (P_V),
- for hot water production (P_{HW}),
- for lighting (P_L),
- for the production of energy on site (P_P).

Allocation
The user allocates values for the following energy positions: P_V, P_{HW}, P_L and P_P. When he does not know which values he should enter, the tool suggests “default values”. These come from literature research (cf. IV.2.6.g.).

P_{HC} calculation
From those given values, the primary and end energy consumption for heating can be determined.

$$P_{HC} = P_{MAX} - P_v - P_{HW} - P_L + P_P \quad \text{and} \quad Q_{HC}=P_{HC} \,/\, (\text{ratio end/primary energy}) \quad \text{Eq. 3}$$

Orientation of the building
Then, the user is asked to specify the orientation of the building in the four directions, as well as the surfaces of exterior walls and windows in each direction. If he does not have this information, a default form of the building is proposed and a default repartition of windows and exterior walls is assessed. The default orientation of the building is realised so that a realistic (nevertheless the largest) share of windows is oriented south-west to south-east, in order to profit from free heat gains during the winter period.
This makes it possible to calculate the maximum heat losses acceptable for the building to fulfil the constraint on the maximum quantity of primary energy consumption selected.

U-Values calculation
Now that the maximum heat losses due to heat exchange with windows and exterior walls is known, and because the surfaces of windows and exterior walls are also known, the maximal average U-value for the walls and windows can be determined. The U-values calculation is done by reversing the EnEV.

Material selection
Because the maximum average U-value of the walls and windows is known, the walls and windows which do not reach this level of performance are taken out of the list which contains all the walls and the list which contains all the windows. Therefore, the costs and the environmental impacts calculated with the limited number of walls (respectively windows) is used in the rest of the program (for costs and environmental impact calculations).
As a result of this process, instead of taking into account all the walls (respectively, all the windows) available to calculate the costs and the environmental impacts of a building, only the walls (respectively windows) which fulfil the pre-requisite energetically conditions (limited U-value) are considered. It is then possible to compare two variants of the same building which fulfil two different energy consumption performances as the variety of

construction elements is different in each case.
Therefore, the costs and environmental impacts associated with the building really correspond with the selected class of primary energy consumption.

NB: The annual heating requirement must be under a certain value to conform to the EnEV. Those limit values can be found in the EnEV itself and are calculated in the program, so that the user also knows if the building fulfils the EnEV conditions.
The whole process of the energy calculation of the second energy module can be seen in Figure 56.

Indeed, all that the user has to do is specify the production and distribution type for each energy position (lighting, ventilation, heating and cooling, and hot water preparation).
Some other studies ([LDK]) have adopted the same process.

IV.2.6.g. Default values for energy consumption in Stilcab

The user has always the option to select "default values" for the energy consumption, as well as for the efficiencies of the different equipment.

Data concerning efficiencies of the different technical equipment available (distribution efficiencies as well as production efficiencies) were either found in literature or in equipment distributor documentation [LOK], [LOG], [IWU].
The values taken into consideration are summed up in the following figure:

		Distribution efficiency	Production efficiency
Heating system	Electrical	1	0,97
	Gas + low temperature	0,776	0,95
	Gas + constant temperature	0,776	0,85
	Heating fuel + low temperature	0,776	0,92
	Heating fuel + constant temperature	0,776	0,82
Hot water system	Electrical	1	0,7
	Decentralised with gas	1	0,75
	Gas + low temperature	0,98	0,95
	Gas + constant temperature	0,98	0,5
	Heating fuel + low temperature	0,98	0,91
	Heating fuel + constant temperature	0,98	0,5

Figure 57

Default production and distribution efficiencies used in Stilcab

Default energy consumption suggested by Stilcab were found in literature, both German and French, and are sometimes typical values for a specified energy use (e.g.: for hot water production and lighting), for a given building age (only recent building construction have been considered in Stilcab), or for a given technical equipment (e.g.: valid only for electrical heating). The literature concerned is: [MÜL], [JOU], [GAB], [BIN], [BAL], [ANG], [LDK] and [ADM].

Energy position		Default value (kWh end energy/m² gross floor area)
Lighting		4
Ventilation		6
Hot water production		12,5
Cooking (only used in the first energy module)		9
Regulation and technics (only used in the first energy module)		6
Household electricity without cooking (only used in the first energy module)		4
Heating	One family houses	130
	Multiple family housings	120
	Educational buildings	126
	Hostels, student habitations	79
	Office buildings	210
	Hospitals	120

Figure 58

Default energy consumption ratio used in Stilcab

The following figures were taken into consideration for the conversion between end-energy and primary energy consumption.

Energy	Factor end energy / primary energy
Electricity	2,58
Gas, heating fuel	1

Figure 59

Primary energy to end energy ratio used in Stilcab [GUA]

APPLICATION OF THE METHOD

According to the developed method, a tool has been realised.
The functionality of the tool is described, as well as its inputs and outputs.
An overlook is given of the several possible uses and users of the tool.
Finally, an application case is presented to illustrate the advantages and drawbacks.

V. Running the tool

V.1. Tool inputs

The tool has an essentially scaleable characteristic. It can function with different levels of completeness and accuracy of input information. This allows for use of the tool at different moments of the planning process and by different users. The Figure 60 presents the input parameters necessary to use Stilcab.

Minimum input for the simplified version	More detailed input (not compulsory)
Gross Floor Area	All different building use surfaces
Use of building (category)	Detailed use by surface
Number of occupants	Complete internal loads
Ground surface and number of floors	Detailed element surface
	Detailed composition of all elements
	Exterior wall and bearing structure material

Figure 60

Parameters necessary to use the tool

The minimum input necessary for the application of the simplified version is basic information which the user always has at his disposal.
The number of occupants is necessary to calculate the consumption of water.
The geometrical inputs (gross floor area, use of the building, constructed area) are required to determine the other geometrical parameters of the building, to select construction elements and for the energy calculations.
A more detailed list of inputs is available in Annex 8.
As can be seen, the inputs necessary are fewer and easier to get than the ones required by other building LCA software.

V.2. Planning schemes and related tasks

V.2.1. Planning schemes

On the following figure (cf. Figure 61), the progress of planning a construction work can be seen. All phases are not necessarily present for all buildings.
The function (use) and the size of the building to be constructed are known as soon as the first phase is begun, indeed in the first step.
During the outline phase (2.1), the first estimation of the costs is done, at the same time as the estimation of the element surfaces. Further in the process, the costs will be checked (2.2 and 3.1.1 and 3.1.2). In phase 3.2, distinctions will be made in the costs between exploitation costs, bill of tender, costs by task, etc.
In phase 3.1.2, materials will be selected for the construction.
The use of Stilcab enables the progress of the planning to be followed. According to the planning phase considered, first the use and the size of the construction are known; then the costs are estimated when choosing default elements; and finally, the costs can be refined according to the materials actually used for each construction part.
The “example of use” in paragraph V.4. illustrates the several possibilities of costs and quantities estimation which are possible when using Stilcab.

Phases	Building owner	Builder: Architect	Builder: Economist	Builder: Engineering and design department
1 - Programming /Feasibility				
Intention to build: program intention, expression of the needs				
Capital cost				
Technical and lawful feasibility				
Checking compatibility "needs/possibility of investment"				
Financial envelope reserved for work				
Program of the architectural contest				
Conceptors competition				
2 - Conceptor /contracting				
2.1 Outline				
Feasibility check				
Architectural program (drafts, models, etc...)				
Note of presentation (architectural and technical)				
Cost of estimated objective (determining quantities/estimate/forecasts)				
Completion date				
2.2 Research contracts				
Examination of the architectural programs				
Checking the cost reliability of the estimated objectives				
Choice of the conceptor or the team of engineers / contracting				
3 - Conception				
3.1 Preparatory project				
Coordinator selection				
3.1.1 Preparatory project of construction (APS)				
Preparatory project of construction (APS)				
Summary descriptive note (descriptive synopsis)				
Determining quantities / provisional estimate of the cost of the work				
Possible calendar of realisation / functional sections				
3.1.2 Detailed preparatory project (APD)				
Modified preliminary construction project				
Description of the works				
Final estimate of the estimated cost (decomposition in separate tasks)				
Security analysis of the file				
Building permit and administrative authorisations				
3.2 Project				
Opening of the "later work intervention file"				
Project plans				
Book of the particular technical specifications				
Bill of tender				
Estimated costs by task / maximum amount of work by task				
Exploitation costs				
Realisation time				
Final development and acceptance of the project				
Companies tender file				
Invitation to companies tender				
Company selection				
4 - Construction / Realisation				
Following of the construction				
Reception of the work				
One year guarantee				
Structural and functional capacity of the building (every 10 years)				

Frequent
Less frequent

Figure 61

Planning scheme in France with different stakeholders [BUH]

V.2.2. Phases of the building's life cycle

Pre-appraisal

Design brief: In this phase the client decides on the type of building, its function and the criteria he wants fulfilled. At this stage the best input, from an LCA perspective, is very general and could be provided by the guideline and rating type instruments. For example the client could require that the building performs optimally over 80 years, meets a $85kWh.m^{-2}.year^{-1}$ primary energy consumption, and uses specific materials.

Design phase: This is when the brief is turned into a building design. This phase itself has little impact but is where the life cycle consequences of the building on the environment are mostly determined. Therefore it is here that the LCA tools need to be applied extensively.

Building: The highest impact of this phase is waste generation. However many material supply decisions are also made during construction and these need to comply with the assessments made in the design stage. It is also important that the subtleties of the environmental strategies are carried through in construction. Most relevant are the guidelines on how to minimise waste, reuse and recycle.

Use: This is the phase in which the client is using the building. The most important impacts here are the use of energy and possibly water. Waste generation is also important. In this phase, general guidelines on maintenance and operational building management should be followed.

Refurbishment: The most important impacts here are the materials chosen to refurbish the building over its lifetime.

End of life: In the end of the life of the building or the demolition stage, guidelines are most appropriate to assist in the reuse, recycling, and disposal of the building components in the most efficient manner.

Stilcab enables the estimation of costs arising during each of the phase of the building life cycle, from phase 2 to phase 5. The estimation is more or less accurate, according to the amount and quality of information one enters.

V.2.3. Connection between planning phases and the use of the tool

The tool Stilcab is flexible. It means it can either be used at the beginning of the design phase of the building or at a more advanced level of the planning process when more information is at the user's disposal. Therefore, the results provided when used at the beginning of the planning phase are rough and those provided at the end of the planning phase are much more detailed (cf. Figure 63).

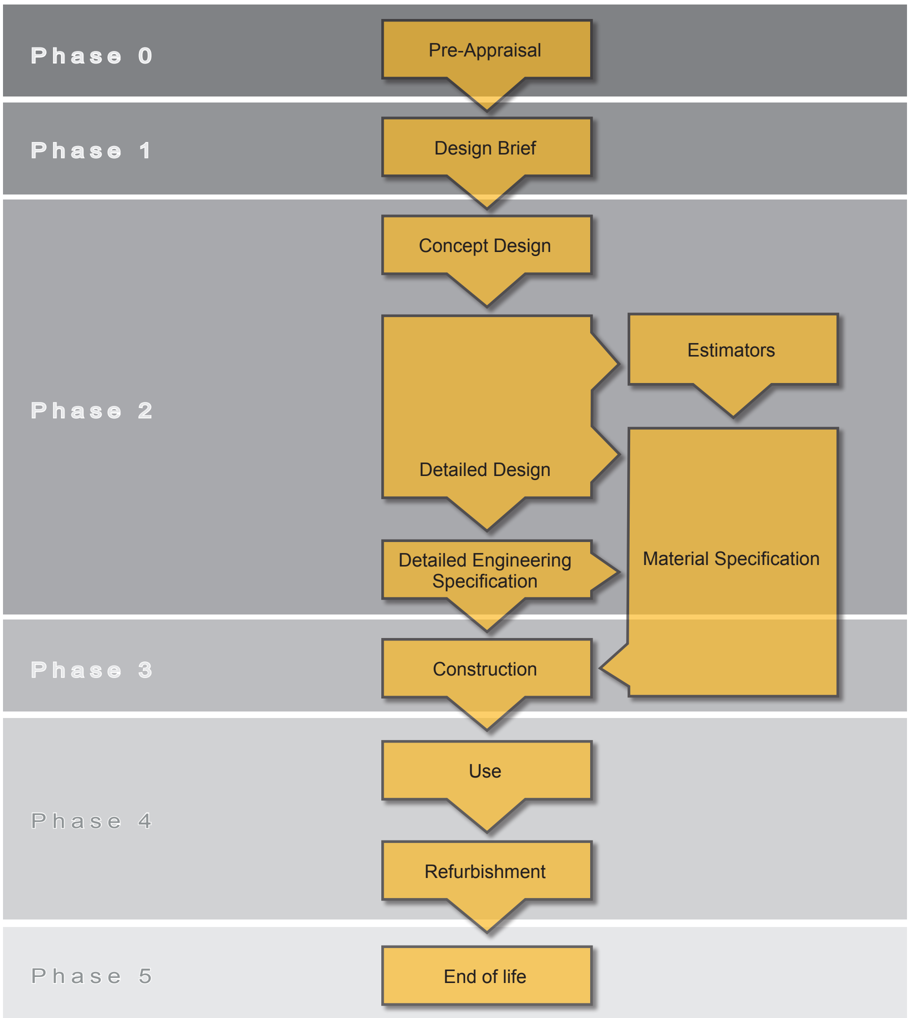


Figure 62

Phases of the building life cycle [RMI]

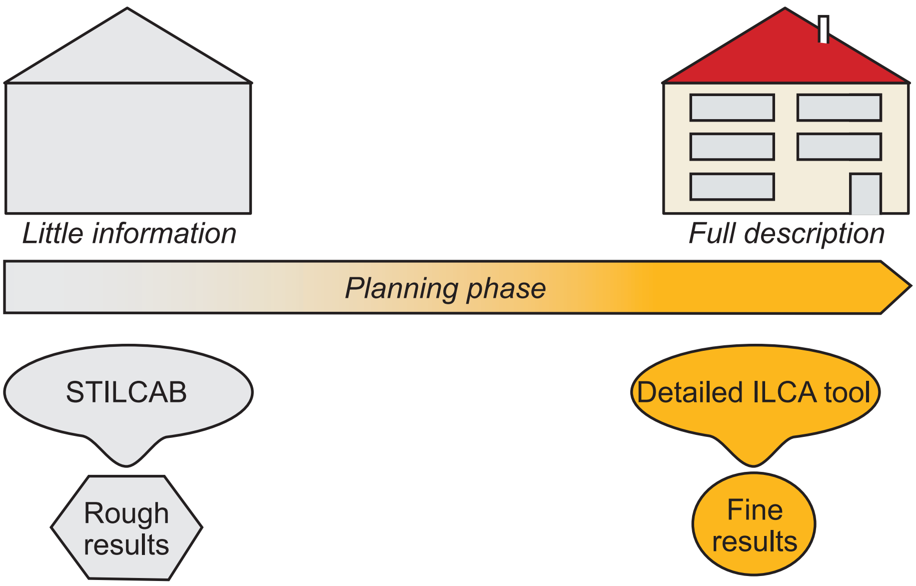


Figure 63

Use of the different tools and results provided according to which planning phase occurs

V.3. Tool outputs

The final results for the user of the tool are (for one building):

- Investment costs: breakdown of costs by year.
- Description of the construction: each detail of the construction such as materials and related quantities becomes available.
- Comparison to alternative buildings: by modifying one or more parameters, it is possible to easily visualize the effects on costs and/or on environmental impacts.
- Energy consumption: different scenarios of electricity mix can be assessed.
- Costs of energy: breakdown of costs according to the use (heating, hot water, equipment, etc.).
- Life cycle costs: renovation and maintenance costs, as well as construction costs.
- Material flows entering and leaving the building site.
- Environmental impacts associated to the use of material and the consumption of energy.

V.4. Example of use

The user wants to analyse one building. He does not have a lot of information concerning the building as he is at the beginning of the design process. He knows what the building's function (its use) is and how big it is (its gross floor area).
Example: school, the gross floor area is 845m².

With the help of the geometrical model (III.4.1.), the user is able to calculate other geometrical information concerning the building. This will not be "exact" information but "retrieved information", determined on the basis of the previous statistical analysis.
*Example: surface of exterior walls for schools = 0,5 * gross floor area. For this school, the surface of exterior walls is 0,5*845 = 422m²*

On the other side, the sensitivity analysis has determined which parameters have the largest potential of improvement for selected outputs (cf. VII.). The user can select up to two outputs for which the four more relevant parameters will be provided by Stilcab. These parameters are different from one building use category to another and from one building to another. They are named X_1, X_2 and X_n.
Example for schools: the significant parameter is the foundation element, when considering the GWP, and windows, when considering the life cycle costs.

The energy module requires or calculates the energy demand according to energy standards, literature, and state of the art methods (i.e.: EnEV, EPBD).
Example: for this school, 145kWh.m^{-2}.year^{-1} primary energy consumption.

At the end the user is only asked for the following input: use and gross floor area of the building, and information concerning parameters X_1, X_2, etc. determined by the sensitivity analysis (cf. VII.).
Example: for this school, the user is asked for the quantity and details of the

material used for the foundation and for the windows as he is interested in improving the costs and the GWP of the building; therefore, he wanted to know where the largest potential for improvement is.

The outputs of the method are traditional ILCA outputs.
*Example: 345 euros/month for maintenance of the building; and 50*$t_{Eq.CO_2}$ *for the construction of the building.*

V.5. Several ways of using the simplified ILCA tool

The tool can be used by:

- Social investors: with the energy consumption section, for example, the social investors can insure low energy costs; therefore the inhabitants of the buildings will not have such difficulties in paying their bills, or their rents.
- Architects: it helps to sum up materials, and can compare several construction alternatives in terms of costs and energy consumption.
- To obtain the High Environmental Quality label (HQE): the targets of the label could be integrated in the future in the software in order to deliver pre-certification.
- Agencies dealing with the planning of renovation and maintenance expenses: facility management enterprises might find it comfortable to have the construction details with associated costs as well as the planning of renovation and maintenance for the next coming years with the associated costs in the same place.
- Town services: urbanism, sustainable development agency, social activities, city energy department.

More broadly, the ILCA allows for:

- The inclusion of environmental considerations in the decision making processes of products;
- The examination of several alternative solutions for one building;
- The encouragement of innovation at the core of an enterprise;
- The energizing of innovation for a whole activity sector;
- The development of strategies (regarding maintenance, bio-architecture, etc.);
- Comparisons, tests;
- The taking of advantage of knowledge of other products (advertisement, competition);
- The promotion of discussion, this can give way to the development of new policies in the building sector.

Thus, all the set objectives of Stilcab are covered:

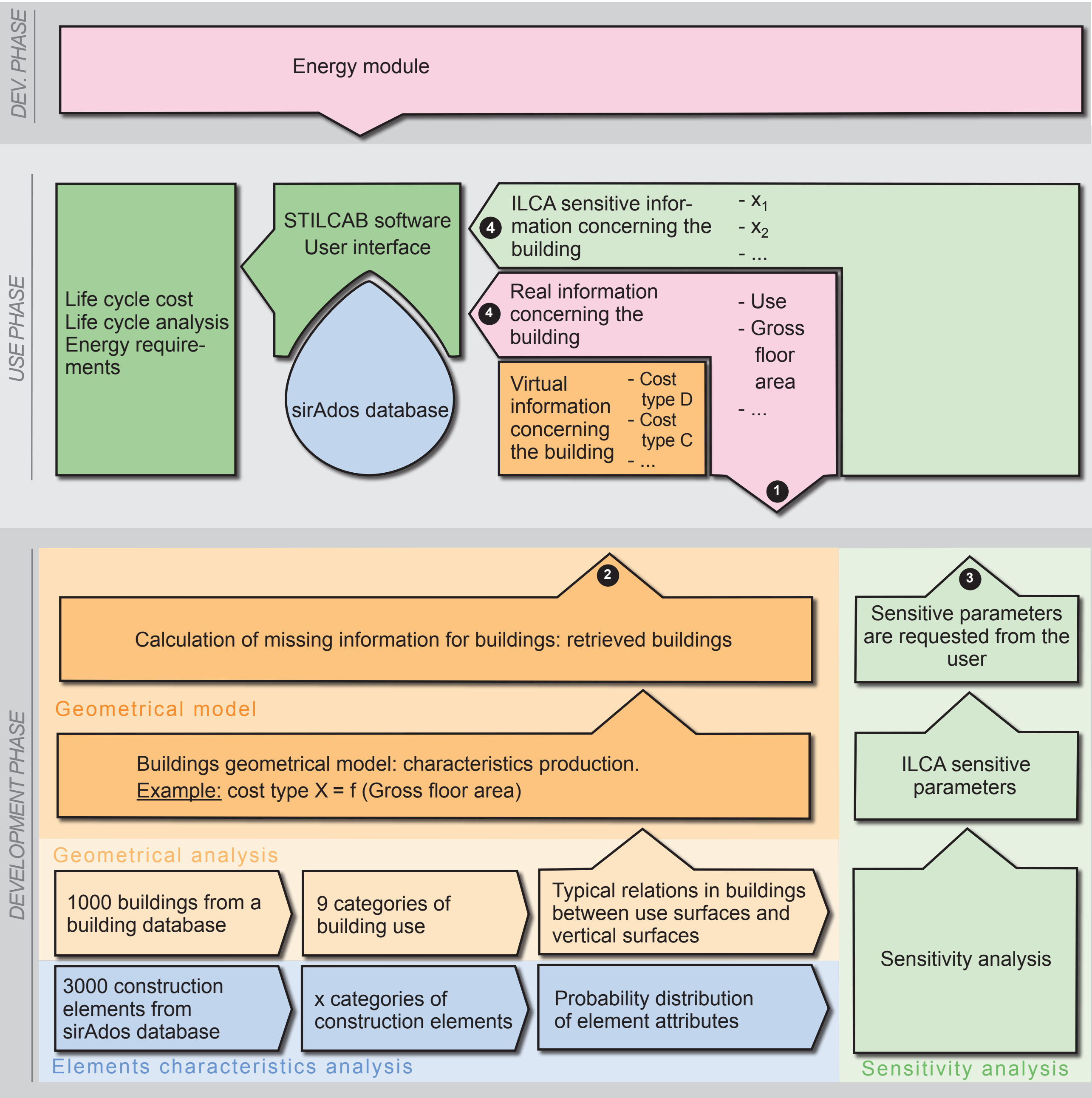
- to determine the energy consumption in advance,
- to determine the costs (all those which would arise),
- and to assess the environmental impacts which a building generates during its construction, its use (including renovation) and its demolition.

V.6. Summary

The following graph (Figure 64) presents the relationship between the several steps of the development of Stilcab and what the user has to do in order to use the method.

Figure 64

Development phase and use phase of Stilcab



VI. A detailed example of application

In this section, an application example is shown.
A kindergarten to be built in Narbonne, in the south of France is selected.

VI.1. First design of the kindergarten

The following characteristics are considered in each version of the application case.

- A rectangle form 28*22m.
- The maximal share of windows to fulfil the EnEV is 30%. Therefore a 30% share is considered, and not the 116m² (which are about 33%) given by the architect (a maximum share of 30% of windows is the upper limit accepted for the EPBD).
- 50 people are supposed to use this building.
- Technical equipment is not considered.
- Costs are default costs for France.

Figure 65

Characteristics of the kindergarten in Narbonne

Default geometry selected	Rectangle
Number of floors	1
Height of the building (m)	3,5
Windows share (%)	30
l (m)	22
L (m)	28
Location	Narbonne - France
Annotations	Version 1 – default values
Building's lifetime (years)	80
Gross floor area (m^2)	616
Constructed area (m^2)	616
Number of occupants	50
Electricity mix	France

At first 4 versions of the building were considered: versions 1 to 4.
The versions have the following differences:

1. Version 1: Class B (110kWh/(m².year)) was selected first for the EPBD, with all default values and a central gas low temperature heating system.

2. Versions 2, 3, 4: Class A (80kWh/(m².year)) was selected for the EPBD, with all default values and a central gas low temperature heating system when possible, and constant temperature when not possible (version 4)

3. Versions 3 and 4: no energy requirements for hot water production because a solar installation was supposed.

4. Version 4: a photo-voltaic production of 10kWh/(m².year) was supposed.

Note: Classes A to G refer to the EPBD classes (see also Figure 55). However, the primary energy consumption indicated in brackets corresponds to an associated class (A to G), defined by the DENA (values in 2006, which are not definitive values at this time since the application conditions of the EPBD are not definitive.) The indicated values (e.g.: 110kWh/(m².year)) are the values considered in the following.

Input summary				
	Version 1	Version 2	Version 3	Version 4
People	50	50	50	50
Geometrical characteristics Gross floor area / L*l / Number of floors / Height / % of windows	616 / 28*22 / 1 / 3,5 / 30	616 / 28*22 / 1 / 3,5 / 30	616 / 28*22 / 1 / 3,5 / 30	616 / 28*22 / 1 / 3,5 / 30
Life duration	80 years	80 years	80 years	80 years
Class of primary energy consumption (kWh/(m².year))	110	80	80	80
Heating system	Gas – centralised - low	Gas – centralised - low	Gas – centralised - low	Gas – centralised - constant
Hot water	Gas – centralised - low	Gas – centralised - low	Solar	Solar
Photo voltaïc (kWh/m².year)	0	0	0	10
Output summary				
Building (construction + renovation + cleaning) costs	Reference	Idem version 1 (cf. here under)	Idem version 1 (cf. here under)	Idem version 1 (cf. here under)
Heating costs	Reference	Less than version 1	More than version 2	More than version 2
Heating impacts (for example CO_2)	Reference	Less than version 1	More than version 2	More than version 2
Maximum value for primary energy consumption per year (kWh/m².y)	110	80	80	80
Primary energy for hot water (kWh/m².y)	13,43	13,43	0,00(1)	0,00(1)
Primary energy for lighting (kWh/m².y)	10,32	10,32	10,32	10,32
Primary energy for ventilation (kWh/m².y)	15,48	15,48	15,48	15,48
Avoided primary energy (kWh/m².y)	0,00	0,00	0,00	25,80
Primary energy authorized for heating (kWh/m².y)	70,77	40,77	54,20	80,00
Umax Average	0,44	0,22	0,32	0,44
Umax for walls	0,31	0,16	0,22	0,31
Umax for windows	1,53	0,78	1,12	1,55
Global warming potential (kg CO_2-Eq) for construction	180866	171306	172418	180728
Costs (€) for construction	561390	564814	564953	561355
Global warming potential (kg CO_2-Eq) for construction, cleaning, maintenance and renovation	275576	252161	260506	275507
Costs (€) for construction, cleaning, maintenance and renovation	2575471	1615734	2281621	2575412
Global warming potential (kg CO_2-Eq) for heating	772783	445287	591947	873526
Costs (€) for heating	182042	104895	139443	205774
CO_2 – all inclusive	1355147	1004237	995030	1291610
Costs (€) all inclusive	2859760	1822876	2523310	2883433

Figure 66

Inputs and outputs from Stilcab for versions 1 to 4
(1) "0" for primary energy consumption of hot water simulates hot water produced with a solar installation even though the solar installation does not have a 100% production efficiency rate

Versions 3 and 4 are more expensive than version 2 because Class A is considered for the primary energy requirements and the amount of renewable energy is increased; therefore, the primary energy for heating increased in the same proportion.
In order to visualise the profit of using solar hot water and photo-voltaic production, the primary energy consumption must be reduced (this means, below Class A, for example, 60 kWh/(m².year)).
Therefore, versions 3 and 4 show the combined effects of:

1. reducing the primary energy requirements by solar hot water production and photo-voltaic production.
2. the primary energy saved for the hot water production and by the photo-voltaic production is re-allocated to the heating energy, so that the sum of primary energy for the building stays at the defined level of Class A.

Two new versions of the kindergarten are assessed: versions 7 and 8.
In version 7 of the project, a precise orientation was given, as follows:

- Window orientation southwest to southeast: 80m²
- Window orientation northwest to northeast: 20m²
- Window orientation others: 5m²

Class A of the EPBD was reduced to 60 kWh/(m².year). Hot water is solar produced and 10 kWh/(m².year) are produced with photo-voltaics.
Version 7 has to be compared with version 8, with default orientation. A gain of U-value has to be pointed out.
Comparison of versions 7 and 8 with version 4 is shown in the next figure (cf. Figure 67).

The only differences between version 7 and version 8 are the maximal U-values calculated according to the orientation of the building and the respect of EPBD and EnEV.
For the two versions (7 and 8), both norms are respected, therefore, both variants of the building require the same energy for heating. However, due to the precision of the orientation in version 7, the U values required are less limited (greater U-value than version 8) as the building is more southern oriented than the default orientation considered in version 8.
Between version 4 and version 7, the amount of primary energy for heating is 20kWh/m².year less. Therefore, there is a lower global warming potential and costs for heating in version 7 (and 8) than in version 4. The U-values calculated for version 4 are also less restrictive than those determined in the two other versions.
The construction costs for version 4 is less than for versions 7 and 8. Nevertheless, the difference is not significant. A significant difference will be justified by the construction element choice which is realised automatically according to the U-values (thermal characteristics) that exterior walls, roof and windows must reach.

VI.2. Revised design of the kindergarten

For the following versions of the same building, new plans of the kindergarten were available as the architect suggested a revised design of the kindergarten.
The number of persons is reduced to 40.

The plans of the building have changed since the first 8 versions. In order to simulate the building with a default geometry and to respect the given gross floor area (also changed since the other versions), the building was assimilated to a 23,9*29,1 m rectangle, with a height of 5,2m. By doing this, the surface of exterior walls, the gross floor area and constructed area of the building (now 696 m²) are respected.
The window share of the exterior walls surface for those three versions was estimated at 24%.

Input summary			
	Version 4	**Version 7**	**Version 8**
People	50	50	50
Geometrical characteristics Gross floor area / L*l / Number of floors / Height / % of windows	616 / 28*22 / 1 / 3,5 / 30	616 / 28*22 / 1 / 3,5 / 30	616 / 28*22 / 1 / 3,5 / 30
Life duration	80 years	80 years	80 years
Class of primary energy consumption	A=80	60	60
Heating system	Gas – centralised	Gas – centralised	Gas – centralised
Hot water	Solar	Solar	Solar
Photo voltaïc (kWh/m².year)	10	10	10
Orientation of the building	Default orientation	80m² SW to SE 20m² NW to NE 5 m² other direction	Default orientation
Output summary			
Building (construction + renovation + cleaning) costs		Less than version 4	Idem version 7(cf. here under)
Heating costs		50000€ less than version 4	Idem version 7
Heating impacts (for example CO_2)		Less than version 4	Idem version 7
Maximum value for primary energy consumption per year (kWh/m².y)	80	60	60
Primary energy for hot water (kWh/m².y)	0,00(1)	0,00(1)	0,00(1)
Primary energy for lighting (kWh/m².y)	10,32	10,32	10,32
Primary energy for ventilation (kWh/m².y)	15,48	15,48	15,48
Avoided primary energy (kWh/m².y)	25,80	25,80	25,80
Primary energy authorized for heating (kWh/m².y)	80,00	60,00	60,00
Umax Average	0,44	0,40	0,36
Umax for walls	0,31	0,28	0,25
Umax for windows	1,55	1,41	1,26
Global warming potential (kg CO_2-Eq) for construction	180728	172480	172480
Costs (€) for the construction	561355	563872	563872
Global warming potential (kg CO_2-Eq) for construction, cleaning, maintenance and renovation	275507	260412	260412
Costs (€) for construction, cleaning, maintenance and renovation	2575412	2276725	2276725
Global warming potential (kg CO_2-Eq) for heating	873526	655157	655157
Costs (€) for heating	205774	154333	154333
CO_2 – all inclusive	1291610	1058145	1058145
Costs (€) all inclusive	2883433	2533305	2533305

Figure 67

Inputs and outputs from Stilcab for versions 4, 7 and 8

(1) “0” for primary energy consumption of hot water simulates hot water produced with a solar installation even though the solar installation does not have a 100% production efficiency rate

Input summary:			
	Version 9	**Version 10**	**Version 11**
Persons	40	40	40
Geometrical characteristics Gross floor area / L*l / Number of floors / Height / % of windows	696 / 23,9*29,1 / 1 / 5,2 / 24	696 / 23,9*29,1 / 1 / 5,2 / 24	696 / 23,9*29,1 / 1 / 5,2 / 24
Life duration	80 years	80 years	80 years
Class of primary energy consumption	B=110	B=110	A=60
Heating system	Gas–centralised	Gas–centralised	Gas–centralised
Hot water	Gas – centralised - low	Gas – centralised - low	Solar
Photo voltaïc (kWh/m².year)	0	0	10
Orientation of the building	Default orientation: 36m² SW to SE 36m² NW to NE 59m² other direction	93m² SW to SE 41m² NW to NE 0m² other direction	93m² SW to SE 41m² NW to NE 0m² other direction
Output summary			
Maximum value for primary energy consumption per year (kWh/m².y)	110	110	60
Primary energy for hot water (kWh/m².y)	13,43	13,43	0,00 (1)
Primary energy for lighting (kWh/m².y)	10,32	10,32	10,32
Primary energy for ventilation (kWh/m².y)	15,48	15,48	15,48
Avoided primary energy (kWh/m².y)	0,00	0,00	20,64
Primary energy authorized for heating (kWh/m².y)	70,77	70,77	54,84
Umax Average	0,28	0,32	0,27
Umax for walls	0,20	0,32	0,27
Umax for windows	1	1,59	1,33
Global warming potential (kg CO_2-Eq) for construction	209894	244001	280214
Costs (€) for construction	705319	793724	843209
Global warming potential (kg CO_2-Eq) for construction, cleaning, maintenance and renovation	304926	362779	403458
Costs (€) for construction, cleaning, maintenance and renovation	2000362	3429195	3655374
Global warming potential (kg CO_2-Eq) for heating	585133	585133	453298
Costs (€) for heating	137838	137838	106782
CO_2 – all inclusive	1236436	1294289	1017731
Costs (€) all inclusive	2253641	3682473	3877596

Figure 68

Inputs and outputs from Stilcab for versions 9, 10 and 11

(1) "0" for primary energy consumption of hot water simulates hot water produced with a solar installation even though the solar installation does not have a 100% production efficiency rate

The comparison between versions 9 and 10 shows that due to the orientation of the building, the U-values calculated are a lot less restrictive. Nevertheless, the costs of construction and the associated global warming potential are higher than in version 9.

This seems to show that the price of construction elements (because all elements which do not respect the U-values limitations are not considered) tends to be reduced when only a limited number of construction elements are available (= the exterior walls and windows with small U-value are not necessarily more expensive than others, are on the contrary less expensive, than all exterior walls considered on average).

Version 11 has lot less CO_2 and lower costs for heating than the other versions. This is due to a combination of solar hot water production, photo voltaic production and reduction of the primary energy consumption for heating. The reduction of the primary energy consumption to dispose of in version 11 leads to a reduction in the U-values permitted.

VI.3. Costs and environmental impacts of the building

Those 9 versions of the same building are presented here to visualise the possibilities of Stilcab. Amongst others, the following is strengthened:

- U-value optimisation by the building's orientation definition;
- Share of energy costs in the overall costs (Figure 69);
- Share of CO_2 due to energy consumption (it could have been any other environmental impact) in the overall CO_2 (Figure 70);
- Examples of energy distribution in the various areas (hot water, heating, etc.);
- Calculation a priori of construction costs and renovation / cleaning / maintenance costs.

By allowing such comparisons between different alternatives of the same building, Stilcab enables decisions to be taken, and energy performances and targets to be reached.

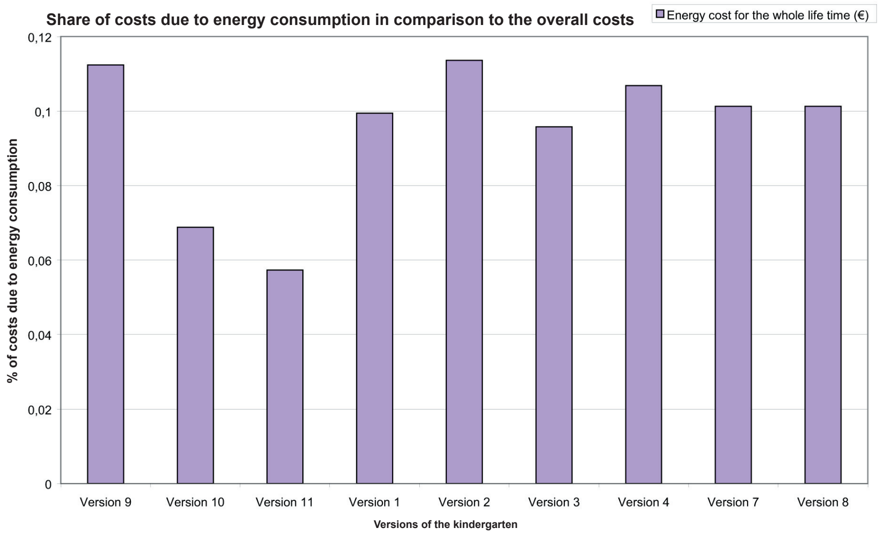


Figure 69

Share of costs due to energy consumption in the building during an 80-year lifetime.

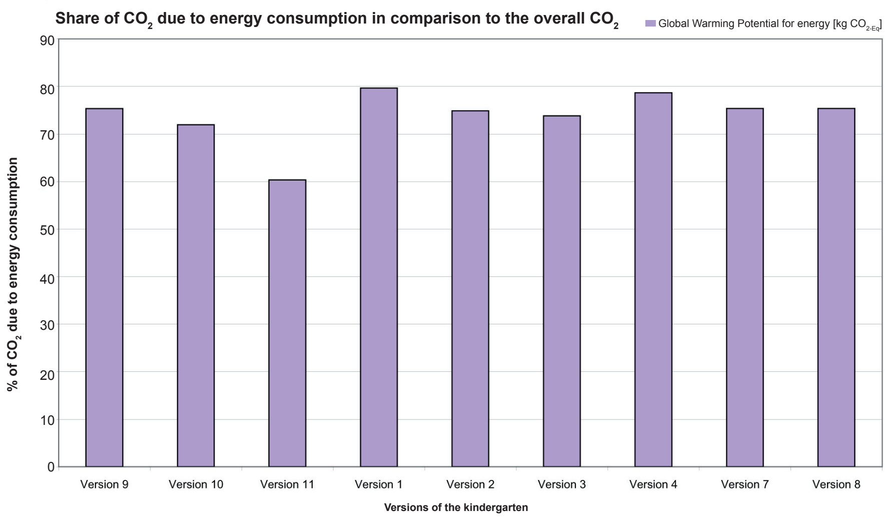


Figure 70

Share of CO_2 due to energy consumption in the building during an 80-year lifetime.

VI.4. Comparison of results of the kindergarten sensitivity analysis

Versions	1 to 8	9	10	11
Improvements potential of costs	Floors and ceilings	Windows	Floors and ceilings	Floors and ceilings
	33%	30%	42%	40%
Improvements potential of GWP	Roof	Roof	Roof	Roof
	19%	30%	27%	25%

Figure 71

Improvement potential for the various versions of the kindergarten

As the choice of construction elements vary predictably from one version to another, the improvements potential also vary. Nevertheless, the trend for improvements regarding costs and GWP is identified.

If reducing the life cycle costs of the kindergarten is desired, the analysis of the 11 alternatives considered shows in almost all cases (except alternative 9), that the largest improvement potential is found by taking care of the choice of elements for floors and ceilings.

In the same manner, the largest improvement of the global warming potential impact can be reached by selecting the appropriate roof element.

NB: Solar hot water production and photo-voltaic simulation:

In order to simulate the production of hot water with solar captors and the production of electricity with photo-voltaic panels, the value “0” should be entered for the hot water production end energy, and the quantity of end energy produced with photo voltaic should be entered for “Electricity production on site”. This is an appoximation as we consider the solar installation as being able to provide 100% of the required energy for hot water production, whereas, along the year, the installation provides about 60 to 70% of it only.

QUALITY OF THE METHOD

The sensitivity of the method is analysed in order to evaluate it and to gain knowledge about building life cycle analysis.
The results in terms of building LCA are compared with the results of other software to validate the present method.
Then, the uncertainty of the method is quantified as well as the uncertainty of another method, in order to assess the quality of both the method and the tool for early design phases.

VII. Sensitivity of the method

The sensitivity is the influence of one parameter (the independent variable) on the value of another (the dependent variable).
The aim of a sensitivity analysis is to identify which parameters have the largest improvement potential on the results of integrated life cycle analysis.
Below are the questions to be answered before presenting the results of the sensitivity analysis and its realisation and implementation in the tool.

- What are the parameters?
- What are the outputs analysed at?
- How large is the potential?

Note: In the following sensitivity analysis, interactions between construction elements are not taken into consideration.

VII.1. Definitions for the sensitivity analysis

VII.1.1. Parameters for the sensitivity analysis

There are two types of parameters:

- the geometrical characteristics of the building and
- the construction elements chosen to represent a particular part of the building's construction.

However, when using the simplified building description model, the geometrical characteristics and the choice of elements can no longer be dissociated. Therefore, there are no longer two types of parameters but only one "mega-parameter".
There are eight mega-parameters as illustrated in the next figure (cf. Figure 72). Please note that the mega-parameters "staircases" and "interior doors" which are mentioned in Figure 33 have been proved to be irrelevant for the sensitivity analysis, therefore they will no longer be taken into consideration.

N°	Description	Corresponding cost type in the DIN 276	Corresponding element surfaces
1	Excavation	Element 310	Quantity 310
2	Foundations	Element 320	Quantity 320
3	Exterior walls	Element 330	Quantity 330
4	Interior walls	Element 340	Quantity 340
5	Floors and ceilings	Element 350	Quantity 350
6	Roofs	Element 360	Quantity 360
7	Windows	Element 3308	Quantity 3308
8	Exterior doors	Doors elements	Quantity doors

Figure 72

Mega-parameters used to describe buildings in Stilcab

VII.1.2. Outputs to be looked at for the sensitivity analysis

The results of a building's ILCA are those previously mentioned in Figure 30, but are now presented as a sum for the whole building and its whole life duration, not for an isolated construction element.

VII.1.3. Improvement potential

A result's improvement potential is referred to as the variation potential of one result when changing the characteristics of one parameter.
For example, a conclusion of the sensitivity analysis could be:

"the exterior walls have 21% of the potential of reduction of the value of global warming potential (GWP) generated by a building during its lifetime, whereas the roof has 10%"
or:
"the share of the overall improvement potential for the GWP when changing the exterior walls is 21% - meaning the remaining 79% of improvement potential depends on other building construction elements".

It means that the improvement potential of the exterior walls is twice as important as the improvement potential of the roof for this building regarding the global warming potential.

VII.2. Sensitivity analysis for building categories

The sensitivity analysis has been realised for the various building categories mentioned in III.2.4. For each category, the mega-parameter values were assessed and results were obtained such as those represented in the following graph (cf. Figure 73), which concerns all the different results of ILCA and one specific category of building use (here, one family housing for 80 years).
In Figure 74, it can be seen that the mega parameter "excavation" and "exterior doors" do not have any potential of improving the GWP statistically generated by buildings in this category. However, this is not the case for interior and exterior walls, which have 27% and 20% of the total possible improvement potential respectively.
This kind of result gives an idea of where the variation potentials are in order to improve a building (cf. III.4.3.), or, in the present case, in order to identify the mega-parameter which is in general responsible for one or another of the impacts, and /or costs.
The sensitivity analysis has been done for all types of buildings and each time all the ILCA results were analysed. The results can be found in Annex 15. Figure 75 presents the summary.

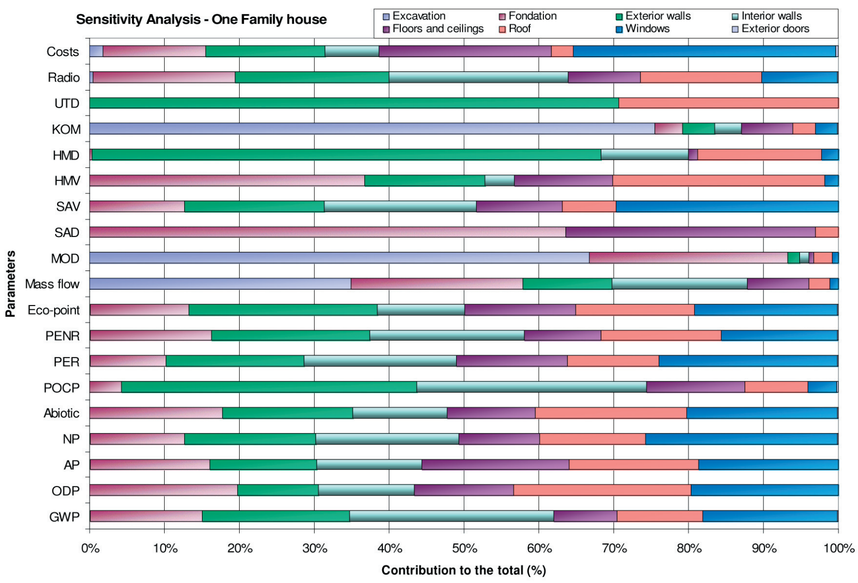


Figure 73

Typical results of the building's ILCA sensitivity analysis, for a specific building use category

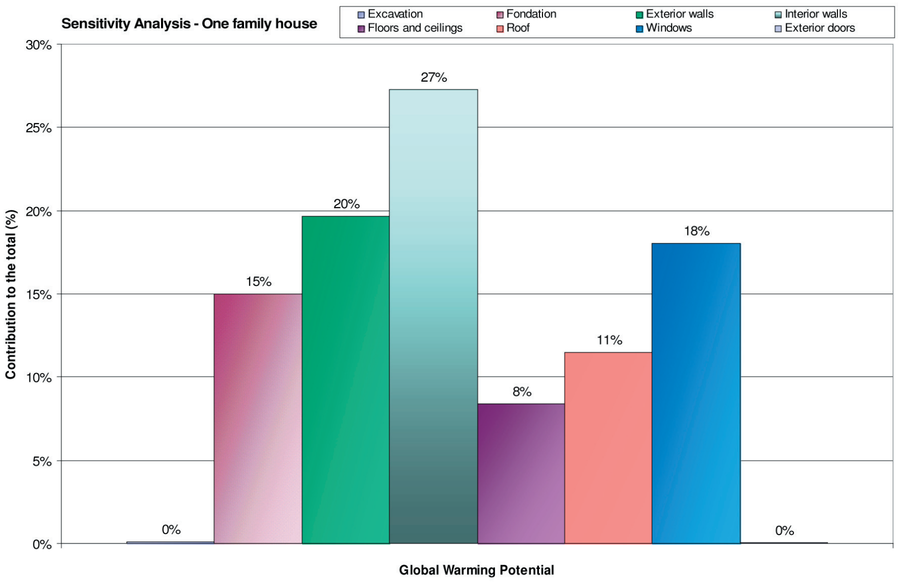


Figure 74

Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for a specific building use category

How to read the chart:
For example, for the category "hostels and student habitations", if improvement of the ozone depletion potential is desired, the largest potential of improvement will be found by looking closer at "windows". To greatly reduce the ODP of the building, one can either act on the quantity of windows, or on their quality (selection).

Figure 75 summarises the output of the present analysis for all building categories and several outputs of an LCA.

Excavation is indeed the largest source of mass which can be composted. Therefore the largest potential for reducing the mass flow and the quantity of compost on a building site is by adjusting the excavation quantity.

A similarity can be seen in the results of "small buildings" on one hand (one family house, multiple family house, fire stations, hostels and student habitations), and "large buildings" (office buildings, hospitals, factories, industry and trade buildings) on the other hand. For those two groups, the improvement potential for one or another LCA output is almost always the same. This might be due not to the quality of the choice of elements but to the quantity of those elements, which is considerable when looking at "large buildings". Large buildings are, for example, often composed of only one floor; therefore "floors and ceilings" can not lead to a large improvement; whereas with "small buildings", the quantity of exterior walls dominates the others, which can lead to a larger improvement potential due to change in the quantity of exterior walls.

Those results can be compared with the ones gained in analysis C, which can be found in Annex 1 (cf. Figure 79). Indeed, the same process was used to describe the buildings, but this time with only 50 buildings instead of 1000 buildings. Each building category is represented with 5 items. In Figure 75, the bold parameters show a correspondence between analysis C (with 50 buildings) and the realisation for all buildings in this category (1000 buildings in total). The rows and columns in italics were not compared. Both analyses show almost the same potentials for the same parameters.

Building categories	Global warming potential	Ozone depletion potential	Primary energy non-renewable	*Eco-points*	Mass flow	*Compost*	Costs
Office buildings <2500m²	Exterior walls	Roof	Roof	Exterior walls	Excavation	Excavation	Windows
One family houses	**Interior walls**	**Roof**	**Exterior walls**	Exterior walls	Excavation	Excavation	Windows
Multiple family houses	Exterior walls	Windows	Exterior walls	Exterior walls	Interior walls	Excavation	Windows
Multiple family houses <4000m²	**Interior walls**	Roof	Exterior walls	Floors and ceilings	Excavation	Excavation	**Floors and ceilings**
Fire Stations	Interior walls	Roof	Exterior walls	Exterior walls	Excavation	Excavation	Windows
Hostels and student habitations	**Interior walls**	Windows	**Exterior walls**	Exterior walls	Excavation	Excavation	**Windows**
Factories	**Interior walls**	**Roof**	**Roof**	Roof	Excavation	Excavation	**Floors and ceilings**
Factories <4000m²	Roof	Roof	Roof	Roof	Excavation	Excavation	Windows
Industry and trade buildings	**Roof**	**Roof**	**Roof**	Floors and ceilings	**Excavation**	Excavation	**Floors and ceilings**
Hospitals	**Interior walls**	Floors and ceilings	**Interior walls**	Floors and ceilings	Excavation	Excavation	**Floors and ceilings**
Educational buildings <2000m²	Roof	Roof	Roof	Roof	Excavation	Excavation	Floors and ceilings
Educational buildings	**Interior walls**	**Roof**	**Exterior walls**	Exterior walls	Excavation	Excavation	Windows
Office buildings	**Interior walls**	**Floors and ceilings**	Exterior walls	Floors and ceilings	**Excavation**	Excavation	**Floors and ceilings**

Figure 75

Largest improvements potential for several LCA results of different building categories

VII.3. Sensitivity analysis for one building, in Stilcab

As in the previous paragraph, a sensitivity analysis is realised. However, this concerns only one specific building at a time and not a building use category as in the case in VII.2.

The following figure shows how the sensitivity analysis has been implemented in Stilcab (cf. Figure 76). The user selects two indicators from a list: global warming potential, ozone depletion potential, etc. and the program displays the results.
For example, in the following screenshot, the user selected "ozone depletion potential" as the first indicator. The program displays that "floors and ceilings" have the largest improvement potential regarding this indicator, and the potential of improvement is about 39%. For the second selected indicator (primary energy non-renewable), the exterior walls have the highest potential (33%).

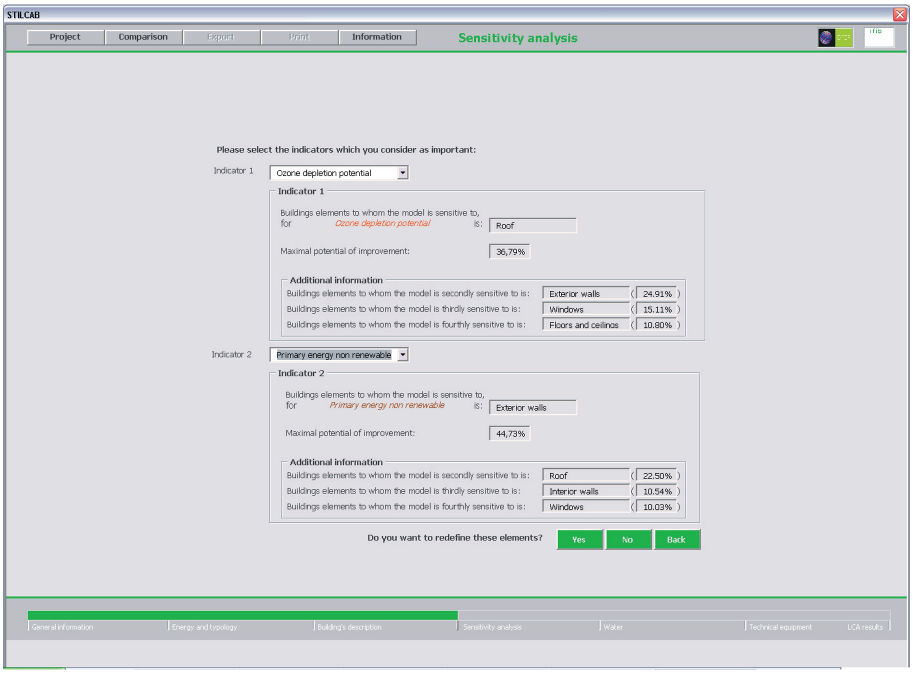


Figure 76

Screenshot of the "Sensitivity analysis"

In the next screen in the program, the user has the possibility to redefine the parameters which have the highest potential (those identified in the previous section; "floors and ceilings" on one hand and "exterior walls" on the other hand, for the current example). When doing so, the user goes deeper into the description of the building by no longer selecting "exterior walls"; now he has the choice between four different kinds of exterior walls.

With the implementation of the sensitivity analysis in the program, the user is given an important piece of information concerning the building. He then knows where he should concentrate his effort to get more precise information in order to optimise the LCA of the building and to have more accurate results.

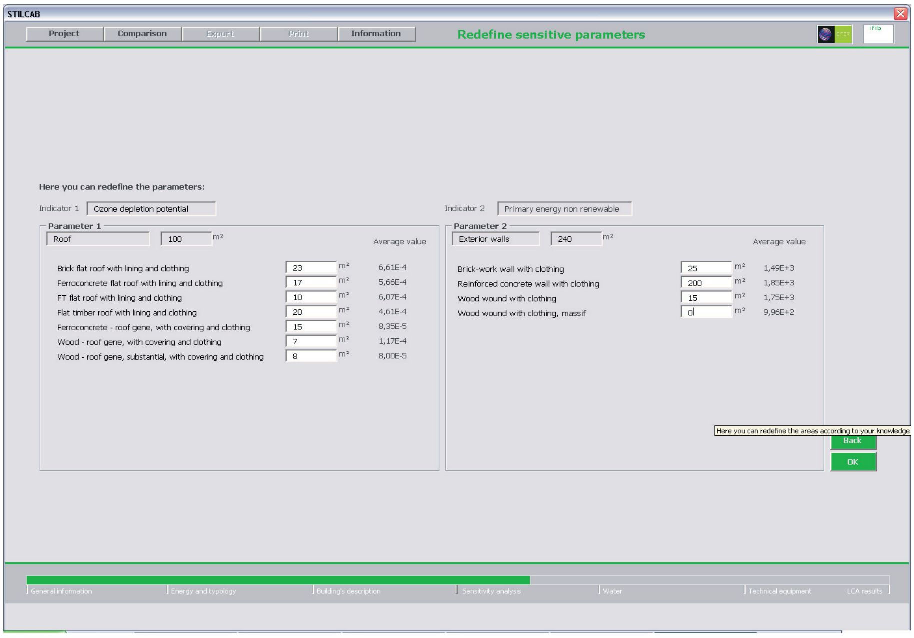


Figure 77

Screenshot of the "Redefine parameters" section

VII.4. Sensitivity analysis for one building

It is also possible to use a special file in Excel in order to analyse one specific building. This process is about the same as the one used in Stilcab which is described in the previous paragraph. However, it does not require opening Stilcab and is therefore more straightforward to use. Of course, the results are not so user-friendly to view but can nevertheless be quickly interpreted, as can be seen in the following figure.

The chart concerns a one-family house with 206m² of gross floor area. The geometry of the building is known and the quantity of each construction elements could be listed (cf. the upper chart on Figure 78).

Quantities are known	
Excavation	451,17 m³
Foundation	219 m²
Exterior walls	367 m²
Interior walls	389 m²
Floors and ceilings	224 m²
Roof	248 m²
Windows	73 m²
Exterior doors	1 unit

One family house	Global warming potential	Ozone depletion potential	Mass flow	Costs
Excavation	0 %	0 %	14 %	0 %
Foundation	9 %	12 %	21 %	10 %
Exterior walls	26 %	14 %	22 %	24 %
Interior walls	25 %	11 %	23 %	7 %
Floors and ceilings	9 %	13 %	11 %	27 %
Roof	17 %	34 %	5 %	4 %
Windows	11 %	13 %	0 %	25 %
Exterior doors	0 %	0 %	0 %	0 %
Maximum	26 %	34 %	23 %	27 %
Parameter	Exterior walls	Roof	Interior walls	Floors and ceilings

Figure 78

Construction element quantities and related improvement potentials for a selection of LCA results (GWP, ODP, mass flow and costs) for one specific building

The lower chart in Figure 78 indicates amongst other thing which construction element has the highest improvement potential for specified results. For example, for the reduction of the global warming potential, the exterior walls have the highest improvement potential, which is about 26% of the whole improvement potential.

This example illustrates that building optimisation is in itself a compromise which must be found between the desired optimisation and the efforts required to reach the objectives. Indeed, concerning the current example, it can be seen that costs can be optimized by realising an action on floors and ceilings, whereas the reduction of mass flows succeeds with a change of the interior walls.
Which parameter is more important to the user is left to his appraisal. One can imagine resorting to a multi-criteria analysis and weighting methods in order to classify the improvement's priorities.

The Excel file which allows this kind of sensitivity analysis is available on the CD, and the corresponding instructions can be found in Annex 17.

VII.5. Sensitivity to element choice and to geometrical quantity variation

The following figure (Figure 79) shows the various possibilities for describing buildings. Starting from the bottom left end of the chart, it is possible:

- to describe buildings in Stilcab by using the range of all geometrical building quantities in a particular category, combined with the whole range of construction elements available for each cost type. This was done in **analysis C** and the results are available in Annex 1. This shows the sensitivity of the model to the model's inputs;
- to improve the previous building description by restricting the choice of elements for each construction part to the average of all elements available for this particular part of the building. This has been done in **analysis D**, with results shown in Annex 2 and discussed hereafter (cf. VII.5.2.). This allows for a look at the sensitivity of the model to the geometrical quantities given in Stilcab;
- to describe the buildings with so-called "retrieved geometrical quantities" (that is to say quantities determined with the geometrical model) and with the range of elements available. This allows for the analysis of the model's sensitivity to the choice of elements (Annex 4, **analysis F**) and also for the examination of the validity of the geometrical model by comparing results of this analysis with those of the following ones;
- to use the geometrical matrix in order to determine all the missing geometrical information of the building, and to consider an average element for each construction part. This is also the **basic use of Stilcab** when using the geometrical matrix,
- to give in the geometrical characteristics of the building as the user knows them and to consider average elements. This is the **normal use of Stilcab** when the user knows more about the description of the building than in the previous description model;
- to describe the building with its real geometrical characteristics and the whole range of elements available. This is done in **analysis E** with results shown in Annex 3;

• to describe a building in **Legep** which requires much more detailed information of the building than Stilcab;
• to look at **reality**.

The following sections compare the results of a very simplified analysis with those of a more detailed model in order to validate the simplfied method.

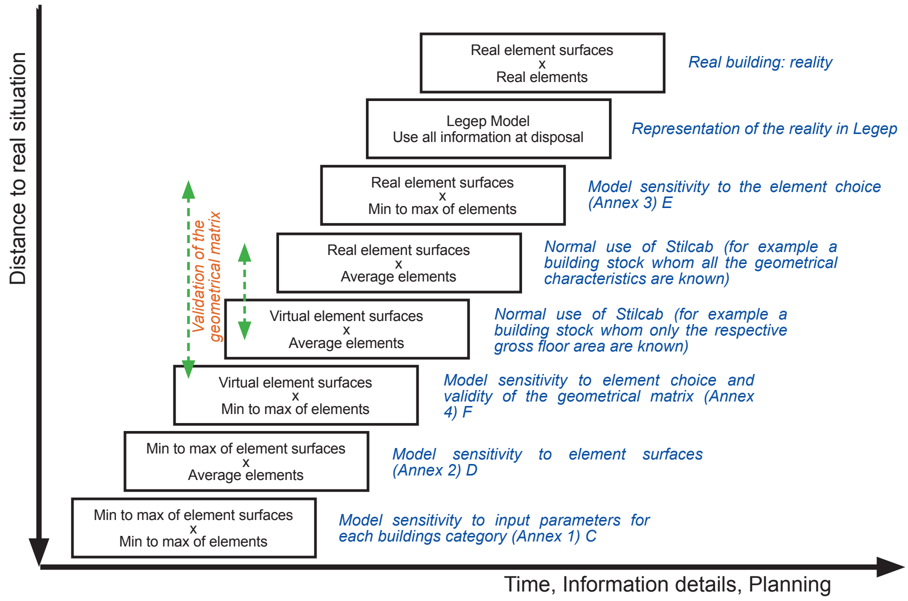


Figure 79

Various representations of buildings with Legep and Stilcab and the sensitivity tested

VII.5.1. Which reality?

Looking at the reality in terms of LCA of buildings means:

• looking at the bills for the construction of the building,
• looking at the material used,
• looking at the quantity of each of those materials which were necessary for construction, and
• looking at the environmental impacts generated.

When doing this, it is possible to compare this with the costs of the building determined by Legep or Stilcab or any other software. The energy requirements of the real building can also be compared with the one calculated by a thermal modelling model or by Legep, for example.
However, it is impossible to compare the environmental impacts calculated by any software with reality. Currently, there is no means of measuring the GWP induced by the erection of a building, as is possible for the costs or for the energy requirements (without mentioning the other environmental impacts). Therefore, when talking about reality and environmental impacts, only models can be trusted (and the software associated with the models) and it must be assumed that reality lies somewhere between the two.

VII.5.2. Typical results of analysis D

In analysis D (cf. also Annex 2), 50 buildings were looked at and arranged into 8 use categories. Each building was described with an average element for each construction part (in total 8 average elements) and the variation range of the geometrical characteristics of the 5 buildings in each category (cf. Figure 79).
The results allow conclusions to be drawn on the range of results for each building category, and how those differ from one category to another. Moreover, it enables the assessment of the sensitivity of the model to the geometrical quantities.
The results are all included in Annex 2. Only the results for office buildings are discussed here (cf. Figure 81). The results are compared with the results for one family houses (cf. Figure 82).
In Figure 81, it can be seen that the assessment of the acidification potential (AP) is sensitive to the quantity of floors and ceilings for office buildings. This means to gain a better idea of the acidification potential of one office building, efforts should be concentrated on more precisely defining the quantity of floors and ceilings (and also the roof) and time should not be wasted in defining the foundations because the model is not sensitive to this input. For some other ILCA results (e.g. for ODP and POCP), it is not as clear as to the acidification potential. For the costs of office buildings, floors and ceilings have a large influence.
Those results are confirmed by looking at the results of analysis E (cf. VII.5.3.).

When looking at the results obtained for "one family houses", it can be stated that the distribution of influences is different from office buildings (except for the excavation). However the results for one family houses agree with those of analysis E.

N°	Description	Corresponding cost type in the DIN 276	Corresponding element surfaces
1	Excavation	Average element 310	Min /max of quantity 310
2	Foundations	Average element 320	Min /max of quantity 320
3	Exterior walls	Average element 330	Min /max of quantity 330
4	Interior walls	Average element 340	Min /max of quantity 340
5	Floors and ceilings	Average element 350	Min /max of quantity 350
6	Roofs	Average element 360	Min /max of quantity 360
7	Windows	Average element 3308	Min /max of quantity 3308
8	Exterior doors	Average element for doors	Min /max of quantity of doors

Figure 80

Mega-parameters used to describe buildings in analysis D

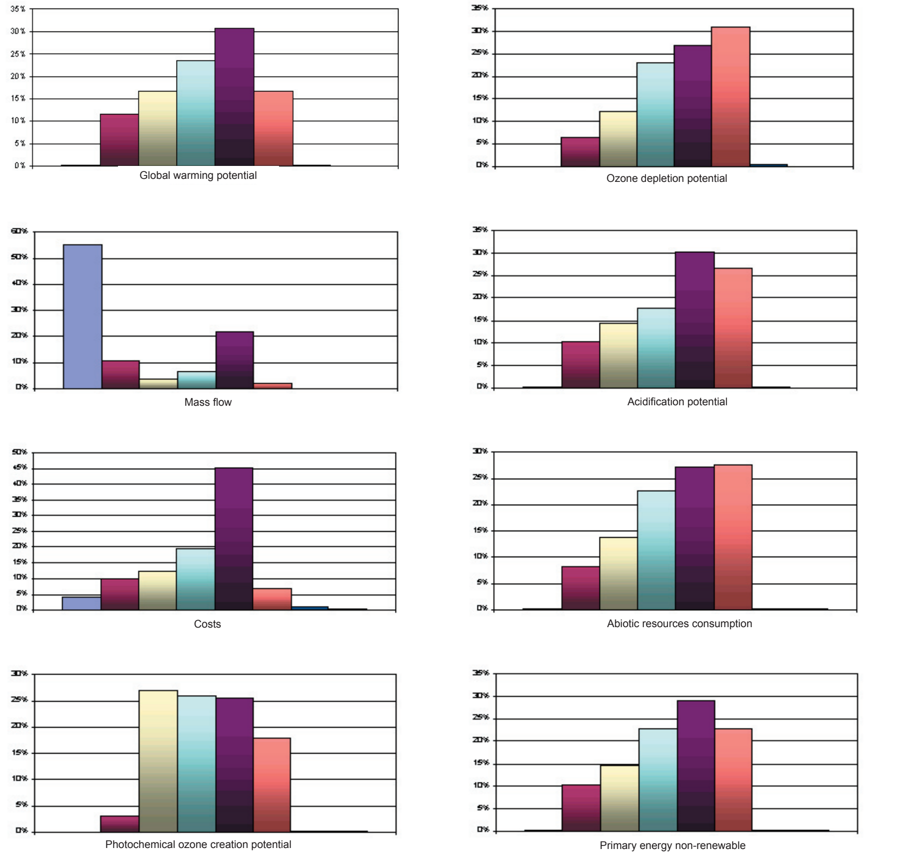


Figure 81

Typical results for analysis D – Here only for the office building category and selected parameters

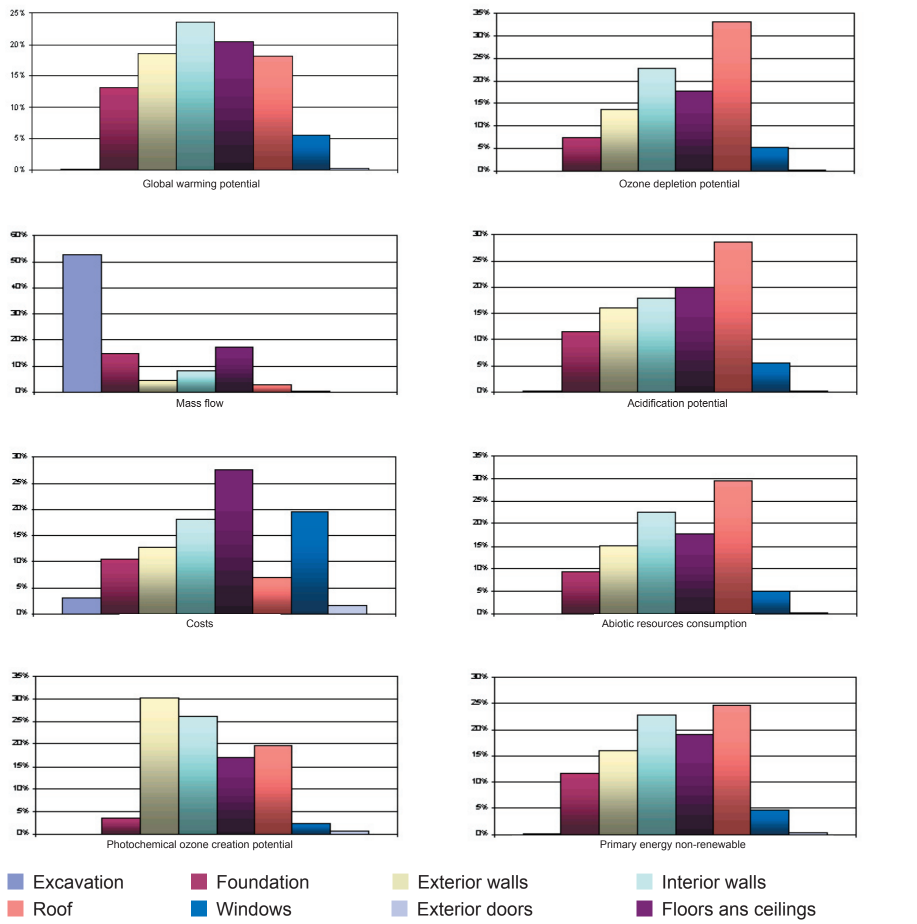


Figure 82

Typical results for analysis D – Here only for one family house category and selected parameters

VII.5.3. Results of analysis E

In analysis E (cf. also Annex 3), 50 buildings were looked at and arranged in 8 use categories. Each building was described with a range of elements (minimum to maximum values) for each construction part and the real quantity of the geometrical characteristics of the 5 buildings in each category (cf. Figure 83). Typical results can be seen in Figure 87 for one family houses and office buildings.

N°	Description	Corresponding cost type in the DIN 276	Corresponding element surfaces
1	Excavation	Min /max of all elements 310	Real quantity 310
2	Foundations	Min /max of all elements 320	Real quantity 320
3	Exterior walls	Min /max of all elements 330	Real quantity 330
4	Interior walls	Min /max of all elements 340	Real quantity 340
5	Floors and ceilings	Min /max of all elements 350	Real quantity 350
6	Roofs	Min /max of all elements 360	Real quantity 360
7	Windows	Min /max of all elements 3308	Real quantity 3308
8	Exterior doors	Min /max of all doors elements	Real quantity of doors

Figure 83

Mega-parameters used to describe buildings in analysis E

The real quantities for each mega-parameter were used in order to describe the buildings. Therefore, when a large improvement potential can be seen on the graphs, it means that the selection of the appropriate element has a determining role to play for the estimation of the overall parameter. For example, the element to be chosen for “floors and ceilings” for office buildings determines the assessment of the costs of each of the five office buildings; this construction part has a major influence on the costs.
However, for one family houses, the statement is milder because “exterior walls” and “windows” as well as “floors and ceilings” have important influences.

When the same form of graph occurs for the five buildings of one category, this form can be considered as typical for all other buildings in this category.
For the category “one family house”, the five graphs always have the same form for the five buildings. Therefore on one hand it can be concluded that the form is typical for the whole category, and on the other hand the following assumptions can be made:

ILCA result considered	Element whose selection has the largest influence	Element whose selection has the second largest influence
Costs	*Floors and ceilings*	*Windows*
Global warming potential (GWP)	Exterior walls	Interior walls
Ozone depletion potential (ODP)	*Roof*	*Floors and ceilings*
Mass flow	Exterior walls	Interior walls
Primary energy non renewable (PENR)	Exterior walls	Roof

N.B.: The influential parameters which are indicated in italics are the same for the two categories looked at.

Figure 84

Conclusions of analysis E for one family houses

For the category “office building”, the five graphs have almost the same forms for the five buildings, with the exception of building number 5. However it can be considered that the form of the other 4 buildings is typical for the category.

Moreover, the following assumptions can be made:

ILCA result considered	Element whose selection has the largest influence	Element whose selection has the second largest influence
Costs	*Floors and ceilings*	*Windows*
Global warming potential (GWP)	Interior walls	Exterior walls
Ozone depletion potential (ODP)	*Roof*	*Floors and ceilings*
Mass flow	Interior walls	Excavation
Primary energy non renewable (PENR)	Interior walls	Exterior walls

N.B.: The influential parameters which are indicated in italics are the same for the two categories looked at.

Figure 85

Conclusions of analysis E for office buildings

When looking at the other 6 categories of buildings the following was stated:

ILCA result considered	Element whose selection has the largest influence								Element whose selection has the second largest influence							
Building categories	Office buildings	One family house	Factories	Hospitals	Hostels	Industry and trade buildings	Multiple family housing	Educational buildings	Office buildings	One family house	Factories	Hospitals	Hostels	Industry and trade buildings	Multiple family housing	Educational buildings
Costs	FC	FC	?	FC	FC	FC	FC	FC	W	W	?	W	W	?	W	W (EW)
GWP	IW	EW	R	EW	IW	?	IW	R	EW	IW	EW	IW	EW	?	EW	EW
ODP	R	R	R	R	FC	R	FC	R	FC	FC	F	FC	R	?	R	?
Mass flow	IW	EW	F	IW?	IW	?	IW	F	EX	IW	?	?	EW /FC	?	FC	EW
PENR	IW	EW	R	R	EW	?	IW	R	EW	R	EW	EW	IW	?	EW	EW

FC: floors and ceilings; IW: Interior walls; EW: exterior walls; R: roof; EX: excavation; W: windows; ?: undefined.
Same color: similarities for all building use categories.

Figure 86

Conclusions of analysis E for all buildings

The colours indicate similarities between all categories. For example, the costs of "floors and ceilings" and "windows" are of primary interest as their influences on the overall costs of the building's lifetime are large.
However, this influence can be due to two different factors.

- The first one is that the influential construction element is very influential for each building in a category.
- The second is that the list of available construction elements for each element cost type is so important that the range of parameter values covered is also great.

However, to reduce the impact of the second factor, the construction elements were strictly selected at the beginning of the process and analysed so that the standard deviation of one parameter (e.g.: CO_2/m^2) in one element category itself is small.
Therefore, the second reason previously mentioned is not considered further, and it can be stated that Figure 86 shows the more influential construction elements for each building category and some LCA results.

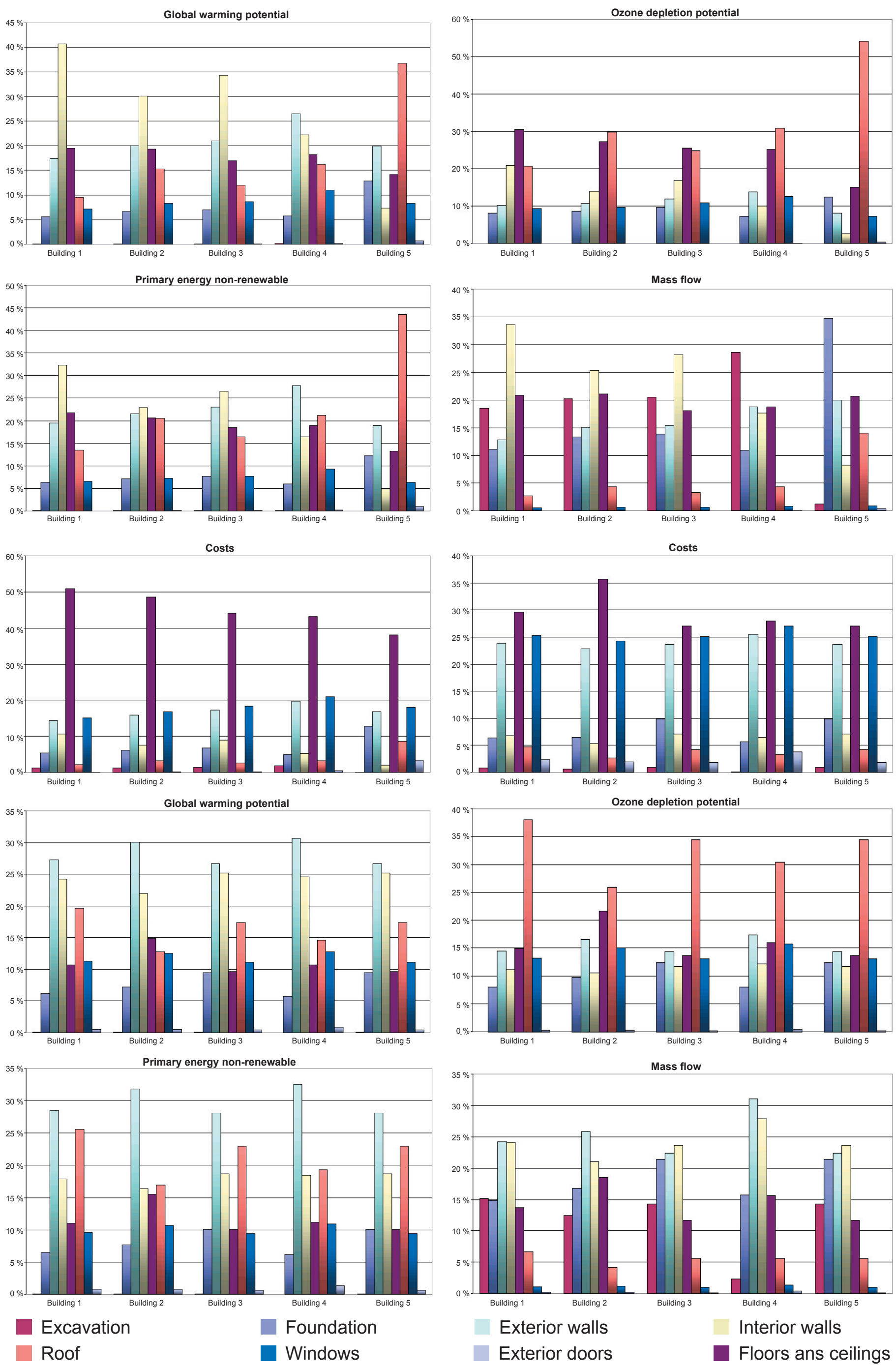


Figure 87

Typical results for analysis E – Here only for one family house category (5 first charts on the left top side) and office buildings (5 charts on the right bottom side) and selected parameters

In Stilcab, a description of a building like the description done in analysis E represents the greatest possible error, when the user of the program enters the real quantities of each construction part and when Stilcab suggests the default construction element. For example, for office building number 5, almost 25% of the overall possible cost estimation error is due to the selection of windows. The user of Stilcab should first stipulate which type of window he is likely to select for this building in order to gain a more precise idea of the costs of the building. At the same time, the choice of interior walls introduces only a minor error in the estimation of the costs of the building.
The description done in analysis E is the last step in the building description in the planning process before the architect defines exactly which material will really be used for the construction. By looking at those graphs, it is possible to assess which construction part materials are more urgent or important to define in order to get a better idea of the ILCA results of the building.

VIII. Validation of the method

The results of the developed method, in terms of building LCA are compared with the results of other software to validate the present method.

VIII.1. Accuracy of detailed ILCA building software

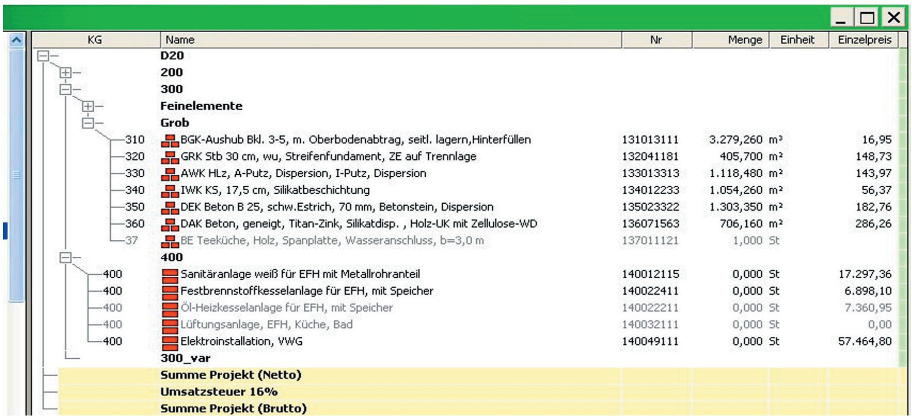
The software considered is Legep [LEG].

VIII.1.1. Hypothesis / Protocol

40 buildings were selected in the building database; 5 buildings per use category. Each building was described twice in Legep:

1. The first time it was described using the “Dummy”;
2. The second time using corresponding elements.

The dummy (cf. Figure 88) used was the same for all buildings, independent of the building category. The dummy is composed of several randomly selected elements. There are 6 elements, each one representing a cost type (cf. Annex 14 for the norm). Windows are not considered.
The term “corresponding elements” stands for the elements that the user found in the elements database which best fit the construction description given in the building database.



KG	Name	Nr	Menge	Einheit	Einzelpreis
	D20				
	200				
	300				
	Feinelemente				
	Grob				
310	BGK-Aushub Bkl. 3-5, m. Oberbodenabtrag, seitl. lagern,Hinterfüllen	131013111	3.279,260	m³	16,95
320	GRK Stb 30 cm, wu, Streifenfundament, ZE auf Trennlage	132041181	405,700	m²	148,73
330	AWK HLz, A-Putz, Dispersion, I-Putz, Dispersion	133013313	1.118,480	m²	143,97
340	IWK KS, 17,5 cm, Silikatbeschichtung	134012233	1.054,260	m²	56,37
350	DEK Beton B 25, schw.Estrich, 70 mm, Betonstein, Dispersion	135023322	1.303,350	m²	182,76
360	DAK Beton, geneigt, Titan-Zink, Silikatdisp. , Holz-UK mit Zellulose-WD	136071563	706,160	m²	286,26
37	BE Teeküche, Holz, Spanplatte, Wasseranschluss, b=3,0 m	137011121	1,000	St	
	400				
400	Sanitäranlage weiß für EFH mit Metallrohranteil	140012115	0,000	St	17.297,36
400	Festbrennstoffkesselanlage für EFH, mit Speicher	140022411	0,000	St	6.898,10
400	Öl-Heizkesselanlage für EFH, mit Speicher	140022211	0,000	St	7.360,95
400	Lüftungsanlage, EFH, Küche, Bad	140032111	0,000	St	0,00
400	Elektroinstallation, VWG	140049111	0,000	St	57.464,80
	300_var				
	Summe Projekt (Netto)				
	Umsatzsteuer 16%				
	Summe Projekt (Brutto)				

Figure 88

Example of a building described with “dummy elements“ (see “Traduction” for the traduction of the key terms)

As can be seen in the following diagram, for each building there are two different sets of results corresponding to the two different descriptions of buildings (cf. Figure 89). Results of type 2 are the ILCA results provided when using the dummy whereas the other results (type 1) are those which come from the use of corresponding elements.

The process of describing each building twice was carried out in order to answer the following question:

“*Is it necessary to enter accurate elements in Legep or can we obtain the same level of quality in the results when less time is spent selecting the appropriate elements, that is to say, can a default element always be used and can the same results be obtained for the building considered as a whole?*”

Clearly, when each part of the building is considered separately, this hypothesis is no longer valid.
But, if this hypothesis is proved to be valid when considering a building and an 80 year life-span, then it is no longer necessary to spend a large amount of

time describing a building in Legep. It will therefore be possible to use default elements and to only give Legep the information concerning the quantity of each element.
It was necessary to carry out the same process for the various building categories in order to verify the hypothesis for each of them and to eventually establish relationships which could be specific to one building category.

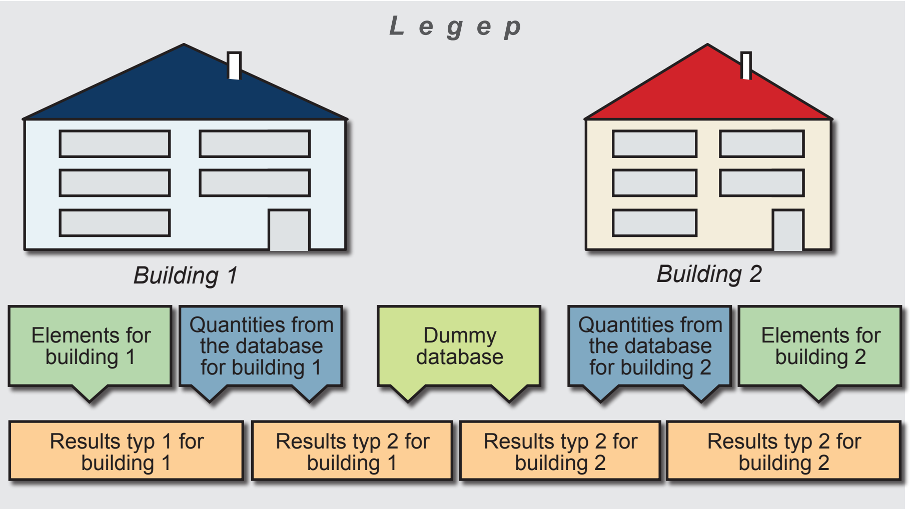


Figure 89

Description of buildings in Legep, following Legep 1 and Legep 2 description models

VIII.1.2. Results of type 1

40 buildings sorted out in 8 use categories were looked at. Three different questions can be answered with the analysis of the results of type 1 provided by Legep:

1. are there any "typical results" for a building category (i.e.: 567€/m² of gross floor area for one family house)
2. are those typical results the same for each category of use, or do the relations depend on the use of the building considered?
3. what is the distribution of the building life cycle costs, between construction costs, renovation costs and cleaning costs?

<u>Typical results:</u>
In order to answer the first two questions, the following figures (cf. Figure 90) were created. All other corresponding graphs can be found in Annex 9.

NB: Only the relations with a reliable variation coefficient are shown on the charts (variation coefficient <0,4).
The construction costs of all buildings varies from 380€/m² to 580€/m² of gross floor area with the exception of hospitals which are more expensive with 810€/m² of gross floor area.
For the global warming potential and for the primary energy non-renewable, it is impossible to draw conclusions concerning all buildings. They have to be looked at separately for each use category. Moreover, as can be seen on the chart concerning GWP, it was not possible to determine ratios for some of the building use categories as the results for the buildings analysed of those categories were not close enough to another.
Figure 91 gathers the results of the analysis of the 40 buildings. Only the relations with a reliable variation coefficient are shown on the charts (variation coefficient <0,4). Those ratios can be used in order to quickly get an estimation of costs (calculated with an assumption of an 80 year lifetime), environmental impacts, mass flow, etc., for the life cycle of the building.

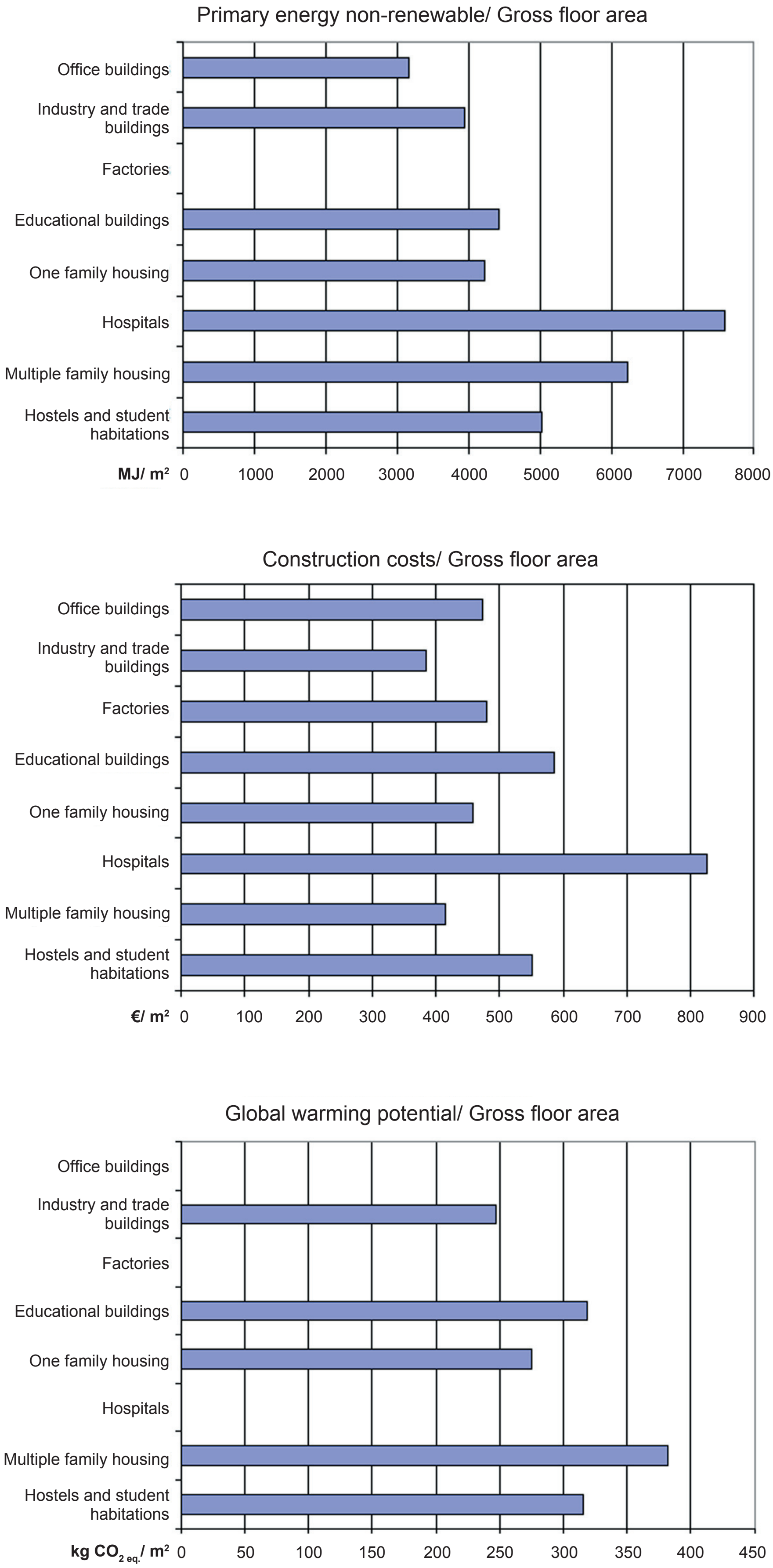


Figure 90

Typical relations for all building use categories, for GWP, PENR and construction costs, for a life time of 80 years

	Construction costs (€/ $m^2_{\text{Gross floor area}}$)	Cleaning costs (€/ $m^2_{\text{Gross floor area}}$)	Renovation costs (€/ $m^2_{\text{Gross floor area}}$)	Total costs (€/ $m^2_{\text{Gross floor area}}$)	Mass flow (kg/ $m^2_{\text{Gross floor area}}$)	GWP (kg $CO_{2\ Eq}$/ $m^2_{\text{Gross floor area}}$)	Acidification potential (kg $SO_{2\ eq}$./ $m^2_{\text{Gross floor area}}$)	Primary energy renewable (MJ/ $m^2_{\text{Gross floor area}}$)	Ecopoints(points/ m^2_{BGF})	Primary energy non-renewable (MJ/ $m^2_{\text{Gross floor area}}$)
Hostels and student habitations	551		436	1569	2203	315	1,75	353	0,67	5020
Multiple family housing	414		396		1561	381				6235
Hospitals	825	887	376	2088	2961		0,28	424	1,23	7582
One family housing	458	351		1282		275	1,41		0,64	4232
Educational buildings	586		526	1492		318	1,47		0,74	4423
Factories	481		411	1172	2421			222		
Industry and trade buildings	384			1038	1902	247	1,41	284		3949
Office buildings	474		323	1105	1831		0,10	125	0,35	3176

Figure 91

Typical relations for all building use categories

Although the figures are average values, they can easily be used to get a rough idea of costs and/or environmental impacts of a given building at the design phase. Furthermore, a comparison of a given building with those values allows for the evaluation of its performances with common agreed values.

<u>Cost distribution:</u>

The following cost distributions (operation costs and end of life costs were not considered) were assessed when considering a lifetime of 80 years. Those distributions can be used in the “facility management” domain, for example.

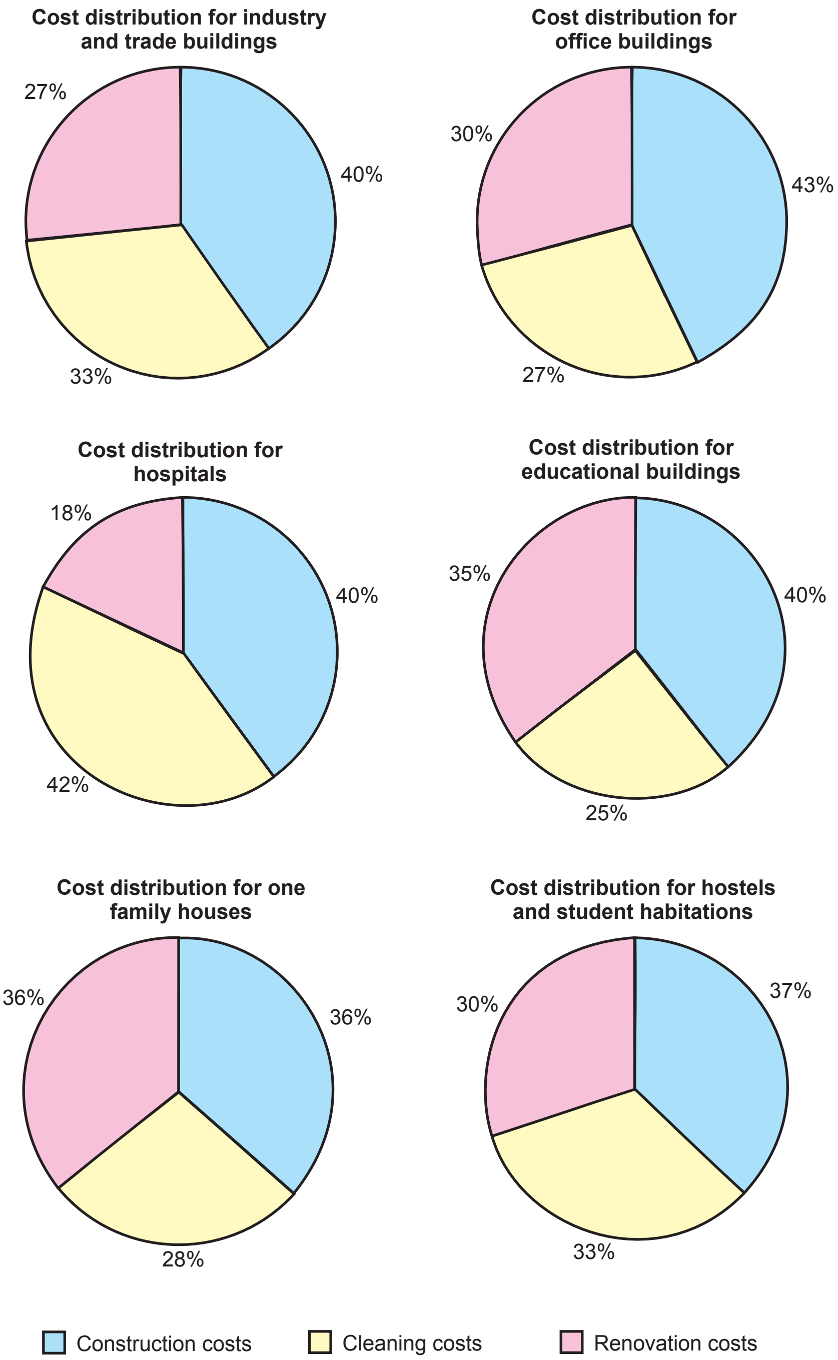


Figure 92

Distribution of cleaning, construction and renovation costs for several building use categories

VIII.1.3. Results of type 2

Results of type 2, from the description of 40 buildings in Legep with the same elements, are used in the next paragraphe (VIII.2.) for the determination of corridors of solutions for Legep.

VIII.2. Validation of the method and the tool Stilcab

Everyone who is aware of the difficulties which occurr in the realisation of building LCA knows how difficult it is to get enough information about the building itself and can also assess the confidence one should have / not have in the results provided by a traditional LCA software.
Indeed, depending on the amount and the quality of available information concerning the building, the results provided by a traditional LCA method are located in a “corridor of solutions”, as represented in Figure 93. The objective of a simplified method of building LCA is to reach the same quality of results with as little information and time as possible. When the corridor of solution of the simplified method is included in the corridor of solution formed by the detailed method, it was worth the trouble of developing a simplified method, as this requires a lot less information about the building to provide the same quality of results.

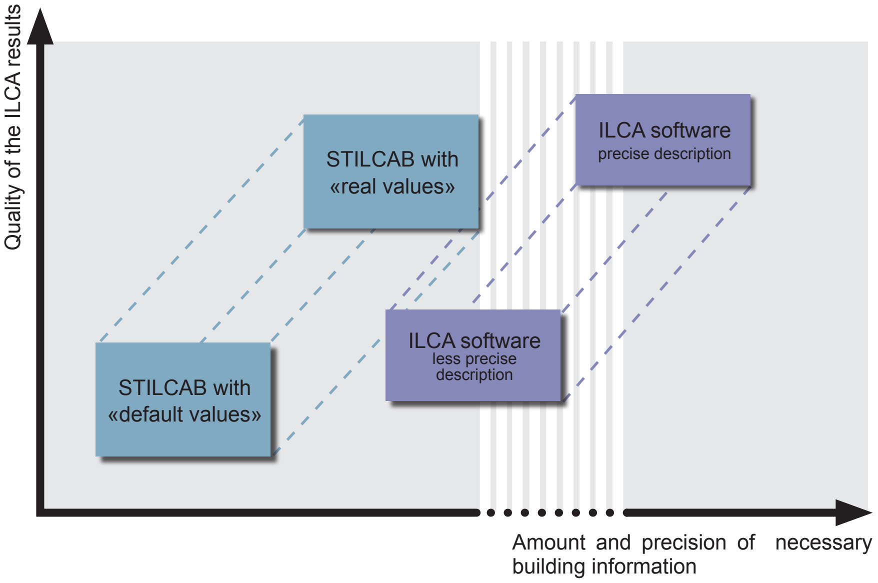


Figure 93

ILCA software: relation between quality of results and the amount and precision of information required about the building - Corridors of solution

The validation of the method and of the tool Stilcab could be realised by the comparison of results: on one hand the results given by a detailed building ILCA software (Legep) and on the other hand the results given by Stilcab. This is what is done in the following paragraph. Furthermore two types of modelling were used for each program: Stilcab and Legep, as shown up in the following figure.

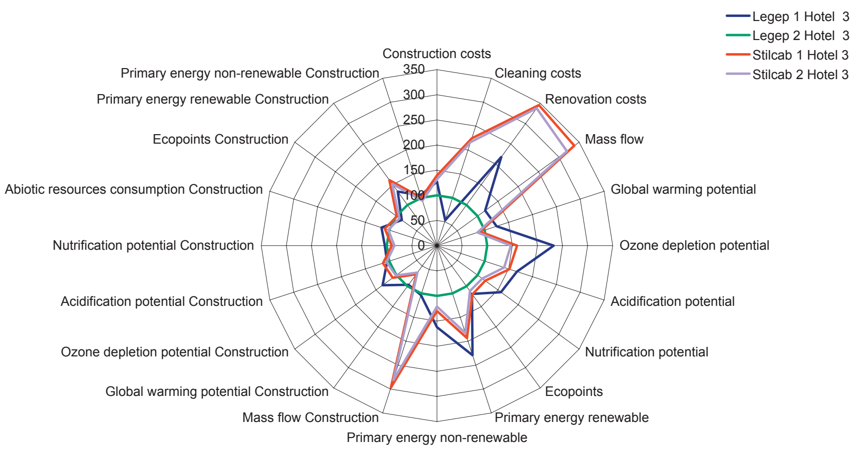


Figure 94

Comparison of results from a traditional ILCA software and those of Stilcab, for one building

The first set of results from Stilcab was collected using default geometrical values for the building description (values coming from the geometrical matrix).
The second set of results from Stilcab refers to the correct geometrical building description.
Results of type 1 and type 2 from Legep are also considered in the following figures.
In Figure 94, the first set of results (detailed ILCA of buildings – precise information) are taken as reference; all other results are reported in the first ones. Depending on which type of results are observed, the four sets give approximately the same results; the order of magnitude of the results is the same. The results shown on the two figures (Figure 94 and Figure 95) are for one building, selected randomly for the illustration in the report. 40 buildings have been analysed with the four methods, and the 160 sets of results have been compared to make it possible to draw general conclusions for the validation of Stilcab (cf. VIII.2.1.).
Figure 95 shows the almost perfect correspondence of the geometrical characteristics calculated with the geometrical model and the real geometrical characteristics (cf. also III.4.1.b.), therefore validating the use of the geometrical matrix to determine missing values necessary for building descriptions.

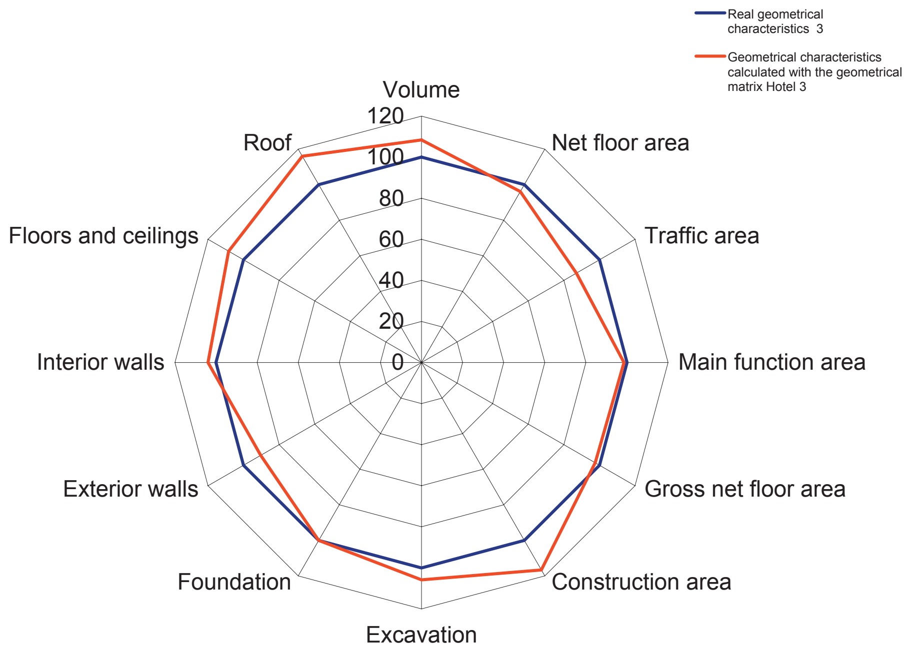


Figure 95

Comparison of the real geometrical characteristics and the characteristics calculated with the geometrical model used in Stilcab with default values

Figure 94 shows discrepancies between the results given by Stilcab and those given by Legep for this particular «Hotel 3» when considering cleaning costs, renovation costs and mass flow (total and for construction). Those differences in the results are coming from the way of assessing those parameters in Stilcab. In deed, to calculate the cleaning and renovation costs of one construction element in Stilcab, the cost of this element is first of all assessed for 80 years in the sirAdos database and then divided by 80 in order to get the corresponding value for one year. Then, in Stilcab this value is multiplied by the factor «life time» (80 years for the graph of the Figure 94). This process leads to errors in Stilcab: the last renovation action should not be taken into consideration. Furthermore, the choice of the construction elements done when describing the building in Legep was different as the elements chosen when describing in Stilcab, which leads to a very different mass flow (for the construction and therefore for the whole life time as well) and different cleaning costs. For the other parameters, the results of Stilcab are included in the corridor formed by the results from Legep.

VIII.2.1. The four description models

40 buildings were described in four ways in Legep and in Stilcab (cf. Figure 94 and Figure 79).

1.Legep 1: Buildings described in Legep with 8 selected construction elements and their corresponding surfaces:

$$B_{legep1} = \sum \left\{ \overset{8}{\underset{1}{Q}}_{real} * \overset{8}{\underset{1}{E}}_{real} \right\}$$ Eq. 4

where: Q is the element surface (expressed in m² or m³)
E is the value of the element's parameter (for example: kg_{CO2}/m^2; €/m³, etc.)

2.Legep 2: Buildings described in Legep with 8 construction elements and the 8 corresponding surfaces. The 8 construction elements are indeed one element for each construction part (i.e. cost type). They were randomly selected from the sirAdos database and remain the same for the description of all buildings. However, the corresponding surfaces of elements are different for each building and come from the building database:

$$B_{legep2} = \sum \left\{ \overset{8}{\underset{1}{Q}}_{real} * \overset{8}{\underset{1}{E}}_{random} \right\}$$ Eq. 5

3.Stilcab 1: Buildings described in Stilcab with default elements for each construction part as available in the "default use" of Stilcab and the surfaces are calculated with the geometrical matrix (in relation to the gross floor area):

$$B_{Stilcab1} = \sum \left\{ \overset{8}{\underset{1}{Q}}_{matrix(=f(grossfloorarea,use))} * \overset{8}{\underset{1}{E}}_{Stilcab} \right\}$$ Eq. 6

4.Stilcab 2: Buildings described in Stilcab but this time with the real surfaces (no longer determined from the gross floor area with the geometrical matrix):

$$B_{Stilcab2} = \sum \left\{ \overset{8}{\underset{1}{Q}}_{real} * \overset{8}{\underset{1}{E}}_{Stilcab} \right\}$$ Eq. 7

The results of "Legep 1" were already analysed and the ratios of VIII.1.2. were established.
The aim of the comparison of ILCA results of Legep 1 and Legep 2 is to conclude what the level of description and the selection of elements from the sirAdos database necessary to get converging results are (cf. VIII.2.2.).
The aim of the comparison of results of Stilcab 1 with results of Stilcab 2 is to assess the validity of the geometrical matrix (already described in III.4.1.b., this will not be further considered here).
The aim of comparison of Stilcab 2 with Legep 1 and Legep 2 is to assess the validity of Stilcab (cf. VIII.2.3.).

VIII.2.2. Comparison of results of Legep 1 and Legep 2

The aim of this comparison (B_{legep1} and B_{legep2}) is to answer the following question:

"Are the level of description and the selection of elements from the sirAdos database irrelevant when one wants to analyse a building as a whole for an 80-year lifetime?"

The results of the comparison are presented below:

	Construction costs in %	Cleaning costs in %	Renovation costs in %	Mass flow in %	Global warming potential in %	Ozone depletion potential in %	Acidification potential in %	Nutrification potential in %	POCP in %	Abiotic resources consumption in %	Renewable primary energy consumption in %	Ecopoints in %	Non-renewable primary energy consumption in %	Waste costs in %
Factories	15		30	16			24	19			30		29	
Office building	15		24	7	12	22	17	9	18	9	18	25	11	27
Educational buildings	17			15	12	24	18	11		22			17	23
One family houses	13		26											
Industry and trade buildings		15		18	20		27	12					23	24
Hospitals			20	25										
Multiple family housing	15		27	15										10
Hostels, student habitations	21		28	15	14			18		30		22	26	20

(dark grey)	The comparison did not provide any conclusions.
(light grey)	No homogeneity was found between the ILCA results of Legep 1 and those of Legep 2 for the 5 buildings in the considered use category.
(white)	The differences are on average greater than 30 % between the results of Legep 1 and results of Legep 2.
X	The difference is x% between results of Legep 1 and Legep 2.

Figure 96

Comparison of Legep 1 and Legep 2 ILCA results

The percentages indicate the average of the differences for all the buildings in the considered use category between the outputs of Legep 1 and those of Legep 2. In Figure 96, only percentages lower than 30 are shown. Respectively, all percentages greater than 30% are not displayed. For those percentages, the difference between the two description modes was considered to be too large; the description modes cannot be considered as being identical.

For several categories (office buildings, educational buildings, hostels and student habitations), the choice of the description mode does not have a large influence on the results for any of the LCA outputs.
For some other categories (one family house) the description of the building in Legep does have a large influence on the results for all LCA outputs.
Finally, for construction costs, renovation costs and the mass flow estimation,

both description modes can be used, as the results do not differ much from each other.

By looking at Figure 96, it can be concluded that in most cases, the description mode in Legep (Legep 1 or Legep 2) does not have a large influence on the LCA outputs. The results are not the same but they are within an acceptable variation range. Moreover, it must be kept in mind that uncertainties in the determination of quantities and the selection of elements is not negligible. The combination of both phenomena also leads to a variation range on the LCA outputs, even if the best possible building description is realised (cf. X.7.).

VIII.2.3. Comparison between Legep and Stilcab results

In the following two figures, the level "100" represents the result of Stilcab 2 ($B_{Stilcab2}$) for the concerned building. Therefore, the results from Legep 1 (B_{legep1}) and Legep 2 (B_{legep2}) have to be compared with this reference level. The aim of the figures is to validate Stilcab by looking at the outputs of a traditional building LCA software (Legep) with two different descriptions of the same building (for each building, there are Legep 1 and Legep 2 versions) and by comparing those results in parallel with the ones given by Stilcab 2.

Indeed, two different descriptions of the same building in Legep give two different sets of results, forming a corridor of solutions. This leads to the conclusion that the results of building LCA are dependent (up to a certain limit) on the quality of the description of the building. Figure 97 shows, for example, the variation range of results given by Legep for five buildings. For the construction costs, Legep 1 and Legep 2 give both results lower than Stilcab, 95% and 80% respectively. This leads to the conclusion that, for this building, Stilcab overestimates the costs of construction as well as the cleaning and renovation costs. The same can be observed for the consumption of abiotic resources, the mass flow, the nutrification potential and the acidification potential. Stilcab underestimates the global warming potential. For ecopoints and primary energy consumption, the comparison does not provide such distinct differences. The same tendency can also be pointed out for the category "one family house".
Although the results of Stilcab are different from Legep's, the difference between the two different description versions in Legep is greater than the difference between Stilcab results and any two Legep results. In other words, the results provided by Stilcab are included in the corridor of solutions formed by the results of a detailed ILCA software.

Assuming that the "reality" of LCA results for a particular building lies between the results of the two description versions in Legep, Stilcab provides a good approximation of the results.
Let's refer to B_{legep1} and B_{legep2} as the results for Legep 1 description and Legep 2 description respectively, and let S be Stilcab results. The difference between S and B_{legep1} or B_{legep2} is always smaller than the difference between B_{legep1} and B_{legep2} :

$$\left|S - B_{Legep1}\right| \prec \left|B_{Legep1} - B_{Legep2}\right| \qquad \text{Eq. 8}$$

$$\left|S - B_{Legep2}\right| \prec \left|B_{Legep1} - B_{Legep2}\right| \qquad \text{Eq. 9}$$

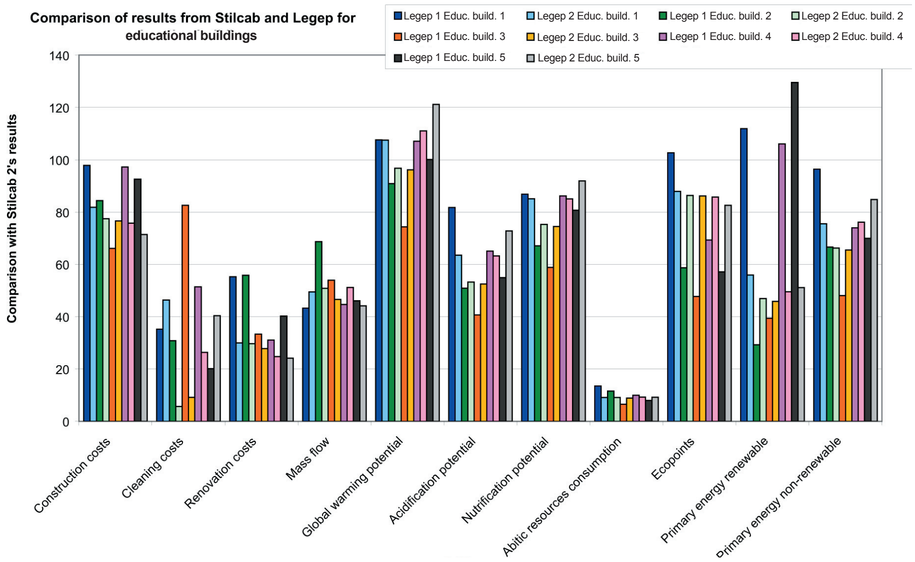


Figure 97

Comparison between ILCA results from Stilcab 2 and from Legep 1 and Legep 2 for five educational buildings. (Stilcab 2's results are taken as a reference level, at 100%)

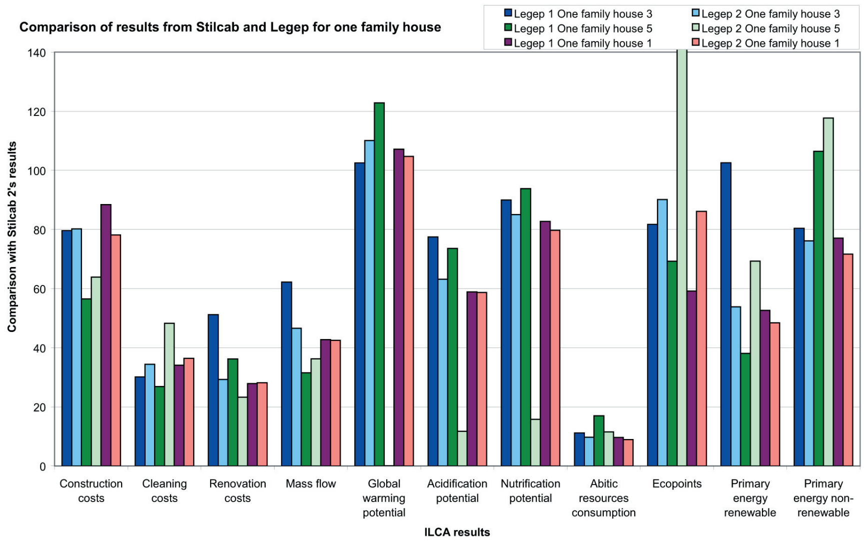


Figure 98

Comparison between ILCA results from Stilcab 2 and from Legep 1 and Legep 2 for three one family houses. (Stilcab 2 results are taken as a reference level, at 100%)

As the corridor of solution formed by Legep's results for given buildings is larger than the corridor of solutions given by the developed simplified method (and implemented in the tool Stilcab), the method and Stilcab are validated.

IX. Uncertainty of the method

IX.1. Hypotheses made

Here are some of the most important hypotheses made by developing and using Stilcab for the analysis of one building:

- The building description is limited to 7 main construction elements;
- The replacement (for the renovation cycles) of construction parts during the lifetime is done with the same construction element (no evolution of the techniques and/or material is considered);
- The lifetime of the building is fixed by the user of Stilcab (and recommended to be 80 years);
- When using "default values", the assumption is made that the geometrical model (which provides default values according to the gross floor area and the use of the building) provides Stilcab with correct values. Nevertheless, those values come from a statistical analysis of 1000 buildings, they do not claim to represent reality;
- Environmental impacts, costs and mass flows occurring during the lifetime of the building are first calculated for an 80 year lifetime, then divided by 80 years to get a "per year" figure, and then multiplied by the lifetime selected by the user; thus introducing an error in the calculations of environmental impacts and costs associated with one element over its lifetime;
- Electricity mix is selected by the user;
- The element choice is restricted and average values per cost types are used;
- The energy consumption of the building during its lifetime is not calculated but assumed: there is no consideration of the building's insulation, of masks, of occupancy schemes; consideration of the building's orientation and of the occupants' behaviour is limited to a few scenarios.

IX.2. Sources of uncertainties

All the previously mentioned hypotheses are sources of uncertainties. Those hypotheses can be classified into two types:

1. ***Modelling uncertainties:***

- The limited number of construction elements in order to describe a building,
- The replacement with the same construction element;
- The calculation procedure for the renovation cycles;
- The energy consumption assessment.

2. ***User hypotheses:***

- Lifetime of the building;
- Assessment of default values for the building geometry;
- Choice of construction elements;
- Impacts and costs associated with one element (environmental inventory data and variation of costs).

The uncertainty analysis of the following paragraph will not consider those “modelling hypotheses” but will concentrate on the user hypotheses.

IX.3. Uncertainty analysis of the simplified method

The equation to determine the final ILCA results in Stilcab is a pure mono dimensional equation in which a lot of parameters intervene but always at the power of 1.

IX.3.1. Uncertainty propagation theory

The whole paragraph is based on [EA4].

IX.3.1.a. Outline and definitions

The uncertainty of measurement is a parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand.

The measurands are the particular quantities subject to measurement. In calibration one usually deals with only one measurand or output quantity *Y* that depends upon a number of input quantities X_i (i = 1, 2 ,…, N) according to the functional relationship:

Eq. 10 $$Y = f(X_1, X_2, ..., X_N)$$

The model function *f* represents the procedure of the measurement and the method of evaluation. It describes how values of the output quantity *Y* are obtained from values of the input quantities X_i. In most cases it will be an analytical expression, but it may also be a group of such expressions which include corrections and correction factors for systematic effects, thereby leading to a more complicated relationship that is not written down explicitly as one function. Furthermore, *f* may be determined experimentally, or exist only as a computer algorithm that must be evaluated numerically, or it may be a combination of all of these.

The set of input quantities X_i may be grouped into two categories according to the way in which the value of the quantity and its associated uncertainty have been determined:

1. Quantities whose estimated and associated uncertainties are directly determined in the current measurement. These values may be obtained,

for example, from a single observation, repeated observations, or judgement based on experience. They may involve the determination of corrections to instrument readings as well as corrections to influence quantities, such as ambient temperature, barometric pressure or humidity;

2. Quantities whose estimated and associated uncertainties are brought into the measurement from external sources, such as quantities associated with calibrated measurement standards, certified reference materials or reference data obtained from handbooks.

An estimate of the measurand *Y* and the output estimate denoted by *y* is obtained from equation (Eq. 10) using input estimates x_i for the values of the input quantities X_i

$$y = f(x_1, x_{2,} ..., x_N)$$ *Eq. 11*

It is understood that the input values are the best estimates that have been corrected for all effects significant for the model. If not, the necessary corrections have been introduced as separate input quantities.

For a random variable the variance of its distribution or the positive square root of the variance, called standard deviation, is used as a measure of the dispersion of values. The standard uncertainty of measurement associated with the output estimate or measurement result *y*, denoted by *u*(*y*), is the standard deviation of the measurand *Y*. It is to be determined from the estimates x_i of the input quantities X_i and their associated standard uncertainties $u(x_i)$. The standard uncertainty associated with an estimate has the same dimension as the estimate. In some cases the relative standard uncertainty of measurement may be appropriate which is the standard uncertainty of measurement associated with an estimate divided by the modulus of that estimate and is therefore dimensionless. This concept cannot be used if the estimate equals zero.

IX.3.1.b. Evaluation of uncertainty of measurement of input estimates

The uncertainty of measurement associated with the input estimates is evaluated according to either a “Type A” or a “Type B” method of evaluation.
The Type A evaluation of standard uncertainty is the method of evaluating the uncertainty by the statistical analysis of a series of observations. In this case the standard uncertainty is the experimental standard deviation of the mean that follows from an averaging procedure or an appropriate regression analysis.
The Type B evaluation of standard uncertainty is the method of evaluating the uncertainty by means other than the statistical analysis of a series of observations. In this case the evaluation of the standard uncertainty is based on some other scientific knowledge.

IX.3.1.b.i. Type A evaluation of standard uncertainty

The Type A evaluation of standard uncertainty can be applied when several independent observations have been made for one of the input quantities

under the same conditions of measurement. If there is sufficient resolution in the measurement process there will be an observable scatter or spread in the values obtained.
Assume that the repeatedly measured input quantity X_i is the quantity Q. With *n* statistically independent observations (*n* > 1), the estimate of the quantity Q is *q* , the arithmetic mean or the average of the individual observed values q_j (*j* = 1, 2, …, *n*)

Eq. 12
$$\overline{q} = \frac{1}{n}\sum_{j=1}^{n} q_j$$

The uncertainty of measurement associated with the estimate *q* is evaluated according to one of the following methods:

- An estimate of the variance of the underlying probability distribution is the experimental variance $s^2(q)$ of values q_j that is given by

Eq. 13
$$s^2(q) = \frac{1}{n-1}\sum_{j=1}^{n}(q_j - \overline{q})^2$$

Its (positive) square root is called the experimental standard deviation. The best estimate of the variance of the arithmetic mean *q* is the experimental variance of the mean given by

Eq. 14
$$s^2(\overline{q}) = \frac{s^2(q)}{n}$$

Its (positive) square root is called the experimental standard deviation of the mean. The standard uncertainty $u(\overline{q})$ associated with the input estimate *q* is the experimental standard deviation of the mean

Eq. 15
$$u(\overline{q}) = s(\overline{q})$$

Warning: Generally, when the number *n* of repeated measurements is low (*n* <10), the reliability of a Type A evaluation of standard uncertainty, as expressed by equation (16), has to be considered. If the number of observations cannot be increased, other means of evaluating the standard uncertainty have to be considered.

- For a measurement that is well-characterised and under statistical control a combined or pooled estimate of variance s_p^2 may be available that characterises the dispersion better than the estimated standard deviation obtained from a limited number of observations. If in such a case the value of the input quantity Q is determined as the arithmetic mean *q* of a small number *n* of independent observations, the variance of the mean may be estimated by

Eq. 16
$$s^2(\overline{q}) = \frac{s_p^2}{n}$$

The standard uncertainty is deduced from this value by the equation $u(\overline{q}) = s(\overline{q})$.

IX.3.1.b.ii. Type B evaluation of standard uncertainty

The Type B evaluation of standard uncertainty is the evaluation of the uncertainty associated with an estimate x_i of an input quantity X_i by means other than the statistical analysis of a series of observations. The standard uncertainty $u(x_i)$ is evaluated by scientific judgement based on all available information on the possible variability of X_i.

The proper use of the available information for a Type B evaluation of standard uncertainty of measurement calls for insight based on experience and general knowledge. It is a skill that can be gained with practice. A well-based Type B evaluation of standard uncertainty can be as reliable as a Type A evaluation of standard uncertainty, especially in a measurement situation where a Type A evaluation is based only on a comparatively small number of statistically independent observations. The following cases must be discerned:

(a) When only a single value is known for the quantity X_i (e.g. a single measured value, a resultant value of a previous measurement, a reference value from the literature, or a correction value) this value will be used for x_i. The standard uncertainty $u(x_i)$ associated with x_i is to be adopted where it is given. Otherwise it has to be calculated from unequivocal uncertainty data. If data of this kind are not available, the uncertainty has to be evaluated on the basis of experience.

(b) When a probability distribution can be assumed for the quantity X_i, based on theory or experience, then the appropriate expectation or expected value and the square root of the variance of this distribution have to be taken as the estimate x_i and the associated standard uncertainty $u(x_i)$, respectively.

(c) If only upper and lower limits *a*+ and *a*– can be estimated for the value of the quantity X_i (e.g. manufacturer's specifications of a measuring instrument, a temperature range, a rounding or truncation error resulting from automated data reduction), a probability distribution with constant probability density between these limits (rectangular probability distribution) has to be assumed for the possible variability of the input quantity X_i. According to case (b) above this leads to

$$x_i = \frac{1}{2}(a_+ + a_-)$$ for the estimated value and *Eq. 17*

$$u^2(x_i) = \frac{1}{2}(a_+ - a_-)^2$$ for the square of the standard uncertainty. *Eq. 18*

If the difference between the limiting values is denoted by 2*a*, equation (Eq. 18) yields

$$u^2(x_i) = \frac{1}{3}a^2$$ *Eq. 19*

The rectangular distribution is a reasonable description in probability terms of one's inadequate knowledge about the input quantity X_i in the absence of any other information besides its limits of variability. But if it is known that values of the quantity in question near the centre of the variability interval are more likely than values close to the limits, a triangular or normal distribution may be a better model. On the other hand, if values close to the limits are more likely than values near the centre, a U-shaped distribution may be more appropriate.

IX.3.2. Calculation of the standard uncertainty of the output estimate

For uncorrelated input quantities the square of the standard uncertainty associated with the output estimate *y* is given by

Eq. 20
$$u^2(x_i) = \sum_{i=1}^{N} u_i^2(y)$$

The quantity

Eq. 21
$$u_i(y)\ i = 1,2,...N)$$

is the contribution to the standard uncertainty associated with the output estimate *y* resulting from the standard uncertainty associated with the input estimate x_i

Eq. 22
$$u_i(y) = c_i u(x_i)$$

where c_i is the sensitivity coefficient associated with the input estimate x_i, i.e. the partial derivative of the model function *f* with respect to *Xi*, evaluated at the input estimates x_i,

Eq. 23
$$c_i = \frac{\partial f}{\partial x_i} = \left.\frac{\partial f}{\partial X_i}\right|_{X_1 = x_1 \ldots X_N = x_N}$$

The sensitivity coefficient c_i describes the extent to which the output estimate *y* is influenced by variations of the input estimate x_i. It can be evaluated from the model function *f* by equation (Eq. 22) or by using numerical methods, i.e. by calculating the change in the output estimate *y* due to a change in the input estimate x_i of $+u(x_i)$ and $-u(x_i)$ and taking as the value of c_i the resulting difference in *y* divided by $2u(x_i)$. Sometimes it may be more appropriate to find the change in the output estimate *y* from an experiment by repeating the measurement at e.g. $x_i \pm u(x_i)$.

If the model function *f* is a sum or difference of the input quantities X_i

Eq. 24
$$f(X_1, X_2, ..., X_N) = \sum_{i=1}^{N} p_i X_i$$

the output estimate according to equation (Eq. 10) is given by the corresponding sum or difference of the input estimates

Eq. 25
$$y = \sum_{i=1}^{N} p_i X_i$$

whereas the sensitivity coefficients equal p_i and equation (Eq. 19) converts to

Eq. 26
$$u^2(y) = \sum_{i=1}^{N} p_i^2 u^2(x_i)$$

If the model function *f* is a product or quotient of the input quantities X_i

Eq. 27
$$f(X_1, X_2, ..., X_N) = c\prod_{i=1}^{N} X_i^{p_i}$$

the output estimate is again the corresponding product or quotient of the input estimates

$$y = c\prod_{i=1}^{N} x_i^{p_i}$$

Eq. 28

The sensitivity coefficients equal $\frac{p_i y}{x_i}$ in this case and an expression analogous to (Eq. 25) is obtained from (Eq. 19), if relative standard uncertainties $w(y) = \frac{u(y)}{|y|}$ and $w(x_i) = \frac{u(x_i)}{|x_i|}$.

If two input quantities X_i and X_k are correlated to some degree, i.e. if they are mutually dependent in one way or another, their covariance also has to be considered as a contribution to the uncertainty.

The covariance associated with the estimates of two input quantities X_i and X_k may be taken to be zero or treated as insignificant if:

(b) the input quantities X_i and X_k are independent, for example, because they have been repeatedly but not simultaneously observed in different independent experiments or because they represent resultant quantities of different evaluations that have been made independently, or if

(c) either of the input quantities X_i and X_k can be treated as constant, or if

(d) investigation gives no information indicating the presence of correlation between the input quantities X_i and X_k.

Sometimes correlations can be eliminated by a proper choice of the model function.

The uncertainty analysis for a measurement — sometimes called the uncertainty budget of the measurement — should include a list of all sources of uncertainty together with the associated standard uncertainties of measurement and the methods of evaluating them. For repeated measurements the number *n* of observations also has to be stated. For the sake of clarity, presenting the data relevant to this analysis in the form of a table is recommended. In this table all quantities should be referenced by a physical symbol X_i or a short identifier. For each of them at least the estimate x_i, the associated standard uncertainty of measurement $u(x_i)$, the sensitivity coefficient c_i and the different uncertainty contributions $u_i(y)$ should be specified.
The dimension of each of the quantities should also be stated with the numerical values given in the table.

A formal example of such an arrangement is given in Figure 99 and is applicable for the case of uncorrelated input quantities. The standard uncertainty associated with the measurement result $u(y)$ given in the bottom right corner of the table is the root sum square of all the uncertainty contributions in the outer right column. The grey part of the table is not filled in.

Quantity X_i	Estimate χ_i	Standard uncertainty $u(\chi_i)$	Sensitivity coefficient C_i	Contribution to the standard uncertainty $u_i(y)$
X_1	χ_1	$u(\chi_1)$	C_1	$u_1(y)$
X_2	χ_2	$u(\chi_2)$	C_2	$u_2(y)$
…	…	…	…	…
$X_{\mathcal{N}}$	$\chi_{\mathcal{N}}$	$u(\chi_{\mathcal{N}})$	$C_{\mathcal{N}}$	$u_{\mathcal{N}}(y)$
y	y			$u(y)$

Figure 99

Schematic of an ordered arrangement of the quantities, estimates, standard uncertainties, sensitivity coefficients and uncertainty contributions used in the uncertainty analysis of a measurement

IX.3.3. Step by step procedure for calculating the uncertainty of measurement

(a) Express in mathematical terms the dependence of the measurand (output quantity) Y on the input quantities X_i according to Eq.10. In the case of a direct comparison of two standards the equation may be very simple, e.g. $Y = X_1+X_2$.

(b) Identify and apply all significant corrections.

(c) List all sources of uncertainty in the form of an uncertainty analysis

(d) Calculate the standard uncertainty $u(\overline{q})$ for repeatedly measured quantities

(e) For single values, e.g. resultant values of previous measurements, correction values or values from the literature, adopt the standard uncertainty where it is given or can be calculated according to the paragraph. Pay attention to the uncertainty representation used. If no data are available from which the standard uncertainty can be derived, state a value of $u(x_i)$ on the basis of scientific experience.

(f) For input quantities for which the probability distribution is known or can be assumed, calculate the expectation and the standard uncertainty $u(x_i)$. If only upper and lower limits are given or can be estimated, calculate the standard uncertainty $u(x_i)$.

(g) Calculate the contribution $u_i(y)$ for each input quantity X_i to the uncertainty associated with the output estimate resulting from the input estimate x_i according to equations (Eq. 12) and (Eq. 13) and sum their squares as described in equation (Eq. 11) to obtain the square of the standard uncertainty $u(y)$ of the measurand.

(h) Report the result of the measurement comprising the estimate y of the measurand and the associated expanded uncertainty U.

IX.3.4. Realisation for Stilcab

The following equations were used to analyse the uncertainty in Stilcab:

Eq. 29
```
R = technicalequipment + lifetime + construction
```

Eq. 30
```
construction = (qtyexcavation × excavationnew)+
               (qtyfoundation × foundationnew)+
               (qtyextwalls × extwallsnew)+
               (qtyintwalls × intwallsnew)+
               (qtyfloors × floorsnew)+
               (qtyroof × roofnew)+
               (qtywindows × windowsnew)
```

Eq. 31
```
lifetime = time × ((gfa × (qtygas × pricegas + qtyelect ×
           priceelect) + foundation + exteriorwalls +
           interiorwalls + floors + roof + windows))
```

Eq. 32
```
exteriorwalls = qtyextwalls × (extwallsclean + extwallsrenov)
```

Eq. 33
```
floors = qtyfloors × (floorsclean + floorsrenov)
```

Eq. 34
```
foundation = qtyfoundation × (foundationclean + foundationrenov)
```

$$interiorwalls = qtyintwalls \times intwallsrenov$$ *Eq. 35*

$$roof = qtyroof \times roofrenov$$ *Eq. 36*

$$windows = qtywindows \times (windowsclean + windowsrenov)$$ *Eq. 37*

$$technicalequipment = (priceboiler + pricesanitary + priceelectro + priceventil + priceheating) \times qty$$ *Eq. 38*

The uncertainty analysis was realized with the software “Chem SW”, available on the Internet as a 30-day free trial version.

The following parameters of the equation were considered as having a rectangular uncertainty distribution with a given half width of 10% of the value each time. Those parameters are the surfaces of construction elements. A rectangular uncertainty distribution of the element surfaces with a 10% half width is justified by the fact that the architect or the user of Stilcab can always make mistakes by reading or estimating the surfaces.

Quantity	Value	Standard uncertainty
qtyfoundation	219 m²	12,1 m²
qtyexcavation	451 m³	26,0 m³
qtyextwall	367 m²	20,8 m²
qtyfloors	224 m²	12,7 m²
qtyintwall	389 m²	21,9 m²
qtyroof	248 m²	14,3 m²
qtywindows	37 m²	2,14 m²
qtyelect	25 kWh/(m².year)	1,44 kWh
qtygas	83 kWh/(m².year)	4,62 kWh
qty	1 unit	0,0577 unit

Figure 100

Parameters of the uncertainty analysis with rectangular uncertainty distribution (N.B. : The indicated values and standard uncertainty on the following figures are an extract of one specific building.)

The following parameters of the equation were considered as having no uncertainty.
Indeed, the price of one kWh of electricity and gas are known with certainty. The same occurs for the gross floor area of the building and the lifetime for which the calculations are made.

Quantity	Value
gross floor area	506 m²
priceelect	0,11 euro/kWh
pricegas	0,06 euro/kWh
time	80 years

Figure 101

Parameters of the uncertainty analysis which are supposed as not having any uncertainty. (N.B. : The indicated values and standard uncertainty on the following figures are an extract of one specific building.)

For the following parameters of the equation, the characteristics of all corresponding available construction elements were considered. Stilcab always takes the average construction elements for each cost type into consideration (except when specified) instead of considering the whole panel of elements available in the database. Therefore, to run the uncertainty analysis, the whole range of elements must be considered in order to quantify the impact of always taking the average value for the element’s characteristic.
The column “standard uncertainty” in the following figure represents the uncertainty determined by the software when taking all elements of the cost type into consideration.

Quantity	Value	Standard uncertainty
excavationnew	54,47 euro/m³	8,61 euro/m³
extwallnew	226,5 euro/m²	10,1 euro/m²
floorsnew	220,0 euro/m²	38,0 euro/m²
foundationnew	198,94 euro/m²	7,84 euro/m²
intwallnew	143,38 euro/m²	9,28 euro/m²
roofnew	217,27 euro/m²	9,27 euro/m²
windowsnew	1254 euro/m²	378 euro/m²
extwallnew	2,758 euro/m²	0,343 euro/m²
floorsclean	6,413 euro/m²	0,451 euro/m²
floorsrenov	2,101 euro/m²	0,156 euro/m²
foundationclean	5,190 euro/m²	0,408 euro/m²
foundationrenov	1,457 euro/m²	0,149 euro/m²
intwallrenov	1,803 euro/m²	0,430 euro/m²
roofrenov	2,917 euro/m²	0,144 euro/m²
windowsclean	22,30 euro/m²	4,07 euro/m²
windowsrenov	55,5 euro/m²	10,2 euro/m²
priceboiler	54710 euro/unit	4450 euro/unit
priceelectro	26110 euro/unit	4110 euro/unit
priceheating	14492 euro/unit	409 euro/unit
pricesanitary	162100 euro/unit	13100 euro/unit
priceventilo	18500 euro/unit	12800 euro/unit

Figure 102

Parameters of the uncertainty analysis for which the real values of the analysed characteristics were considered. (N.B. : The indicated values and standard uncertainty on the following figures are an extract of one specific building.)

For the uncertainty analysis, the values and standard uncertainty of the technical equipment (priceboiler, priceelectro, priceheating, pricesanitary and priceventilo) were adjusted when considering one family houses and other types of buildings. Otherwise, the values and standard uncertainties are the same, for all building use categories.
The results of the uncertainty analysis are presented in the following sections.

IX.3.5. Results of the Stilcab uncertainty analysis

First, the costs of buildings during their lifetimes are observed. The lifetime is always supposed to last 80 years. During this period, the building is built, renovated, maintained and used. Each phase of the building's lifetime is simulated by a term in the equation mentioned above (cf. IX.3.4. Eq. 28 to Eq. 38) so that it is possible to look at the share of each life phase in the overall uncertainty.
In a second step, the uncertainty of the CO_2 evaluation is observed.

Running the analysis for 50 buildings was considered. However, due to the high similarity of results independent of the use category and the size of buildings, the analysis was only carried out on 17 buildings. Below the results of 15 buildings are presented.

IX.3.5.a Cost uncertainty

The following figure (cf. Figure 103) presents the results of the uncertainty analysis of Stilcab concerning the cost calculation over 80 years for 15 buildings.
The analysis only concerns the uncertainty which is generated by the user of Stilcab. It does not concern or take into consideration the analysis of uncertainty of the basis data of Stilcab (user hypothesis and no modelling uncertainty).

	Building 1	Building 2	Building 3	Building 4	Building 5
Value	1255000	1424100	1632000	913600	2104200
Uncertainty (+/-)	88400	98200	107000	69600	149000
Uncertainty (%)	7,04	6,90	6,56	7,62	7,08

	Building 1	Building 2	Building 3	Building 4	Building 5
Value	41660000	21559000	19553000	6246000	25368000
Uncertainty (+/-)	2600000	1330000	1220000	400000	1660000
Uncertainty (%)	6,24	6,17	6,24	6,40	6,54

	Factory	Industry	Hospital	Hostel	School
Value	7905000	25056000	68810000	44910000	32770000
Uncertainty (+/-)	464000	1670000	4400000	2910000	2010000
Uncertainty (%)	5,87	6,67	6,39	6,48	6,13

Figure 103

Uncertainty of the costs calculation for 80 years, for one family houses, office buildings and five other buildings

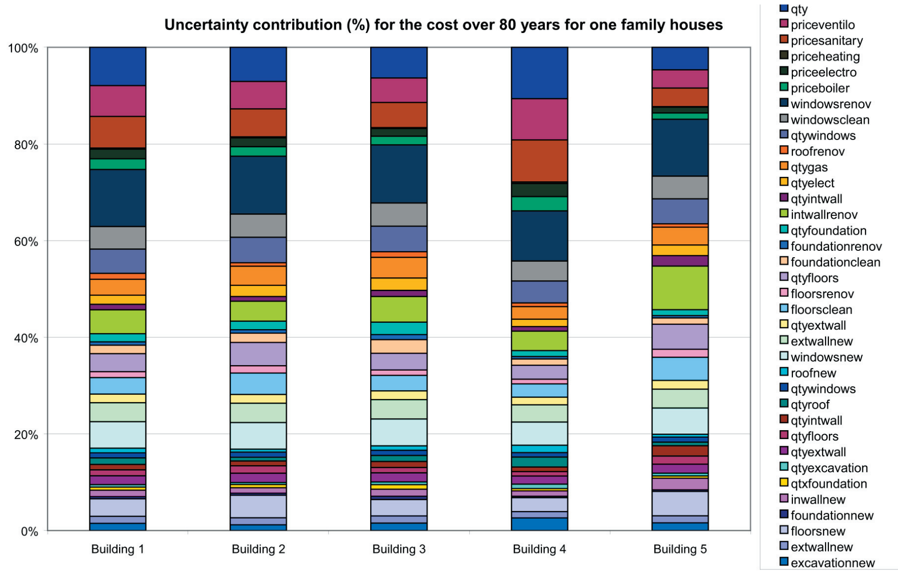


Figure 104

Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for one family houses

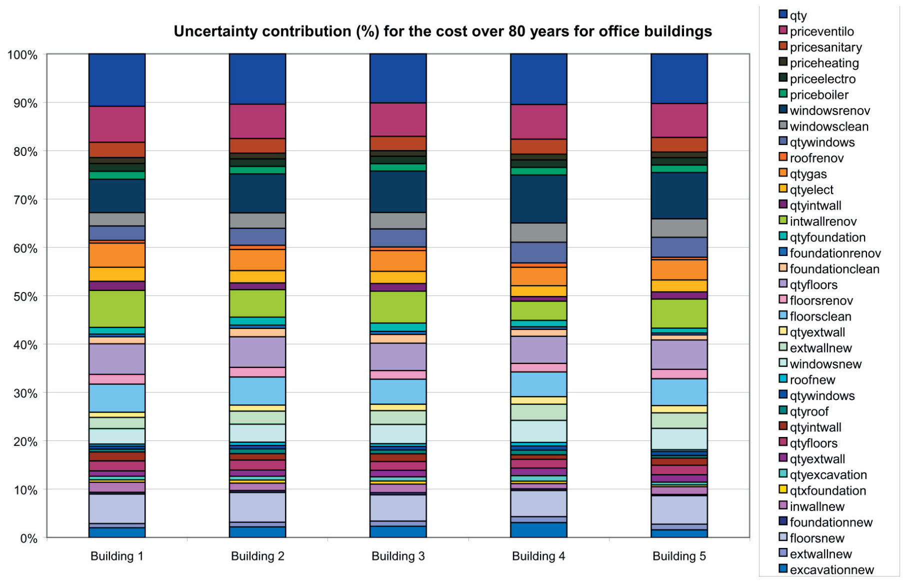


Figure 105

Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for office buildings

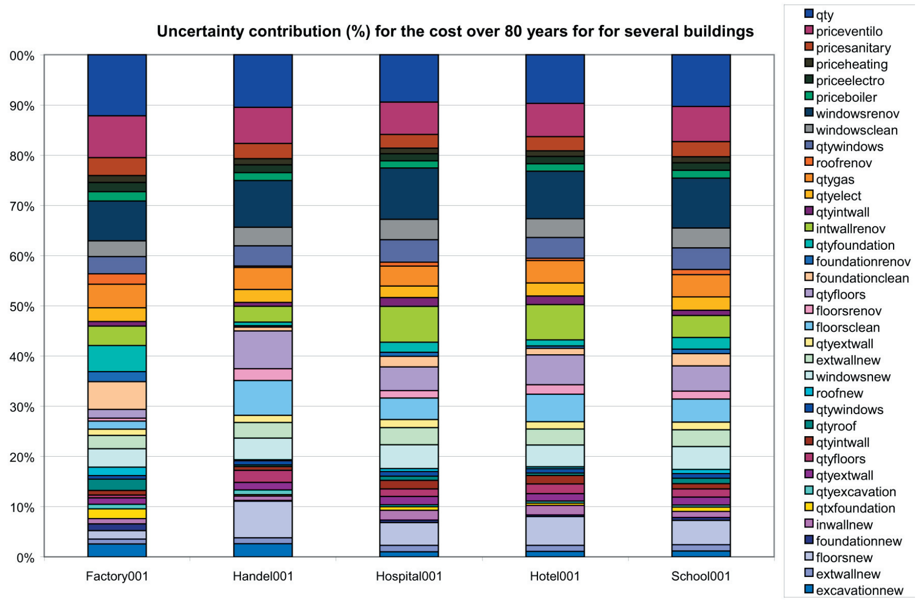


Figure 106

Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for five other buildings

Average one family houses	Average office buildings	Factories	Industry buildings	Hospitals	Hostels	Educational buildings	
23%	24%	29%	25%	22%	23%	24%	**Contribution technical equipment**
5%	6%	7%	6%	6%	7%	7%	**Contribution energy part**
52%	52%	54%	53%	49%	50%	51%	**Contribution construction**
42%	40%	38%	39%	43%	42%	41%	**Contribution renovation and maintenance**
27%	20%	18%	22%	24%	22%	23%	**Contribution windows**
2%	3%	3%	3%	1%	1%	1%	**Contribution excavation**
5%	4%	15%	2%	6%	3%	7%	**Contribution foundation**
8%	6%	6%	7%	7%	7%	7%	**Contribution exterior walls**
9%	10%	6%	5%	12%	12%	7%	**Contribution interior walls**
14%	21%	6%	26%	16%	20%	17%	**Contribution floors and ceilings**
3%	2%	5%	0%	2%	1%	2%	**Contribution roof**

Figure 107

Repartition of the total uncertainty on cost calculation over several parts of the building and several life phases

The overall uncertainty of cost estimation after a life period of 80 years is always about the same, independent of the building use category or the size of the buildings. It is about 7%, which is quite acceptable.
Moreover, as can be seen in the following charts (cf. Figure 104, Figure 105 and Figure 106), the uncertainty distribution has the same profile for all buildings. Indeed, windows are responsible for around 20 to 28% of the total uncertainty and technical equipment (sanitary equipment, boilers, heating system, electro-installation, ventilation systems) for about 23-25%. A more detailed distribution of the total uncertainty is given in Figure 107.

The contribution of windows to the overall uncertainty is larger for one family houses than for other buildings.
Energy related uncertainty is relatively low when compared to construction and renovation / maintenance associated uncertainty.
For the building parts, windows and floors and ceilings (as well as interior walls) are the biggest contributor to uncertainty. Indeed, excavation, foundation, exterior walls and roofs contribute almost nothing to the uncertainty of the costs.

IX.3.5.b. CO_2 uncertainty

The following figure (cf. Figure 103) presents the results of the uncertainty analysis of Stilcab concerning the CO_2 calculation over 80 years for 3 buildings.
The analysis only concerns the uncertainty which is generated by the user of Stilcab. It does not concern or take into consideration the analysis of uncertainty of the basis data of Stilcab (user hypothesis and modelling uncertainty).

	One family house 1	One family house 5	Multiple family housing 1
Value	869100	1678100	15391000
Uncertainty (+/-)	63200	131000	1180000
Uncertainty (%)	7,27	7,81	7,67

Figure 108

Uncertainty on CO_2 calculation for 80 years for three buildings

The overall uncertainty of the CO_2 estimation after a life period of 80 years is always about the same, independent of the building use category or the size of the buildings. It is about 7,5%, which is quite acceptable.

Moreover, as can be seen in the following charts (cf. Figure 110), the uncertainty distribution has almost the same profile for the three buildings. Indeed, gas is responsible for around 35% of the total uncertainty and electricity for about 15%. A more detailed distribution of the total uncertainty is given in Figure 110.

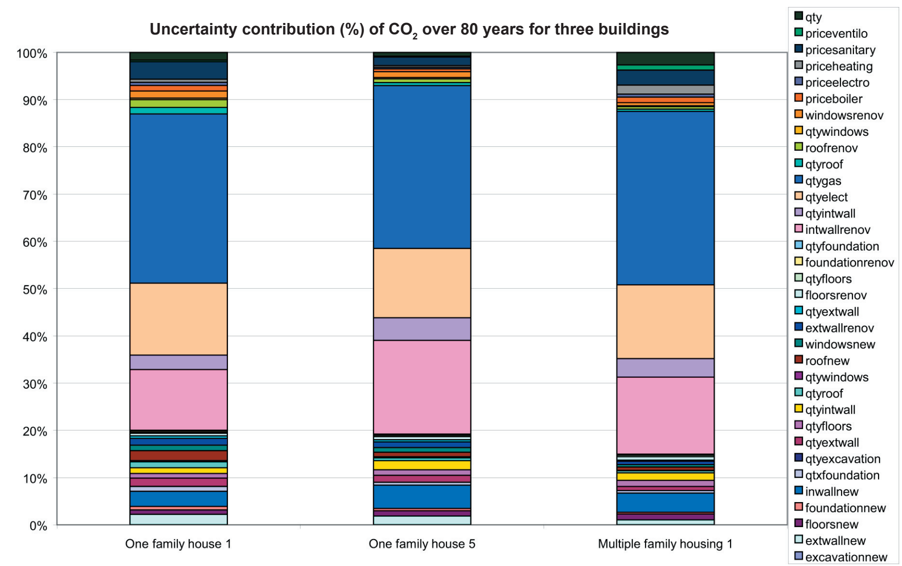


Figure 109

Contribution of the different parameters to the overall uncertainty of CO_2 calculation for 80 years for three buildings

Energy related uncertainty is about 50 % of the whole uncertainty of CO_2, which is the main difference with the same analysis realised previously on costs.
For the building parts, interior walls are the biggest contributor to uncertainty. Indeed, excavation, foundation, exterior walls, windows and roofs contribute almost nothing to the uncertainty of CO_2.
All results and graphics from the uncertainty analysis of Stilcab concerning costs and CO_2 over 80 years can also be found in Annex 16.

Average	One family house 1	One family house 5	Multiple family housing 1	
7%	8%	4%	10%	**Contribution technical equipment**
50%	51%	49%	52%	**Contribution energy part**
21%	23%	19%	21%	**Contribution construction**
26%	23%	30%	24%	**Contribution renovation and maintenance**
2%	3%	2%	1%	**Contribution windows**
0%	0%	0%	0%	**Contribution excavation**
1%	2%	1%	1%	**Contribution foundation**
4%	5%	4%	2%	**Contribution exterior walls**
25%	2%	31%	25%	**Contribution interior walls**
3%	2%	3%	3%	**Contribution floors and ceilings**
3%	6%	3%	2%	**Contribution roof**

Figure 110

Contribution of several building parts to the overall uncertainty on CO_2 calculation for 80 years

In the paragraph X.3.4., a building (R) is simulated as being the sum of three independent parameters: «technicalequipment», «lifetime», and «construction»: `R = technicalequipment + lifetime + construction.`
Of course those three parameters are not independent in a building. For example the choice of a specific kind of exterior walls may have a non negligible effect on the energy requirements of the building (amongst others, for heating). This kind of interactions between construction elements and energy requirements within a building has not been considered, neither in the uncertainty analysis where a building is decomposed in three parameters, nor in Stilcab where the energy requirements of the building are an input of the user.
Nevertheless, as explained in IV.2.6.f., in oder to comply with the energy requirements selected by the user of Stilcab, the method sorts out the construction elements which would not able the fulfillment of the given conditions regarding the energy requirements.
The analysis of interactions, within a building, between the choice of construction elements and the consumption of primary energy could be the activity of a further research work. It could be then integrated in Stilcab.

X. Uncertainty analysis of building LCA tool

X.1. Uncertainty analysis – pre requisite

X.1.1. Sensitivity analysis vs. uncertainty analysis

The analysis of uncertainties is the study of the influence of data uncertainty on the results of the model. The uncertainties of every piece of data are gathered together in the global uncertainty of the model. There are two extreme cases possible:

- The uncertainty of one parameter is large but its effect on the model's results is small (low sensitivity, case C, cf. Figure 113);
- The uncertainty of a parameter is low but its effect on the model's results is important, due, for example, to a large quantity of this parameter in the model (case A).

The uncertainties are very often difficult to reduce or to remove. Therefore, it is necessary at least to have an idea of their significance: this is done by carrying out an uncertainty analysis.

The following chart and figures (Figure 111, Figure 112, Figure 113) illustrate the differences between "uncertainty on assumption", "sensitivity of the model" to one parameter and "uncertainty of forecast".

	Sensitivity of the model	Uncertainty on assuption	Uncertainty on forecast
Comparison 1-2	+	=	+
Comparison 1-4	-	+	=
Comparison 2-3	=	-	-

Figure 111

Evolution of mocel uncertainty on forecast in regard to model sensitivity and uncertainty of assumption (to be read with Figure 112)

X.1.2. Link between sensitivity and uncertainty

To decrease the uncertainty of the forecast, it is therefore necessary, when the same model is used, to lower the uncertainty of assumption.
Case 1 (of Figure 112) underlines the fact that when the model is not so sensitive, the uncertainty of assumption does not have a large effect on the forecast's uncertainty. The reverse situation is shown in case 2 where the sensitivity of the model is higher, the uncertainty of assumption stays the same, but the influence on the forecast's uncertainty is larger.
Naturally, for the same model's sensitivity (cases 2 and 3), the larger is the uncertainty of assumption, the larger the uncertainty on forecast will be.

<u>Case 1 : High sensitivity and parameter uncertainty insignificant</u>

Ideal parameters must be considered in the simplified method for building LCA.

<u>Case 4 : Low sensitivity and parameter uncertainty insignificant</u>

Not considered in the simplified model for building LCA.

Case 2 : Significant uncertainty and great sensitivity and Case 3: Significant uncertainty and low sensitivity

These two cases are ambiguous as the parameter's uncertainty is significant in both cases.

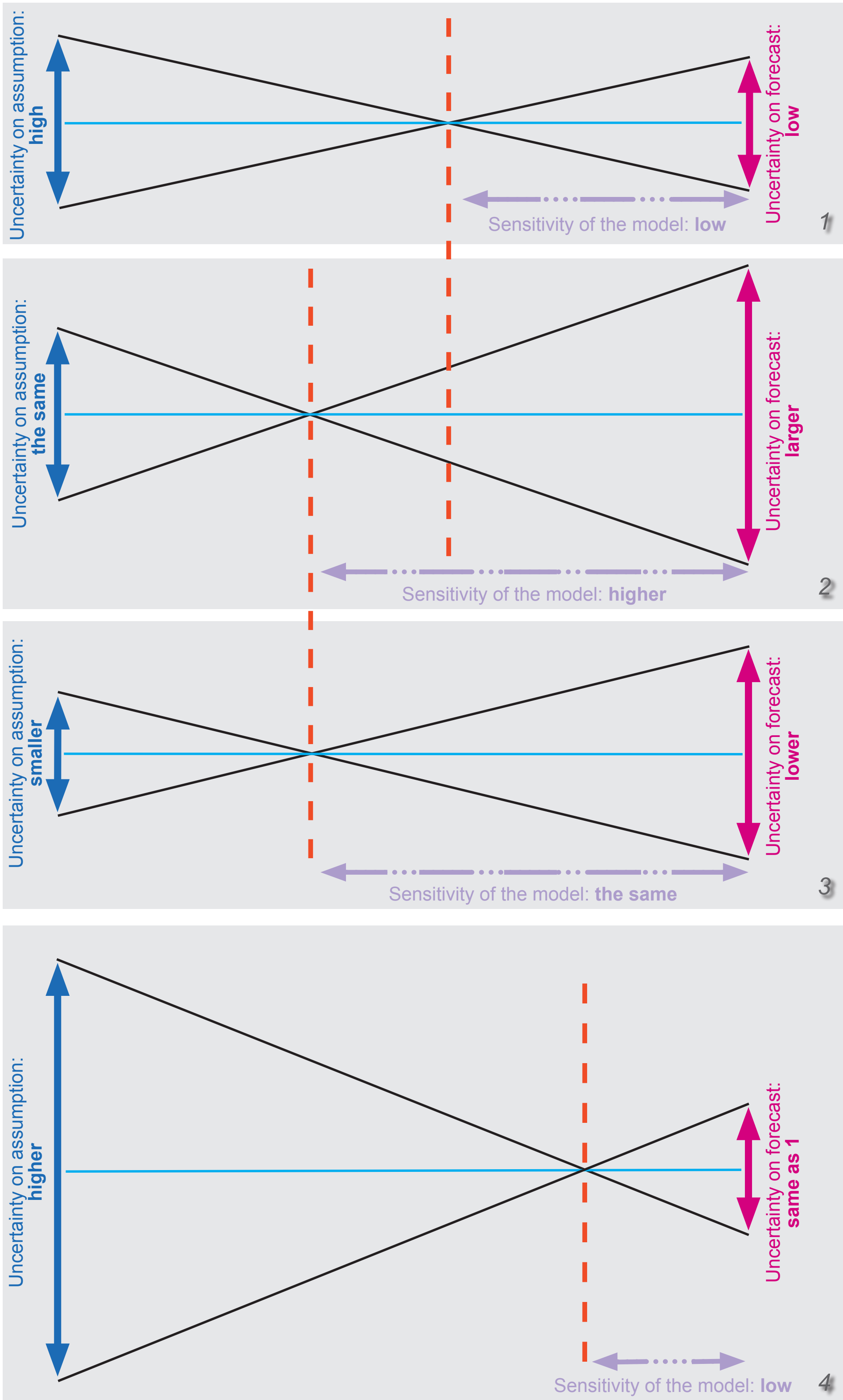


Figure 112

Link between model sensitivity, uncertainty of assumption and uncertainty of forecast

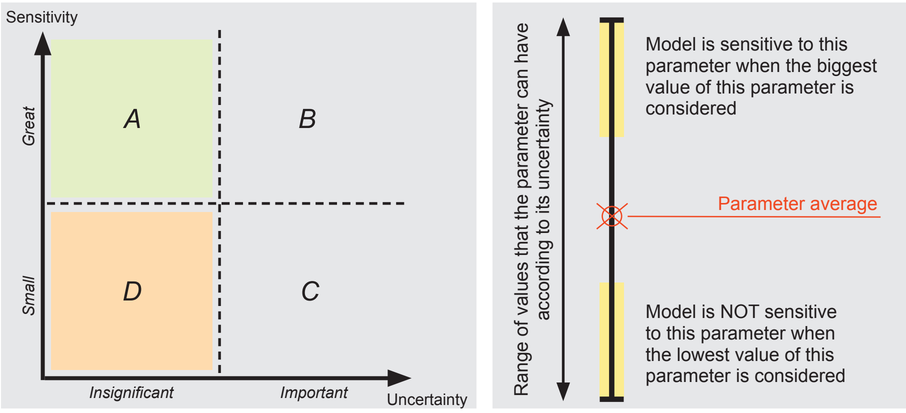


Figure 113

The four possibilities for a parameter's location in the plan "sensitivity - uncertainty"

Whereas the parameter's uncertainty is self-dependent, the model's sensitivity to one parameter relies on the model itself (and therefore to all the others parameters considered in the model). This means that it is necessary to first manage the quality "uncertainty" before coming to a conclusion about the "sensitivity".
The main difficulty with cases B and C lies in the uncertainty. It is therefore impossible to assess anything in regard to the model's sensitivity to parameters with large uncertainty. In fact, according to the value taken by this parameter (which is assumed to have large uncertainty), the sensitivity of the model will change.
The sensitivity and the uncertainty analysis (for the inputs) of Stilcab as a tool for building LCA have already been done. Yet, the uncertainty analysis of another building LCA software (Legep) will be realised.

X.1.3. Questions to be answered by an uncertainty analysis

The uncertainty analysis should answer the following questions:

1. "When can two buildings be considered as different when considering the GWP (or cost) induced during their respective lifetimes?" or "Can two buildings be considered as different when the difference between the two buildings' cost (or GWP, etc.) is 5%, 10%, 15%, or more?"
2. Is this difference not only due to the different quality level of construction (one environmentally friendly material choice and one not) but also to the uncertainty in the inventory data, in the system boundaries set, in the unknown parameters (such as the various cycles of renovation, cleaning and maintenance, etc.)?

X.1.4. Process to follow when running uncertainty analysis

The following points are necessary for realising the uncertainty analysis:

- identify method to assess uncertainty,
- identify the uncertainty sources,
- quantify the uncertainties,
- and interpret them in terms of quality of the end results.

X.2. Methods to assess uncertainties in building LCA software

To run sensitivity and/or uncertainty analysis, there are several methods possible (cf. Figure 114).

	Sensitivity	Uncertainty
Definition	Parameter's effect on the value of another parameter	Total effect of input parameter uncertainties on results
Tools	Scenario analysis Experimental plans One way sensitivity analysis Tornado diagram…	Method : 1. Assess uncertainty for each data 2. Spreading of uncertainties to the results by using the model Tools: Scenarios analysis Experimental plans Monte Carlo simulation

Figure 114

Definition and available tools for sensitivity and uncertainty analysis

Due to the complexity of building LCA software such as Legep, it is no longer possible to consider uncertainty propagation theory from one end of the software to the other. It is necessary to have recourse to other mathematical tools; among others are the Monte Carlo simulation and the experimental plans, both of which are briefly described below.

X.2.1. Experimental plans

X.2.1.a. Principle

The experimental plans are a series of experiments (or simulations) done to identify the parameters which have the biggest influence on results.
The objective of the experimental plans is to make the minimum number of simulations and to obtain maximum precision of results.
The main advantages of the experimental plans are on one hand the possibility to determine an equation which describes the influence of each parameter and on the other hand to be able to quantify the dependences between several parameters.

X.2.1.b. Process

There are five stages in the process of running experimental plans.
At first, it is necessary to define the desired objectives and the results of the model to be studied.
Then, it is necessary to draw up the list of all of the model's basis data.
For each one, it is necessary to assign consequent levels (generally two levels, three levels at most; beyond that the experimental plan becomes impossible to manage). A level is a value which the data can take.
The third stage is the choice of the simulation matrix, which is discussed a little more in detail further.
Finally, after the realization of the experiments, it is necessary to analyze the results and to determine the effects of each analyzed parameter.

In comparison to the other available tools for sensitivity analysis and uncertainty analysis (cf. Figure 114), the experimental plans have the following main advantages:

- They are relatively easy to set up,
- The results are easy to exploit (because they are in matrix form),
- They allow for the deduction of a simplified model,
- The method is independent from the one who runs it (the operator), contrary to Monte Carlo simulations,
- It is possible to identify the possible interactions between parameters.

X.2.1.c. Simulation matrix

The simulation matrix is a practical and easy way to plan the experiments to be carried out. It gives information about the values taken for each parameter for each simulation. On the other hand, the results of each experiment can be stored in a methodical and orderly way in the matrix.
There are several types of matrix available for the realization of the experimental plan.

X.2.1.c.i. Complete matrix

The complete experimental plan (requiring the complete matrix) has the following shape for the study of three parameters (A, B and C) as well as their interactions of order 1 (AB, AC and BC).

Exp.	A	B	C	AB	AC	BC	Result 1	Result 2
1	-	-	-	+	+	+		
2	+	-	-	-	-	+		
3	-	+	-	-	+	-		
4	+	+	-	+	-	-		
5	-	-	+	+	-	-		
6	+	-	+	-	+	-		
7	-	+	+	-	-	+		
8	+	+	+	+	+	+		

“+” and “-“ represent the two levels of value which can take the parameter

Figure 115

Complete simulation matrix for 3 parameters, matrix 2^3

The number of simulations to be realized is:

$$\text{Number of simulations} = 2^{(\text{number of input parameters})}$$

So, when studying more important quantities of parameters for the experimental plans, the number of necessary simulations quickly grows. It is then possible to consider the use of a fractional matrix and associated fractional experimental plans.

X.2.1.c.ii. Fractional matrix

The fractional matrix is a complete matrix containing “aliased” parameters. This means that in a column of the complete matrix used (here 2^3), another parameter (D) will be associated. It creates a “generator of aliases” and all the

columns of the complete matrix are modified to become a “fractional matrix” 2^{4-1}.
By doing so, it is possible to study more parameters with the same number of simulations.

Exp.	A	B	C	AB	AC	BC=D	Result 1	Result 2
1	-	-	-	+	+	+		
2	+	-	-	-	-	+		
3	-	+	-	-	+	-		
4	+	+	-	+	-	-		
5	-	-	+	+	-	-		
6	+	-	+	-	+	-		
7	-	+	+	-	-	+		
8	+	+	+	+	+	+		

Figure 116

Fractional simulation matrix for 4 parameters, matrix 2^{4-1}

Example of how to read the matrix: for the simulation 3, the parameters A, C and D will be given their minimal value while the parameter B will be given its maximum value.

Unfortunately, there is a major inconvenience with the use of the fractional matrix: it is impossible to separate the effect of the parameter D from the interaction between the parameters B and C afterwards. Therefore, the selection of the parameter to be aliased with another is crucial.

X.2.2. Monte Carlo simulation

X.2.2.a. Introduction and history

[CRY] *Simulation* is any analytical method that is meant to imitate a real life system, typically used when other analyses are too mathematically complex or too difficult to reproduce. Spreadsheet risk analysis uses both a spreadsheet model and simulation to analyze the effect of varying inputs on outputs of the modelled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables over and over to simulate a model.
Monte Carlo simulation was named after Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance such as roulette wheels, dice, and slot machines exhibit random behaviour. The random behaviour in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that either a 1, 2, 3, 4, 5, or 6 will come up, but you don’t know which for any particular trial. It is the same with any variables that have a known range of values but an uncertain value for any particular time or event (e.g. interest rates, staffing needs, stock prices, inventory, phone calls per minute). For each variable, you define the possible values with a *probability distribution*. The type of distribution you select depends on the conditions surrounding the variable. For example, some common distribution types are:

Figure 117

Common distribution types

During a simulation, the value to use for each variable is selected randomly from the defined possibilities.

X.2.2.b. Discussion

A simulation calculates numerous scenarios of a model by repeatedly picking values from the probability distribution for the uncertain variables and using those values for the cell. Normally, a simulation program calculates hundreds or thousands of scenarios in just a few seconds. Since all those scenarios produce associated results, track is kept of the *forecasts* for each scenario. Forecasts are cells (usually with formulas of functions) that are defined as important outputs of the model. These are usually cells such as totals, net profit, or gross expenses. For each forecast, the simulation program remembers the cell value for all the trials (scenarios). During the simulation, you can watch a histogram of the results, which shows how they stabilize toward a smooth *frequency distribution* as the simulation progresses. After hundreds or thousands of trials, you can view sets of values, the statistics of the results (such as the mean forecast value), and the certainty of any particular value.

X.2.2.c. Example of Monte Carlo building simulation application

Monte Carlo simulation can be used “pure” with:

- The value of a given parameter for construction elements (e.g. cost/m²);
- The element surface considered.

The following figure illustrates typical probability distribution for each of the two previously mentioned items.

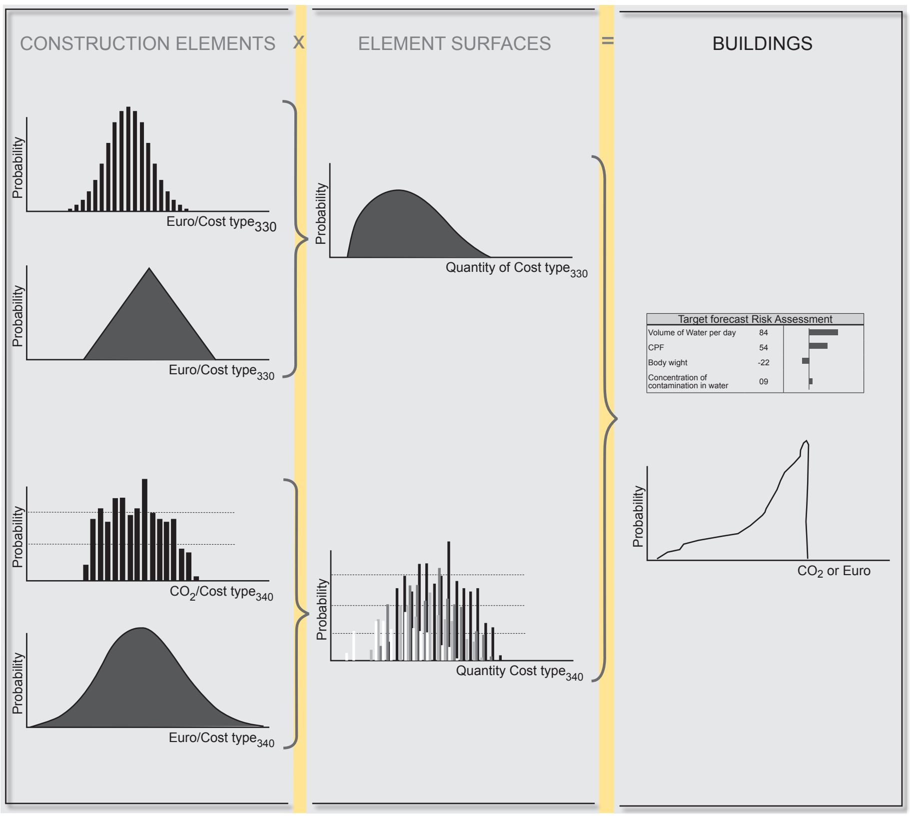


Figure 118

Monte Carlo applied to buildings: probability distribution of construction elements and probability distribution of elements surfaces for each cost type

X.2.3. Summary and comparison of the two methods

Monte Carlo consists of performing a large number of successive simulations with the same model but with different input parameters each time:

1. Specify uncertainties, width and probability distribution functions for all input data,
2. Select values for variables from the probability distributions,
3. Calculate the results using the selected input values (this is automatically done when using programs such as Crystal ball),
4. Iterate until mean and distribution do not change and calculate the probability distribution of the output data.

Cf X.2.2. for more information about Monte-Carlo.

Experimental plans are a succession of carefully planned simulations:

1. Define objectives to reach and output to optimize,
2. Determine all the input parameters and their associated levels (two or three maximum for each parameter),
3. Choose the experiment matrix (complete or fractional in most cases),
4. Run the experiment (or simulation),
5. Analyse the results and determine effects of parameters.

The principle of Monte Carlo simulation is about the same as with the experimental plans. There are two main differences:

- While experimental plans use three values maximum per parameter, Monte Carlo considers the parameter's value, at random, following its probability distribution. It allows for many more trials than experimental plans and for trials which best fit reality;
- Experimental plans allow identifying interactions between parameters, which is not possible with Monte Carlo.

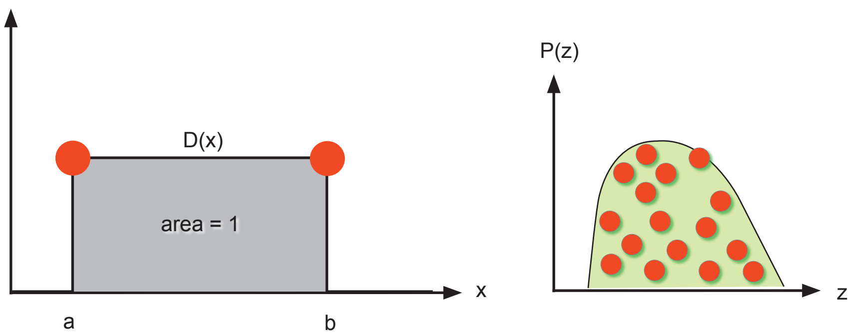


Figure 119

Differences between experimental plans (left) and Monte-Carlo simulation (right)

X.3. Uncertainty sources in models

	Sources of uncertainty	Breakdown according to parameter type/source		Description / Examples
Inventory data	Empirical parameters (probabilistic assessment)	Parameter uncertainty	Measurement errors Inherent randomness Subjective judgement Approximation	
		Variability	Geographic variability Temporal variability Technological variability	Variation across regions, countries, etc. Variation with age, season, etc. Variations not accounted for by regional or temporal variability
User data	Model parameters (Parametric sensitivity analysis / multivariate analysis)	Uncertainty arising from choice of variables to specify system	Decision variables Model domain parameters	Quantities over which decision maker exerts direct control Quantities specifying spatial and temporal domain of system model
		Disagreement	Value parameters	Preferences of decision makers
Model's developer data	Model structure / form (Sensitivity analysis)	Limitations on form of model	Choice of LCA method	Degree of sophistication of model
		Limitations of LCA model structure	Spatial limitations Inherent model uncertainties Temporal limitations	Aggregation over plants, regions, etc. Aggregation over time Epistemological and paradigmatic uncertainty (particular “world view” forced by LCA model)

Figure 120

Summary and definition of relevant uncertainty sources for LCA models [NOT]

In this board (cf. Figure 120), as well as in the article which accompanies it [NOT], P.Notten distinguishes three types of sources of uncertainty. Every category is defined by the analysis method which is convenient for it:

1. The empirical parameters;
2. The parameters of the model;
3. The structure of the model.

The last two categories can be gathered together under the name “parameters of the model”, whereas the first one concerns “the use of the model”.
The empirical parameters include the majority of the input data necessary for the elaboration of inventory. Most being measurable properties, the probability theory can be applied to them.
On the other hand, the choice of model parameters and decision variables (the

second category) falls under the operator's control; they have no real values. Therefore, a probability method cannot be applied to them. It is necessary to resort to a sensitivity analysis.
The third and last class of uncertainties found in this board is the one concerning the model, strictly speaking. A model being a simplification of reality, it cannot be exact. A sensitivity analysis is, in this case also, the most suitable way to estimate the uncertainties of the model.
However, taking into consideration the spatial and temporal intrinsic limits of LCA model, part of the model uncertainties cannot be reduced.

Yet we mainly linger over the second category of uncertainties, that is to say the one concerning the model parameters, and to a lesser extent the third category, concerning the model used itself. Indeed, the first category of uncertainties (cf. Figure 120) exclusively concerns the results of the inventory, which are the data which are supplied by institutes / organizations such as Ecoinvent.
The second category of uncertainties concerns all the ILCA model input parameters necessary when using the model; these are the values which the user of the model enters so that the model makes impact calculations.
Finally, the third category of uncertainties (bound to the model's structure) is independent from the user and its choices; it depends only on choices made by the model's developer.

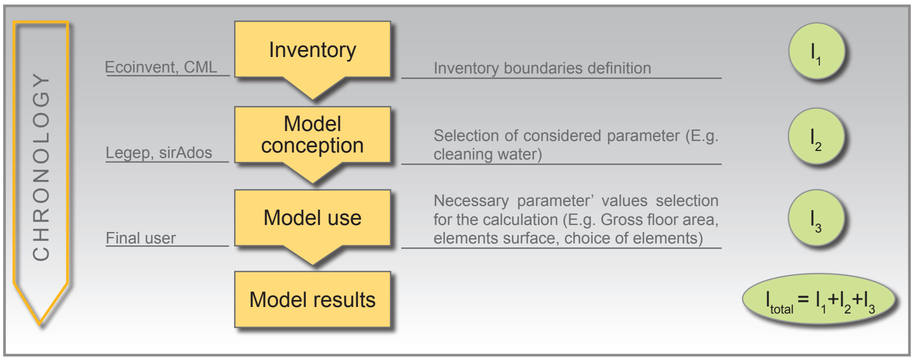


Figure 121

Model's life cycle, from inventory to results, the different actors, their choice and respective uncertainties

Thus, the context of the end user is considered. Therefore, the data of inventories and other data already included in the model are not in our possession and thus unknown to us.
The only values which are available are those which the user supplies in the model (geometrical, constructive and evolutionary description of the building) as well as some values that the developer left transparent for the user (unit price, ecological balance assessment, etc.).

Therefore the uncertainty analysis is strengthened by these data.
For greater simplicity, "internal data of Legep" are data that the developer left transparent for the user, and "input data of Legep" are data supplied by the user.

To proceed to the uncertainty analysis, it is necessary to:

- Identify the uncertainty sources in Legep;
- Determine their uncertainty range.

For the second point, a distinction is done between:

- The internal data of Legep and
- The input data of Legep.

Furthermore, it is necessary to remember that the uncertainty of every stage in the elaboration of the ILCA results (inventory - model - use) is included in the global uncertainty of these results (cf. Figure 121).
So, when we linger over the uncertainties concerning the results of Legep, the effect of the other uncertainties are already included.

A set of representative buildings is used to do the analysis.

X.4. Sources of uncertainty in building LCA software

X.4.1. Uncertainty sources

All building LCA software are made from hypotheses and choices.
Some of these are hypotheses concerning the system "building", others concerning the LCA itself.
Moreover, the user of such software must provide information (input) which can also be partially false. Below is a list of uncertainties which might occur in realising a building's life cycle analysis with the software Legep.

X.4.1.a. Uncertainties resulting from the creation of the model (internal data of the sirAdos database)

- Error with material flows for a specific construction element;
- Error with energy flow for a specific construction element;
- Error with the estimation of the life expectancy of each construction element;
- Method of determination of the impact indicators (intern to LCA);
- Error with cost for a specific construction element.

X.4.1.b. Uncertainties resulting from the Legep user (user input)

- Assumptions made about buildings' life: use of the building, number of occupants, life expectancy;
- Uncertainty during the use phase of the building (habitants' behaviour);
- Description of the building: selection of the construction elements, rough element surfaces;
- Cycles of maintenance, cleaning, renovation.

X.4.2. Uncertainties to be analysed

The following uncertainties can be analysed. They are sorted out according to 5 several topics: basic data, building composition, renovation, life duration, and occupant behaviour.

X.4.2.a. Basis data

- Inventory: these are the basics data which come from the life cycle inventory and which can be read in the sirAdos database in a specific sheet. These are the impacts related to one unit of a specific material (or construction element).
- Electricity mix: (cf. IV.2.6.b.), this is the electricity mix considered for the calculation of environmental impacts due to the consumption of energy during the lifetime of the building (for heating, for hot water production, etc.).

X.4.2.b. Building composition

- Construction element surfaces: these refer to the geometry of the building.
- Choice of construction elements: this refers to the user's choice of construction elements which best fit the description of the building at a given time.

X.4.2.c. Renovation

- Renovation cycle: this is the lenght of time after which a construction element has to be renovated or replaced in the building.

X.4.2.d. Life duration of the building

- Lifetime of the building: this is the life span for which the LCA calculation is realised.

X.4.2.e. Occupant behaviour

- Energy consumption: this is the energy consumption during the lifetime of the building.

X.5. Analysed uncertainties

X.5.1. Inventory data

In September 2003, a conference took place in Karlsruhe: "International Workshop on Quality of Life Cycle Inventory Data". It was visited by the international LCA experts such as Greg Norris of the university of Harvard, Rolf Frischknecht of the Ecoinvent centre in Switzerland, and the SETAC was represented by Guido Sonnemann. All agree on the fact that the "blind" usage of systems and process inventory results presents numerous risks. The quality of inventory data was widely discussed. All the experts made the same statement: there are data, there are appropriate ways of using these data but there are also uncertainties. The remaining difficulty is not yet the search for new data but the establishment of quality criteria allowing an intelligent and meaningful use of inventory data. So, during workshops organized during

this conference, criteria such as reliability, precision, credibility, capacity, transparency, accessibility (format, semantics, confidentiality), relevance and representativeness were discussed. Concerning the means available to handle, analyze and/or estimate these criteria, several techniques were underlined (cf. Figure 120).
The inventory data are the data concerning the impacts of materials on the environment. This data is present in the sirAdos database (cf. Figure 122).

Designation	Unit	Abiotic	CO_2	Ozon layer	SO_2
Gasoline lead free starting from regional storage in Switzerland	t	1035,339	867,7916	0,00728	6,224
Gasoline lead free starting from regional storage in Europe	t	1045,357	952,9587	0,007344	7,861
Pulverized lignite	TJ	2384,494	39424,74	0,000942	334,119
Lignite - bricks	TJ	2287,978	34698,27	0,0009024	294,113

Figure 122

Extract of the sirAdos database – "Sachbilanz Tabelle", translated into English

This data comes from Ecoinvent (Switzerland), GEMIS (Germany) and specific values from the Baustoff Oekoinventare [KOH].
This data concerns materials. A construction element is then made of several materials according to a recipe which can also be found in the sirAdos database.

Questions:

When considering the previous extract of the database one more time (cf. Figure 123), several possibilities appear:

1. Does the value A have the same uncertainty as B and C (material dependent)?
2. Does the value A have the same uncertainty as D and G (impact dependent)?
3. Does the value A have the same uncertainty as B, C, D, E, F…and I (impact and material dependent)?

How uncertain are the values A, B, C, D, E, F….?

Answers:
Figure 125 summarises the different possibilities which can be taken into account to simulate uncertainties of the inventory data.

Designation	Unit	Abiotic	CO_2	Ozone layer	SO_2
Gasoline lead free starting from regional storage in Switzerland	t	A	B	C	…
Gasoline lead free starting from regional storage in Europe	t	D	E	F	…
Pulverized lignite	TJ	G	H	I	…
Lignite - bricks	TJ	…	…	…	…

Figure 123

Extract of the sirAdos database

X.5.2. Electricity mix

For all construction elements and their production (embodied energy), the energy mix considered is the European mix. Indeed, it is considered that all materials used for the construction come from Europe.
For the consumption of energy during the lifetime of the building, the user has the possibility in Legep to select the electricity mix desired (as well as in Stilcab) or he can create his own electricity mix (cf. Figure 124).
Considering uncertainty in the definition of the electricity mix in Germany is nonsense as the real mix is known (the net electricity production in Germany in 2004 was about 54% coal, 30% nuclear, 10% gas and 4% hydraulic [LEG]).
However, it might be interesting to compare the impacts of the evolution of the electricity generation in Germany in the coming years on building life cycle analysis.
Therefore, one can consider the definition of several scenarios of electricity generation in Germany for the coming years. It might be possible to consider one optimistic and one pessimistic scenario (optimistic and pessimistic in regard to environmental impacts and not regarding costs or political decisions).

However, the definition of an «optimistic» and a «pessimistic» scenarios remains an open question. An optimistic scenario can consider more renewable energy (wind energy), less coal and gas and more nuclear electricity. A pessimistic scenario does not take renewable energy into consideration, and less nuclear energy and more gas, for example.

Note: the definitions of «optimistic» and «pessimistic» scenarios consider the evolution of only some of the environmental impacts in the positive direction (e.g.: less global warming potential when considering more nuclear electricity production than when considering coal). We can only regret that this choice leads also to the evolution of other environmental impacts in the negative direction (e.g.: more radioactive contaminated wastes), we can only agree that the positive direction is the direction leading to less impacts and the negative one is the direction leading to more impacts. In the following, the scenario 1 is the optimistic scenario, scenario 2 being the pessimistic one.

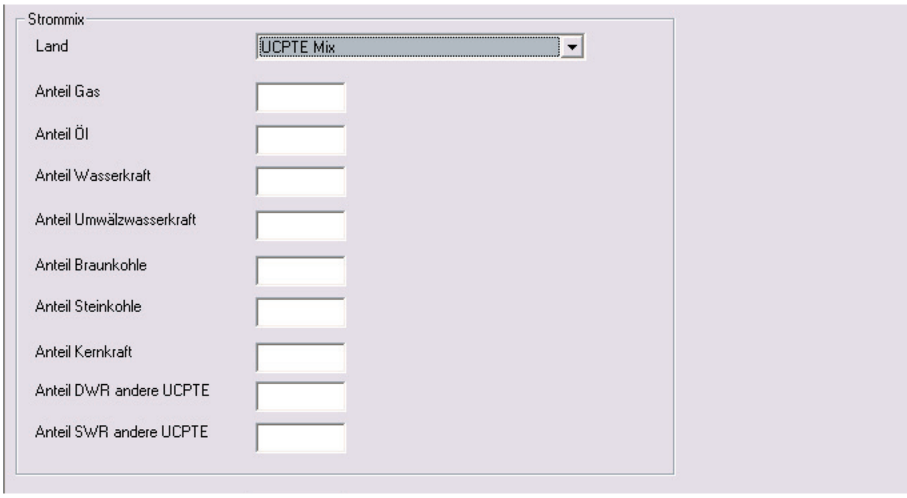


Figure 124

Defining own electricity mix in Legep

X.5.3. Surfaces of construction elements

A building can be described with either 4 elements or 40 elements in Legep. Those construction elements can either be "detailed elements" and/or "elements" and/or "macro elements".
At this time, there is no simplified model of building description in Legep.
Therefore, "varying the surfaces of elements" can mean "varying the quantity of up to 40 elements simultaneously"; which is not worth an attempt. However, when using a simplified building description model, it is possible to vary the

surface of each of the required elements simultaneously.
In order to assess the influence of the uncertainty on construction element surfaces on the overall results of Legep, the simplified building description model developed for Stilcab is used. This one is based on the selection of 7 construction elements to describe each building. One element for:

1. excavation
2. foundation
3. exterior walls
4. interior walls
5. floors and ceilings
6. roof
7. windows

Some questions remain to be answered. Indeed, a simplified description model of buildings with 7 elements introduced new errors. Moreover, how uncertain the quantities of elements are and if they are all of the same uncertainty, has to be determined and fixed.

X.5.4. Choice of construction elements

For each category of elements in the sirAdos database, several (20-30) other elements or combination of elements which have the same function in the building exist. Therefore, the user of the software is able to select one or another of those elements, according to his idea of the building and the availability of corresponding elements in the database. However, the element description found in sirAdos is short and an error can occur in the selection.
In order to simulate the uncertainty which takes place by either selecting an incorrect element or selecting the element which best fits because the perfect element (i.e. representing reality exactly) is not available in the database, the analysis considers taking others construction elements into consideration in order to consider the “best ones”.
The replacement by another construction element has to be done in a systematic way, according to one parameter; for example, the price (the price remains one of the most important criteria when selecting materials). Some other criteria can be also taken into consideration (same U-value, same function).

X.5.5. Element renovation cycle

For each element in the sirAdos database, there are several associated “secondary elements”. Those secondary elements are impacts and costs which occur at a given cycle during the life cycle of the building. They represent operations like cleaning, maintenance and renovation. An element can have no secondary element or several secondary elements in different categories (one for renovation and two for maintenance, for example).
The aim here is to assess the influence of the uncertainty on the cycles in which renovation occurs.

How uncertain are the renovation cycles (+/- X years)? A badly maintained building can be simulated with +20% of the life duration of all secondary elements before realising the maintenance or the renovation, whereas a well maintained building can be simulated with a reduction of 20% of the life duration of all secondary elements before realising the maintenance or the

renovation.
As already mentioned there are three categories of secondary elements: renovation, cleaning and maintenance. They will be handled according to the same process.

X.5.6. Building life span

Some studies suggest a building life span of about 50 years ([JUN]) and state that the end part of the life cycle typically has a significant influence on environmental life cycle analysis where the future is typically valued the same as the present. However, most of the studies suggest a life span of 80 years. For the uncertainty analysis, two others life spans (respectively 60 and 100 years) are comsidered.

X.5.7. Energy consumption

As already mentioned in IV.2.6.d., the consumption of energy in the building during its lifetime is considerable. Therefore an uncertainty in the evaluation of this consumption immediately has great impacts on the results of building's LCA. However, there is often a difference between what is assumed to be the energy consumed and what is really consumed. This can be modelled here as a source of uncertainty. First the "real" energy consumption of the building must be set as the one calculated by Legep. Then, to simulate the uncertainty, the real consumption will be varied between the German average (typical values for this building) and the consumption according to the Passiv Haus Standard. To modelise the energy consumption of the building, To modelise the primary energy consumption of a building, a certain amount of kWh/m².year is considered. However, neither the location of the thermal insulation, nor the possible heat storage in floors, nor the shadow effect are considered. The analysis looks only at the amount of primary energy consumption expressed in kWh/m².year.

The following figure (cf. Figure 125) sums up the possibilities and problems related to each of the mentioned sources of uncertainties.
The uncertainty analysis is realised here after for 25 randomly selected buildings. For each of those buildings, experimental plans are realised (following a complete matrix scheme). Analysis and results are presented in the next paragraph.

Figure 125

Uncertainty sources and suggested estimation

	Basis case	Case 1	Case 2
1- Ecological inventory	Default values in SirAdos, coming from Ecoinvent, GEMIS, Bau Oekoinventar	All CO_2 values: -20% All SO_2 values: -10%	All CO_2 values: +20% All SO_2 values: +10%
		Values for sand: -20% Values for gas: -15%	Values for sand: +20% Values for gas: +15%
		All impacts and all material the same: -25%	All impacts and all material the same: +25%
2- Quantity of elements This supposes that a simplified model of building description is used. This model considers only 7 construction elements (E1 to E7) and their associated surfaces (M1 to M7). Each element has a specific function in the building.	M1: m³ excavation M2: m² foundation M3: m² exterior walls M4: m² interior walls M5: m² floors and ceilings M6: m² roof M7: m² windows According to the building database	M1 to M7: -10% from the base case	M1 to M7: +10% from the base case
3- Electricity mix = electricity mix for the energy consumption during the use phase of the building	German electricity mix in 2006	Scenario 1: More renewable energy (wind energy), less coal and gas, more nuclear	Scenario 2: No more renewable energy, less nuclear energy and more gas.
4- Choice of construction elements This model considers only 7 construction elements (E1 to E7) and their associated quantity (M1 to M7). Each element has a specific function in the building.	Elements E1 to E7 which correspond most to the description of the building in the database.	E1 to E7 which are the least expensive in the considered category.	E1 to E7 which are the most expensive in the considered category.
5- Renovation cycle	Default values from Legep	Badly maintained building: +20% of the life duration of all secondary elements before realising the maintenance or the renovation	Well maintained building: -20% of the life duration of all secondary elements before realising the maintenance or the renovation
6- Energy consumption	Consumption calculated by Legep in the basis case	German average energy consumption for this category of building	Passiv Haus Standard
7- Life span of the building	80 years	60 years	100 years

X.6. Selection of buildings for Legep uncertainty analysis

X.6.1. Buildings considered

There are 25 buildings considered so far, sorted out in 5 use categories: office buildings, educational buildings (schools, universities…), hospitals (also including senior homes), multiple and one family housing.

A short description of the 25 buildings is given below. It is done according to the DIN 276.

Reference	310 (m^3)	320 (m^2)	330 (m^2)	340 (m^2)	350 (m^2)	360 (m^2)	330.8 (m^2)
Educational building 1	6412	3511	5666	5955	5949	4117	566,6
Educational building 2	1048	794	592	785	0	850	59,2
Educational building 3	853	509	469	463	41	643	46,9
Educational building 4	804	467	919	702	397	510	91,9
Educational building 5	559	144	698	566	504	156	69,8
Hospital 1	12000	6692	12732	21175	12144	6752	1273
Hospital 2	18171	4069	4200	3831	4662	4232	420
Hospital 3	561	1009	682	634	207	1186	68,2
Hospital 4	19440	4120	7567	14455	9537	4390	756,7
Hospital 5	6786	2561	4293	8305	5180	2561	429,3
One family house 1	349	110	288	288	191	214	29
One family house 2	305	133	329	270	275	145	32,9
One family house 3	451	219	367	389	224	248	36,7
One family house 4	28,8	61,3	194	174	113,9	95,6	19,4
One family house 5	630	136	487	893	452	202	48
Office 1	13885	2685	4984	13134	9496	2850	498
Office 2	7815	1671	3024	5101	4945	2381	302
Office 3	7650	1671	2976	5461	4071	1750	297
Office 4	3279	405	1118	1054	1303	706	112
Office 5	6850	1216	4371	6570	5773	1590	437
Multiple family housing 1	2559	1046	2375	6483	4448	1250	237
Multiple family housing 2	1446	610	2518	4506	3576	617	251
Multiple family housing 3	542	487	1184	1963	1501	491	118
Multiple family housing 4	1049	338	799	716	884	397	79
Multiple family housing 5	6312	1764	5197	9464	6947	2068	519

Figure 126

Description of the 25 buildings – Geometrical characteristics

Figure 127

List of buildings considered (Source: [BKI])

Reference	Name, description	Completion of EnEV	Construction year	Gross floor area [m²]
Office 1	Administration building with 2 TG-floors (161 places) restaurant (100 places), housekeeper quarters.	Yes	1976	13753
Office 2	Tax office with single offices and session spaces, attic not developed, storage rooms and archive spaces under ground floor, parts the under ground floor usable as a shelter.	No	1986	6246
Office 3	Administration building (110 AP) for the airport-technology area; expenses for the technology head offices which concern the whole project are not taken into consideration.	Yes	1990	5671
Office 4	Computer centre with single offices and group spaces for flexible use.	Yes	1988	1632
Office 5	Office surfaces have been constructed altogether for a public institution, shops in the ground floor are rented.	No	1995	7344
Multiple family housing 1	Building with 44 rented apartments (37 to 110m²) in the EG, 3 floors and an upper floor. Cellar spaces under ground floor.	Yes	1977	5543
Multiple family housing 2	Building with 28 owner-occupied flats (69 to 101m²), 2 under floors with underground parking (57 places), 4 to 7 floors.	Yes	1978	4470
Multiple family housing 3	Building with 12 owner-occupied flats (85 to 93m²). 3 full floors and 1 under ground floor.	Yes	1977	1959
Multiple family housing 4	Dwelling-house and business house with tooth-technical lab and offices in the first floor, houses in the floors and developed upper floor. Use rooms and technical spaces under ground floor.	Yes	1977	1251
Multiple family housing 5	Housing estate (59 dwellings). 19 dwellings as 2-3-room flats and 3-bedroom flats, in each case with terrace and garden connection; 2 dwellings as 2-room flats; 38 dwellings as 2-3 -room flats and 3-bedroom flats, each with balcony.	No (almost)	1984	8979
Educational building 1	High school with 24 classrooms, 12 course areas, subject-specific classrooms (physics, chemistry, works, art, music), library, scientific collections.	Yes	1994	9697
Educational building 2	Kindergarten on the ground floor (4 groups), clothes, community, side, and sanitary rooms	No	1988	794
Educational building 3	Kindergarten (2 groups), play gallery, clothes, community, side, and sanitary rooms	Yes	1988	575
Educational building 4	Kindergarten with 5 groups. Building of services and child houses as massive construction with clothes, community, side, and sanitary rooms; 2 glasshouses with playground.	No (almost)	1992	1087
Educational building 5	Kindergarten (3 groups), input area over public passage accessible, clothes, community, side, and sanitary rooms.	Yes	1990	632
Hospital 1	Hospitals with 234 beds; entrance hall, patient admission, treatment rooms, emergency clinic, central operation department, birth room, intensive care; office space for the administration, library, kitchen	Yes	1990	18835
Hospital 2	Nursing centre, consisting of 2 independent spaces with library, restoration, cinema, kitchens and meeting hall as well as underground parking; above average construction standard; people elevator; goods elevator.	Yes	1989	8898
Hospital 3	Cure buildings with meeting hall, restoration, secondary rooms.	Yes	1987	1213
Hospital 4	Paediatric clinic (90 beds) with nurses' hostel (39 apartments) and underground parking (75 places).	Yes	1991	14686
Hospital 5	Geriatric home (84 places), with ms station (16 places), daily care (12 places). Bath department in the under floor, collectively used facilities in ground floor, rooms in 3rd floor.	Yes	1985	7822
One family house 1	Single family house with lodger flat (141m²). Floors, developed upper floor. Lodger flat (45m²), not developed	No (almost)	1977	305
One family house 2	Single family house with garage (122m²). Floors, partly developed upper floor, cellar area under ground floor. Garage partly under ground.	No (almost)	1980	414
One family house 3	Single family house with lodger flat and double garage. Under floor, floors with gallery.	No (almost)	1979	506
One family house 4	One and two-family houses, middle standard, no cellar	Yes	1998	183
One family house 5	Low energy standard; sound-insulating window because of train at proximity	No	1996	589

X.6.2. Building description in Legep

Each building is described in Legep with 7 functional elements, as shown in the next figure.
The following equation is used to assess all LCA results.

Where: $$B_{legep} = \sum \left\{ M_{real}{}_1^7 * E_{real}{}_1^7 \right\}$$

- M is the quantity of the corresponding element (expressed either in m² or in m³)
- E is the element selected for the function i.
- B is the building.

N° $_{(i)}$	Function description	DIN 276 (E_i)	Surfaces, volume (M_i)
1	Excavation	Element 310	Volume 310
2	Foundation	Element 320	Surface 320
3	Exterior walls	Element 330	Surface 330
4	Interior walls	Element 340	Surface 340
5	Floors and ceilings	Element 350	Surface 350
6	Roof	Element 360	Surface 360
7	Window	Element 330.8	Surface 330.8

Figure 128
Description of buildings with 7 elements

For the calculation of the EnEV, a default orientation of the building was assumed every time.
It is as follows:

- One quarter of the exterior walls is oriented in each direction (N–S–W– E)
- One half of the roof area is oriented towards the south, the other half towards the north.
- One half of the window area is oriented towards the south; the other two quarters are oriented towards the east and west.

The windows area is set up to 10 % of the exterior wall area.

X.7. Legep uncertainty analysis

X.7.1. Parameters to be varied

The following parameters will be analyzed:

1. Quantity of elements
2. Electricity mix
3. Choice of elements
4. Renovation cycle
5. Energy consumption
6. Life span of the building
7. Ecological inventory

X.7.2. Definition of the basis case for all buildings

1. Quantity M1 to M7 according to the building database (default quantity)
2. Calculation with the German Mix
3. Construction elements E1 to E7 which best correspond to the description of the buildings in the building database
4. Default value of Legep for the renovation cycles of each element
5. Energy consumption calculated by Legep according to the description of the buildings in the database and its orientation
6. A life time of 80 years
7. Default ecological inventory

X.7.3. Definition of the various variation levels for each parameter

X.7.3.a. Quantity of elements

Basis case: Quantity M1 to M7 according to the building database (default quantity)
Case 1: 10% reduction of all the quantities (M1-10%M1)
Case 2: 10% augmentation of all the quantities (M1+10%M1)

X.7.3.b. Electricity mix

Basis case:

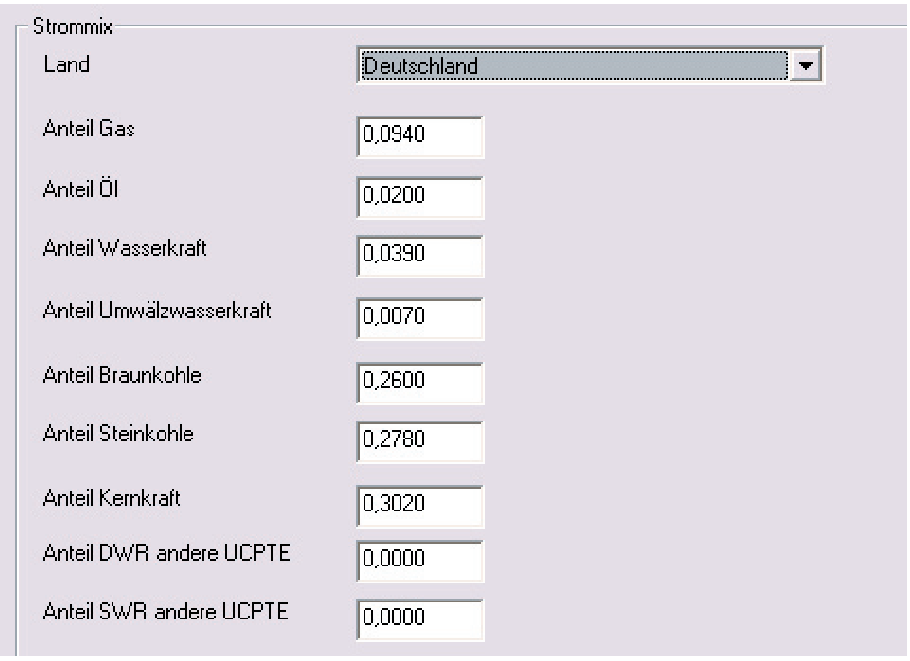


Figure 129

German electricity mix considered for the basis case
Translation: Gas = gas; Öl = Heating fuel, Wasserkraft = hydro electricity, Umwälzwasser = hydraulic with pumping, Braunkohle = brown coal, Steinkohle = hard coal, Kernkraft = nuclear.

Case 1: Scenario 1

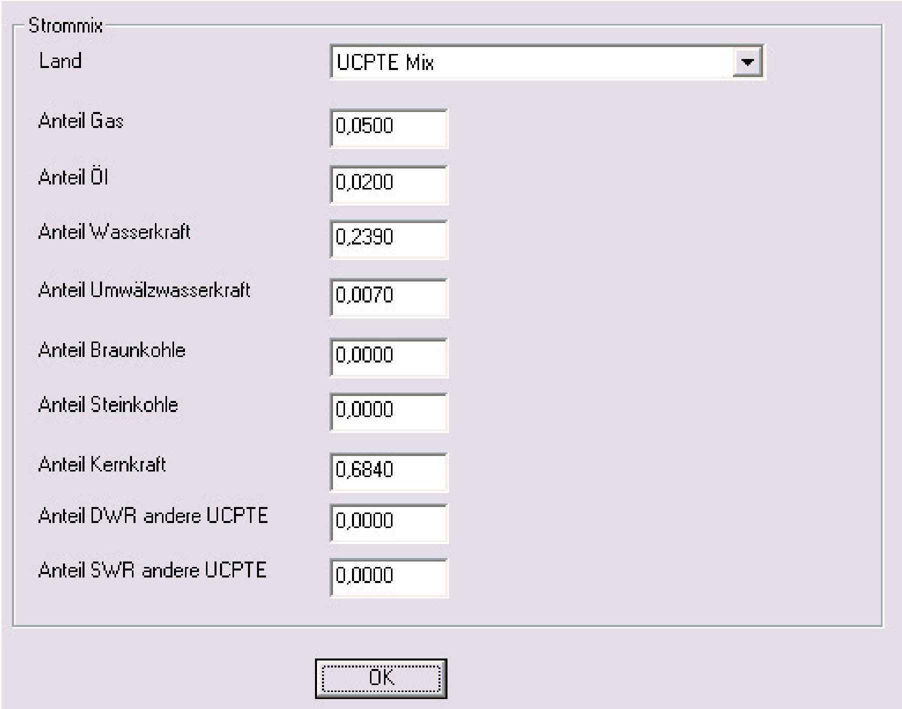


Figure 130

Scenario 1: German electricity mix considered for Case 1

Gas is reduced to 5%
Fuel is reduced to 2%
Hydroelectricity is raised to around 24% (it simulates a constant level of hydroelectricity but a 20% raise in wind-energy)
Coal is reduced to 0%.
Nuclear energy is augmented to 68%.

Case 2 – Scenario 2

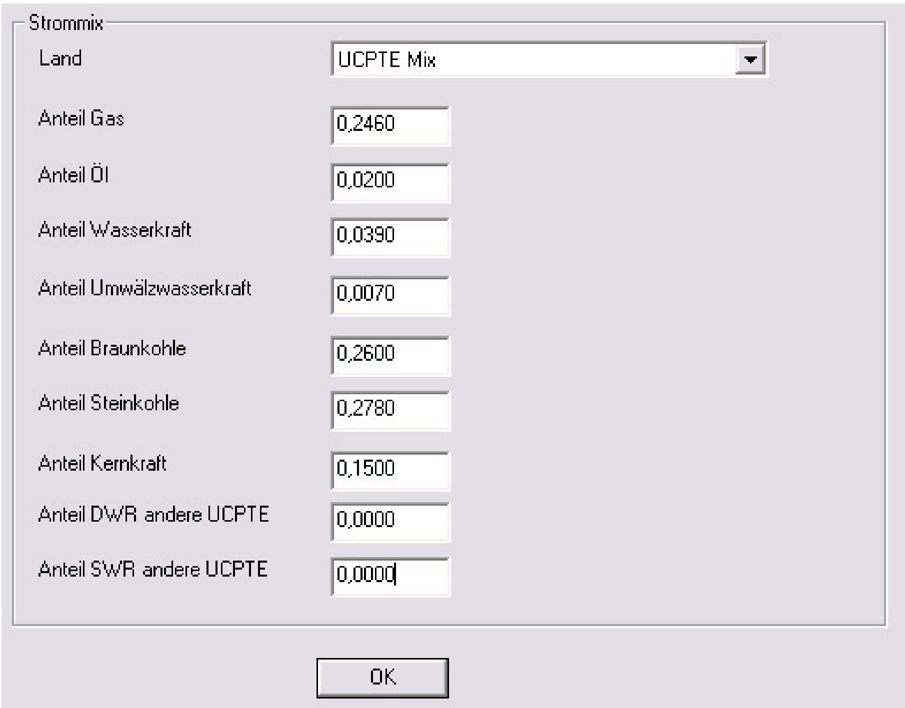


Figure 131

Scenario 2: German electricity mix considered for Case 2

Gas is augmented by about 15% which is reduced from the nuclear production of electricity.

X.7.3.c. Choice of construction elements

Basis case: Construction elements E1 to E7 which best correspond to the description of the buildings in the building database
Case 1: Cost of construction of an element is considered as the relevant parameter for the construction element selection. For each element E1 to E7, instead of the best corresponding element, the third cheaper element in the category was selected.
Case 2: Cost of construction of an element is considered as the relevant parameter for the construction element selection. For each element E1 to E7, instead of the best corresponding element, the third more expensive element in the category was selected.

X.7.3.d. Renovation cycle

Basis case: Default values given in sirAdos
Case 1: This is the “badly maintained building case”, a 20% raise in all time parameters of the construction elements chosen is considered. This is done for renovation, maintenance and cleaning “secondary” elements.
Case 2: This is the “well maintained building case”, a 20% diminution in all time parameters of the construction elements chosen is considered. This is done for renovation, maintenance and cleaning “secondary” elements.

X.7.3.e. Energy consumption

Basis case: Energy consumption calculated by Legep (includes the same energy uses as the EPBD).
Case 1: German average energy consumption for this building category. For office building: 190 kWh/(m^2.year) (cf. [TOW]).
Case 2: Passiv Haus Standard[i].

X.7.3.f. Life span of the building

Basis case: 80 years.
Case 1: 60 years.
Case 2: 100 years.

i Passivhaus: www.passiv.de [PAS]

X.8. Conclusions of the uncertainty analysis

For more clarity in the text in this section, only graphs concerning office buildings are shown below. Graphs for the four other building use categories are available in Annex 18.

X.8.1. Surfaces of construction elements

Figure 132

Effect of changing the quantity of construction elements on the various LCA results (1)

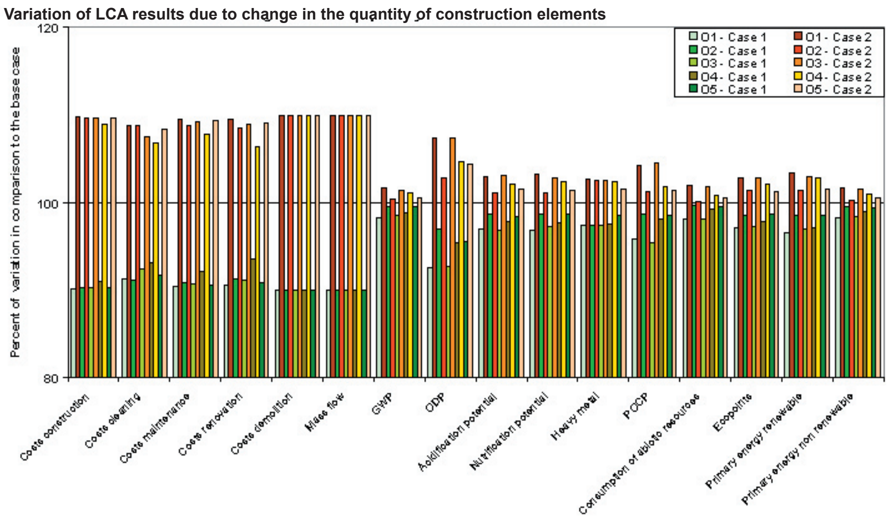


Figure 133

Effect of changing the quantity of construction elements on the various LCA results (2)

Changing the quantity of construction elements has a direct influence on the LCA results concerning the construction phase. The influence is the same for each building considered: when the quantity of elements has been reduced by 10%, the mass flow and others characteristics are also reduced by a factor of 10% and vice versa when the quantity of elements has been increased by 10%.

In the same way, mass flow as well as all costs are either reduced or increased by 10% according to the variation of element quantity considered.
This is valid for each building and for each category of buildings. Therefore the average variations given in Figure 134 can be used as a reference for all buildings.

However, for the environmental impacts, the effect of varying the quantity of construction elements is relatively low as the environmental impacts are mostly influenced by the primary energy consumption of the building during its operation phase. Therefore, the effect on the global warming potential after 80 years, for example, is about +/- 2%. The other influences are shown on the following chart.
For the category of one family houses, the influence is even smaller than for the other categories.

		Construction costs	Cleaning costs	Maintenance costs	Renovation costs	Demolition costs	Mass flow	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Office buildings	1	-10	-8	-9	-9	-10	-10	-1	-5	-2	-2	-2	-3	-1	-2	-2	-1
	2	10	8	9	8	10	10	1	5	2	2	2	3	1	2	2	1
Hospitals	1	-10	-9	-8	-9	-10	-10	-2	-6	-3	-3	-3	-3	-1	-3	-4	-2
	2	10	9	8	9	10	10	2	6	3	3	3	3	1	3	4	2
Educational buildings	1	-8	-4	-6	-6	-10	-10	-1	-5	-2	-2	-2	-3	-1	-2	-3	-1
	2	8	4	6	6	10	10	1	5	2	2	2	3	1	2	3	1
One family houses	1	-8	-5	-5	-7	-10	-10	0	-3	-1	-1	-1	-2	-1	-1	-1	0
	2	8	5	6	7	10	10	0	3	1	1	1	2	1	1	1	0
Multiple family houses	1	-9	-7	-7	-8	-10	-10	-2	-6	-3	-3	-3	-4	-2	-3	-4	-2
	2	9	7	8	8	10	10	2	6	3	3	3	4	2	3	4	2

1: Average effect of reducing the quantity of construction elements
2: Average effect of increasing the quantity of construction elements

Figure 134

Variation (%) of the impacts of a change in construction elements quantity by 10%, for several environmental impacts calculated after 80 years

	Construction costs	Cleaning costs	Maintenance costs	Renovation costs	Demolition costs	Mass flow	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Average effect of reducing the quantity of construction elements	-9	-7	-7	-8	-10	-10	-1	-5	-2	-2	-2	-3	-1	-2	-3	-1
Average effect of increasing the quantity of construction elements	9	7	7	8	10	10	1	5	2	2	2	3	1	2	3	1

Figure 135

Average variation (%) of the impacts for a change in construction elements quantity of 10%, for several environmental impacts calculated after 80 years

X.8.2. Electricity mix

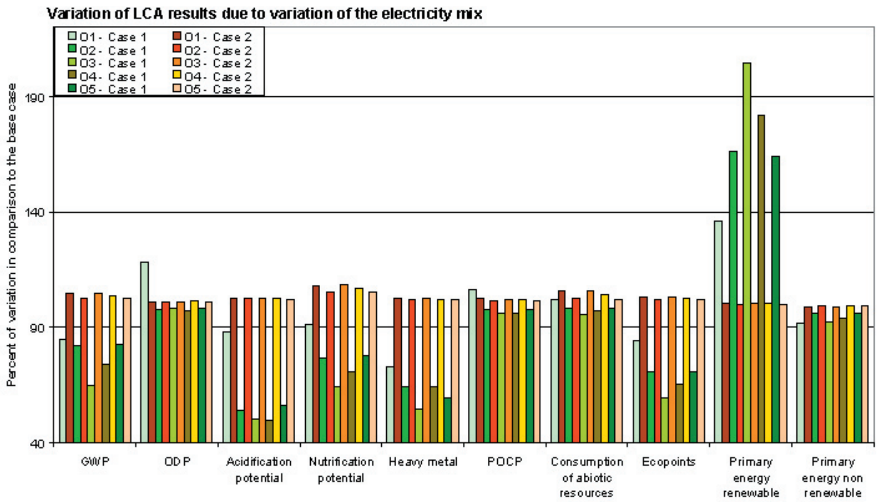


Figure 136

Effect of the electricity mix variation on the various LCA results

Changing the electricity mix in Legep can only have an effect on environmental impacts related the use of the building, that is to say related to the consumption of electricity during the 80 year lifetime of the building.

The scenario 1 generates a reduction of about 34% on average of the global warming potential, and large reductions of all other environmental impacts (except POCP and ODP), for each building and each category as can be read in Figure 137 and Figure 138. Global warming potential, acidification potential, nutrification potential, heavy metal and ecopoints are more or less reduced when considering the scenario 1 for the electricity mix, whereas primary energy renewable increased and ODP, POCP and the consumption of abiotic resources stay more or less constant (slight diminution for POCP and abiotic resources). This is characteristic for the electricity mix considered in the first case. This mix is based on less fuel and gas share in the mix and much more

		Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Office buildings	1	-22	2	-40	-24	-37	-1	-2	-30	71	-6
	2	4	1	3	7	2	2	4	3	0	-1
Hospitals	1	-35	-3	-53	-35	-40	-5	-4	-38	84	-8
	2	5	1	3	8	2	3	6	3	0	-1
Educational buildings	1	-30	-3	-54	-33	-36	-3	-3	-36	89	-7
	2	4	1	3	8	2	2	5	3	0	-1
One family houses	1	-44	8	-61	-45	-55	-4	-5	-51	142	-12
	2	7	3	4	13	4	5	10	4	1	-1
Multiple family houses	1	-38	-3	-53	-36	-43	-6	-5	-41	103	-9
	2	5	2	3	9	3	3	7	3	0	-1

1: Average effect of changing the German electricity mix for the scenario 1.
2: Average effect of changing the German electricity mix for the scenario 2.

Figure 137

Effects on the impacts for a change in electricity mix for several environmental impacts calculated after 80 years

renewable and nuclear energy. Therefore, the influence on the environmental impacts is large as very polluting energy production means are replaced with renewable energy sources, to produce electricity.

The scenario 2 generates only negative effects by changing the environmental impacts from -1% to 7% (respectively -1% for primary energy consumption renewable, and 7% for the nutrification potential).

The second electricity mix tested (scenario 2) does not have such an influence on the environmental impacts of all the buildings looked at. It generates a slight increase in the environmental impacts for all buildings and building categories. For the one family houses category, the influence of the second electricity mix is a little larger than for the other categories. Nevertheless, the average effects shown on Figure 138 can be considered as valid for all buildings.

Looking at the electricity mix and related evironmental impacts, it is necessary to remind that «radioactivity» or «radioctiv waste» are not considered in this analysis. They could be integrated in a further study.

Figure 138

Average effects on the impacts for a change in electricity mix for several environmental impacts calculated after 80 years

	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Average effect of changing the German electricity mix for the scenario 1	-34	0	-52	-35	-42	-4	-4	-39	98	-8
Average effect of changing the German electricity mix for the scenario 2	5	2	3	9	3	3	7	3	0	-1

X.8.3. Choice of construction elements

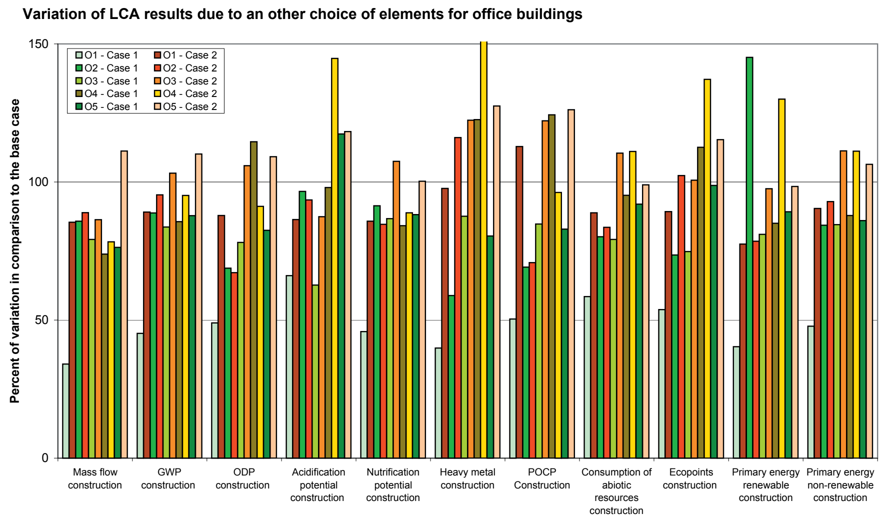


Figure 139

Effect of the choice of construction elements on the various LCA results (1)

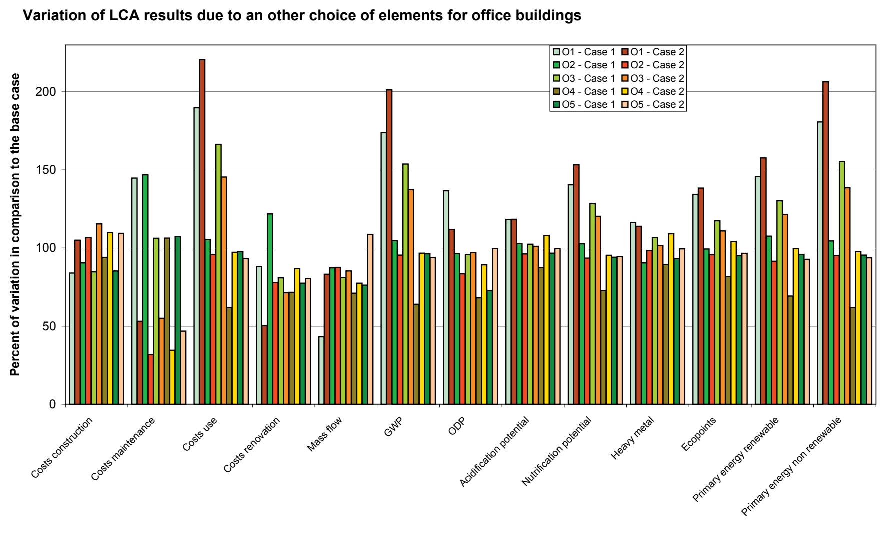


Figure 140

Effect of the choice of construction elements on the various LCA results (2)

The selection of construction elements for Case 1 and Case 2 is realised according to the price of the construction element and its function and material. At first, the initial construction elements were replaced by construction elements of the same cost type and either the most expensive (Case 2) or the cheapest (Case 1) one.
It is then not a surprise that the influence on the building construction costs is large.

Then, the choice of elements for Case 1 and Case 2 was reevaluated. The most expensive and the cheapest elements were not considered anymore but instead the third more expensive elements and respectively the third cheaper element than the base case element.
Nevertheless, the effects on construction, cleaning, maintenance and renovation costs are large.
For the use costs, the cheaper the construction elements are, the more expensive the use costs are. This can also be noted when looking at the heating energy requirement results. In the same way, the costs for heating are also greater with cheaper construction elements than with expensive ones. The waste treatment costs are also increased when considering expensive construction elements, almost in the same proportion as the construction costs.
The selection of expensive construction elements generates more mass flow, primary energy renewable and non-renewable, ecopoints, global warming potential, nutrification and acidification potential for the construction than cheaper elements which actually reduced the environmental impacts, when looking at the construction phase only.

However, when considering not only the construction phase but the whole lifetime of the building, the effects on environmental impacts is balanced as the energy consumption during the lifetime is also taken into consideration.

For this parameter, as well as for the parameter “energy consumption” (cf. I.3.), no valid conclusions can be drawn for all buildings. The variations made on the buildings are relative to the base case, different each time.

X.8.4. Element renovation cycle

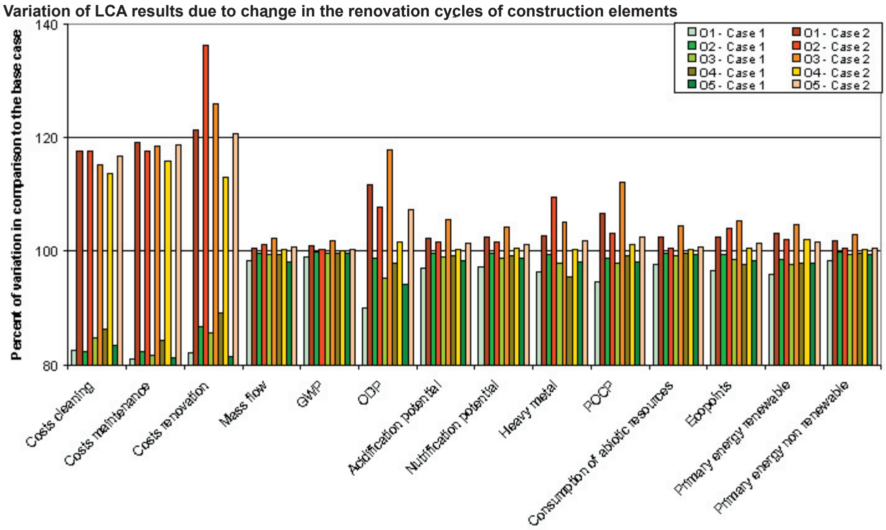


Figure 141

Effect of changing the construction element renovation cycles on the various LCA results

		Cleaning costs	Maintenance costs	Renovation costs	Mass flow	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Office buildings	1	-16	-18	-15	-1	0	-5	-1	-1	-3	-2	-1	-2	-2	-1
	2	16	18	23	1	1	9	2	2	4	5	2	3	3	1
Hospitals	1	-17	-17	-9	0	0	-1	0	0	-1	0	0	-1	-1	0
	2	17	17	38	2	2	13	4	4	10	7	2	8	6	2
Educational buildings	1	-8	-12	-11	0	0	-1	0	0	1	-5	0	0	-2	0
	2	8	12	14	1	0	4	1	1	3	4	1	2	2	1
One family houses	1	-9	-11	-15	-2	0	-4	-1	-1	-2	-3	-1	-1	-1	-1
	2	9	11	18	2	0	4	1	1	1	4	1	1	1	1
Multiple family houses	1	-15	-15	-15	-3	-2	-8	-4	-4	-5	-5	-3	-4	-5	-3
	2	15	15	22	3	2	9	4	4	5	7	4	4	5	3

Figure 142

Effects on the impacts of a change in renovation, maintenance and cleaning cycles of all construction elements for several environmental impacts and construction costs

1: Average effect of increasing the cycles of elements by 20%
2: Average effect of reducing the cycles of elements by 20%

Changing the renovation, maintenance and cleaning cycles of all construction elements necessary for the description of a building leads to a change in the maintenance, cleaning and renovation costs calculated for 80 years of almost the same importance as the change of the cycles (here +/-20%).

However, there is no considerable change in the mass flow after 80 years. This is due on one hand to the “maintenance” parts which do not take mass into consideration in Legep, on the other hand, “cleaning” only takes the water necessary for cleaning operations into account, and finally, it seems that the mass flow generated by the 20% augmentation of the renovation cycle can not contribute as much as one thinks to the overall mass flow of the building after 80 years.
The effect of changing the cycles is small when looking at the environmental impacts of the building over its lifetime.
The influence of changing the renovation cycles are the same for each building and for each building category. It is therefore possible to use the figures presented in the following chart (cf. Figure 143) for all buildings.

	Cleaning costs	Maintenance costs	Renovation costs	Mass flow	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable
Average effect of increasing the cycle of elements by 20 %	-13	-15	-13	-1	-1	-4	-1	-1	-2	-3	-1	-2	-2	-1
Average effect of reducing the cycle of elements by 20 %	13	15	23	2	1	8	2	2	4	5	2	4	3	1

Figure 143

Average effects on the impacts for a change in renovation, maintenance and cleaning cycles of all construction elements for several environmental impacts and costs of construction

X.8.5. Energy consumption

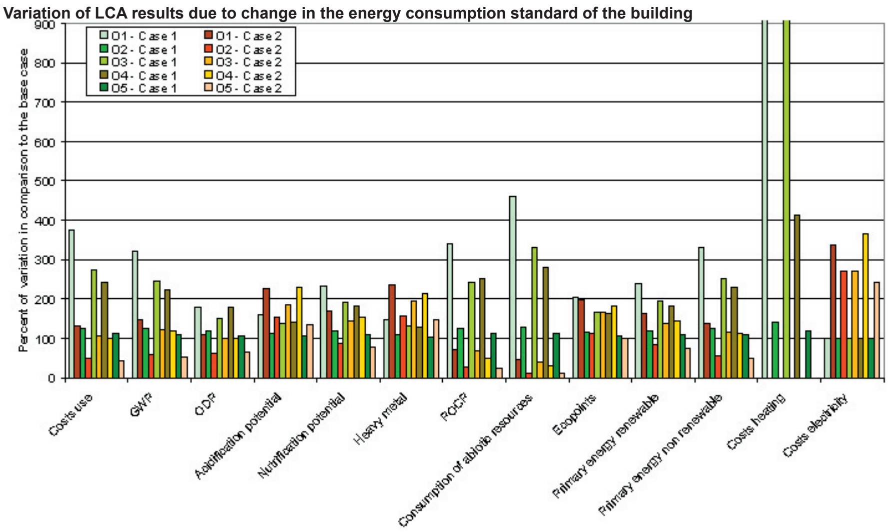


Figure 144
Effect of changing the energy consumption of buildings on the various LCA results

		Use costs	Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Heavy metal	Photochemical ozone creation potential	Consumption of abiotic resources	Ecopoints	Primary energy renewable	Primary energy non renewable	Heating costs	Electricity costs
Office buildings	1	125	105	47	31	67	23	115	163	51	68	109	489	0
	2	-14	-1	-13	86	27	90	-52	-72	52	20	-7	-100	197
Hospitals	1	190	154	81	42	94	29	186	264	67	79	164	877	0
	2	49	57	19	111	70	104	-3	-15	84	51	52	-100	193
Educational buildings	1	112	96	56	31	64	18	93	151	45	60	103	369	0
	2	11	20	4	81	38	62	-19	-35	50	29	16	-100	146
One family houses	1	18	21	17	6	14	4	32	41	10	15	22	226	0
	2	-32	-45	-31	-55	-48	-53	-27	-29	-50	-47	-44	-100	-62
Multiple family houses	1	155	128	52	34	73	25	140	210	56	76	133	531	0
	2	29	34	3	84	43	83	-17	-30	61	40	28	-100	193

1: Average effect of changing the energy requirements to the German average
2: Average effect of changing the energy requirements to the Passiv Haus standard

Figure 145

Effects on the impacts for a change in energy consumption standards for several environmental impacts and costs of the construction

The passiv haus standard is simulated in Legep by:
• setting the heating requirements to 0kWh/m².year
• setting the hot water energy requirements to 0kWh/m².year
• assuming that all other energy requirements are covered by electricity as energy type, that is to say 40kWh/m².year of end energy requirements covered only with electricity.
This is the reason why the heating and the hot water energy requirements are set to 0 for the Passiv Haus standard. This also explains why the cost for heating is also equal to 0 for case 2 ("-100" in the Figure 145).

The "standard end energy consumption" are averages for Germany for each type of buildings. This amount is distributed into several energy type (gas for heating purposes and for hot water production and only a little share of electricity).
The German average heating end energy requirement is 190kWh/(m².year). This is transformed in m³ gas necessary to get 190kWh/(m².year) and set up in Legep as shown on Figure 146. However, the hot water energy requirements as well as the electricity requirements determined by Legep in the base case are conserved because they already come from statistical data about German building- related consumption. At the end, for each building, the base case and the corresponding case 1 differ from another only by the quantity of kWh/m² assumed for space heating (Figure 146).

The results in Figure 145 indicate totally unexpected performances of the case 2 : with the exception of the category "one family houses" the performances of several parameters of case 2 are not better than the base case performance and only slightly better than the case 1. This should not be so as the case 2 consumes no gas and only 40kWh/m² of electricity. Even if the environmental

impacts are more unfavorable for the electricity mix than for the gas, the results shown on Figure 145 cannot be explained. The environmental impacts of case 2 should be much lower than those of case 1 and those of the base case.
A closer analysis of the way Legep determines the different energy consumptions (for hot water, space heating, etc.) shows that the space heating requirements in Legep are completely under estimated, except for the building category “one family houses”, the only category where the results shown in Figure 145 are as expected. But for this category, another problem is underlined: Legep divides (internally) the consumption of electricity in three parts: for lighting, for domestic electrical equipment and for space heating support. For the first two, Legep uses default values for the category “one family houses”, independent of the building size. This simplification of the calculations in Legep leads to an over estimation of the electricity requirements of this building category, which in turn leads to superior results for case 2 than for the base case for this category.

The results of the three scenarios comparison are therefore misleading and no general conclusion concerning energy consumption can be drawn from them.

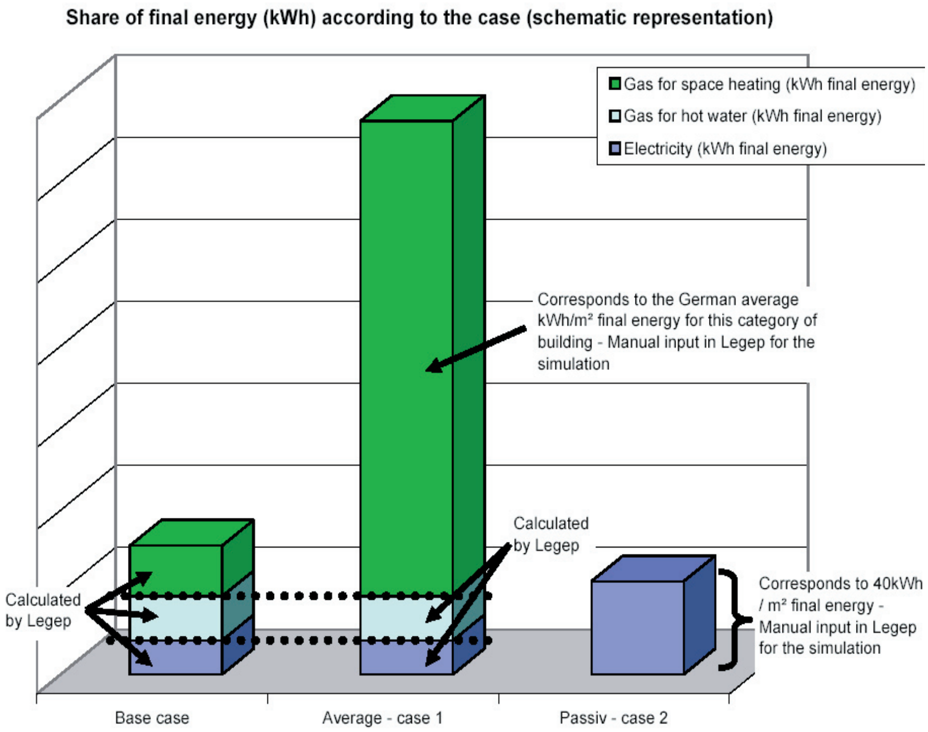


Figure 146

Share of final energy (kWh) according to the case (schematic representation)

X.8.6. Building life span

The renovation costs are in the case 2 somewhat higher, in the case 1 somewhat deeper. That is connected with the fact that the necessary renovation arises repeatedly if the life span is longer. The deviations of the environmental impacts depend likewise on the life span, i.e. on the energy consumption during the life span of the building (cf . Figure 147).

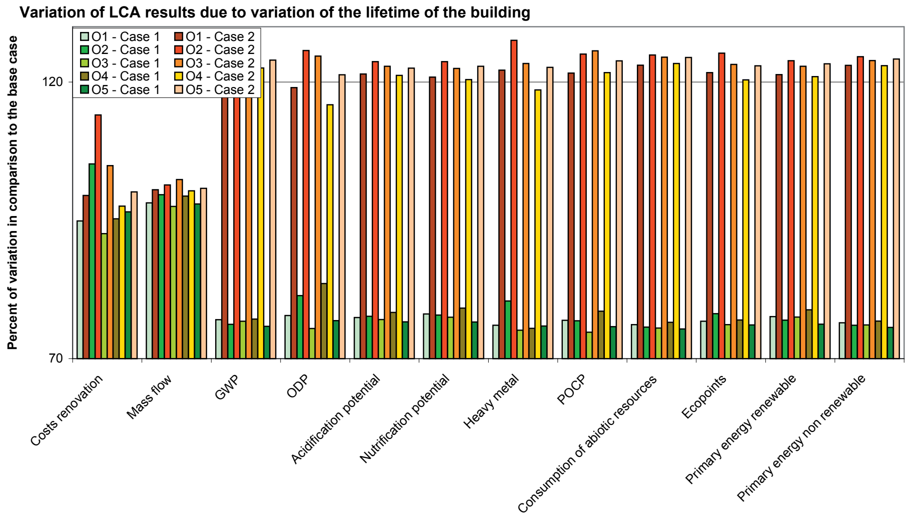


Figure 147

Effect of the building's lifetime on the various LCA results

X.8.7. Combined uncertainties

For the 5 office buildings, the combination of 4 parameters uncertainties is analysed:

1. Renovation cycle
2. Electricity mix
3. Life time of the building
4. Quantity of construction elements

The parameter "choice of elements" is let aside as its only variation would false the analysis of this combination (its effects would be pre-dominant in comparison with the effects of the other parameters). The parameter "energy consumption of the building" is also let aside due to the conclusions drawn in paragraph X.8.5..

To combine the 4 parameters, each of them taking three levels (base case, case 1, case 2), a total of m^n experiment are necessary to be done.

m: number of levels for each parameter.

n: number of parameters.

In the current analysis, 81 experiments are necessary.

Graphs for each of the 5 office buildings can be found in Annex 18.

Figure 148 shows the average effects for the 5 buildings for the 81 experiments. This is also represented in Figure 149.

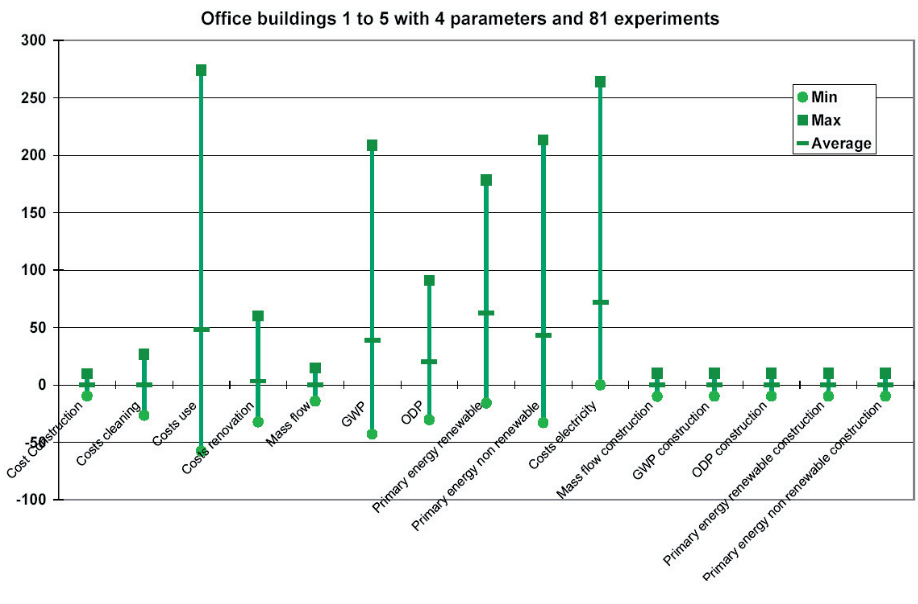


Figure 148

Average effects for the five buildings, 81 experiments

	Cost Construction	Costs cleaning	Costs use	Costs renovation	Mass flow	GWP	ODP	Primary energy renewable	Primary energy non renewable	Costs electricity	Mass flow construction	GWP construction	ODP construction	Primary energy renewable construction	Primary energy non renewable construction
Office 1															
Min Office 1	-10	-26	0	-32	-14	-18	-17	-8	-12	0	-10	-10	-10	-10	-10
Max Office 1	10	26	274	31	11	209	91	161	213	236	10	10	10	10	10
Average Office 1	0	0	102	0	-1	85	36	79	87	79	0	0	0	0	0
Standard deviation Office 1	8	16	123	18	8	85	26	53	89	112	8	8	8	8	8
Office 2															
Min Office 2	-10	-27	0	-22	-11	-19	-6	-3	-5	0	-10	-10	-10	-10	-10
Max Office 2	10	26	173	60	13	126	38	150	128	172	10	10	10	10	10
Average Office 2	0	0	60	15	1	51	19	70	54	57	0	0	0	0	0
Standard deviation Office 2	8	16	80	23	8	52	13	47	54	81	8	8	8	8	8
Office 3															
Min Office 3	-10	-23	0	-31	-13	-37	-14	-5	-10	0	-10	-10	-10	-10	-10
Max Office 3	10	23	143	40	15	109	80	178	111	264	10	10	10	10	10
Average Office 3	0	0	48	3	1	37	30	79	45	88	0	0	0	0	0
Standard deviation Office 3	8	14	67	19	9	45	25	58	45	125	8	8	8	8	8
Office 4															
Min Office 4	-9	-20	0	-22	-11	-28	-9	-5	-7	0	-10	-10	-10	-10	-10
Max Office 4	9	20	143	20	11	105	61	159	108	264	10	10	10	10	10
Average Office 4	0	0	48	-1	0	39	25	70	44	88	0	0	0	0	0
Standard deviation Office 4	8	15	30	18	8	14	10	31	12	67	8	8	8	8	8
Office 5															
Min Office 5	-10	-25	-58	-31	-14	-43	-30	-16	-33	0	-10	-10	-10	-10	-10
Max Office 5	10	25	11	31	12	3	12	67	1	142	10	10	10	10	10
Average Office 5	0	0	-15	0	-1	-18	-9	16	-15	47	0	0	0	0	0
Standard deviation Office 5	8	15	30	18	8	14	10	31	12	67	8	8	8	8	8
Offices 1 to 5															
Min	-10	-27	-58	-32	-14	-43	-30	-16	-33	0	-10	-10	-10	-10	-10
Max	10	26	274	60	15	209	91	178	213	264	10	10	10	10	10
Average	0	0	48	3	0	39	20	63	43	72	0	0	0	0	0
Standard deviation	8	15	88	19	8	62	26	54	64	106	8	8	8	8	8

Figure 149

Average, minimal and maximal effects for the five buildings, 81 experiments

The outputs : use costs, global warming potential, ozone depletion potential, primary energy renewable and non-renewable and electricity costs can be very different from the base case, in average.

An interesting conclusion of this analysis is that although all considered parameters vary, the LCA results for most of the inputs do not vary so much. This puts into evidence a certain consistency in the LCA results of Legep.

A further analysis illustrates this. A ranking of the five office buildings is done. This allows to look if the ranking of the five buildings according to their environmental impacts and costs during their life time changes when the input parameters of those buildings change.
In deed, the objective of LCA is not only to get knowledge about costs and environmental impacts of a building but to compare the knowledge for one building with the one of other buildings.
When the ranking of the five buildings remains the same, it suggests that uncertainty on those input parameters does not have an influence for the comparison of buildings.
The results of the ranking analysis are shown in Figure 150. A grey case signalised that the ranking of the five office buildings changed when changing the corresponding parameter.

	Costs construction	Costs cleaning	Costs use	Costs renovation	Mass flow	GWP	ODP	Primary energy renewable	Primary energy non renewable	Costs electricity	Mass flow construction	GWP construction	ODP construction	Primary energy renewable construction	Primary energy non-renewable construction
Electricity mix case 1	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Electricty mix case 2	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Renovation cycle case 1	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Renovation cycle case 2	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	change	change	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	change	change	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Lifetime case 1	OK	OK	OK	OK	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	change	OK	change	change	change	OK	OK	OK	OK	OK
	OK	OK	OK	change	OK	change	OK	change	change	change	OK	OK	OK	OK	OK
	OK	OK	OK	change	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
Life time case 2	OK	OK	OK	change	OK	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
	OK	OK	OK	change	OK	change	OK	change	change	change	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	change	OK	change	change	change	OK	OK	OK	OK	OK
	OK	OK	OK	OK	change	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
	OK	OK	OK	OK	change	OK	OK	OK	OK	change	OK	OK	OK	OK	OK
Quantity of elements case 1	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Quantity of elements case 2	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Figure 150

Results of the ranking analysis

With the modification of the electricity mix to case 1, the ranking of the five buildings (for their acidification potential, global warming potential and heavy metal, like partially shown on Figure 150) changes.
In contrary, for the following parameters, the ranking does not change, by neither of the outputs looked at: electricity mix case 2, renovation cycle case 1 and case 2 (except for renovation costs and material flow), elements quantity (except for ecopoints of the construction).
In contrast, for the parameter „building life span“, the cost of electricity and water change as well as the renovation costs and some of the environmental impacts, but neither acidification potential nor ozone depletion potential are affected by this.

The conclusion of the ranking study is quite positive because the change of the selected input parameters have no large effect over the ranking of buildings with regard to the LCA results.

X.8.8. Ecological inventory

Unfortunately it was not possible to modify the inventories of materials in the sirAdos database like mentioned in X.5.1. and in Figure 125. If it had been possible, this would have meant changing about 2500 inventories, as each of them is potentially relevant for the LCA of a building.
This was not possible because a link failed betwen the database and Legep which enables the effect of a variation in the database to be seen in the Software.
An other possibility is to look at the materials which are mostly responsible for the overall environmental impacts of buildings.
The following figure (Figure 151) shows the materials which are responsible for most of the environmental impacts.

In deed, only 21 materials are responsible for more than 90% of each

Average 5 buildings	Masse	Global warming potential kg CO2 Eq.	Ozone depletion potential kg CFC11 Eq.	Acidification potential kg SO2 Eq.	Consumption of abiotic resources kg Sb Eq.	Primary energy renewable MJ	Primary energy non-renewable MJ	Total Ecopoints	
Aluminium, 35% rec. , moulded	0%	3%	3%	3%	3%	3%	2%	3%	Technical equipment
Panel aluminium, primary	0%	2%	1%	2%	1%	4%	2%	1%	Construction
Aluminium, primary	0%	9%	7%	9%	7%	22%	11%	6%	Construction
Reinforced concrete	4%	7%	3%	3%	6%	10%	8%	9%	Construction
Bituminous emulsion (150-400 g/m²)	0%	0%	7%	0%	5%	0%	2%	0%	Construction
C 20/25 (B25) non reinforced	52%	25%	4%	11%	5%	1%	11%	3%	Construction
C 20/25 (B25) WU non reinforced	8%	4%	1%	2%	1%	0%	2%	0%	Construction
Glas (d=4mm-10mm)	1%	6%	1%	2%	7%	0%	4%	1%	Construction
Cast iron	0%	9%	8%	9%	6%	1%	7%	5%	Technical equipment
Gravel (wet)	15%	1%	2%	1%	1%	0%	1%	0%	Construction
Ballast gravel (dry)	11%	0%	0%	0%	0%	0%	0%	0%	Construction
Copper	0%	3%	3%	13%	4%	1%	3%	6%	Technical equipment
Brass	0%	1%	0%	2%	1%	0%	0%	3%	Construction
Coniferous wood (spruce, pine, fir) dry, ready to saw	2%	-18%	0%	1%	1%	50%	1%	0%	Construction
PE Foil 0,2 mm	0%	1%	5%	1%	3%	0%	2%	1%	Construction
PVC shock resistant	0%	2%	5%	2%	4%	0%	2%	1%	Technical equipment
Schnittflor PP	0%	4%	16%	10%	12%	1%	6%	3%	Construction
Steel 40% rec. Unalloyed	0%	3%	1%	2%	1%	0%	3%	2%	Technical equipment
Galvanised panel steel	2%	24%	10%	16%	13%	3%	20%	50%	Technical equipment
Vinyl foam	1%	4%	20%	5%	16%	0%	8%	2%	Construction
Floor cement	5%	0%	0%	0%	0%	0%	0%	0%	Construction

Figure 151

Materials responsible for most of the environmental impacts

environmental impacts considered, calculated over the life time of buildings, without energy consumption aspects.
Those materials come, for a third of it, from the technical equipment (sanitary, heating systems, etc.): cast iron, steel plate. Cement and aluminium are the most important when looking at the building without technical equipment.

Although this analysis is not an uncertainty analysis regarding ecological inventory, it gives valuable information concerning buildings LCA. It is yet

known that a limited number of material (and therefore a limited number of corresponding ecological inventories) has an influence on the overall impacts of a building on the environment. An uncertainty on other material's ecological inventories as those ones has no relevance. But, a little uncertainty on those 21 materials ecological inventories has a large influence on the whole building LCA.
A further study could analyse the effect of uncertainty of those 21 materials on office building LCA and compare it with other buildings category; although it is forseen that the list of the 21 materials remains the same for all buildings considered) as soon as this would be possible in Legep software.

X.9. Conclusions for buildings LCA in general

As demonstrated by the ranking analysis, uncertainties on the selected input parameters have little influence when comparing buildings LCA:

- *little uncertainty in relative.*

When assessing a specified building, attention should be given as uncertainty of some input parameters (choice of elements and energy consumption in particular) do have a large influence on the results:

- *eventually large influence of some input parameters in global.*

The material analysis provides usefull information concerning the input uncertainty which is the most difficult to assess, the ecological inventory uncertainty:

- *large importance of a limited number of materials for the environmental impacts.*

Through the uncertainty and material analysis done with Legep, the validity of LCA results is demonstrated, even if the uncertainty on input parameters is important. This has only positive consequences for the method and the tool developed in the thesis because:

- *the building description model used for the uncertainty analysis (cf. X.8.) is the same as the one developed and implemented in Stilcab (description of buildings according to functional elements);*
- *the elements used in Stilcab are coming from sirAdos database, like in Legep.*

CONCLUSIONS AND PERSPECTIVES

During the last decades, Life Cycle Analysis (LCA) in general has been of great value as a tool to judge, qualify or rank industrial products and services according to the environmental impacts generated during their life span. However, when applied to buildings, LCA turned out to become a cumbersome process, mainly due to the complexity and the diversity of buildings that are one-of-a-kind products and which all have their own particularities. In fact, every building is a conglomerate of a large number of materials in specified quantities, exposed to a multitude of interventions during their lifetime: operation, maintenance, renovation, refurbishment, transformations etc.

Several LCA based tools can be found on the market to calculate, describe, model and/or classify the impact of buildings during their lifetime. All of them require a detailed description of the building as well as a well-developed building construction element database and material inventory data. They all claim to obtain detailed and reliable results if a high degree of precision is achieved in the description of the building. However the detailed description of the building itself is time consuming and requires information, which is usually not (or not completely) at the user's disposal in the early stages of design.

The aim of the thesis was to develop a Simplified Tool for Integrated Life Cycle Analysis of Buildings (Stilcab) and to demonstrate that a simple, less cumbersome description of buildings allows reaching almost the same quality of results as a complete conventional integrated LCA (ILCA) tool. With the developed method and the resulting tool, results are achieved with the reduced input data available at early design stages. Furthermore, this type of tool also allows calculation for large number of buildings (building stocks). An additional feature is the possibility to realise a sensitivity analysis in order to identify the potentials of improvement for a specified category of building or for a particular building.

The increasing interest on buildings LCA is mainly political.
When the protection of the environment became a public issue, the large impacts of the built environment on nature could not remain unnoticed. The rising need of comfort led to a growth of the energy consumption of buildings, to a reduction of the number of persons per habitation, to an increase of surface per person, etc. Badly constructed buildings tend to be demolished instead of refurbished, adding to the already considerable societal energy and mass flows. At the same time, energy consumption, declining energy resources and energy independence became also daily topics. The combination of these concerns led to the idea of identifying, monitoring and finally controlling energy and material consumption of each product: LCA was born.

Starting out in academic research, practical tools were progressively becoming available to realise the life cycle analysis of buildings. But the complexity of those tools and the vast amount of information needed for the calculations have been mayor obstacles to their generalisation.
The necessity of a simplified method appears in particular in the early design phase when the detailed information simply does not exist but when the potential to influence the final results is very high. Furthermore traditional LCA was not relied to (life-cycle) cost calculation and the interdependence between the cost and benefits of environmental design could not be established during the design process.

The starting point of the simplification resides therefore in the description of buildings. For the development of the simplified method, buildings are considered to be a composition of different construction elements with their respective surfaces and quantities. Two hypotheses were central:

- considering the whole lifetime, construction elements characteristics do not differ fundamentally;
- the specific quantities of the building elements depend on few characteristics of the building and can therefore be retrieved with sufficient accuracy from general characteristics (like gross floor area etc.).

To confirm the first hypothesis, construction elements of a large number of realised buildings and their characteristics (like cost / m², kg $CO_{2\ Eq.}$ / m², etc.) were analysed. Based on this information and additional properties like cleaning cycles and renovation cycles, so-called meta-information for each element and each characteristic were created and implemented in the method.

For the second hypothesis, buildings and their geometry were statistically investigated according to buildings use category and DIN 277. A geometrical matrix resulted from this analysis, allowing calculating geometrical characteristic of a building from its use category and its gross floor area.

The building description model that was created has as main advantage to be easy to use since it requires little information. It is also flexible since it adapts itself to the planning phase considered. If nothing is known about the building except its use and its gross floor area the building description model already allows a first complete description of the building based on statistical values. Together with information concerning construction elements, this enables to get an estimation of the building's costs and environmental impacts. Later on in the planning process when more information concerning the building is at hand, default-values for the building and the different elements can be replaced by real design-values and therefore results of the LCA become more accurate in the sense that they correspond more and more to really designed building.

To realise the building LCA, it is essential to consider also water and energy consumptions of the building and its occupants. For the water, statistical values are taken into account whereas for the energy consumption of the building, a new method was developed. This method takes into consideration the new Energy Performance of Buildings Directive (EPBD) and the Energieeinsparverordnung (EnEV) as a basis to formulate suggestions for the choice of construction elements for the building's envelope. Only construction elements that respect the maximal U-values are selected and presented to the designer, taking also into account the geometry and the orientation of the building. The cumbersome trial and error process of energy calculation is replaced by a target oriented performance approach that excludes non-compliant solutions from the beginning.

The method was implemented in a tool named Stilcab, which can be used by different actors and is largely self-explaining. Based on a large database of different construction elements it takes into account different types of building use (housing, offices etc.). The strength of Stilcab is its adaptability to the quality and quantity of input information available at a particular planning phase. Although the method was developed for the German context, it has been extended for the French construction market and used with success for the analysis of several building-projects in France.

Improvements of buildings in terms of energy consumption, costs and / or environmental impacts are the scope of LCA. Therefore it is necessary to identify the potentials for such enhancements. The sensitivity analysis for a whole range of buildings allowed determining what the potentials for improvement are and where they are in the construction. The sensitivity analysis has been done for several types of buildings and each LCA result, enabling the identification of the largest improvement potentials for mass flow, primary energy consumption, costs, etc. for the different buildings categories. The sensitivity analysis was implemented in Stilcab, according to the same procedure. It allows assessing which parts of a given building should be changed to reach significant improvements in the LCA results.
Some results of the sensitivity analysis could be identified as key steps for the improvement of building's LCA. For example, the choice of floors and ceilings (building structure) is of primary concern for all building categories since its influence on the overall costs over the lifetime is the largest. The second largest is the choice of windows. Some dissimilarity was also pointed out between two building categories: one construction element is not always responsible for the maximum of impacts or costs. Ratio such as construction costs or generated global warming potential per m² of gross floor area have been established for each buildings category; thus leading to a better knowledge of the built environment. Those values can also be used as reference ratio for comparison when one wants to obtain good performances for a particular building.

Since assumptions were necessary to develop the simplified method, it is important to look at the uncertainty generated by these hypotheses. Taking into account the construction elements, the geometrical matrix as well as the energy consumption and the technical equipment of buildings, it was possible to establish the distribution of the total uncertainty of the results (for example the cost calculation), for each category of buildings. The uncertainty due to the assumptions made for the development of the method is about 7% for the cost estimation after a life time of 80 years, independently of the building use category. Moreover, the distribution of uncertainty responsibility over the several construction elements and energy or technical equipment could be established for all buildings category, showing that windows are responsible for about 20 to 28% of the uncertainty on costs. Respectively, the same study conducted on global warming potential showed an overall uncertainty of about 8%, 50% of it being due to energy related uncertainty.

Finally the uncertainty of the detailed integrated building LCA tool "Legep" was investigated. After having considered different methods for uncertainty analysis, experimental plans appeared to be the most appropriate. The following parameters were analysed: quantity of construction elements, electricity mix, choice of construction elements, renovation cycle, energy consumption and life span of the building. For 25 buildings, all parameters were varied according to the experimental plans method to determine uncertainties. Afterwards, uncertainties of every parameter were combined. An interesting conclusion of this analysis is that although all considered parameters vary, the LCA results for most of the inputs do not vary so much.

Another objective of LCA is to compare one building with another. A ranking study was conducted by comparing the ranking of five buildings according to their environmental impacts and costs during their life time before and after changing the input parameters. When the ranking of the five buildings remains the same, it suggests that uncertainty on those input parameters does not have an influence for the comparison of buildings.

The responsibility of construction materials for generating environmental impacts was looked at allowing establishing a list of 21 materials (out of more than 100 materials considered), which are responsible for more than 90% of all environmental impacts (energy consumption of buildings not being considered). In fact, 30% of the impacts are coming from materials used in the technical equipment of buildings: cast iron and steel plate. Cement and aluminium are following. This analysis provides valuable information concerning buildings LCA. The fact that a limited number of construction materials (and therefore a limited number of corresponding ecological inventories) are responsible for the overall impacts of buildings on the environment has not been shown before. An uncertainty on many material's ecological inventories has little relevance for the final result. On the contrary, even a small uncertainty in the ecological inventory of those 21 materials has a large influence on the whole building LCA.

Through the uncertainty and material analysis done with Legep, the validity of LCA results is demonstrated, even if the uncertainty on input parameters is important. This has only positive consequences for the method and the tool developed in the thesis. The building description model used for the uncertainty analysis is the same as the one developed and implemented in Stilcab (description of buildings according to functional elements); the construction elements used in Stilcab originate from the same database as the one used in Legep.

The simplified method for integrated life cycle analysis of buildings (Stilcab) fulfils all the specified objectives. Its strengths are:

- its adaptability to the planning phase considered (i.e. to the amount of information concerning the building available at that time),
- its flexibility when the user gets more information,
- its ability of providing all the LCA results (costs, energy requirements and environmental impacts) in a very short time,
- the originality of the calculation of the energy requirements allowing to design by respecting directly the constraints of the two energy standards (EPBD and EnEV).

Furthermore, Stilcab can easily be adapted to other national context.
The geometrical model developed for Stilcab can be directly used for the assessment of large building stocks, and to determine missing values in the description of buildings.

Developing and validating the method, knowledge was gained concerning the built environment and the possibility to improve its performances regarding costs and environmental impacts. The material study proved that a limited number of construction materials are responsible for a large part of the environmental impacts. Therefore, a deeper analysis of the ecological inventory of those materials would be the starting point of further investigations concerning LCA of buildings.

The simplified method and the associated tool can be used:

- by architects to sum up the materials and compare several alternatives in terms of costs, environmental impacts and energy consumption;
- by environmentally oriented investors and developers who can insure low energy costs;
- by facility management companies dealing with the planning of renovation and maintenance expenses. They may find it comfortable to have the construction details with associated costs as well as the planning of renovation and maintenance for the next coming years with the associated costs in the same place.

In a later future, it can eventually be used in the purpose of buildings labelling according to the EPBD.

Stilcab was already used for several projects in France, amongst others for one kindergarten in the south of France. The European Institute for Energy Research (EIfER) in Karlsruhe will go on using Stilcab with application cases in different cities and different kinds of buildings. The method has been proven to be easy to use all along the planning phase and to obtain reliable LCA results. Improvement potentials have been identified and profit was made of the new knowledge of the built environment.

Glossary

Building, construction

Building (or construction) is the gathering of a defined quantity of construction elements forming a closed volume, covering a defined ground area and with a space floor equivalent to the gross floor area. Moreover, the building has a given function (a use) and a given lifetime during which several actions take place (actions corresponding to the secondary elements). All materials necessary for the construction of a building are part of it. Everything outside the exterior limits of the building does not belong to it (garden, street, networks, etc.).

Use category

A use category describes the main use of a building. The categories considered in this report are those defined by STaBu (StaBu: Statistiches Bundesamt - German Statistical institute). The French equivalent is INSEE (National Institute for Statistics and Economic Studies). They are briefly listed in Figure 21.

Construction element

Construction elements are elements of construction which can be found in the sirAdos database in order to describe a building. Many elements are necessary to describe one building, according to the description model one selects. In the database, a large quantity of information is linked to the selection of one particular construction element (its construction costs, its associated secondary elements, its costs, the environmental impacts associated with its construction, etc.). There are three types of construction elements in sirAdos: detailed elements, elements and macro-elements.

Detailed element

The "Feinelement" of the sirAdos database are referred to as detailed elements in this report. A detailed element is, for example, a layer of gips on the exterior wall. In the database, a large quantity of information is linked to the selection of one particular detailed element (its construction costs, its associated secondary elements, its costs, the environmental impacts associated to its construction, etc.).

Element

The "grobelement" of the sirAdos database are referred to as "elements" in this report. An element is, for example, a double glazed window with a wood frame. In the database, a large quantity of information is linked to the selection of one particular element (its construction costs, its associated secondary elements, its costs, the environmental impacts associated to its construction, etc.).

Macro element

The "makroelement" of the sirAdos database are referred to as "macro-elements" in this report. A macro-element is, for example, a roof with plates. In the database, a large quantity of information is linked to the selection of one particular macro-element (its construction costs, its associated secondary elements, its costs, the environmental impacts associated to its construction, etc.).

Use surface

The use surfaces are the surfaces described in the German norm DIN 277. They are horizontal surface characteristics for a building. They refer to circulation surface, technical surface, gross floor area, and so on. Indeed, the German building regulations require a documentation of the use surface determined according to the DIN 277.

Element surfaces
These are the quantities (expressed in m² or m³) of construction elements necessary to describe a building. There are construction elements for each cost type.

Cost type
The cost types refer to the "Kosten Gruppe" of the German norm DIN 276 and DIN 277. Indeed, the German building regulations require a description of the construction costs which is organised according to the DIN 276 and DIN 277.

Secondary element
The secondary elements refer to the "folge element" which are present in sirAdos. There are three different kinds of secondary elements: renovation, maintenance and cleaning. A cycle is associated which each secondary element. This represents the rhythm in which the secondary element occurs (e.g. cleaning of the floor 2 times / month).

Gross floor area (m²)
The gross floor area is the translation of the German BGF (Brutto-Grundfläche) which is defined in the DIN 276. It is the total floor area contained within a building including the horizontal area of external walls [TBS].

Secondary function area: NNF (m²)

Net floor area: NGF (m²)

Traffic area: VF (m²)

Main function area: HNF (m²)

Construction area: KGF (m²)

Function area: FF (m²)

Net floor area: NF (m²)

Constructed area (m²)
The constructed area is the translation of the German BF (Bebaüte Fläche) which is defined in the DIN 276.

Lifetime, life duration (years)
Lifetime or life duration is the time basis for which the calculations of the LCA results are made.

S.H.O.B. (Surface Hors Oeuvre Brute), S.H.O.N. (Surface Hors Œuvre Nette)
SHOB of construction is equal to the sum of the floor spaces of each level of the construction: ground floors and all floors; intermediate levels such as mezzanines and galleries; storage spaces and basements as well as terraced roofs [SHO]. It is the equivalent of "gross floor area" in English. SHON (Surface Hors Oeuvre Nette) is equivalent to "floor inside gross". Those terms are used in France.

Environmental Impact Assessment (EIA)
EIA is an analytical process that systematically examines the possible environmental consequences of the implementation of projects, programmes and policies [UNS].

Environmental Effect
An environmental effect is the result of environmental impacts on human health and welfare. The term is also used synonymously with environmental impact [UNS].

Global warming
This phenomenon is believed to occur as a result of the build-up of carbon dioxide and other greenhouse gases. It has been identified by many scientists as a major global environmental threat [UNS].

Global Warming Potential (GWP)
This is the aggregate measure of the contribution to the greenhouse effect of some gases through their conversion into carbon dioxide equivalents [OED].

Greenhouse Effect
This is the warming of the earth's atmosphere caused by a build-up of carbon dioxide and other greenhouse or trace gases that act like a pane of glass in a greenhouse, allowing sunlight to pass through and heat the earth but preventing a counterbalancing loss of heat radiation [UNS].

Carbon dioxide equivalent
Carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential. For example, the global warming potential for methane over 100 years is 21. This means that an emission of one million metric tons of methane is equivalent to emissions of 21 million metric tons of carbon dioxide [OED].

Ozone depletion
This is the destruction of ozone in the stratosphere, where it shields the earth from harmful ultraviolet radiation. Its destruction is caused by chemical reactions in which oxides of hydrogen, nitrogen, chlorine and bromine act as catalysts [UNS].

Ozone Depletion Potential (ODP)
The aggregate measure of the ozone layer depletion potential of some substances, calculated with the conversion factor of halogenated hydrocarbons that contribute to the depletion of the ozone layer into CFC -11 equivalent [OED].

Acidification
This is the increase of hydrogen ions, usually expressed as the pH value of environmental media [UNS].

Acidification Potential (AP)
The aggregate measure of the acidifying potential of some substances, calculated with the conversion factor of sulphur oxides and nitrogen and ammonia into acidification equivalents (H+ ion) [OED].

Eutrophication / nutrification
This is the slow aging process in which a lake or estuary evolves into a bog or marsh and eventually disappears. During eutrophication, the lake becomes so rich in nutritive compounds (especially nitrogen and phosphorus) that algae and other microscopic plant life become superabundant, thereby choking the lake and causing it to eventually dry up. Eutrophication is accelerated by discharges of nutrients in the form of sewage, detergents and fertilizers into the ecosystem [UNS].

Non-renewable natural resources
Non-renewable natural resources are exhaustible natural resources such as mineral resources that cannot be regenerated after exploitation [OED].

Renewable natural resources
Renewable natural resources are natural resources that, after exploitation, can return to their previous stock levels by natural processes of growth or replenishment. Conditionally renewable resources are those whose exploitation eventually reaches a level beyond which regeneration becomes impossible. Such is the case with the clear-cutting of tropical forests [OED].

New and renewable energy sources
New and renewable energy sources are energy sources including solar energy, geothermal energy, wind power, hydropower, ocean energy (thermal gradient, wave power and tidal power), biomass, draught animal power, fuel-wood, peat, oil shale and tar sands [OED].

Primary Energy Consumption
This describes the direct use at the source, or the supply to users without transformation, of crude energy; that is, energy that has not been subjected to any conversion or transformation process [UNS].

Energy supply (apparent consumption)
Total primary energy domestic supply (sometimes referred to as energy use) is calculated by the International Energy Agency as the production of fuels + inputs from other sources + imports - exports - international marine bunkers + stock changes. It includes coal, crude oil, natural gas liquids, refinery feedstock, additives, petroleum products, gases, combustible renewable and waste, electricity and heat. Domestic supply differs from final consumption in that it does not take distribution losses into account. The supply and use of energy commodities are converted to kg oil equivalent using standard coefficients for each energy source [OED].

Energy Conversion Factors
These specific coefficients are used to determine equivalence between units of mass and volume, energy and work and power; conversion factors are also used to convert quantities of energy production and consumption from their original physical units into a common unit of measurement [UNS].

Classification
Part of the life cycle impact assessment. Sorting of the inventory is carried out according to the type of environmental impact they contribute to, e.g. global warming and acidification [BAU].

Goal and scope definition
Phase during which the purpose of an LCA study is defined and specifications on the LCA model and procedure are determined. The goal and scope of an LCA study is usually determined by the commissioner and the practitioner in collaboration [BAU].

Inventory analysis
Phase during which the LCA model is build according to the specifications determined in the goal and scope definition, data are collected and calculations indicating the environmental load of the product are made [BAU].

LCA Model
The LCA model of a product or service describes the material flow from its cradle where raw materials are extracted from natural resources through production and use to its grave, the disposal [BAU].

LCI life cycle inventory
This is a LCA study that goes as far as an inventory analysis, but does not include impact assessment [BAU].

Life cycle assessment
Method for the environmental assessment of products and services, covering their life cycle from raw material extract to waste treatment. The method includes a step by step work description and principles for modelling the product life cycle [BAU].

LCI results
These are substances and energy flows as well as other physical actions crossing the system boundary between an anthropogenic process and the environment. The LCI does not contain all of these flows and actions, but only those whose total quantity is expected to influence the quality status of the environment in a relevant way (e.g. an emission of oxygen into the air is normally not tabled in the LCI) [JOL].

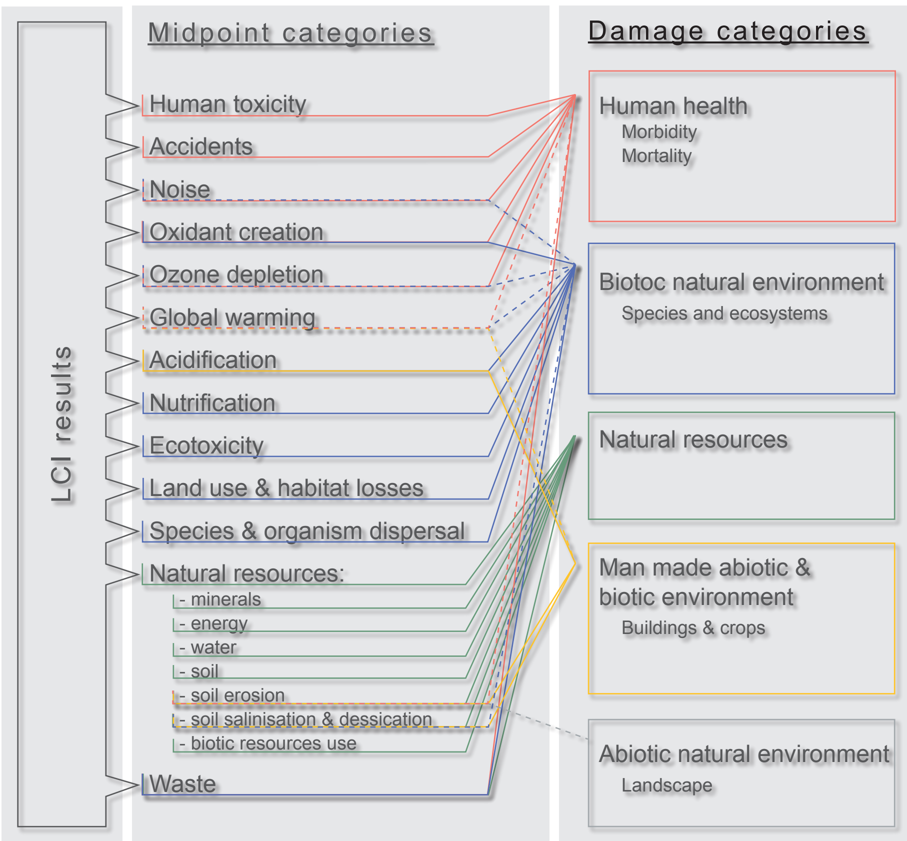


Figure 1

General structure of the LCIA framework. Dotted arrows: currently available information between midpoint and damage levels is particularly uncertain [JOL]

Midpoint categories (cf. Figure 1)
These represent environmental issues of concern to which various flows or actions tabled as LCI results contribute, involving common or similar processes (e.g. acidification, ionising radiation). In practice, the historical development of midpoint categories is the result of interaction between scientific discoveries and societal processes: the issue of acidification was developed around 1960

when the increase in combustion gas induced substantial acidity changes in water bodies and soil, and the issue of stratospheric ozone depletion developed around 1970 when the decrease of stratospheric ozone was detected and explained, followed by a public debate of the problem. Midpoint categories may appear less significant if the corresponding problem is solved or if public concerns change [JOL].

A midpoint indicator
This is the quantified representation of the corresponding midpoint category. The indicator may represent the quality status of an object or an important process in nature, but it may also be limited to an index that is useful for the successive determination of a quality status. There are currently two different types of midpoint indicators used:
Either (type 1) they are based on common impact processes and bundle the substance flows or physical changes from the LCI results up to a certain intermediate point, from which links to various damage categories are, in principle, possible (examples of type 1 are the midpoint indicators for ozone depletion and global warming), or (type 2) they bundle substance flows or physical changes from the LCI results with non-similar impact processes, but which explicitly address one damage category (example for type 2 is the indicator for human toxicity which bundles various substance flows that are known to cause diseases and premature deaths in humans: fate, exposure and effect of these substance flows can be treated similarly, but environmental processes and types of diseases generally differ from one chemical to another). Type 2 midpoint indicators can be difficult to link to damage categories, if characterisation factors within a given midpoint indicator do not match the data structures of the corresponding damage indicators: if a damage indicator is expressed in lost human life years, it is insufficient to characterise toxic substances on the basis of e.g. their no-effect-level, because there is no clear relationship between life years lost and the substance flows aggregated on the basis of no-effect-levels. In fact, exceeding no-effect-levels with certain substances may quickly lead to death, whilst other types of intoxications are limited to a temporary disease [JOL].

Damage categories (cf. Figure 1)
These classify damages to various parts of the environment, which are of concern to society. The currently prevailing opinion is that these “parts of the environment” consist of the biotic environment (living organisms in nature), the abiotic environment (non-living elements of nature) and the human population (being a special case of a living organism that is believed to merit particular considerations). In contrast to the midpoint categories, the damage categories are intended to represent quality changes of “ultimate” concern: whilst acidification of water bodies or soil is a matter of concern because of the consequences of such acidification, the loss of human life years, the extinction of a plant species or the destruction of a crystal cave is considered as a damage in itself, or an environmental quality change of “ultimate” concern [JOL].
The damage categories can be grouped with respect to “areas of protection”, such as human health, natural environment, natural resources, the man-made environment; they can also be classified according to intrinsic and functional values.

Damage indicator
This is the quantified representation of the quality status of a part of the environment that is addressed by a damage category. The quality status of the human population can e.g. be expressed by the number of life years lost

(mortality) and/or the number and duration of various disease cases (morbidity), whilst the quality status of non-human organisms can be expressed by the geographical extension and the population density (occurrence) of a species [JOL].

Weighting method
This indicates the environmental harm of pollutants or a resource relative to other pollutants and resources. Weighting methods evaluate all kinds of environmental loads or problems on a single scale and can be used to express the overall environmental impact as a single number [BAU].

Arithmetic mean
The sum of values divided by the number of values [EA4].

Correlation
The relationship between two or several random variables within a distribution of two or more random variables [EA4].

Correlation coefficient
The measure of the relative mutual dependence of two random variables, equal to the ratio of their covariance to the positive square root of the product of their variances [EA4].

Corridor of solution
A corridor of solution is the space delimited by the largest range of results obtained for one problem. For example the lower and upper limits of a corridor can be the results get by using Stilcab with “default values” and the results gets by using “real values”. Both values defined a corridor of solution.

Covariance
The measure of the mutual dependence of two random variables, equal to the expectation of the product of the deviations of two random variables from their respective expectations [EA4].

Experimental standard deviation
The positive square root of the experimental variance [EA4].

Expanded uncertainty
A quantity defining an interval concerning the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand [EA4].

Experimental variance
The quantity characterising the dispersion of the results of a series of n observations of the same measurand given by equation (Eq. 13) in the text [EA4].

Input estimate
The estimate of an input quantity used in the evaluation of the result of a measurement [EA4].

Input quantity
A quantity on which the measurand depends, taken into account in the process of evaluating the result of a measurement [EA4].

Measurand
The particular quantity subject to measurement [EA4].

Output estimate
The result of a measurement calculated from the input estimates by the model function [EA4].

Output quantity
The quantity that represents the measurand in the evaluation of a measurement [EA4].

Probability distribution
A function giving the probability that a random variable takes for any given value or belongs to a given set of values [EA4].

Random variable
A variable that may take any of the values of a specified set of values and with which a probability distribution is associated [EA4].

Relative standard uncertainty of measurement
The standard uncertainty of a quantity divided by the estimate of that quantity [EA4].

Standard deviation
The positive square root of the variance of a random variable [EA4].

Standard uncertainty of measurement
The uncertainty of measurement expressed as the standard deviation [EA4].

Type A evaluation method
The method of evaluation of uncertainty of measurement by the statistical analysis of a series of observations [EA4].

Type B evaluation method
The method of evaluation of uncertainty of measurement by means other than the statistical analysis of a series of observations [EA4].

Uncertainty of measurement
A parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand [EA4].

Variance
The expectation of the square of the deviation of a random variable about its expectation [EA4].

Variation coefficient
The variation coefficient is the ratio between the standard deviation and the average.

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Traduction

German	English
Name	Name
Menge	Quantity
Einheit	Unit
Einzelpreis	Price per unit
Gesamtpreis	Total price
Lebenszyklus Kosten	Life cycle costs
Summe Projekt	Sum for the project
Umsatzsteuer	V.A.T.
Zyklus	Cycle
Stoffmasse	Mass flow
Monodeponie	Specific deposit
Sonderabfalldeponie	Special waste deposit
Sonderabfallverbrennung	Special waste incineration
Treibhauspotential	Green house effect
Ozonschichtabbaupotential	Ozone depletion potential
Versauerungspotential	Acidification potential
Überdüngungspotential	Nutrification potential

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Charts for Sensitivity Analysis C

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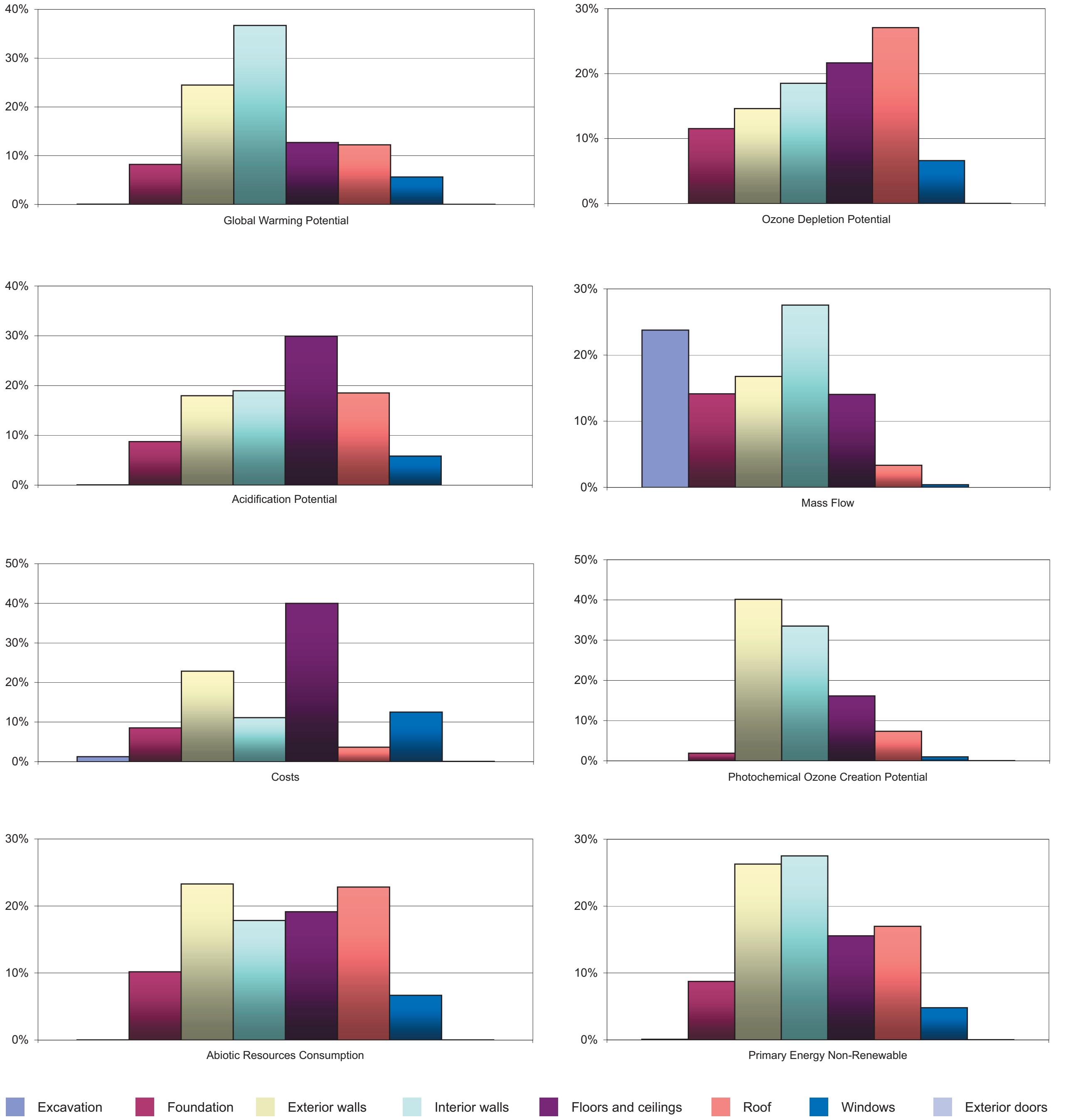
Global Warming Potential
Ozone Depletion Potential
Acidification Potential
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Costs
Photochemical Ozone Creation Potential
Abiotic Resources Consumption
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Excavation
Foundation
Exterior walls
Interior walls
Floors and ceilings
Roof
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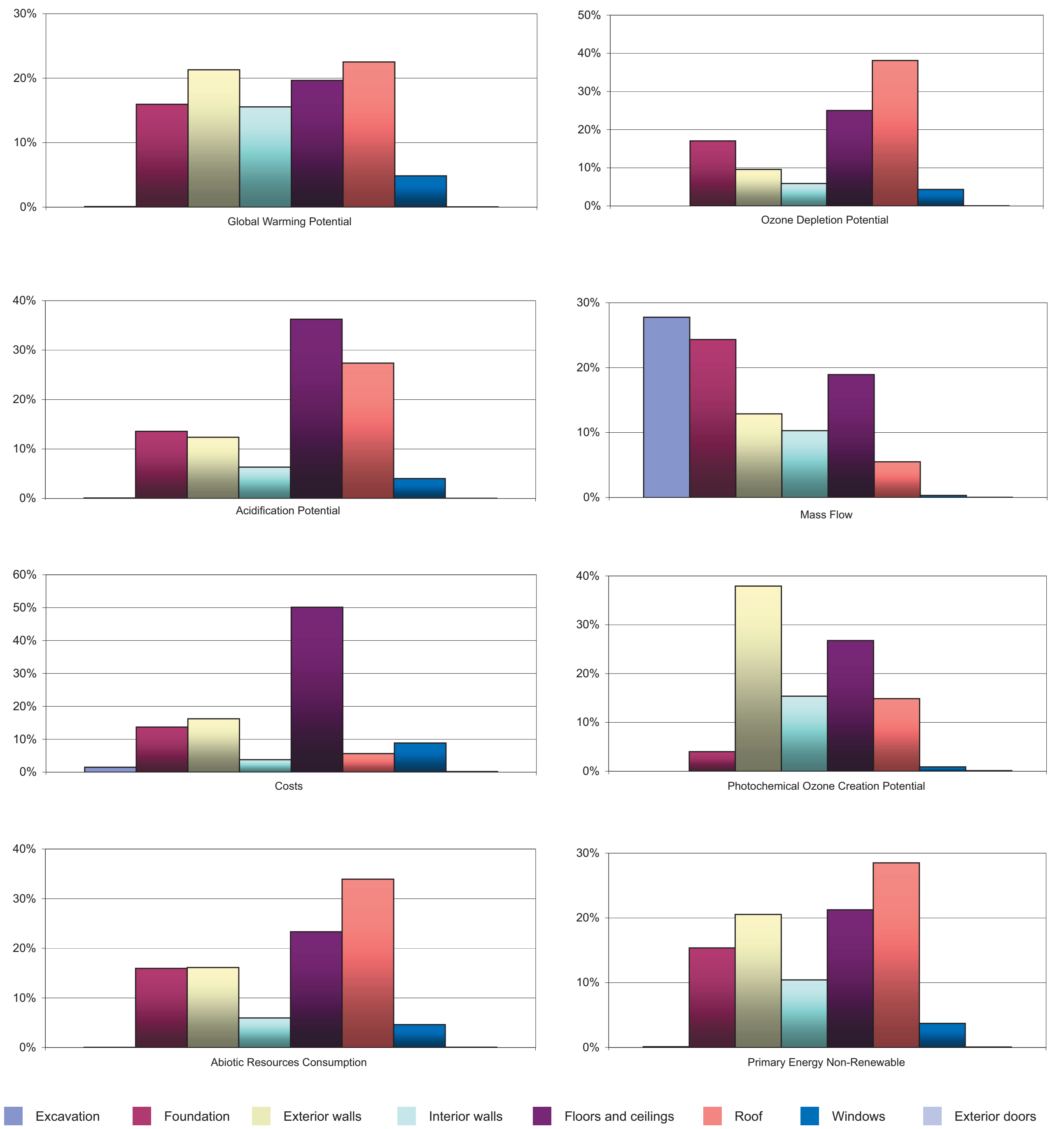
Exterior doors

Industry and Trade Buildings



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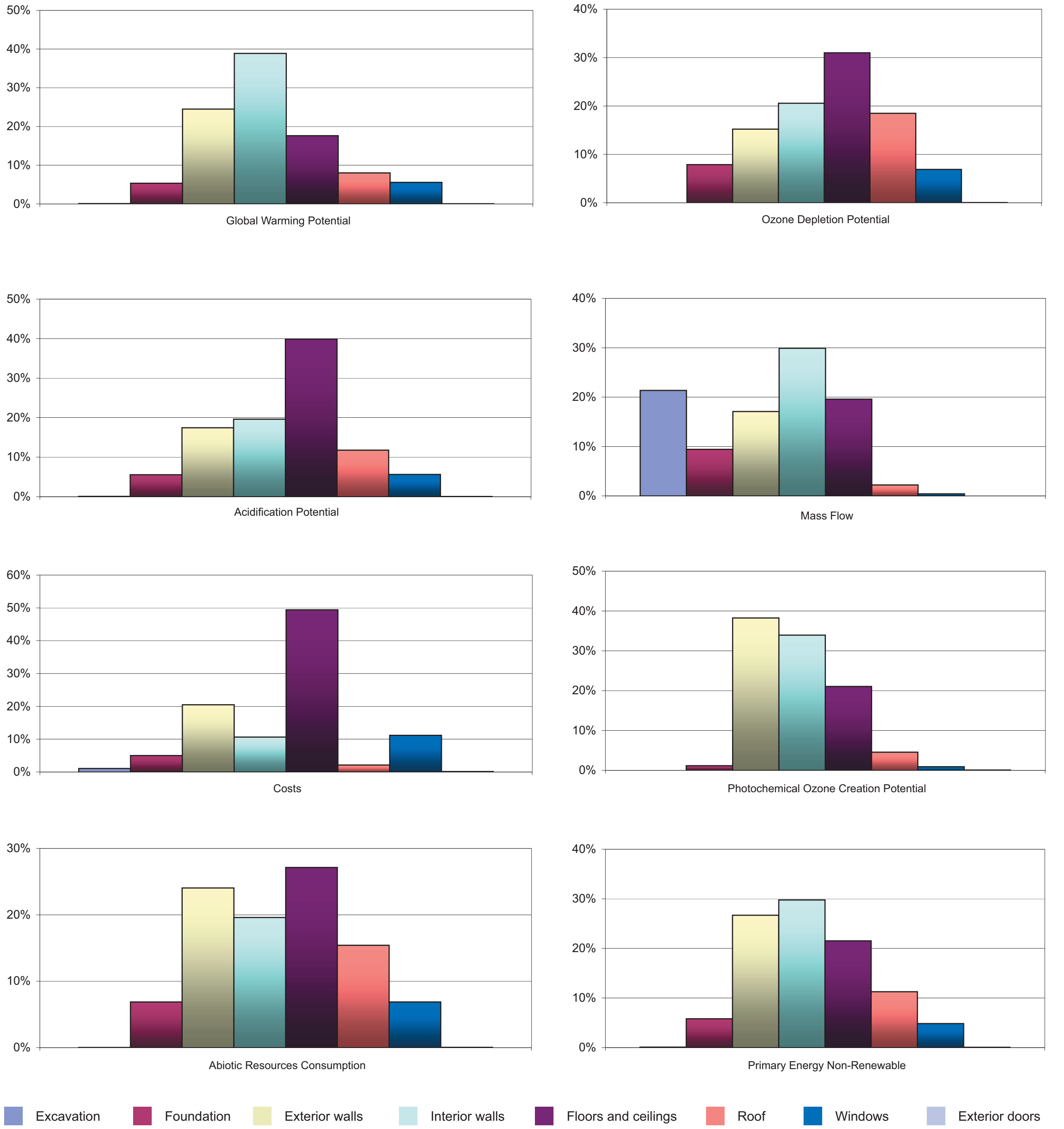

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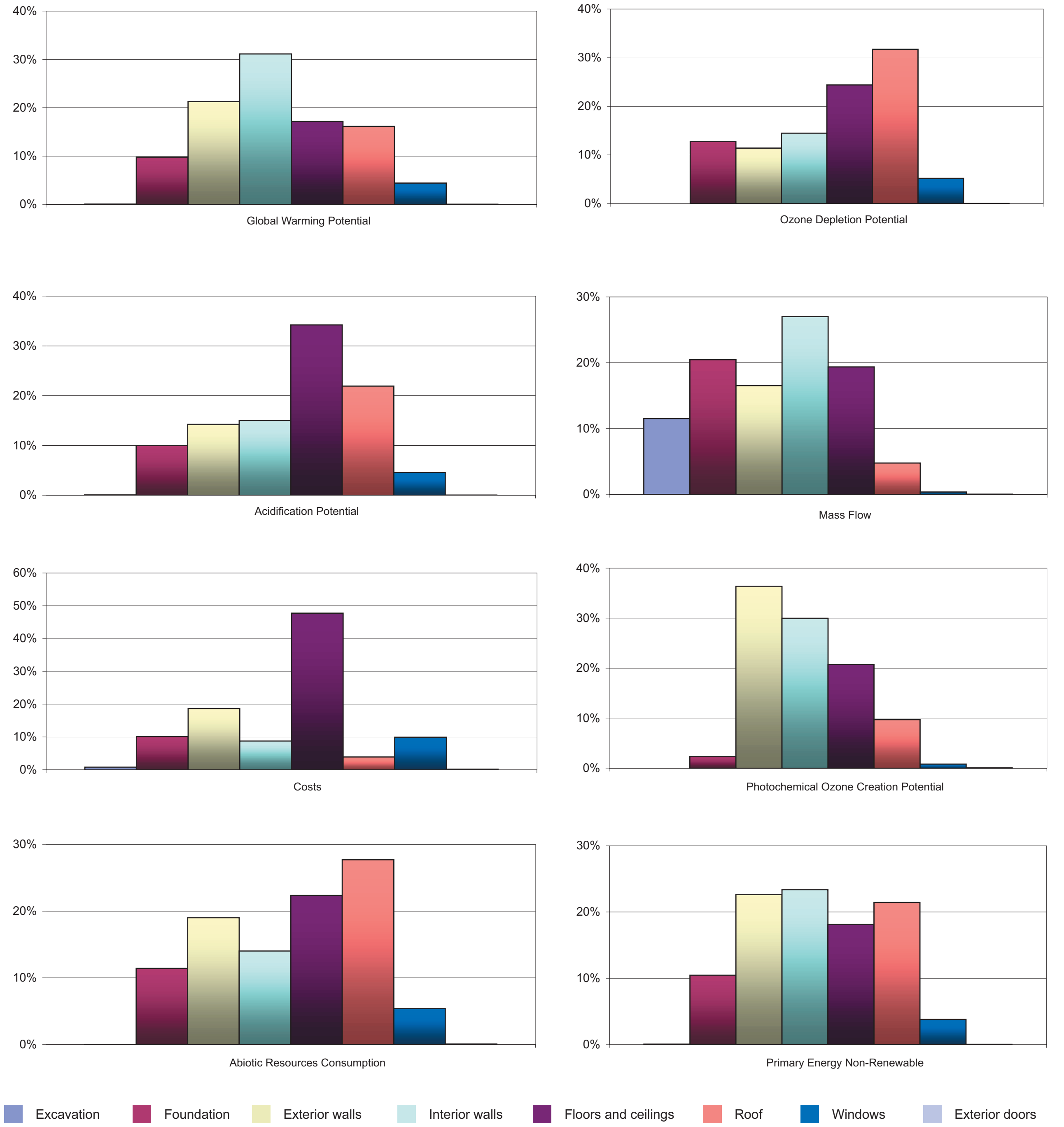

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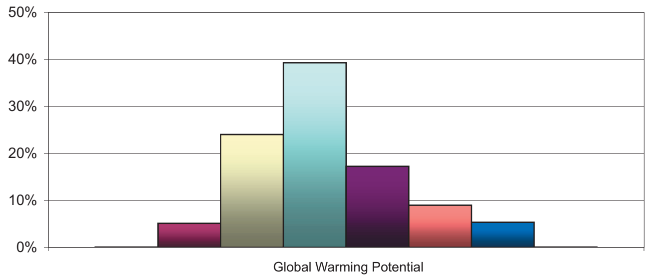
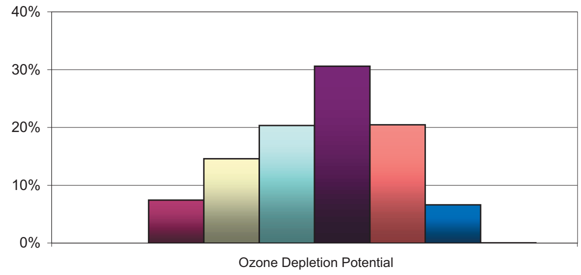
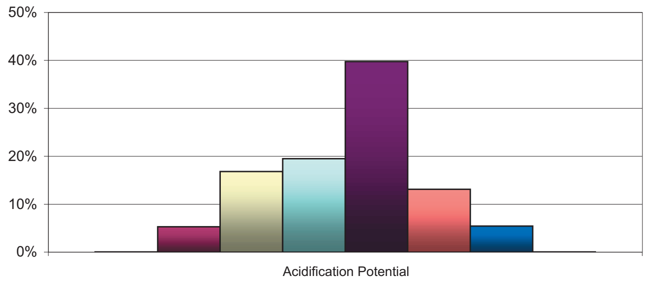
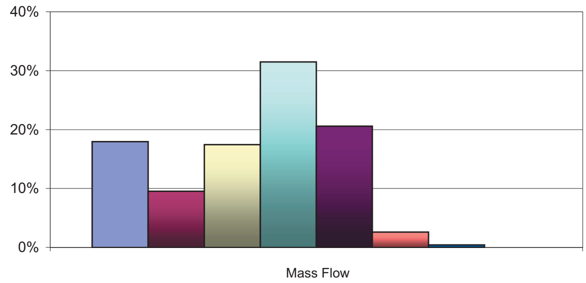
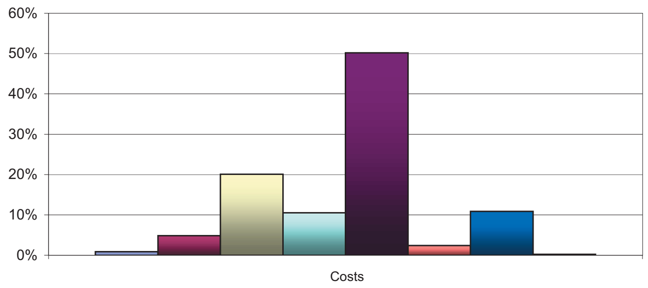
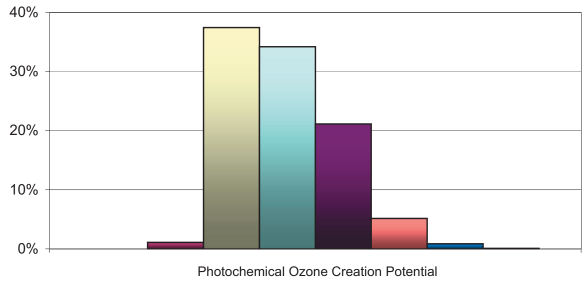


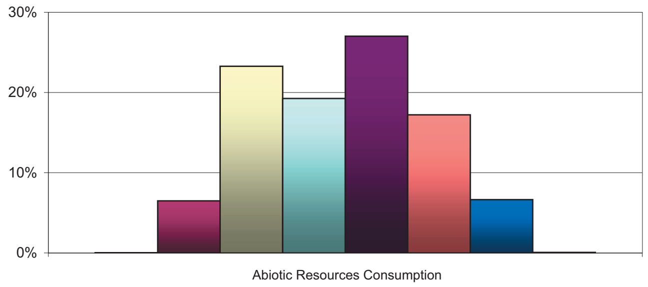


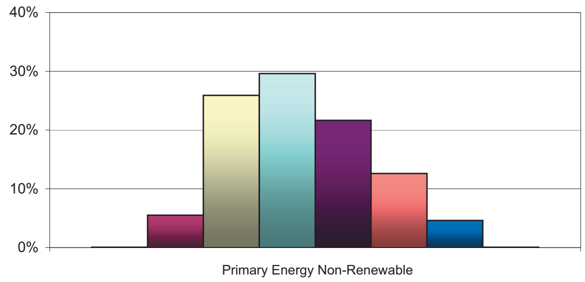




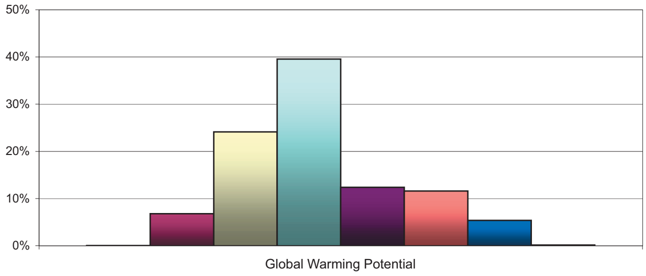


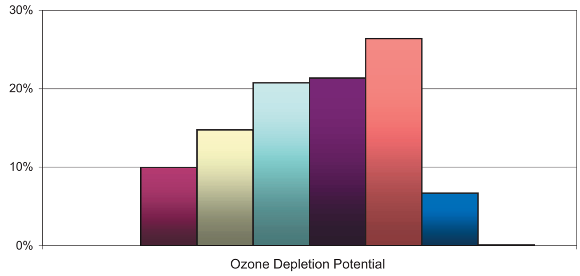


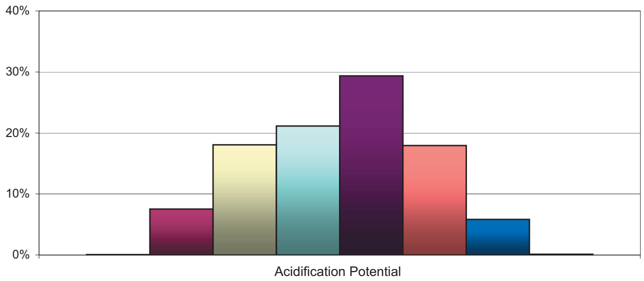


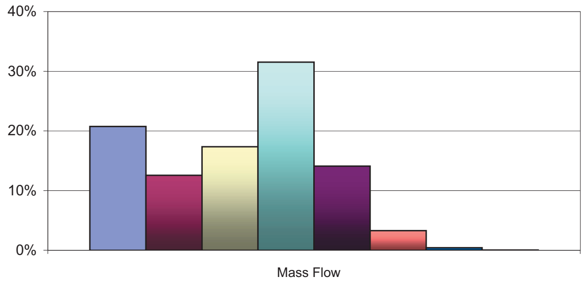


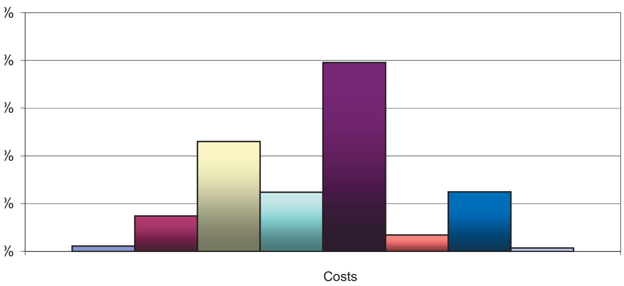
One Family Housing

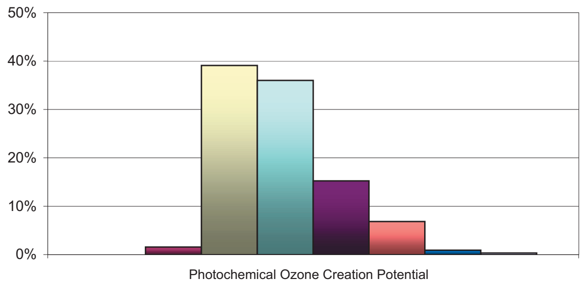


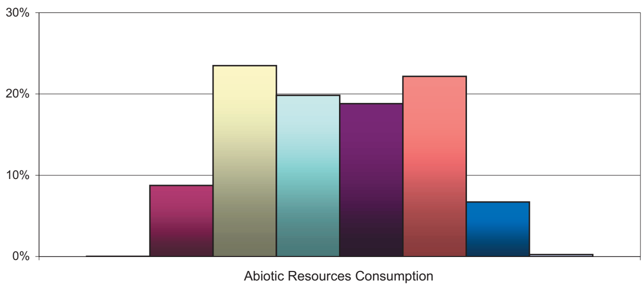


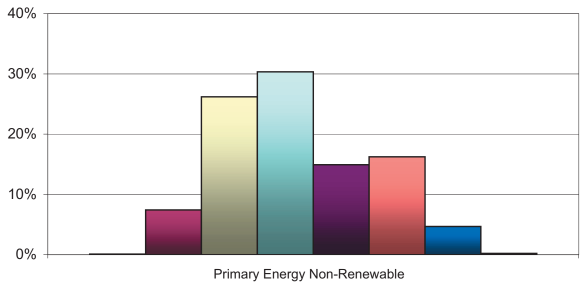






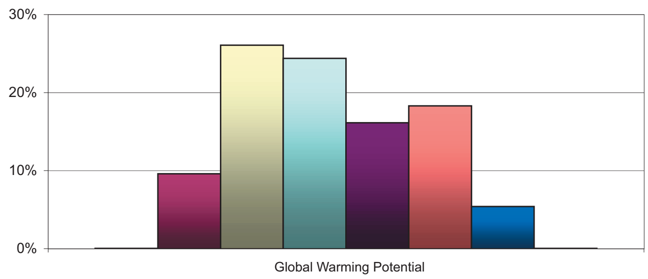


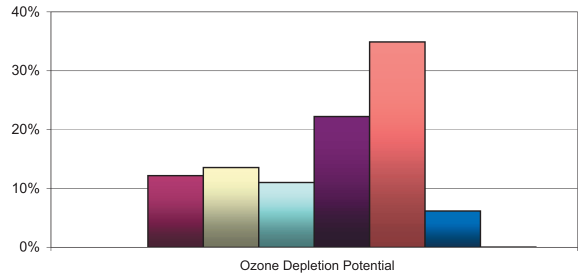


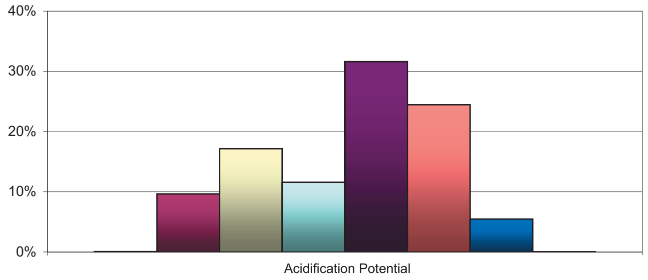


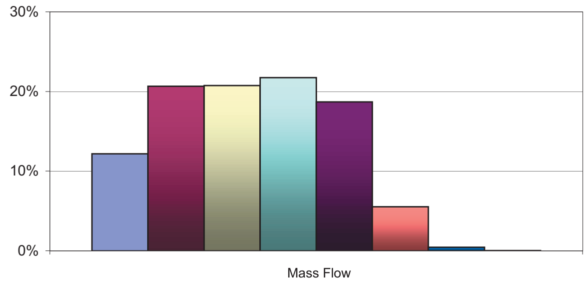
Excavation Foundation Exterior walls Interior walls Floors and ceilings Roof Windows Exterior doors

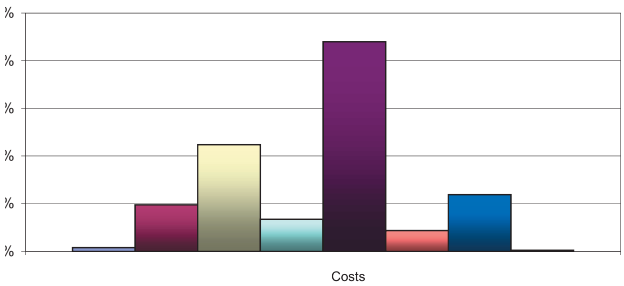
Educational Buildings

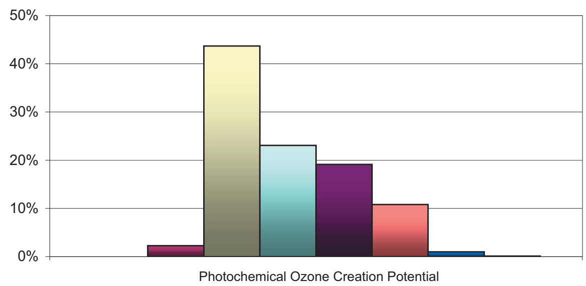


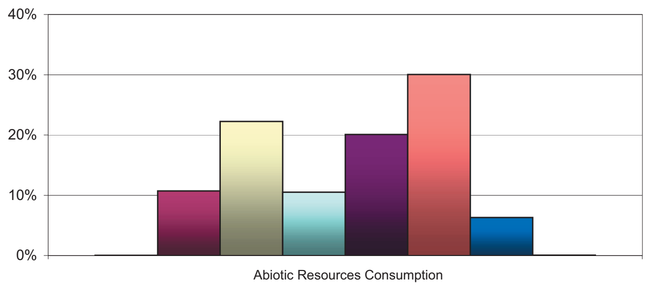


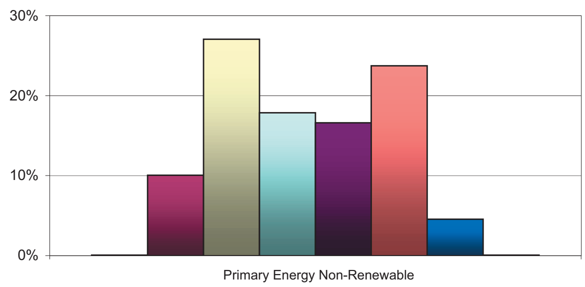






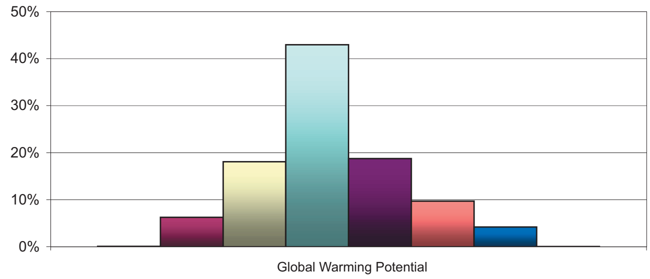


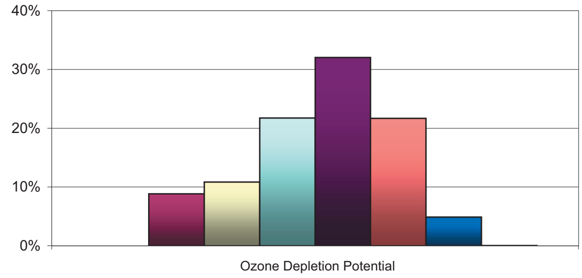


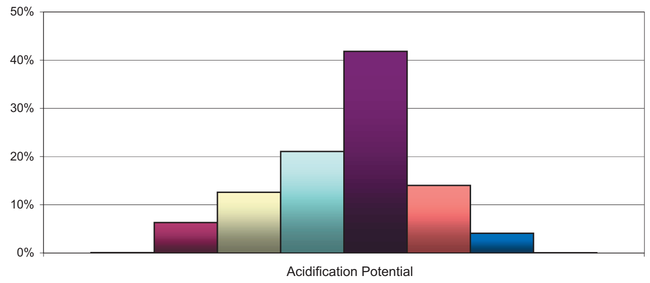


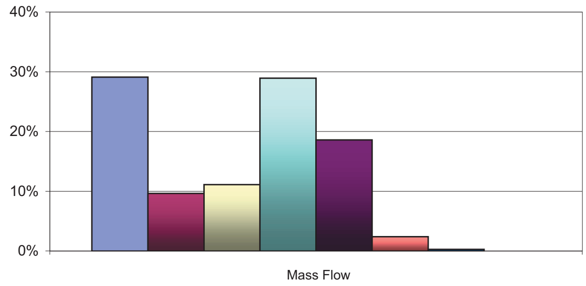
Excavation Foundation Exterior walls Interior walls Floors and ceilings Roof Windows Exterior doors

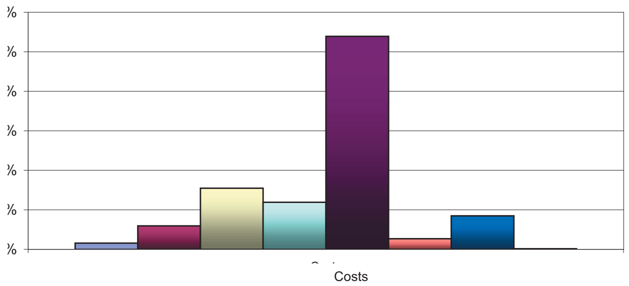
Office Buildings

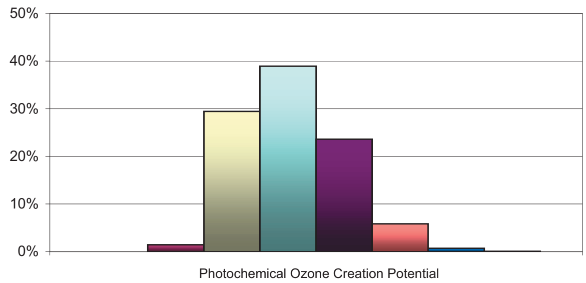


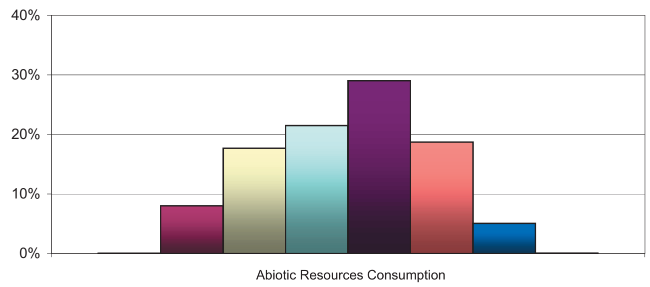


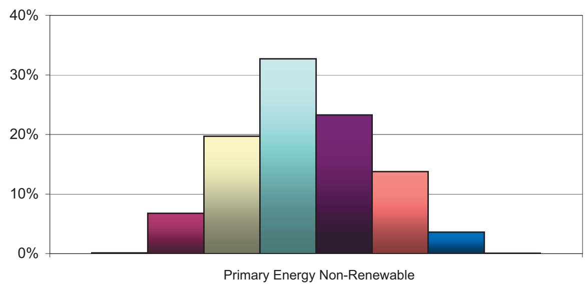










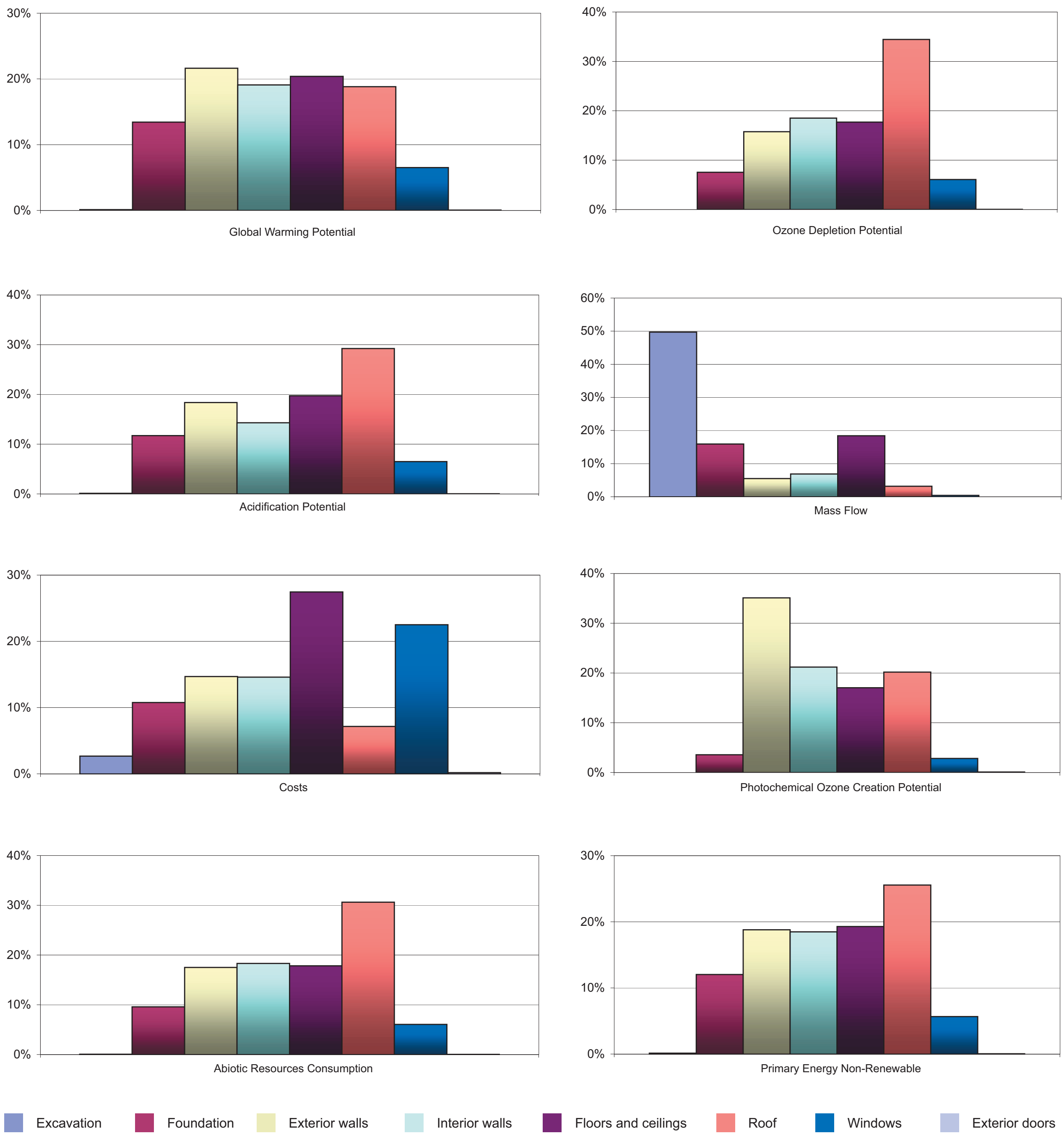


Excavation Foundation Exterior walls Interior walls Floors and ceilings Roof Windows Exterior doors

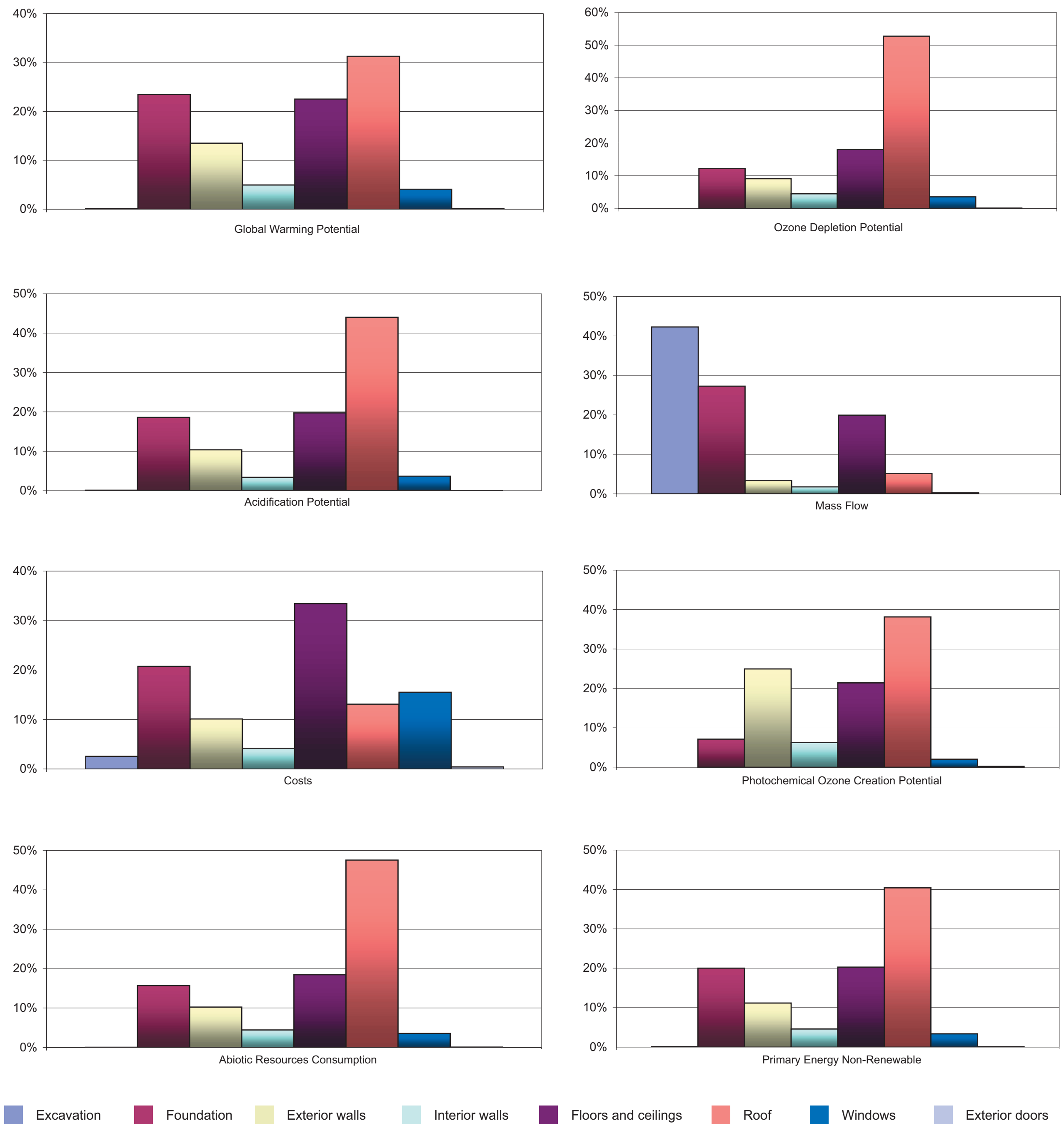
Annex 2

Charts for Sensitivity Analysis D

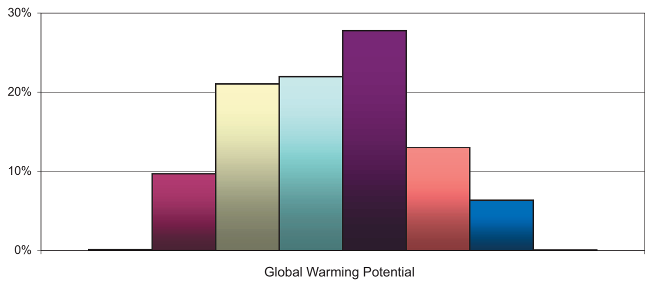
Hospitals

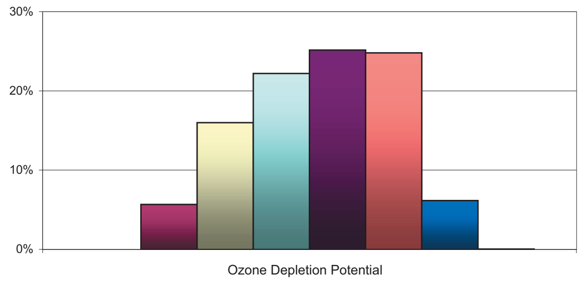

30%
20%
10%
0%
Global Warming Potential
40%
30%
20%
10%
0%
Ozone Depletion Potential
40%
30%
20%
10%
0%
Acidification Potential
60%
50%
40%
30%
20%
10%
0%
Mass Flow
30%
20%
10%
0%
Costs
40%
30%
20%
10%
0%
Photochemical Ozone Creation Potential
40%
30%
20%
10%
0%
Abiotic Resources Consumption
30%
20%
10%
0%
Primary Energy Non-Renewable
Excavation
Foundation
Exterior walls
Interior walls
Floors and ceilings
Roof
Windows
Exterior doors

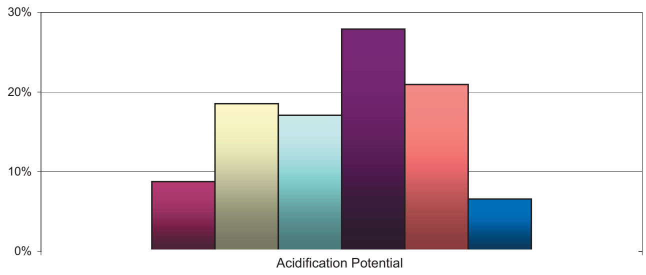
Industry and Trade Buildings

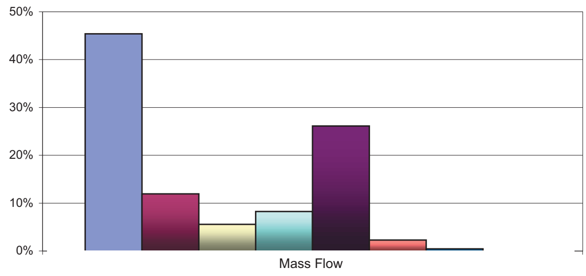


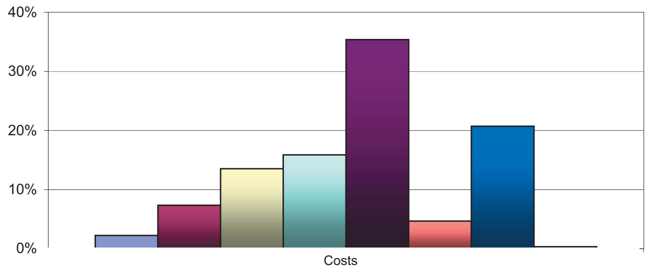
Hostels and Student Habitations

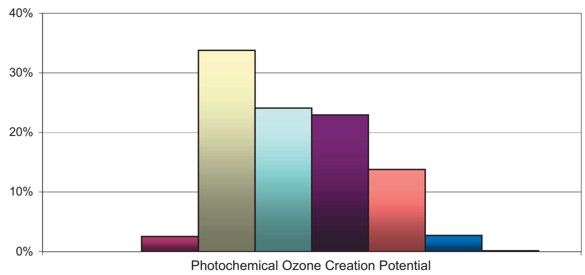


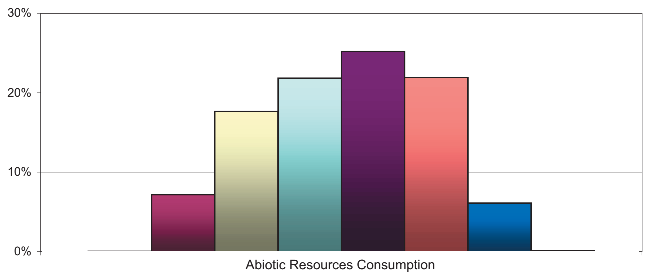


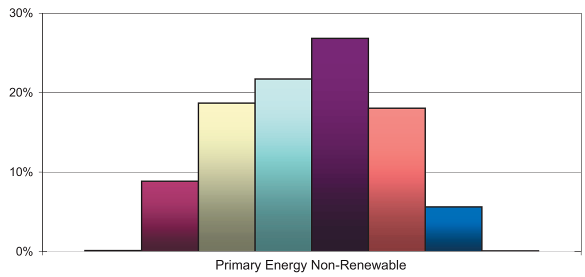






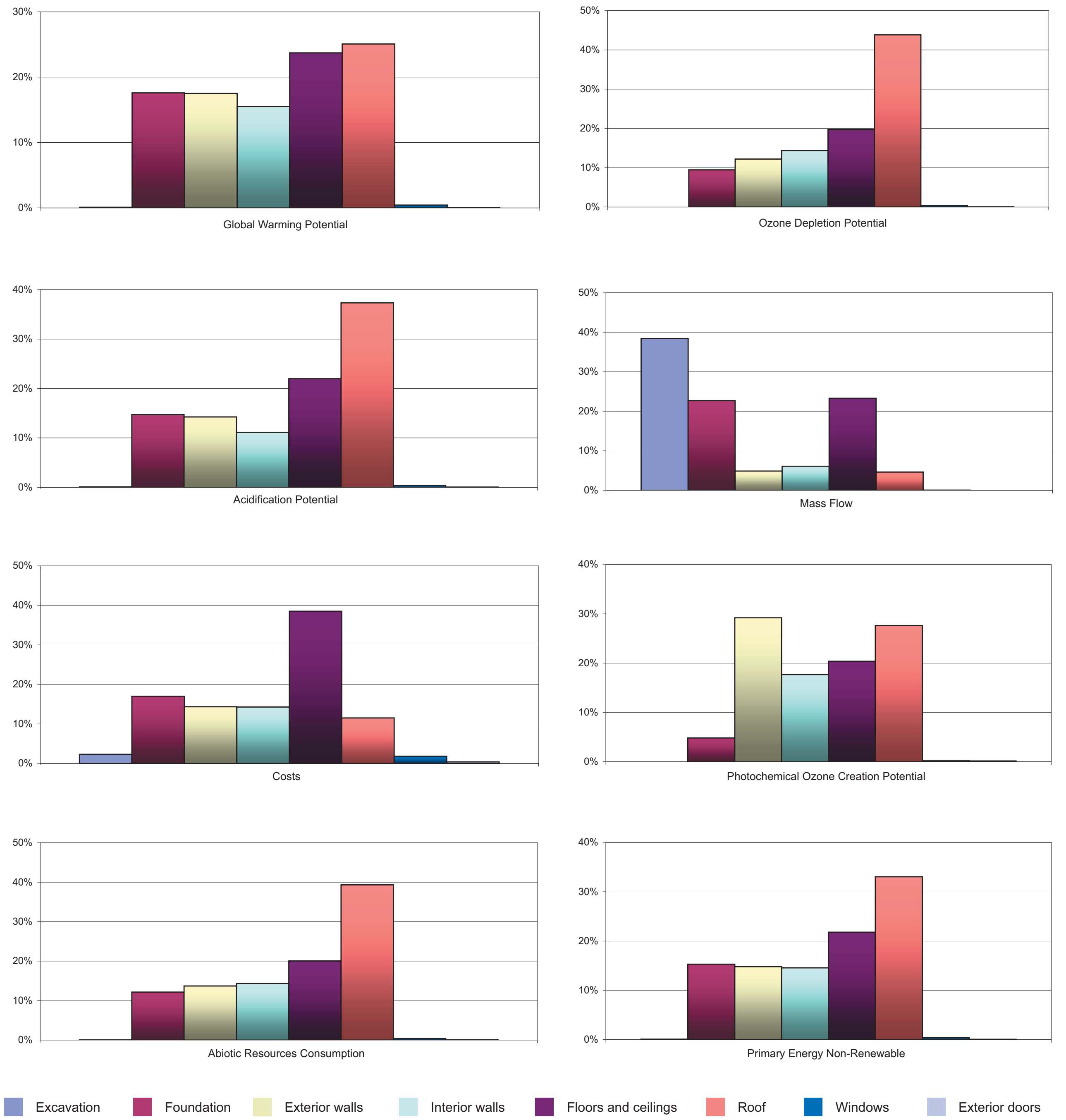




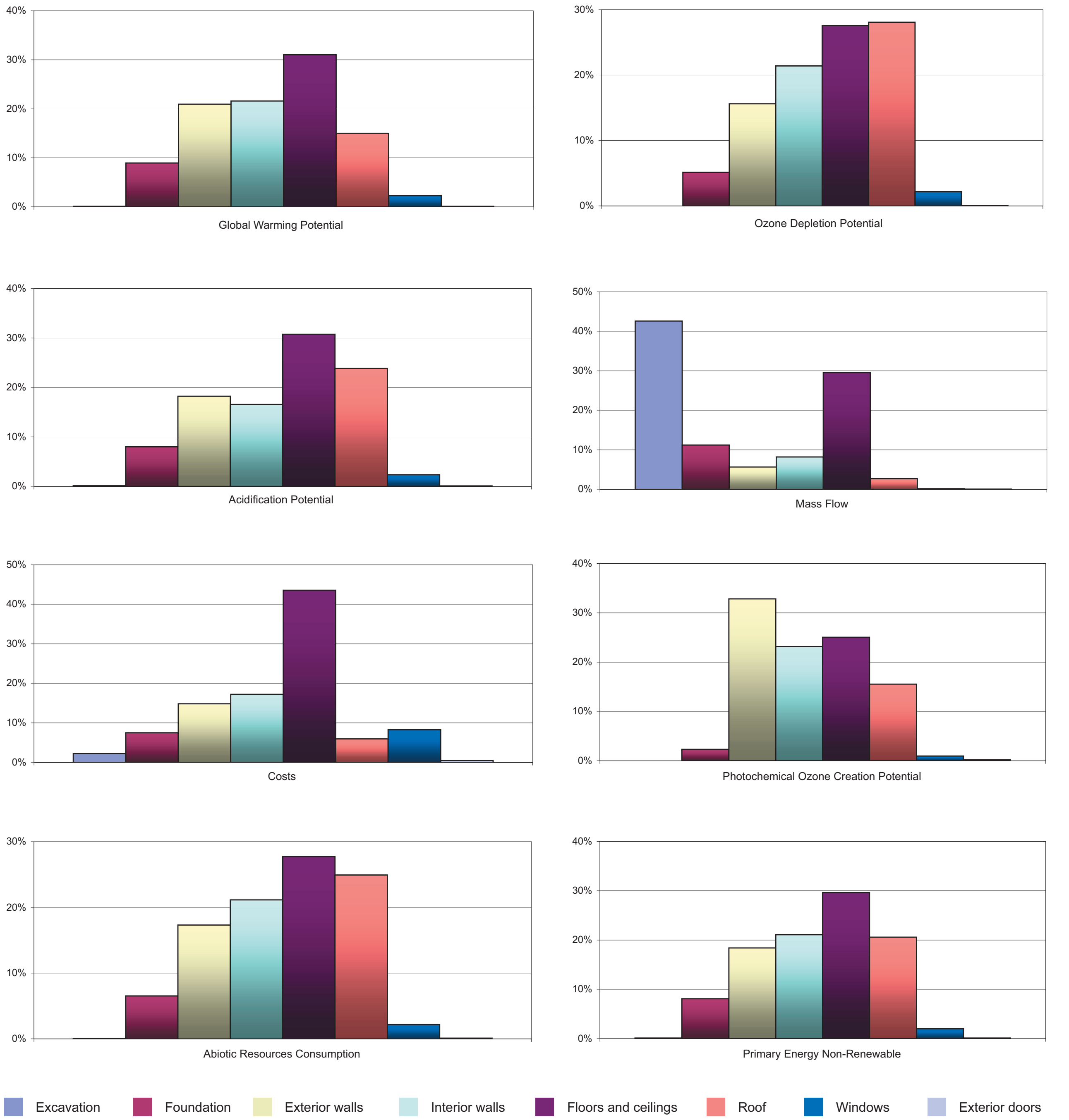


Excavation Foundation Exterior walls Interior walls Floors and ceilings Roof Windows Exterior doors

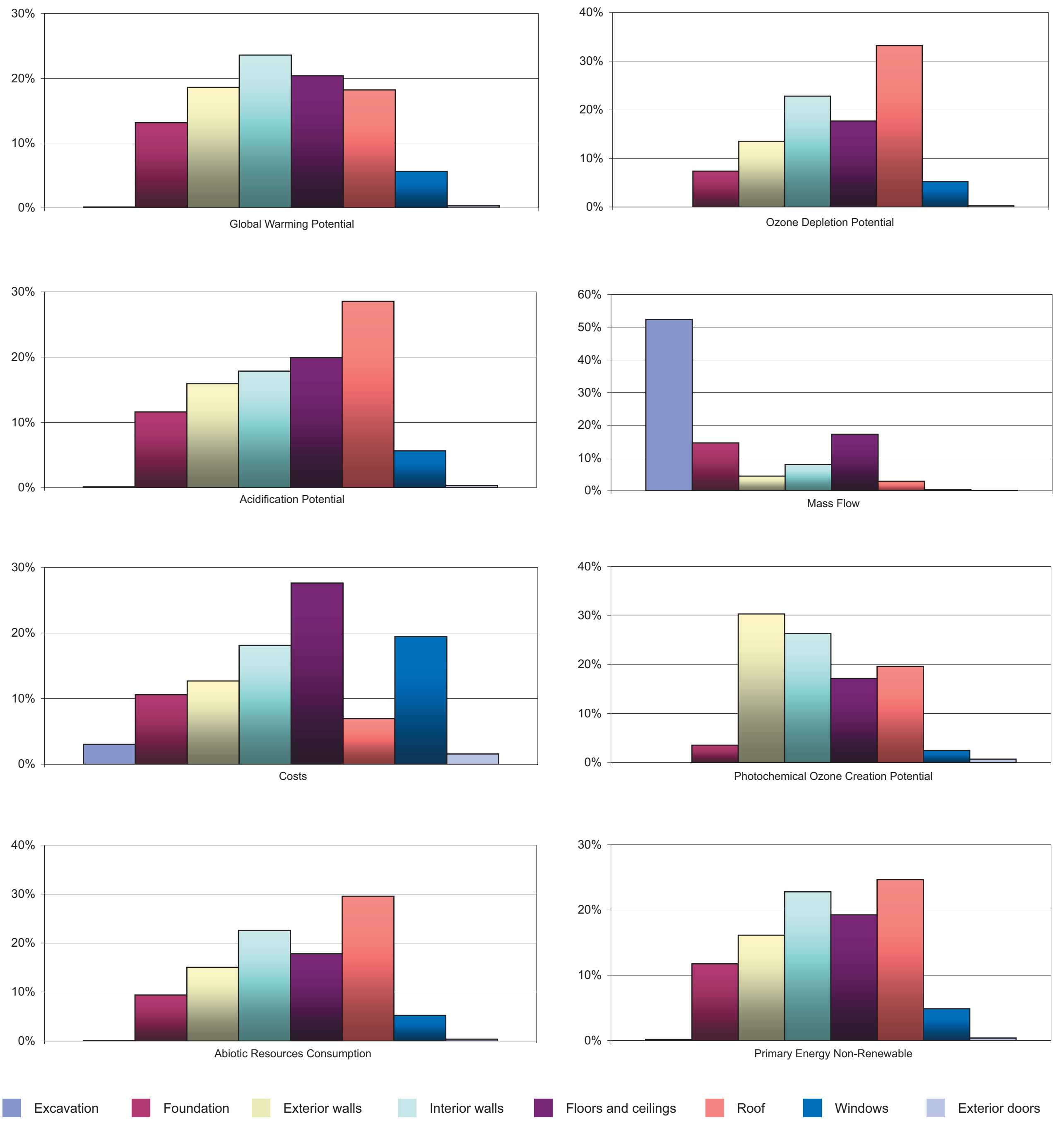
Factory Buildings



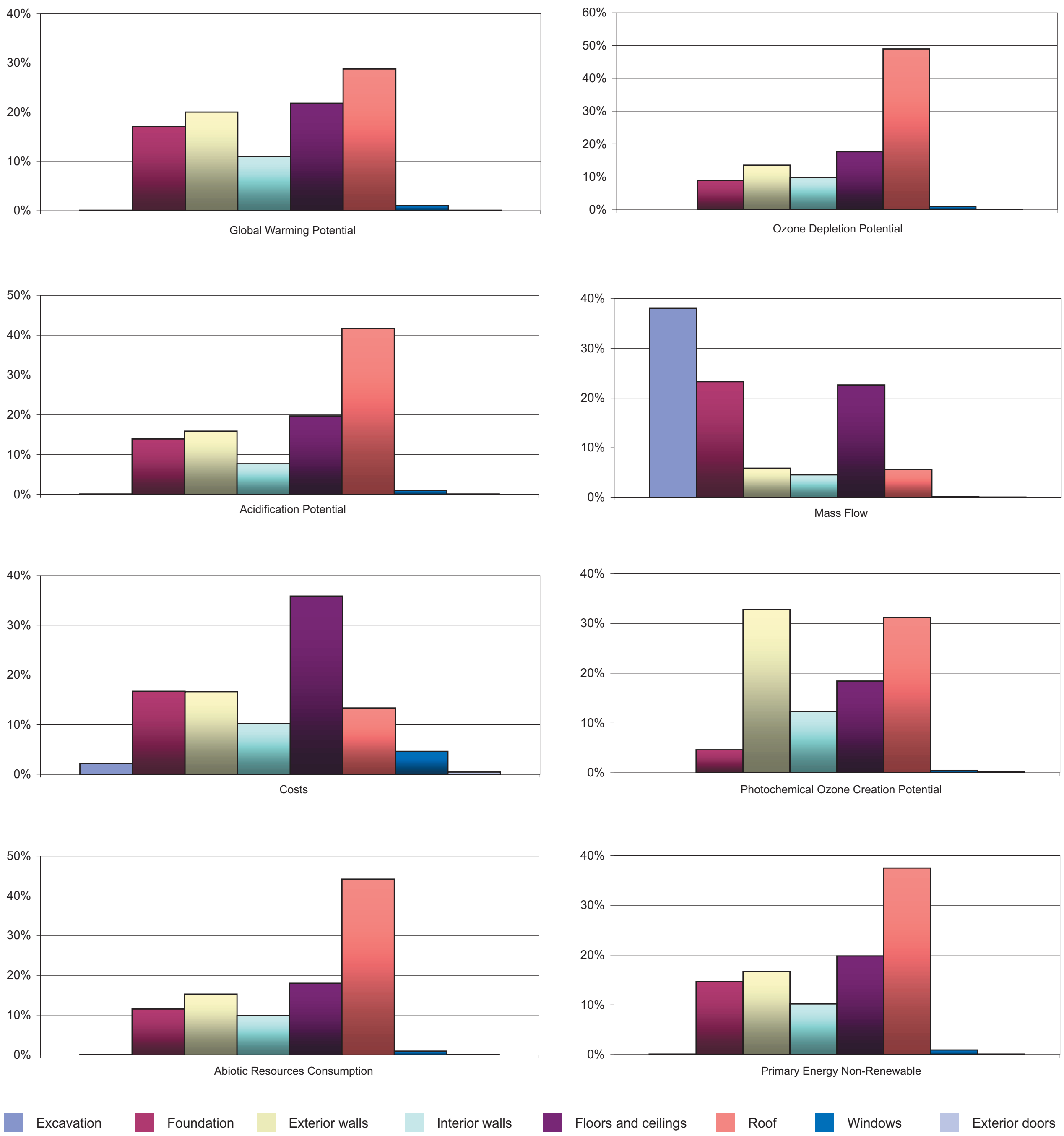
Multiple Family Housing



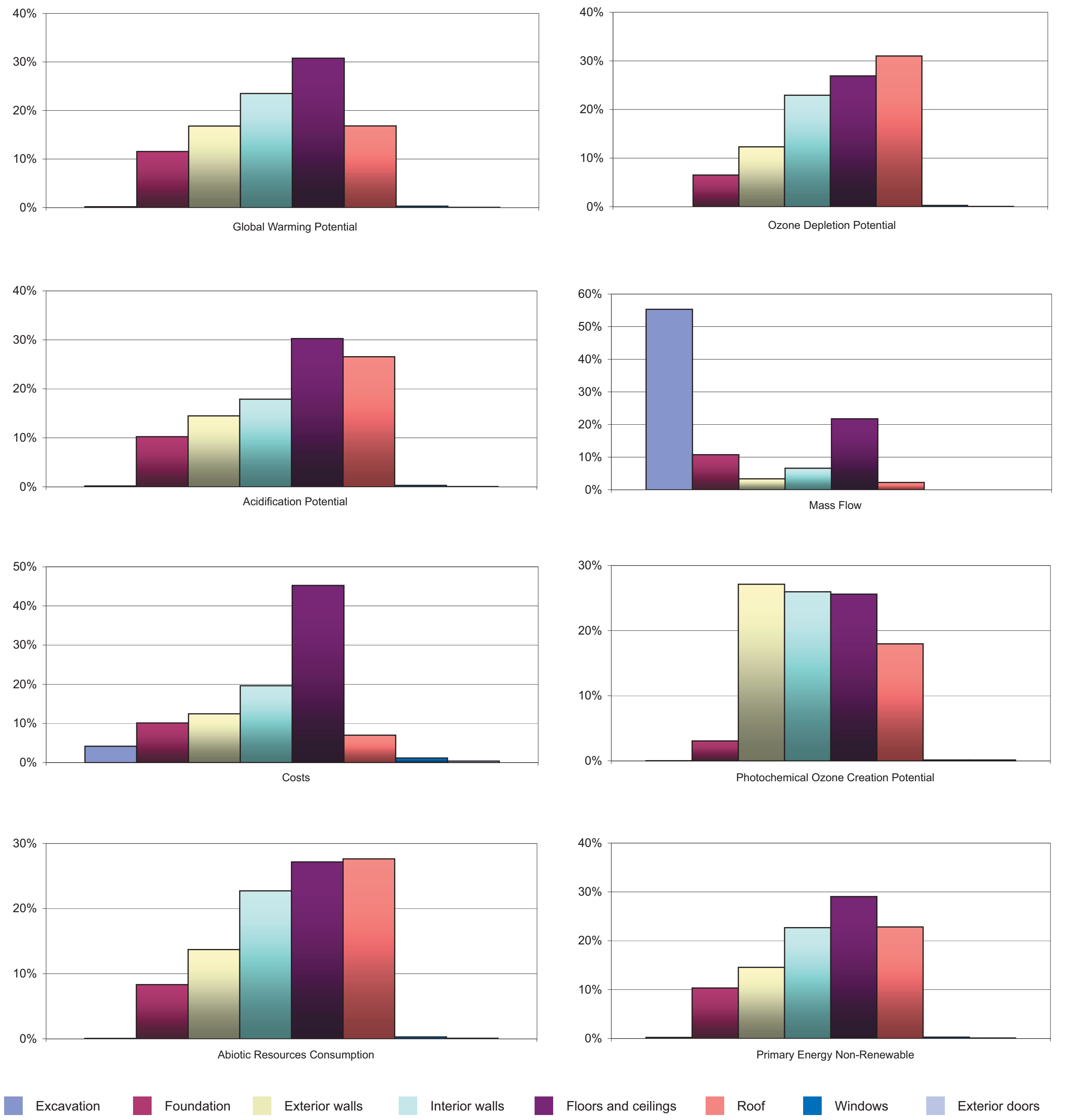
One Family Housing



Educational Buildings



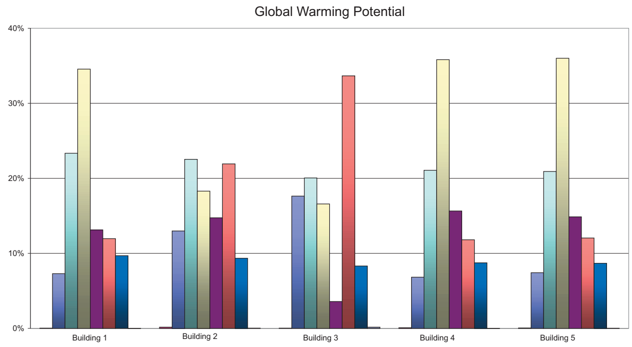
Office Buildings

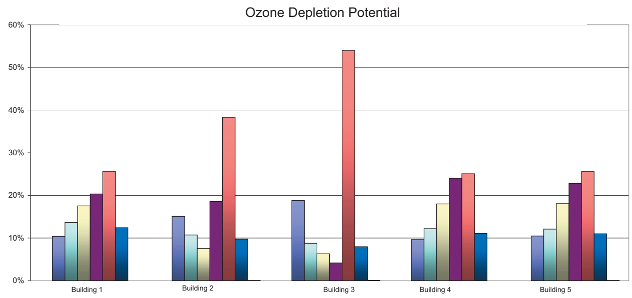


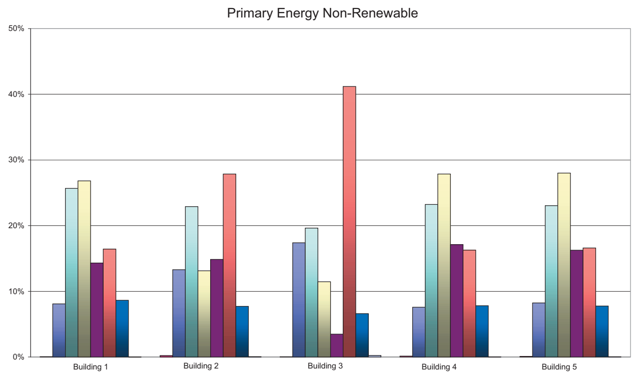
Annex 3

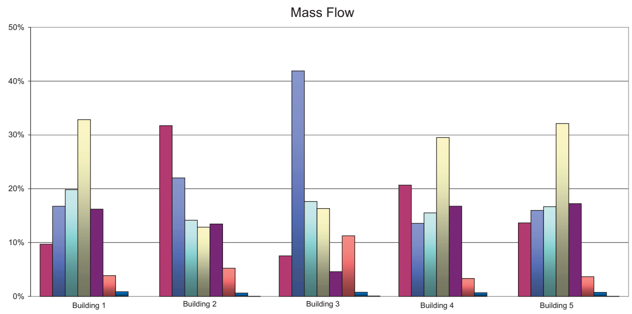
Charts for Sensitivity Analysis E

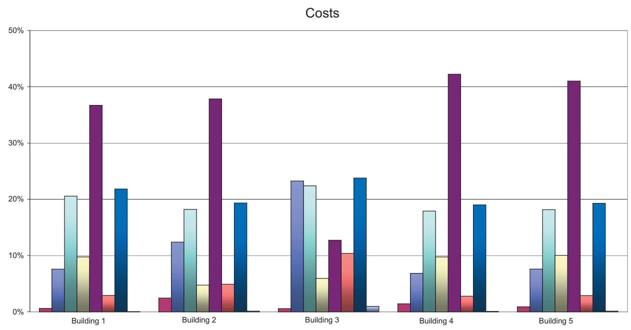
Hospitals





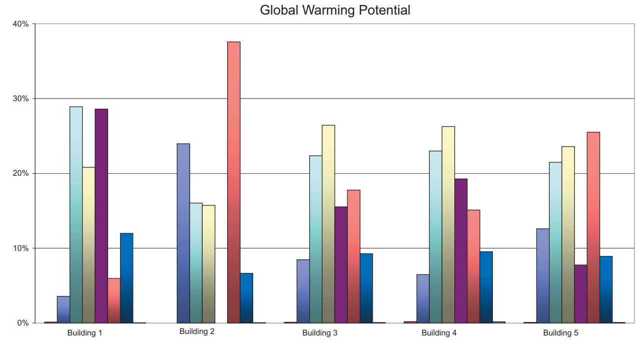


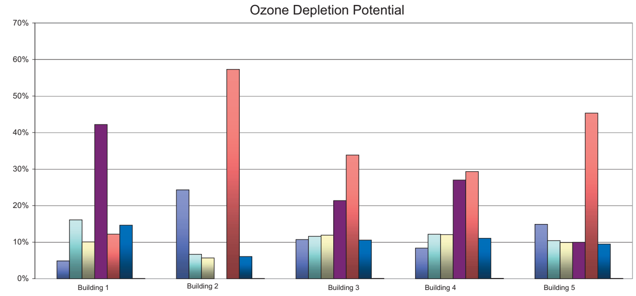


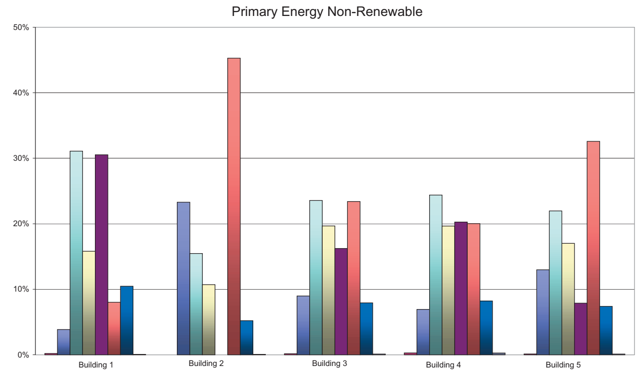


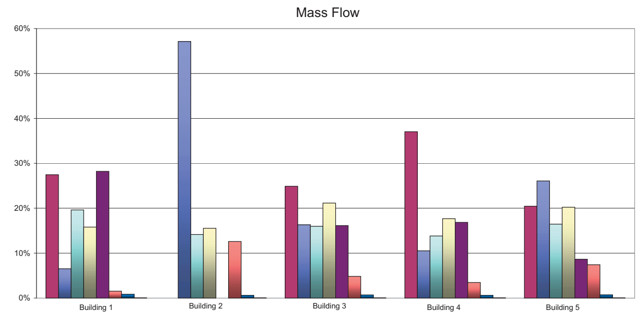
Excavation
Foundation
Exterior Walls
Interior Walls
Floors and Ceilings
Roof
Windows
Exterior Doors

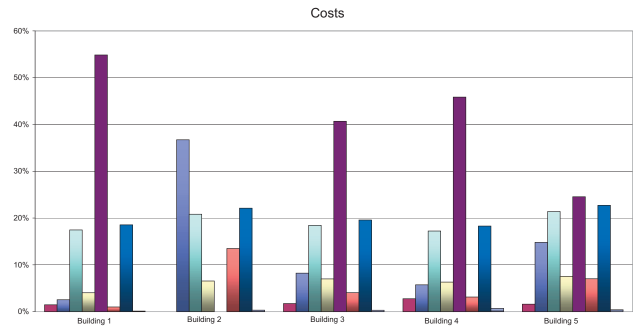
Industry and Trade Buildings





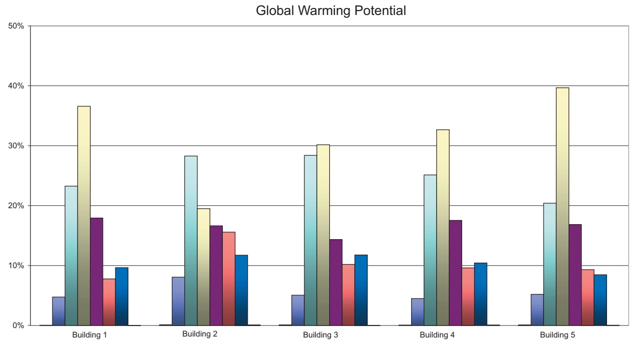


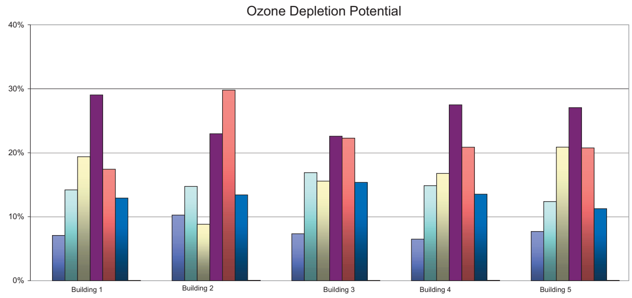


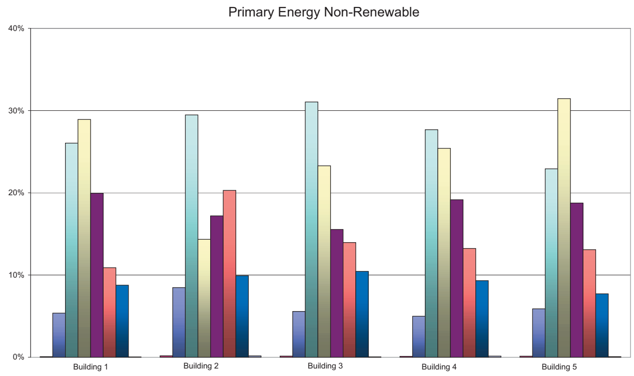


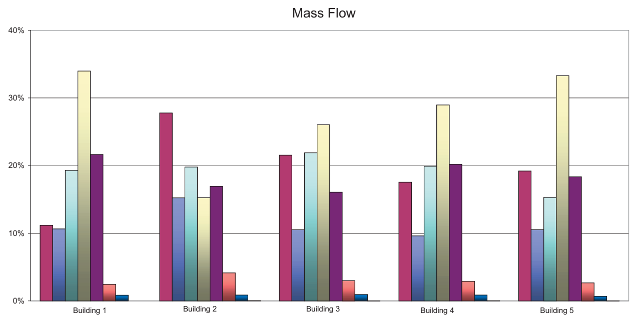
Excavation
Foundation
Exterior Walls
Interior Walls
Floors and Ceilings
Roof
Windows
Exterior Doors

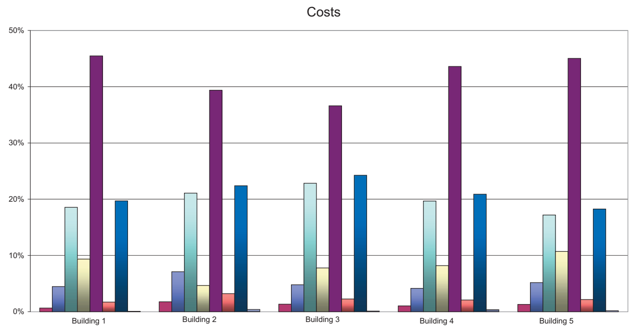
Hostels and Student Habitations

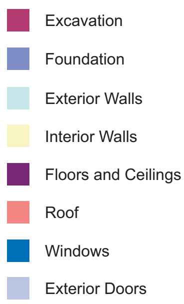




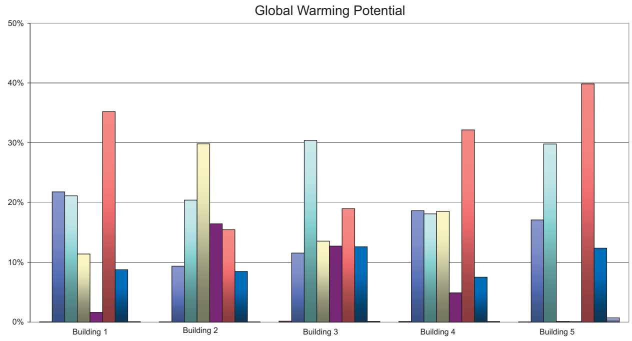


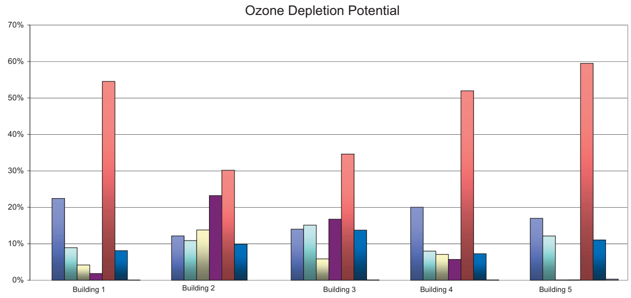


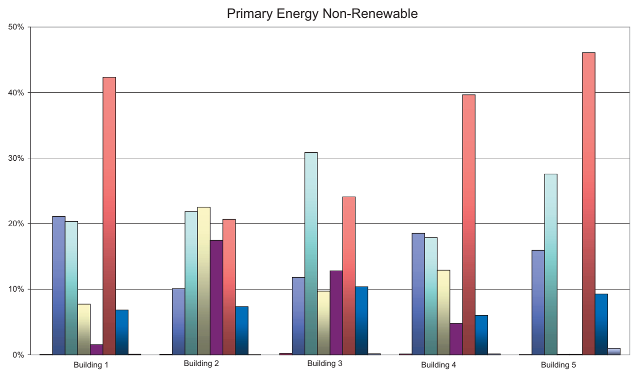


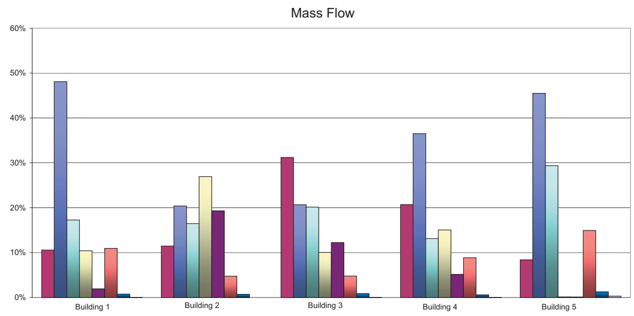


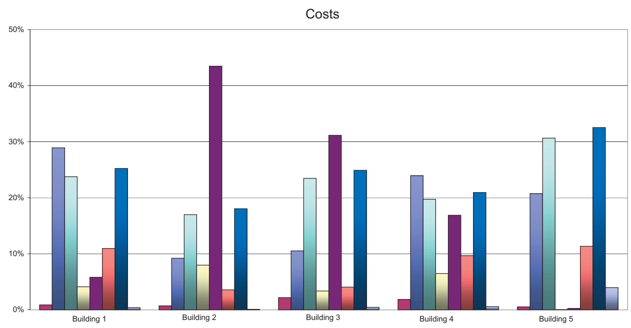
Factory Buildings





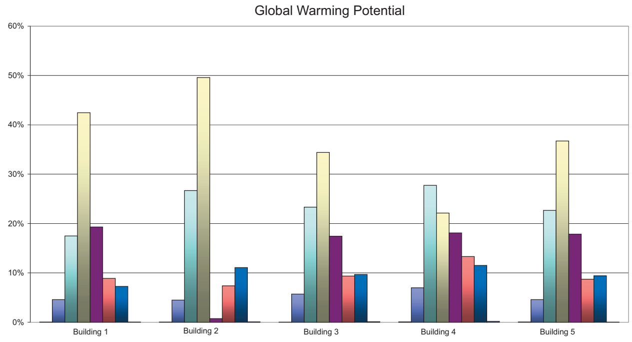


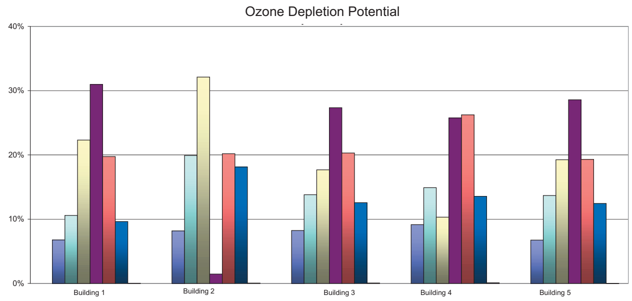


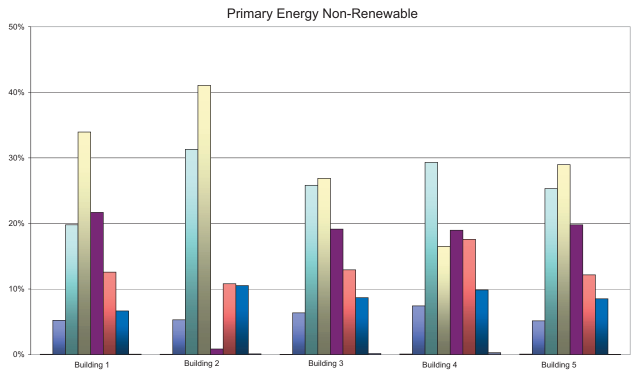


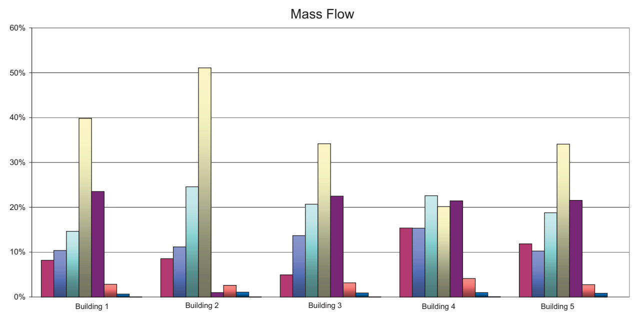
- Excavation
- Foundation
- Exterior Walls
- Interior Walls
- Floors and Ceilings
- Roof
- Windows
- Exterior Doors

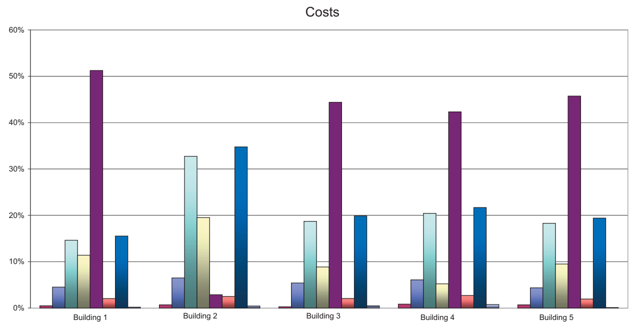
Multiple Family Housing





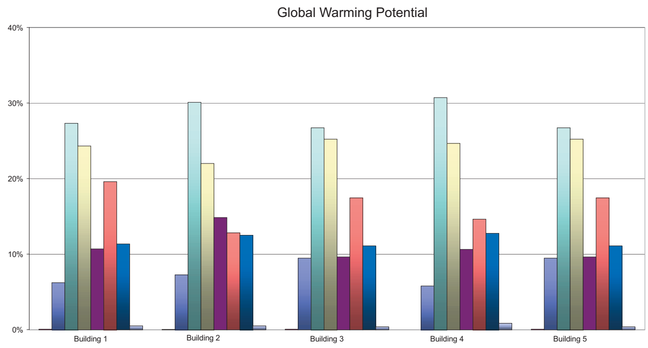


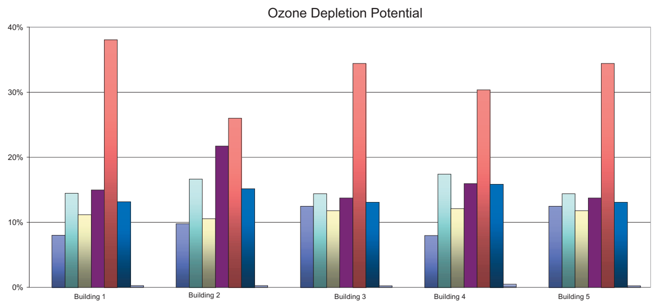


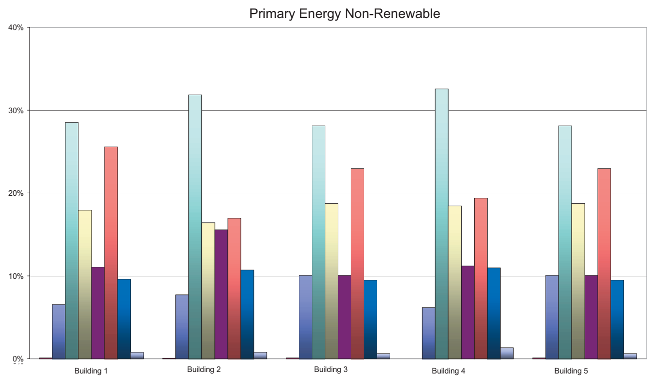


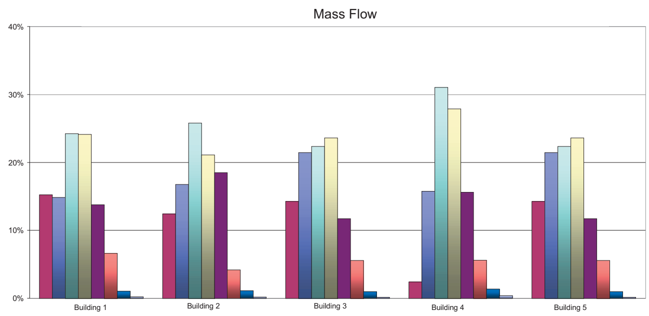
- Excavation
- Foundation
- Exterior Walls
- Interior Walls
- Floors and Ceilings
- Roof
- Windows
- Exterior Doors

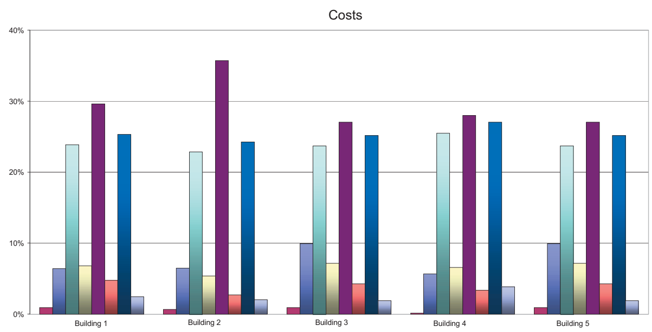
One Family Housing





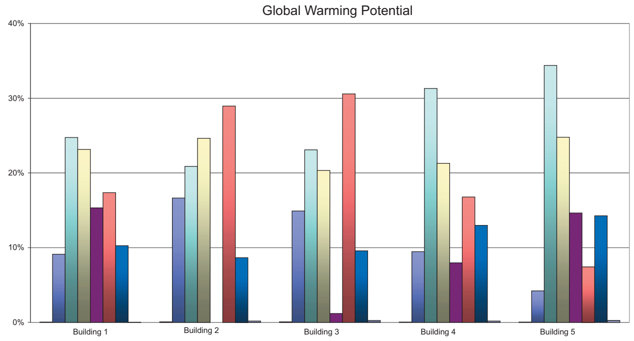


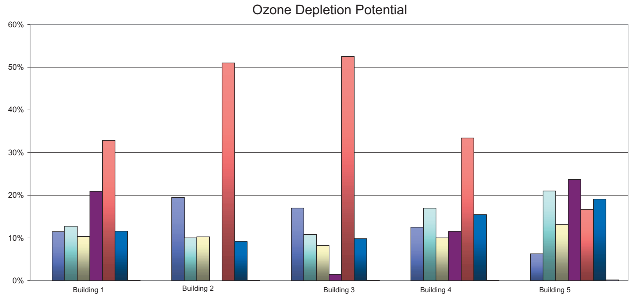


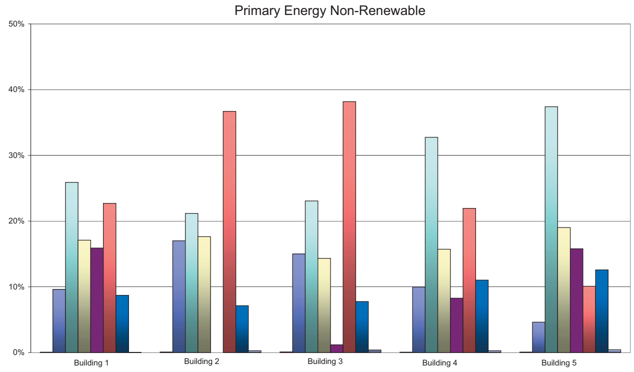


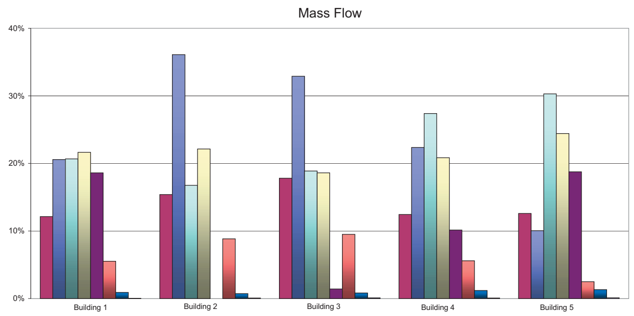
- Excavation
- Foundation
- Exterior Walls
- Interior Walls
- Floors and Ceilings
- Roof
- Windows
- Exterior Doors

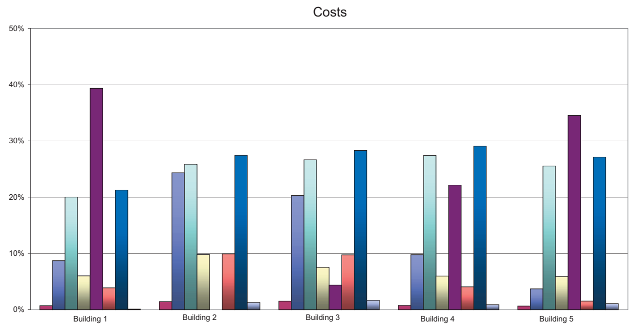
Educational Buildings





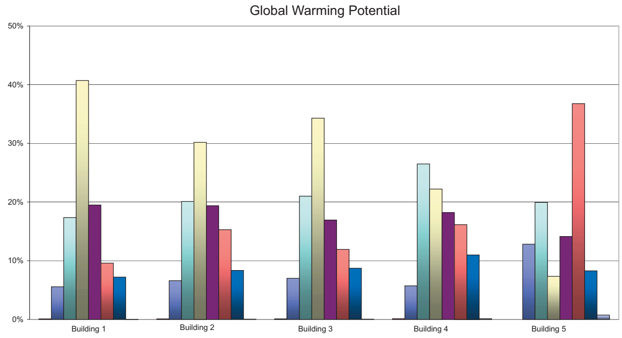


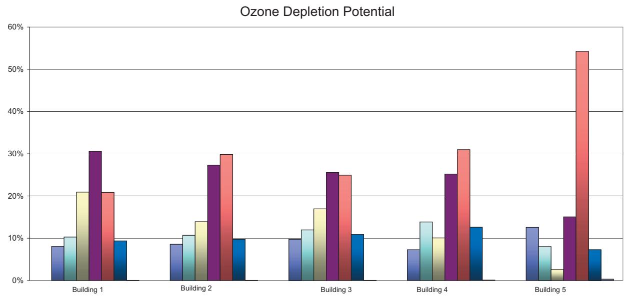


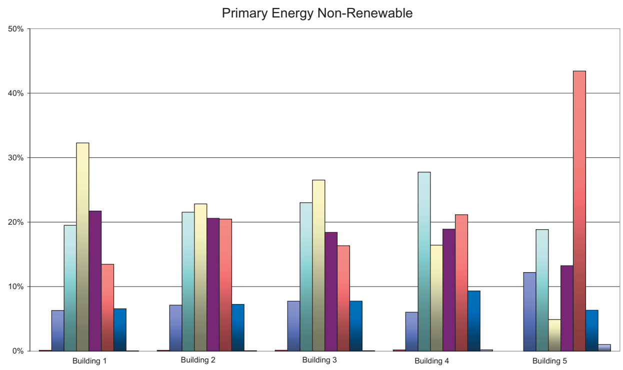


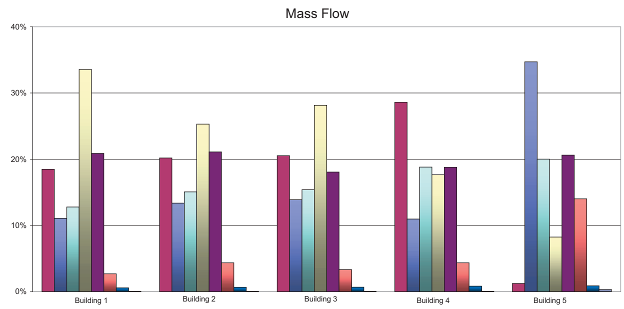
- Excavation
- Foundation
- Exterior Walls
- Interior Walls
- Floors and Ceilings
- Roof
- Windows
- Exterior Doors

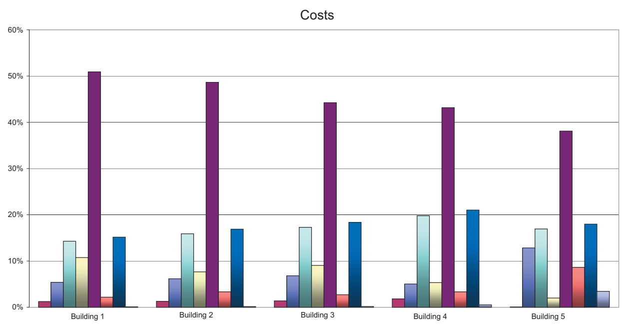
Office Buildings









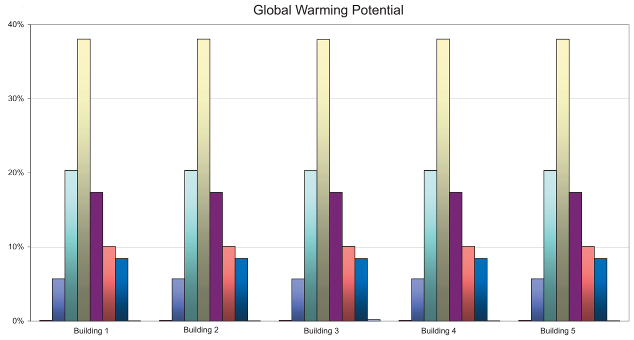


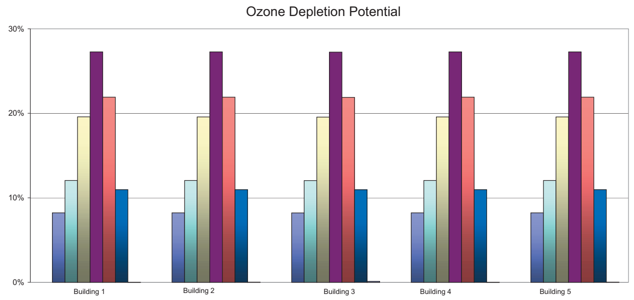
- Excavation
- Foundation
- Exterior Walls
- Interior Walls
- Floors and Ceilings
- Roof
- Windows
- Exterior Doors

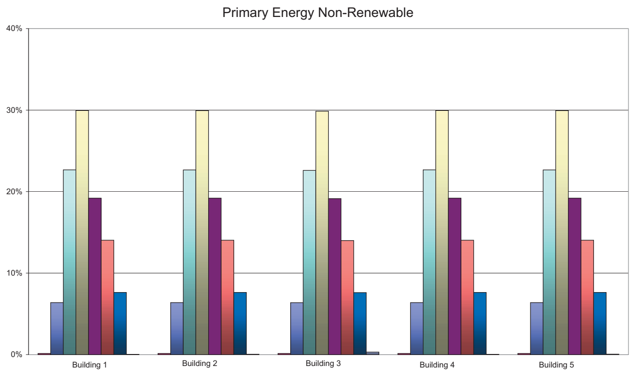
Annex 4

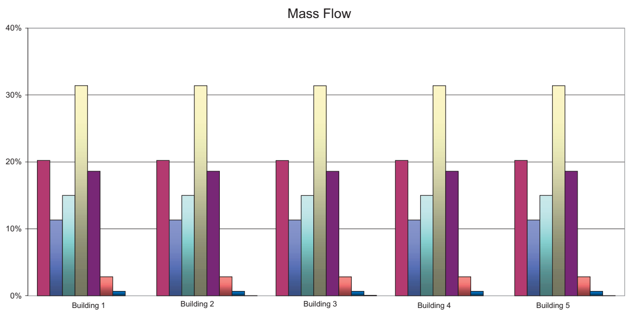
Charts for Sensitivity Analysis F

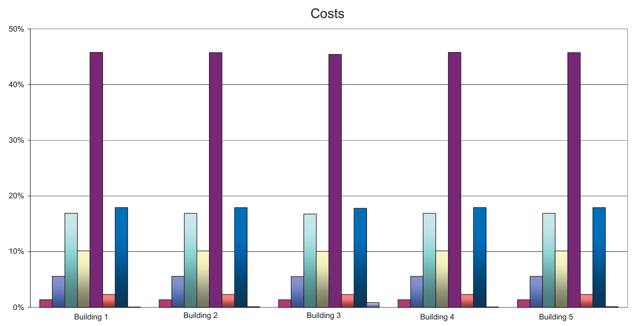
Hospitals

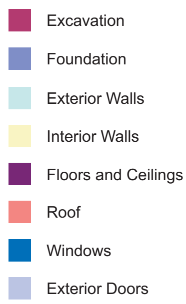

Global Warming Potential
40%
30%
20%
10%
0%
Building 1
Building 2
Building 3
Building 4
Building 5


Ozone Depletion Potential
30%
20%
10%
0%
Building 1
Building 2
Building 3
Building 4
Building 5

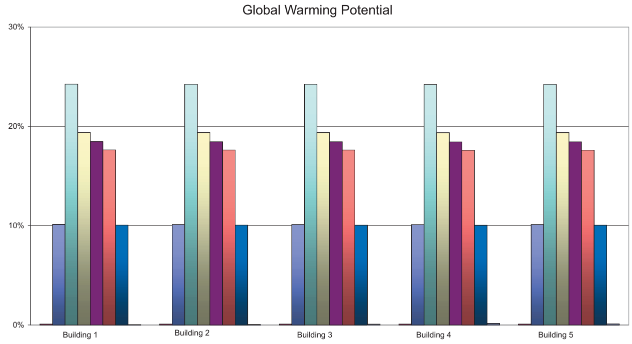

Primary Energy Non-Renewable
40%
30%
20%
10%
0%
Building 1
Building 2
Building 3
Building 4
Building 5

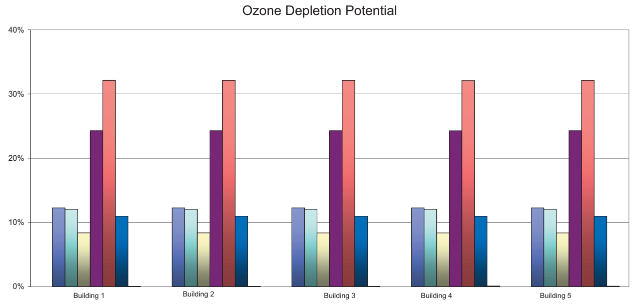

Mass Flow
40%
30%
20%
10%
0%
Building 1
Building 2
Building 3
Building 4
Building 5

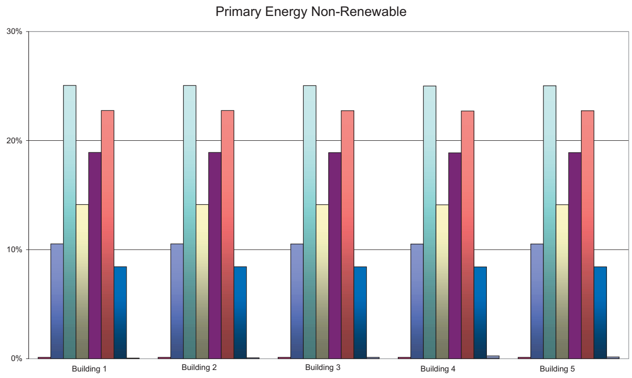

Costs
50%
40%
30%
20%
10%
0%
Building 1
Building 2
Building 3
Building 4
Building 5

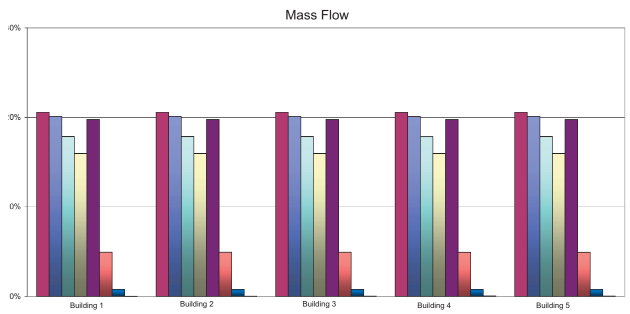

Excavation
Foundation
Exterior Walls
Interior Walls
Floors and Ceilings
Roof
Windows
Exterior Doors

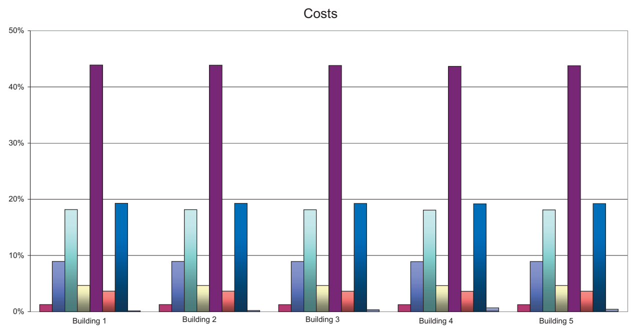
Industry and Trade Buildings











- Excavation
- Foundation
- Exterior Walls
- Interior Walls
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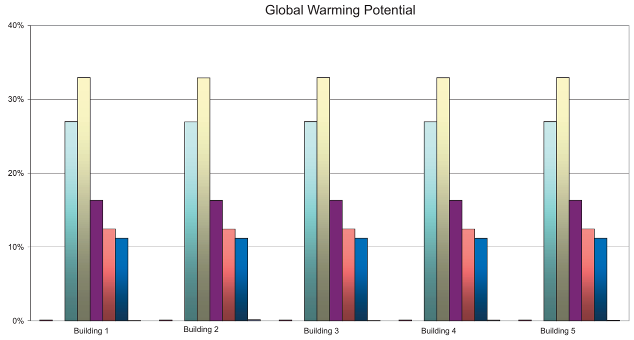
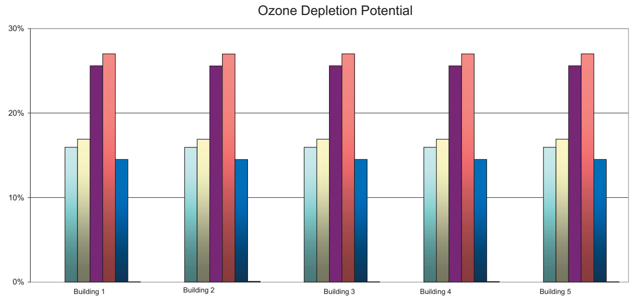
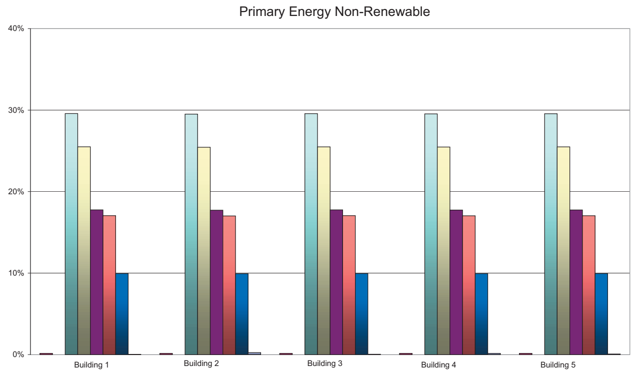
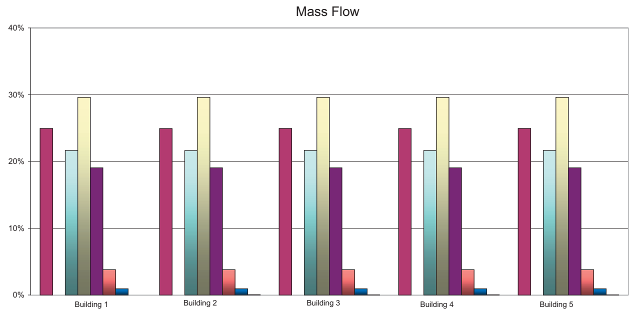
- Windows
- Exterior Doors

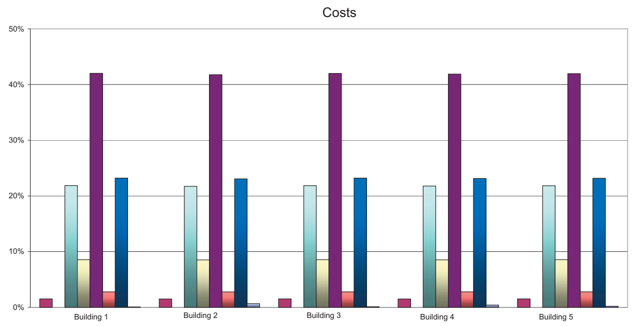
Hostels and Student Habitations











Excavation
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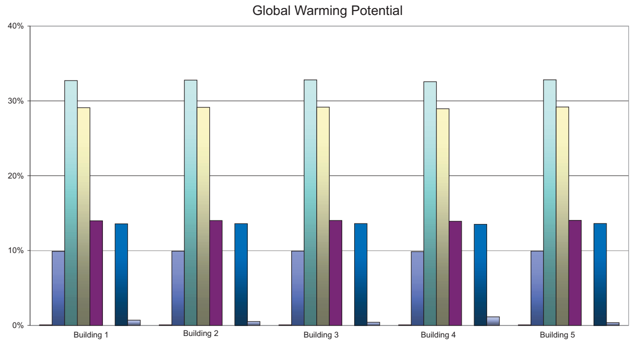
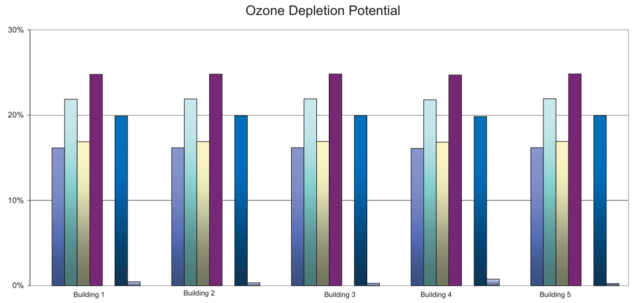
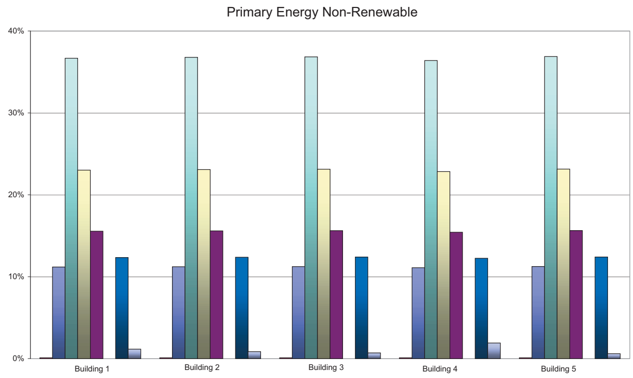
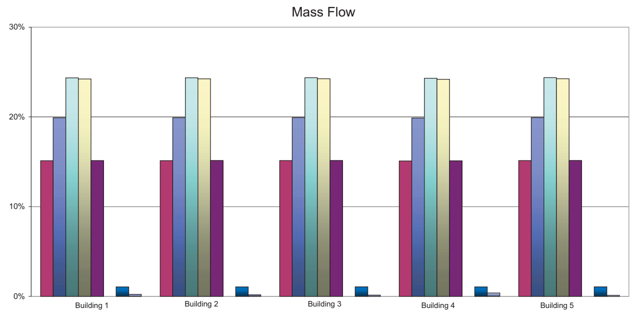
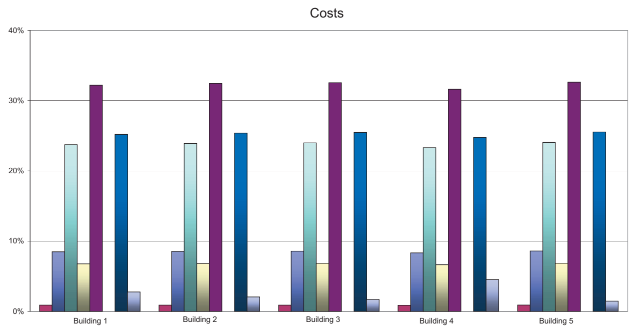
Factory Buildings











- Excavation
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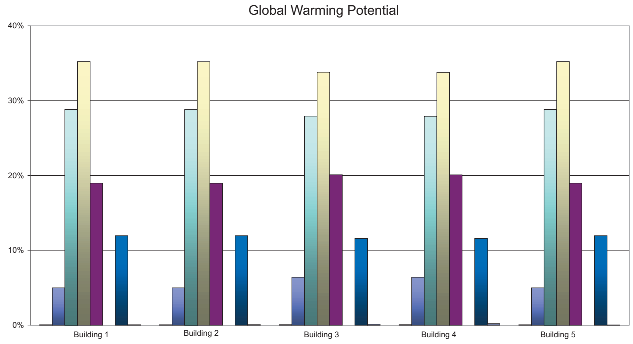
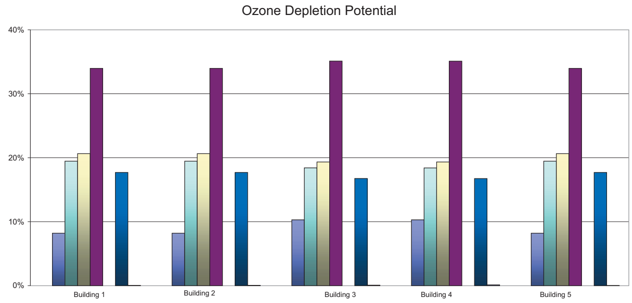
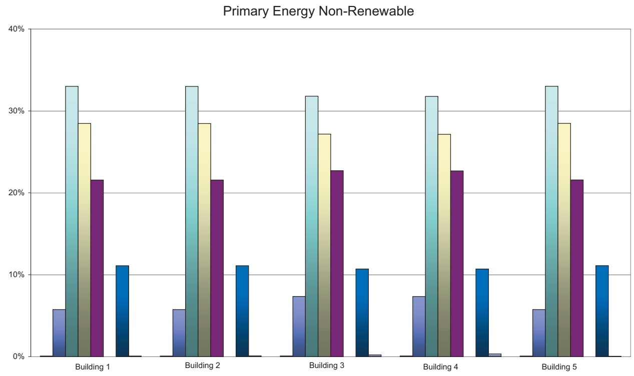
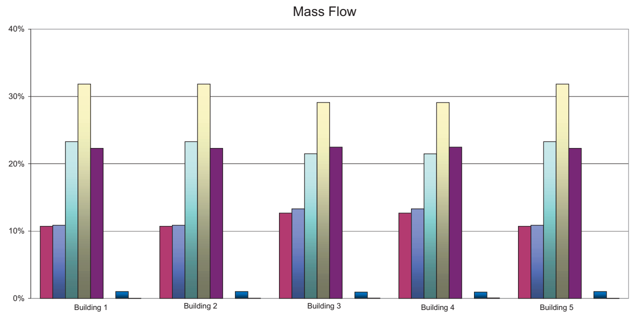
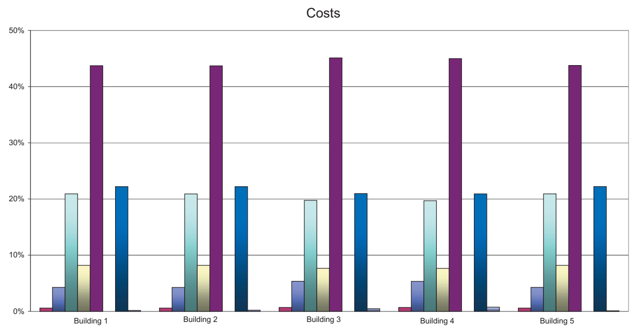
Multiple Family Housing

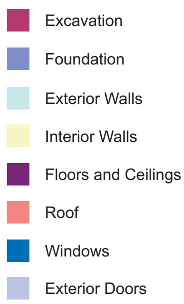




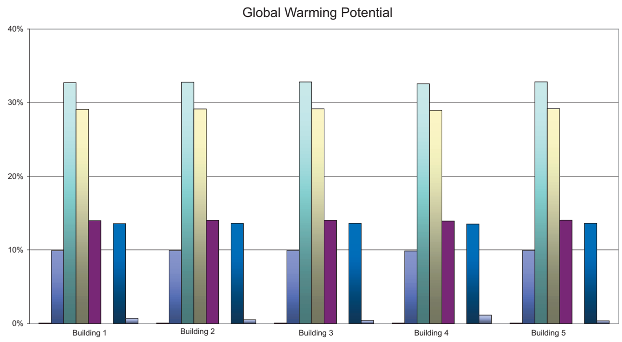


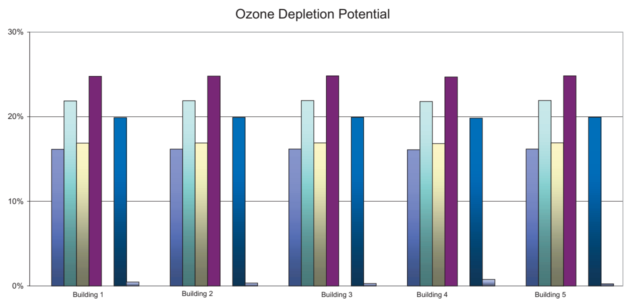


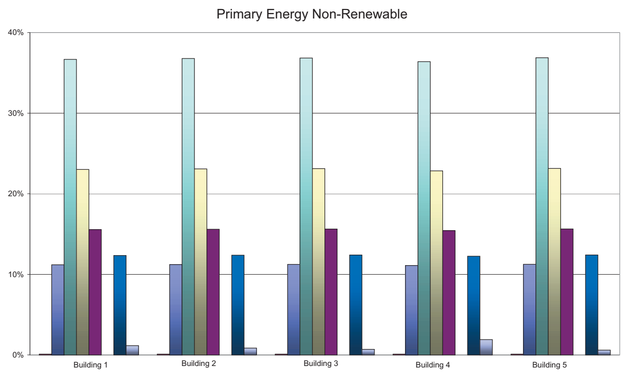


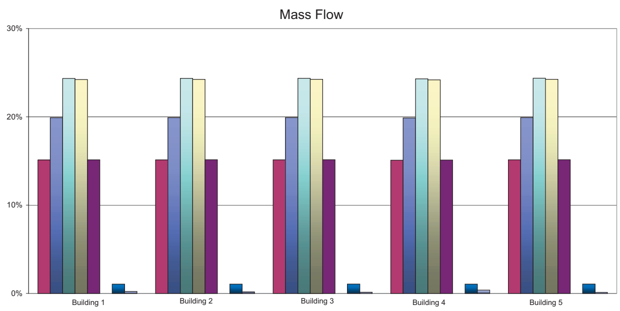


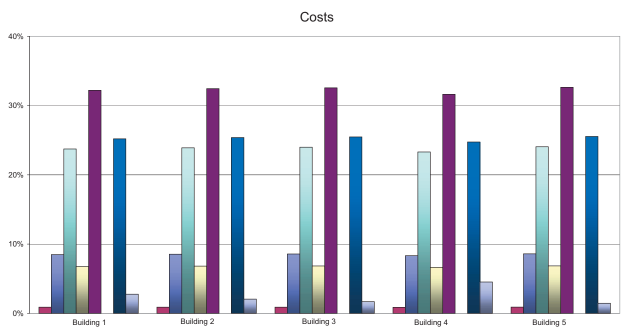
One Family Housing











- Excavation
- Foundation
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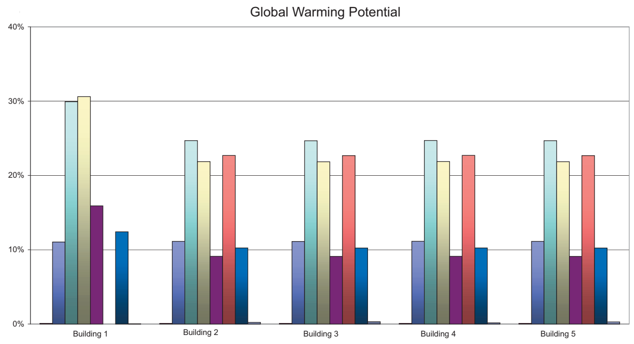
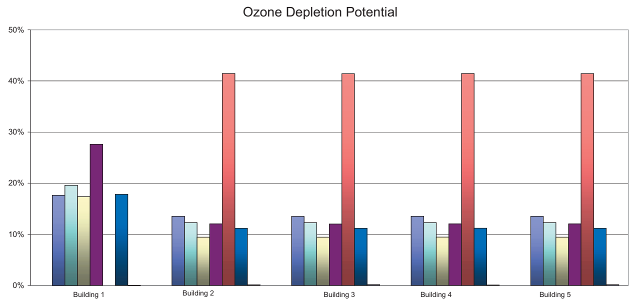
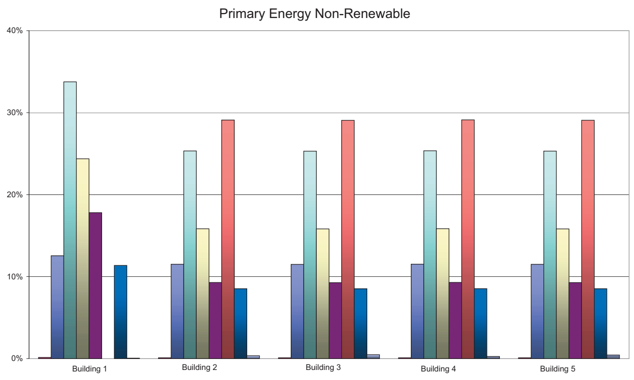
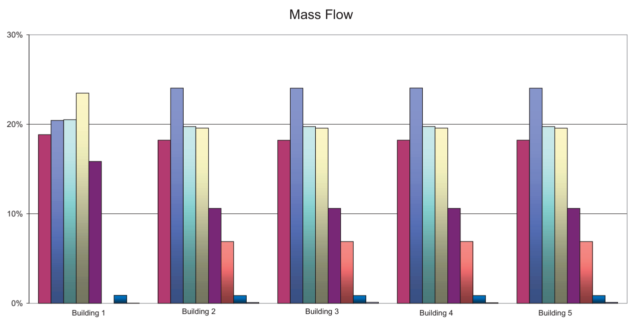
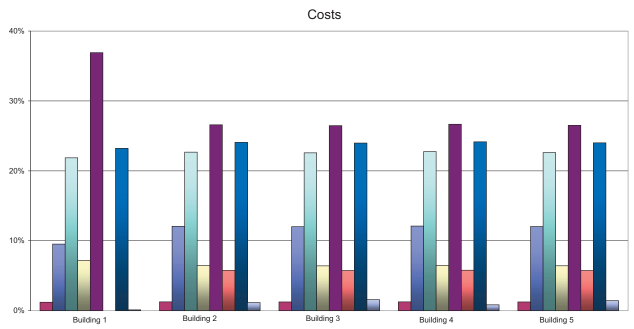
Educational Buildings

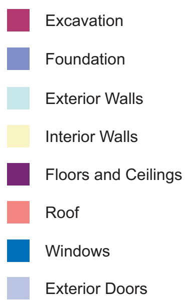




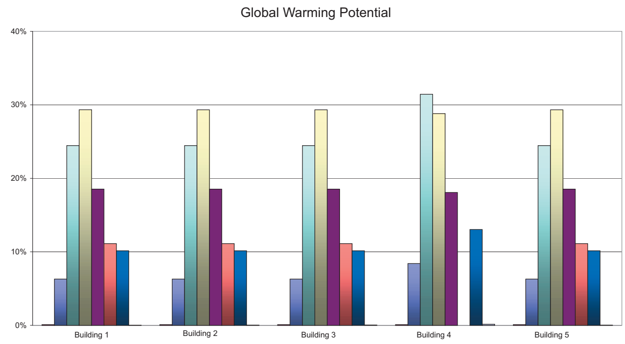


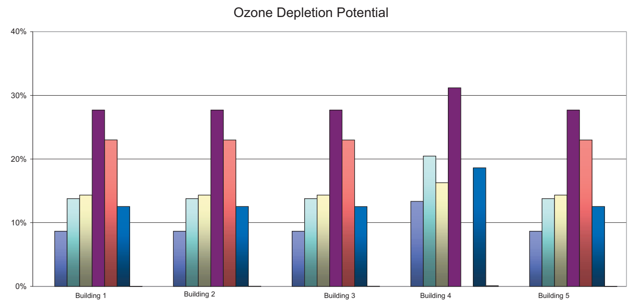


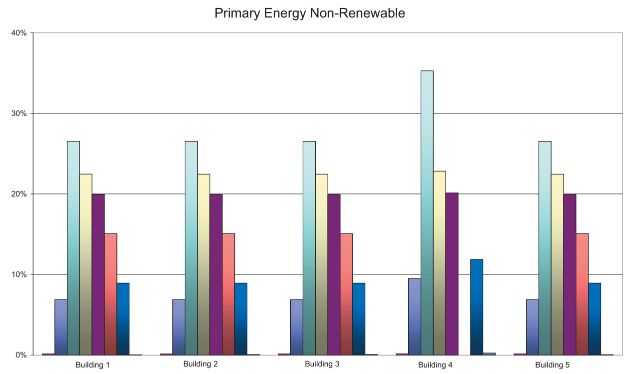


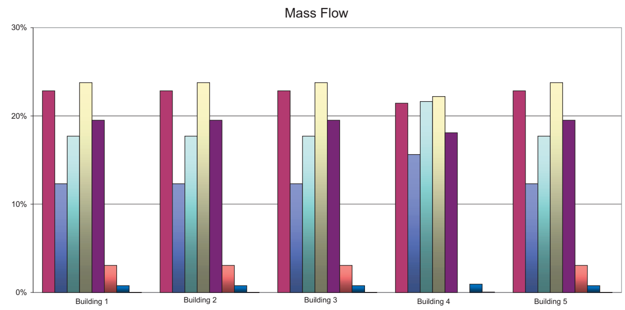


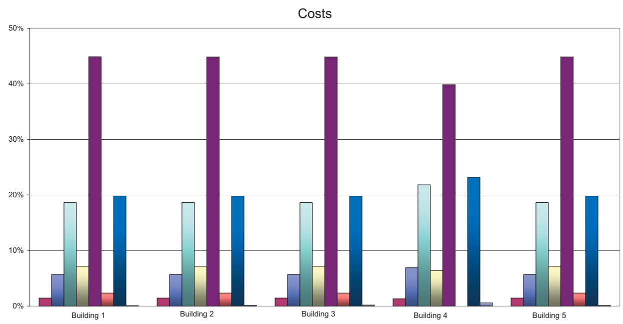
Office Buildings











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Annex 5

Description of STILCAB

One aim of the thesis is to obtain a simplified method for the life cycle analysis of buildings, a prototype has been developed to illustrate the possibilities of such a method. The following figures are screenshots of Stilcab. They allow the reader to distinguish what the necessary input data are and what results such a method can provide.

I. Description of the Stilcab prototype

1.1. Stilcab‘s objectives

STILCAB is a simplified tool for the analysis of the life cycle of buildings. It was developed by the Institute für Industrielle Bauproduktion (ifib) at the University of Karlsruhe.
The basis of this software is Legep, which was also developed by the Institute, as well as the data base of structural construction components: sirAdos.

In comparison to most building life cycle analysis software, STILCAB has two principal advantages: The first is that with STILCAB, you should not have to invest more than 5 minutes to enter the data necessary for the analysis of the building. STILCAB is a simple and fast tool. The second advantage of STILCAB is that it can be used as early as the first steps of the design phase.

The software makes use of several analyses:

- a typological building analysis in order to create a geometrical model of buildings,
- sensitivity and uncertainty analyses.

The outcomes of those studies appear in the software as "default values" which are always suggested to the user.

1.2. Stilcab’s results

For a building, STILCAB provides the following information:

- capital costs: inventory of the annual maintenance costs, the cost of building materials, energy costs;
- the description of construction: each detail of the construction, materials to be used as well as their amounts are provided;
- comparisons of various building alternatives: while modifying one by one parameters, it is both possible and easy to visualize the effects of the these changes on the costs and/or the environmental impacts, which will enable you to choose the optimal characteristics for the construction of your building;
- energy consumption: various scenarios of energy consumption can be assessed;
- energy costs: inventory of the costs according to the use of energy (heating, production of hot water, various equipment etc.);
- costs of the building during its lifetime: costs of restoration and maintenance, as well as construction costs;
- flow of materials entering and leaving the building;
- environmental impacts associated with the materials used and the consumption of energy.

1.3. Stilcab's details

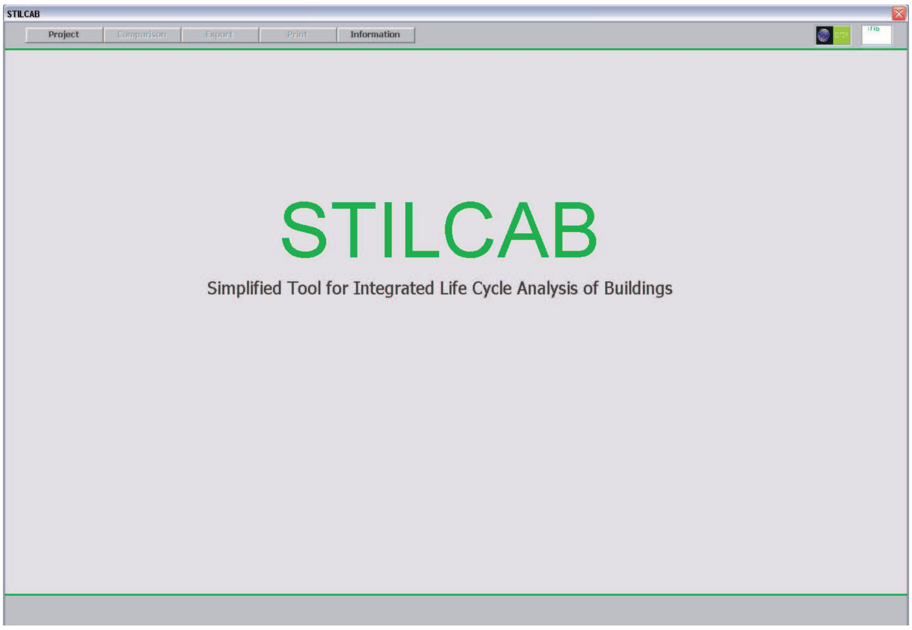


Figure 1

Screenshot of the prototype's detail

On the left side of the screen, the user can always find the "vertical menu".

1.4. Stilcab - The first page

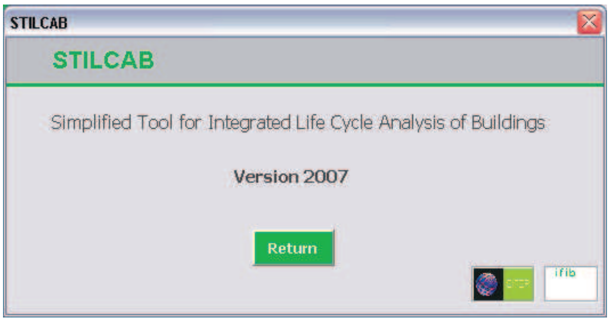


Figure 2

Screenshot of the prototype presentation

1.5. Stilcab - The top menu

Under "Project", it is possible to start a new project or to exit the program.
Under "Comparison", it is possible to compare the results of one project with the results of up to 4 others projects, or to visualize the results of the current project.
Under "Export", the user can export the inputs and outputs of the current project either in an Excel file, a Word file or in a database. When exporting to an Excel file, graphics of the results will be automatically realised according to which results the user selected and tables with the input and output values.

When exporting to a Word file, a report is automatically generated, with most of the inputs and the outputs of the project.
The “Print” menu allows the edition of a word document or an Excel document.

The “Information” menu provides access to the Help file, and information about the program.

On all pages, the two symbols on the top right corner give direct access to either the ifib website or the EIfER website.

1.6. Stilcab - The navigation bar

This allows the user to displace himself in the program into several chapters. The navigation bar shows the current chapter. (The navigation bar is not to be seen on the first screen of Stilcab.)

II. The steps

Stilcab is easy and quick to use. The process leading to the end results has been differentiated in seven steps. Thanks to the so-called “horizontal menu”, it is always possible to know which step is the current one.

The first step is the general description of buildings with the definition of several basics characteristics for the calculations, such as the gross floor area (BGF) and the ground floor area (BF), or the number of years.

The second step is the energy calculations which can be realised with two different methods. Either the energy calculation is independent of the EnEV and the EPBD or it follows those regulations. In the second case, a typology of the building will have to be given, and eventually the orientation of the building and the surfaces in each direction as well.

The third step is the description of the building itself. The description is realised according to the DIN 276. For each Kosten Gruppe (construction parts) the associated quantity must be given (if not, the program suggests a default value). Moreover, if the user has more information at his disposal, he can also choose construction elements according to the materials.

The fourth step is the sensitivity analysis. According to the geometrical characteristics of the building, the program will inform which construction part has the largest potential of variation for a particular indicator, which can be selected by the user in a list.

The fifth step concerns the water requirements. The yearly consumption can be directly entered or determined according to the number of occupants. Default values can also be used if necessary.
The sixth step concerns the technical equipment: sanitation, heating systems, hot water production system, and electronic equipment.

The last step is the display of the ILCA results. Stilcab calculates the building’s costs, environmental impacts and energy consumption during its lifetime.

The several steps are summarized in the following figure:

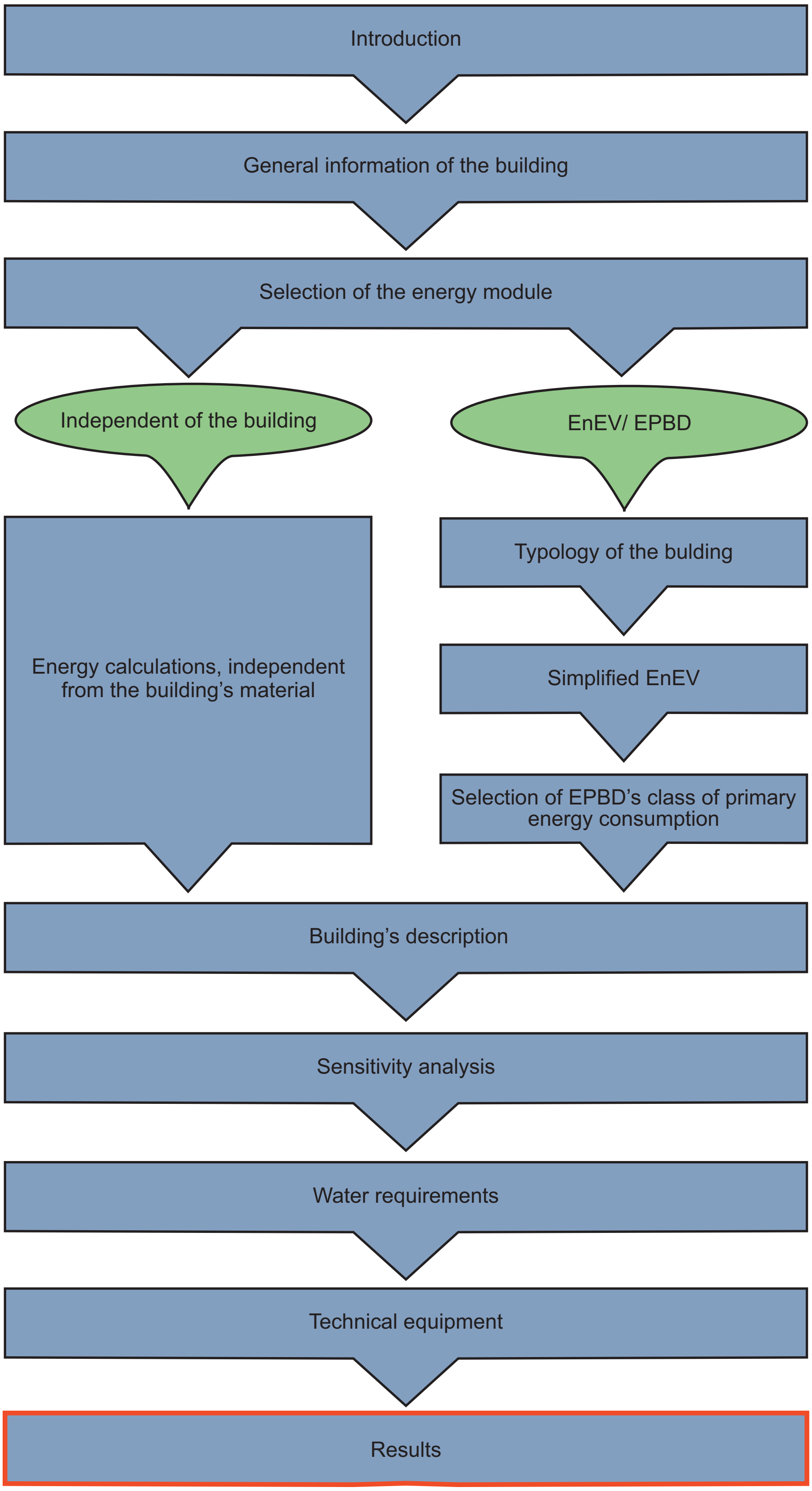


Figure 3

The path in STILCAB

Or in a more detailed version:

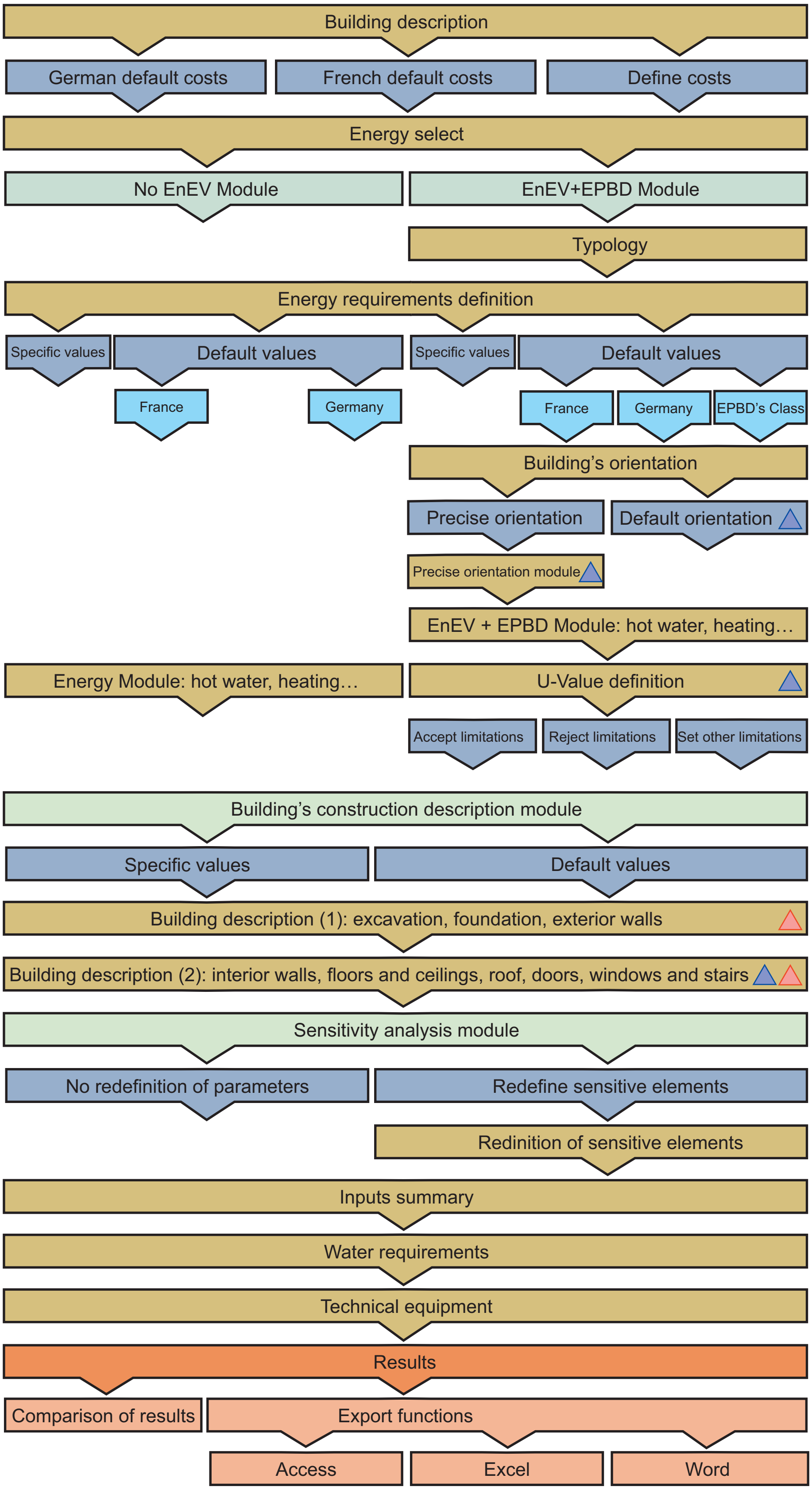


Figure 4

Detailed path discription in STILCAB

III. User input - General information

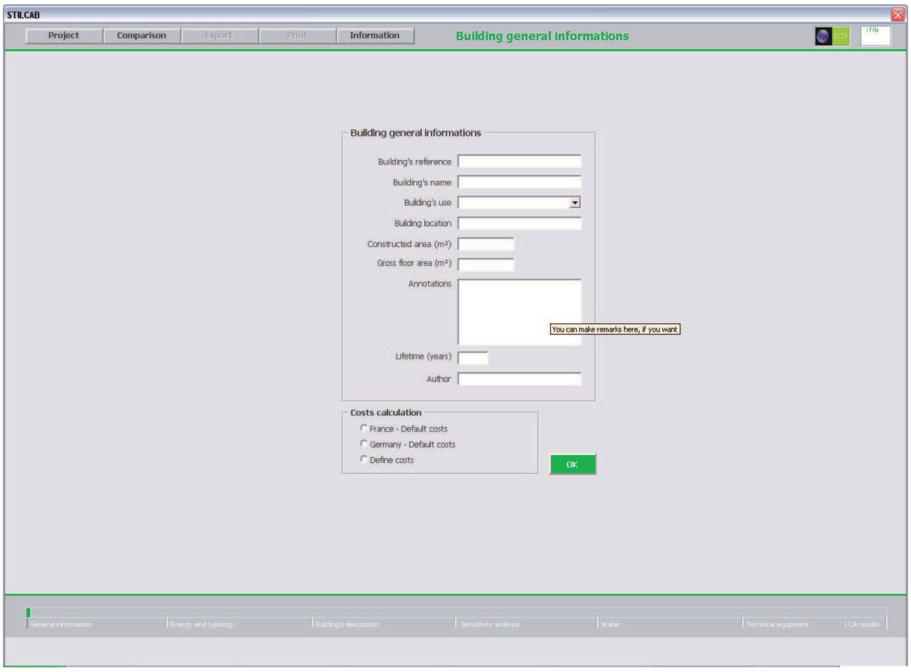


Figure 5

Screenshot of the user's input in «General information»

On this page, the user must give information about the building: reference, name, the use, the location, the gross floor area, the built area, the lifetime, the author name, and the costs selected for calculations. Only four pieces of information are compulsory: use, BF (built area), BGF (gross floor area) and the life duration.
The use of the building is selected in a list of suggested use.
According to the compulsory information, the results will be calculated (life duration), and a proposition of the geometrical share of building's parts will be made (BF, BGF, use of the building).

III.1. Use of the building

The use of the building is selected in a list of suggested uses:

- Hostel, students habitation
- House, double house
- Factory
- Industry and trade
- Hospital Fire station
- Multiple family housing
- Office building
- School, university, educational
- Others

The selection of the building use is particularly important as most of the energy default values depend on the building's use, as well as on the water consumption and the default values for the building's geometrical characteristics.

III.2. Constructed area (Bebaute Fläche)

This is the ground floor area of the building, in m².

III.3. Gross floor area (Brutto-Grundfläche)

The gross floor area of the building is the area of all stories, except under roof areas, balconies, etc.

III.4. Lifetime of the building for the calculation

The lifetime of the building is the number of years which is assumed to realise the LCA calculations. A duration of 80 years is suggested, as this value is mainly used by the scientific community when considering building LCA.
If the user only wants to compare the construction results, a life duration of one year is enough.

III.5. Costs calculations

It is possible to modify the default costs taken into consideration in Stilcab by selecting one of the following options.

- France default costs
- France define costs
- Germany default costs

Selection of the option "Germany default costs" will run the calculations according to costs from the German building elements database.
Selection of the option "France default costs" will run the calculations according to costs adapted from the German Market to the French.
The selection of the option "France define costs" will lead the user to a new screen.

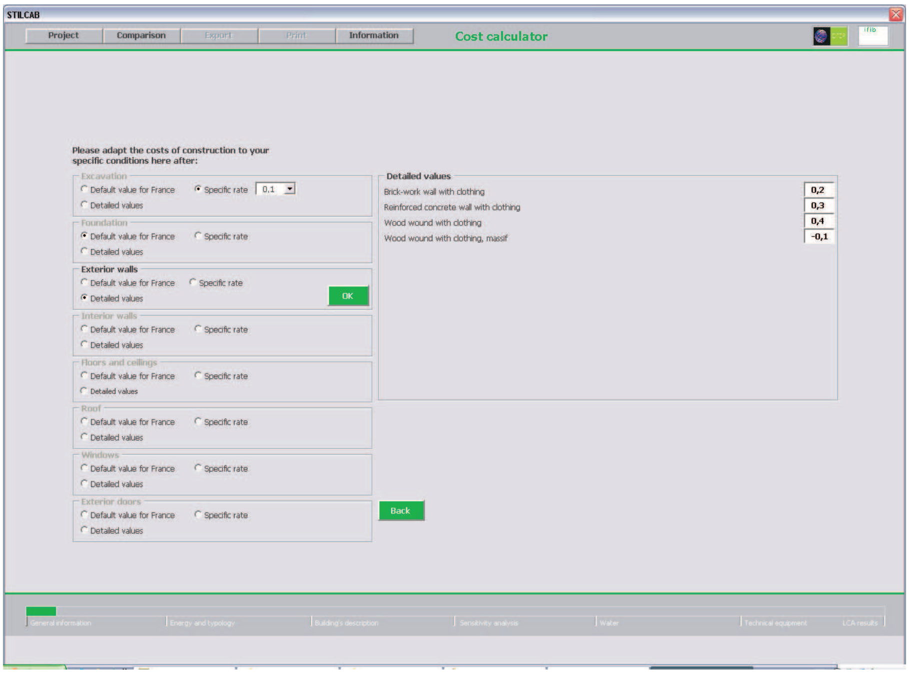


Figure 6

Screenshot of the user's input in «Cost calculator»

In this new screen, it is possible to adjust the default German costs to the desired costs using virtual ratios (“specific rate”), to enter a price for a category of building materials (“desired values”), and to select the already adjusted costs (“default value for France”), which represent the costs in France.
The option “Specific rate” calculates the “new costs” with the selected ratio and the German default costs.

Moreover, on the horizontal bottom area, the user finds the “horizontal menu”. This allows him to displace himself in the program in the various chapters. The chapter which appears darker is the current chapter.

IV. Building’s construction (1) and (2)

The user can first select to use default values or to enter his own values for the whole description of the building.

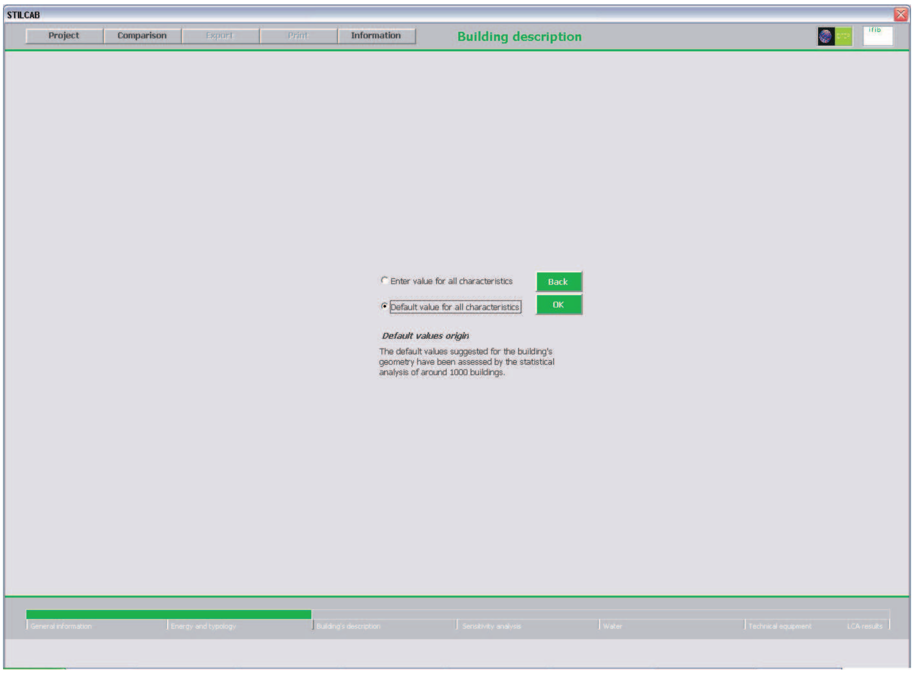


Figure 7

The use of default values for the building’s description

The building’s construction is defined according to the German norm DIN 277. In “Building’s construction (1)” (cf. Figure 8), the user is reminded which value he gave for gross floor area. Then, the user has to define three parts of the building: excavation, foundation and the exterior walls. For each part, the user has the choice between:

- Default value: this is the case in which the user does not know anything about the building. A value will be automatically calculated according to several parameters:
- Gross floor area;
- Built area;
- The building’s use;
- The statistical analysis of 1000 buildings.

- Enter a value: the user must only enter one value. This is the case in which he does not know which material the building will be built with, but he already knows the form and the quantity of each part.
- Detailed value: the user can describe the building and give the appropriate input in m² corresponding to different construction materials.

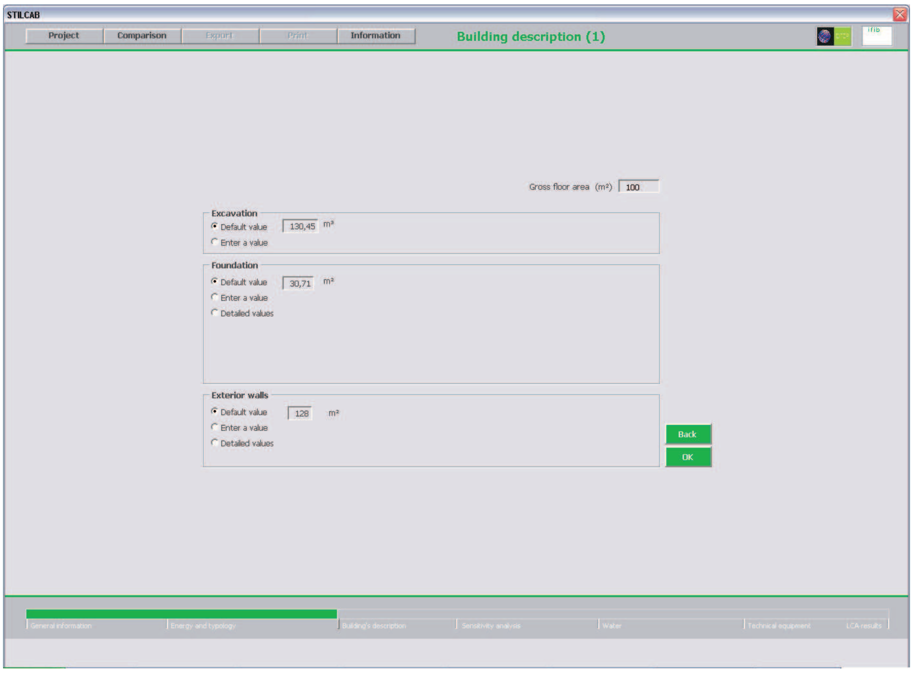


Figure 8

Screenshot of the user's input in «Building's description (1)»

When the option "default value" is selected, the program proposes values for each building part. Those values are calculated according to the information entered in the "building general information" screen.

However, the user always has the chance to change the suggested values and to enter his own.
When selecting “detailed values”, the user is asked to provide better information about the construction elements he really wants to select. Therefore, instead of using the information “30,71 m² of foundations”, the program will be informed about the foundations “really” used in the construction: a list of typical foundations will then be suggested.

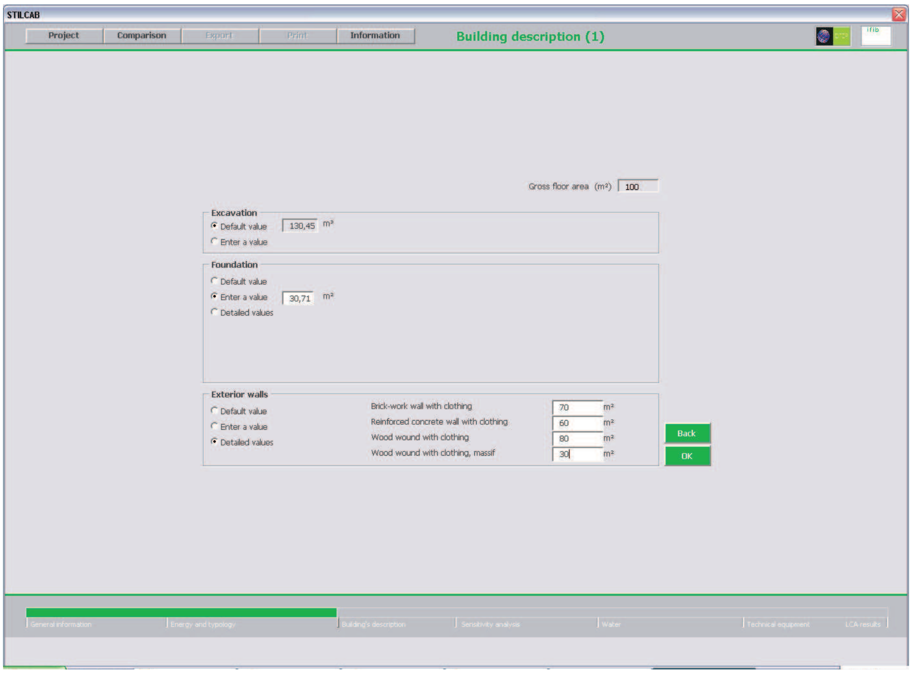


Figure 9

Building’s description (1)

The previous screen deals with: excavation, foundation and exterior walls. The following screen “Building’s description 2” deals with the interior walls, the floors and ceilings, the roof, the stairs, windows and doors. The process is however the same as before.
The building’s construction is defined according to the German norm DIN 277.

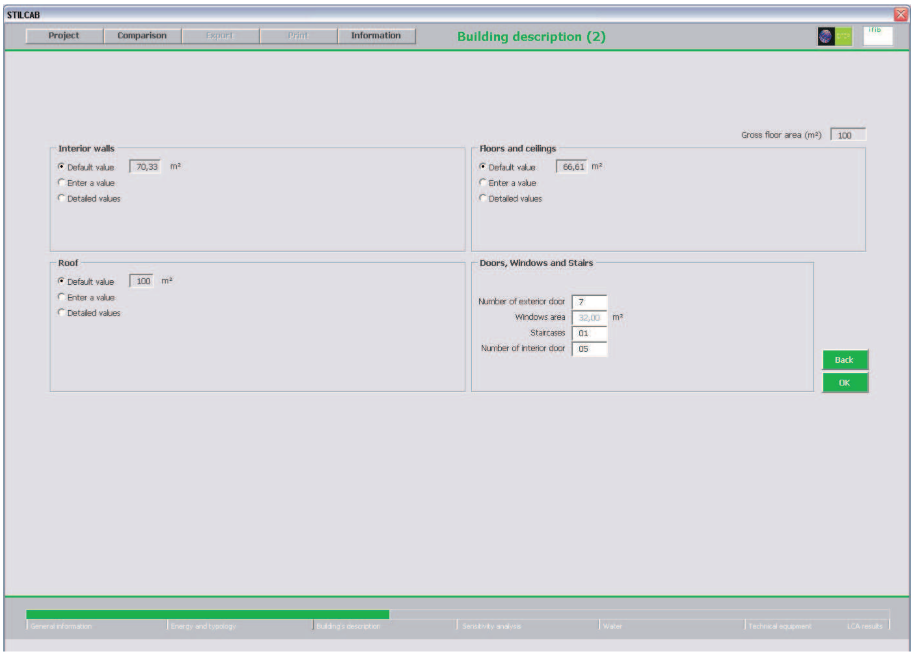


Figure 10

Building’s description (2)

The following building parts have to be described:

- excavation
- foundations
- exterior walls
- interior walls
- floors and ceilings
- roof
- exterior doors
- interior doors
- windows
- staircases

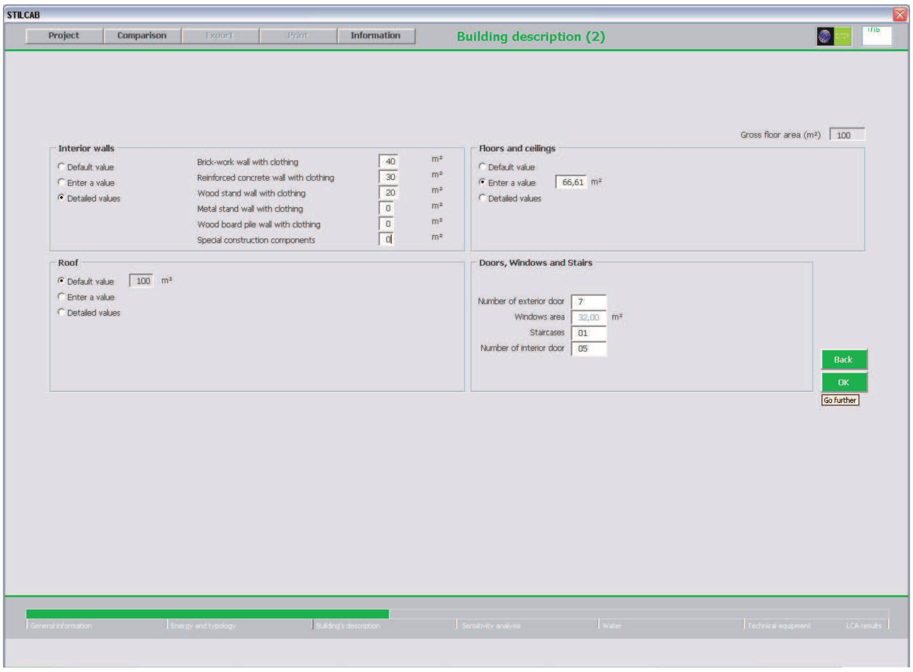


Figure 11

Screenshot of the user's input in «Building Description (2)»

V. Prototype – Sensitivity Analysis

The aim of the following screens (cf. Figure 12) is to allow the user to find out which construction part is the decisive one regarding a selected indicator. The user can select two indicators in a list of indicators:

- CO_2,
- Costs,
- Ozone depletion potential,
- Primary energy non renewable,
- Primary energy renewable,
- Mass Flow,
- Ecopoints,
- Radioactivity.

Then, in the two tables below, the program displays the results. For example, in the following screenshot, the user selected "ozone depletion potential" as the first indicator. The program displays that "Floors and ceilings" have the biggest potential regarding this indicator, and the potential is about 36%. For the second selected indicator (primary energy non renewable), the exterior walls have the highest potential (44%).

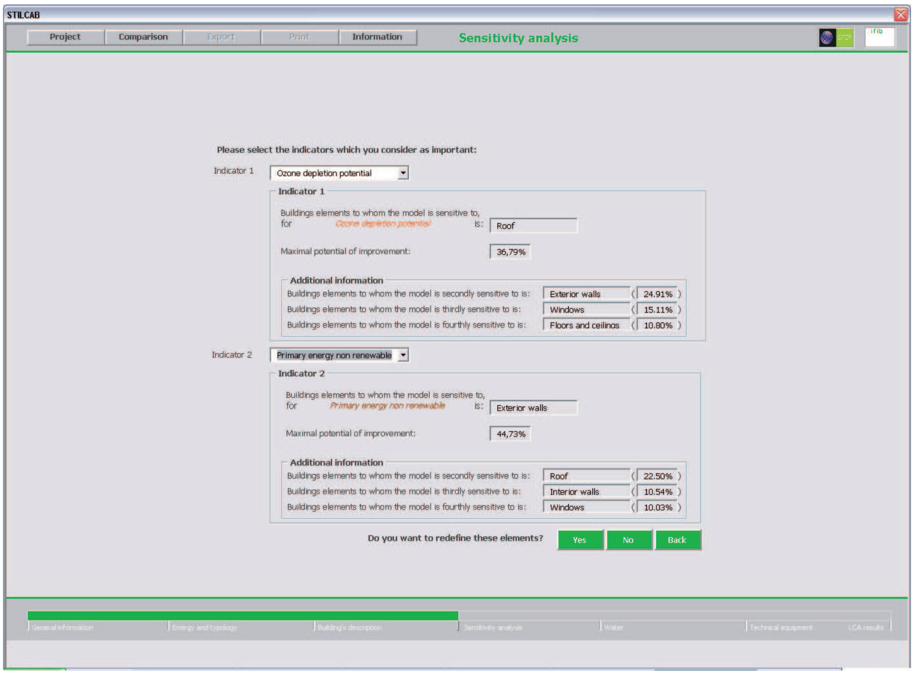


Figure 12

Screenshot of the «Sensitivity analysis»

The user is then asked if he wants to redefine those parameters (roof on one side and exterior walls on the other side) or not.
This is what happens (cf. Figure 13) when the user wants to redefine some parameters. He then has the chance to go a deeper level in the description of the building. He is now at the same level where he would be if he had chosen "detailed values" in the "building's description 1 and 2".

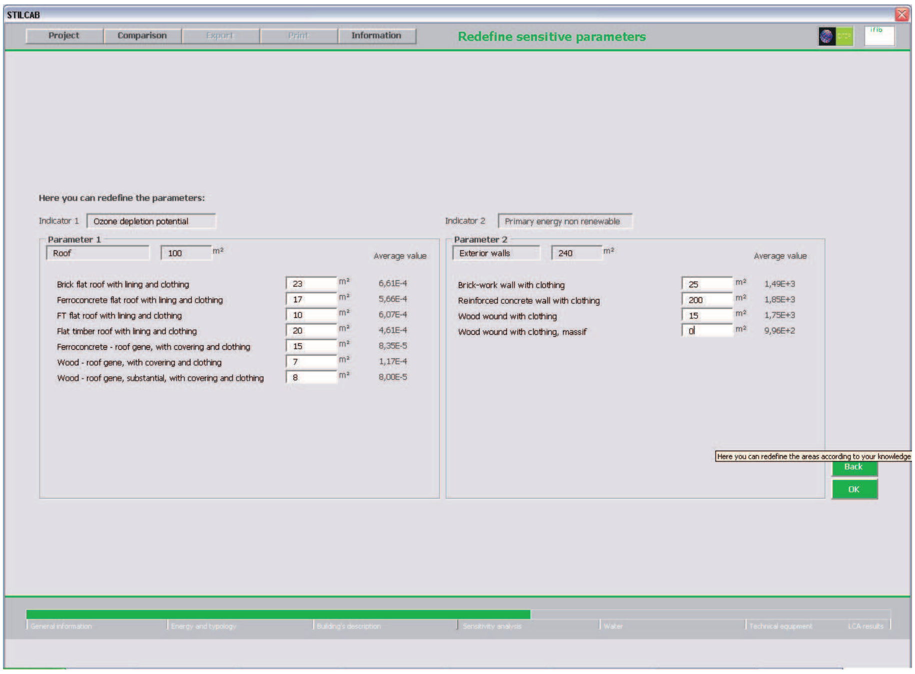


Figure 13

Screenshot of the «Redefinition of sensible information»

V.1. Redefine the first parameter

A reminder of the parameter which has the largest potential regarding the first indicator selected is given here with the quantity that the user entered previously. Now the user has the chance to go a deeper level in the description of this parameter. He is no longer asked to give in the quantity of a construction part, he can now select an element which actually corresponds to the building he is looking at.

V.2. Redefine the second parameter

A reminder of the parameter which has the largest potential regarding the second indicator selected is given here with the quantity that the user entered previously. Now the user has the chance to go a deeper level in the description of this parameter. He is no longer asked to enter the quantity of a construction part, he can now select an element which actually corresponds to the building he is looking at.

VI. Water requirements

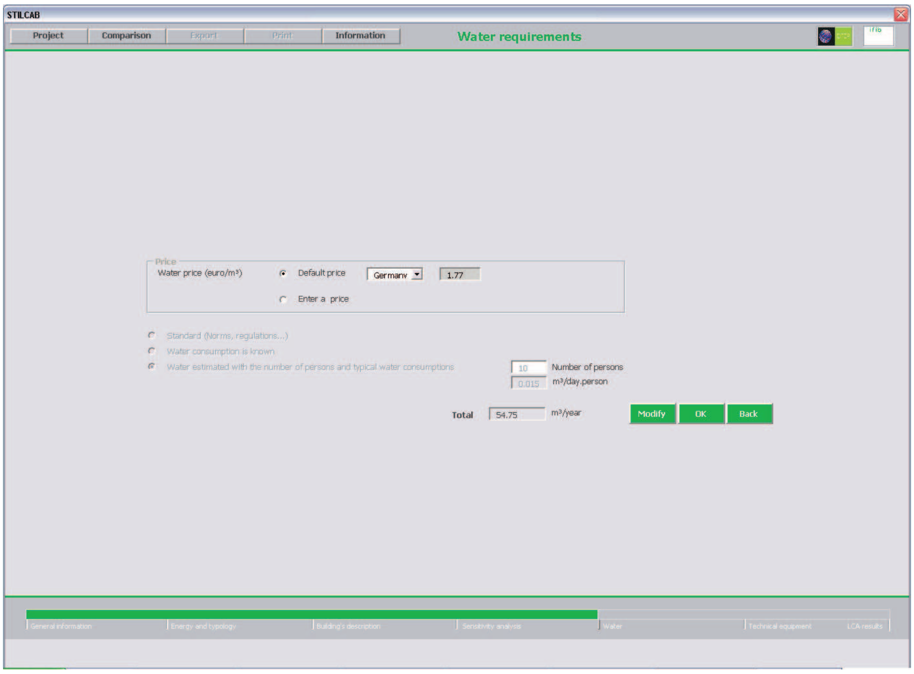


Figure 14

Several possibilities to enter water requirement information

VI.1. Water requirements

The user is asked to fill in the following information concerning the price and the quantity of fresh water required for the users of the building.

VI.2. Water price

First he has to select the country, on which the default price pro m³ of water depends.
If the user wants to give in a specific price pro m³ of water, he can do it by selecting “Give a price”.

VI.3 Water consumption

The user has several possibilities at his disposal. He can select between:

- Standard: norms or regulations in application in Germany, France or in Europe;
- Known parameter: he already knows how much water is consumed in the building;
- Estimation: the consumption of water is calculated according to the building’s use, the number of occupants, and data found in the literature.

Again here, when the user only knows a little about the building, he can select the “estimation” function, when he knows more about it, he can choose another possibility.

According to this information, the cost for the fresh water supply will be calculated.

VII. Energy requirements

VII.1. Selection of the energy module

There are two different modules for the energy calculations.
The first module realizes the assessment of all energy consumption according to the use of energy (heating, hot water, ventilation...) independently of the building's geometry and orientation.
The second module follows the simplified EnEV regulation and the new EPBD classification, and requires indications concerning the geometry of the building (typology) and possibly the orientation (if not available, the calculations will be realised with a standard default orientation).

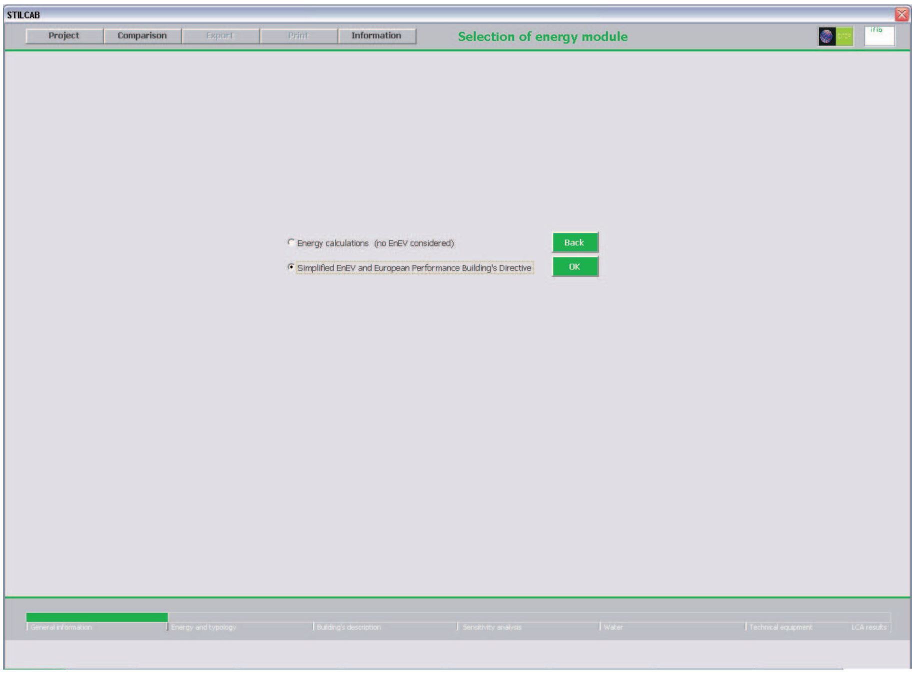


Figure 15

Selection of the energy option

VII.2. Energy requirements – Energy case 1

A screen appears which asks the user if he wants to use default values for the wall energy calculations, or if he knows more about the energy requirements of the building and therefore can give information such as centralised/ decentralised hot water production system, the end energy for lighting, and so on.

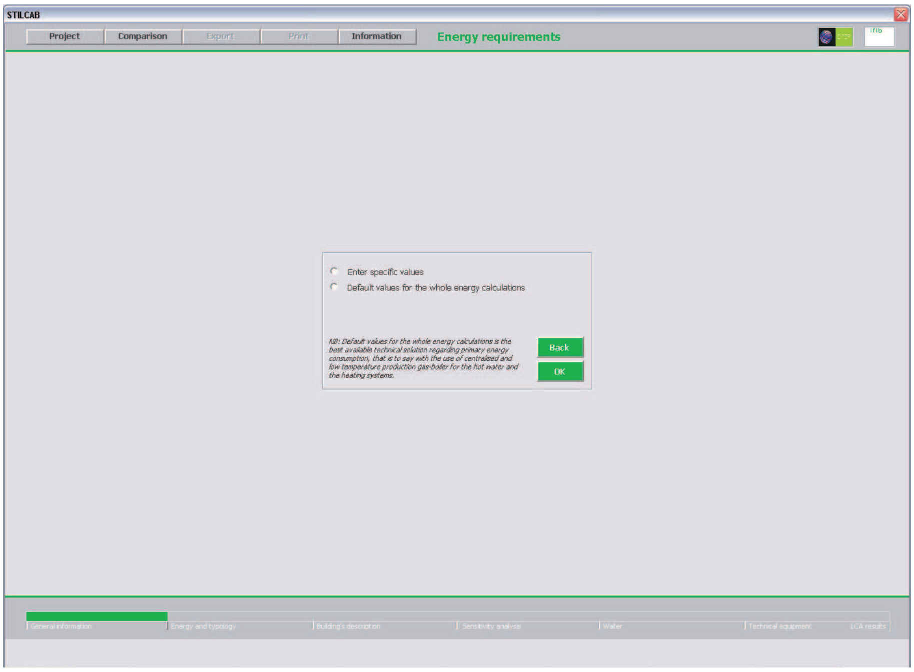


Figure 16

Energy requirements - Energy case 1

VII.3. Energy requirements – Energy case 1 Default value

If the user selects "default value", he is then asked to enter "France" or "Germany". This information is used to determine the electricity mix and the cost of energy.

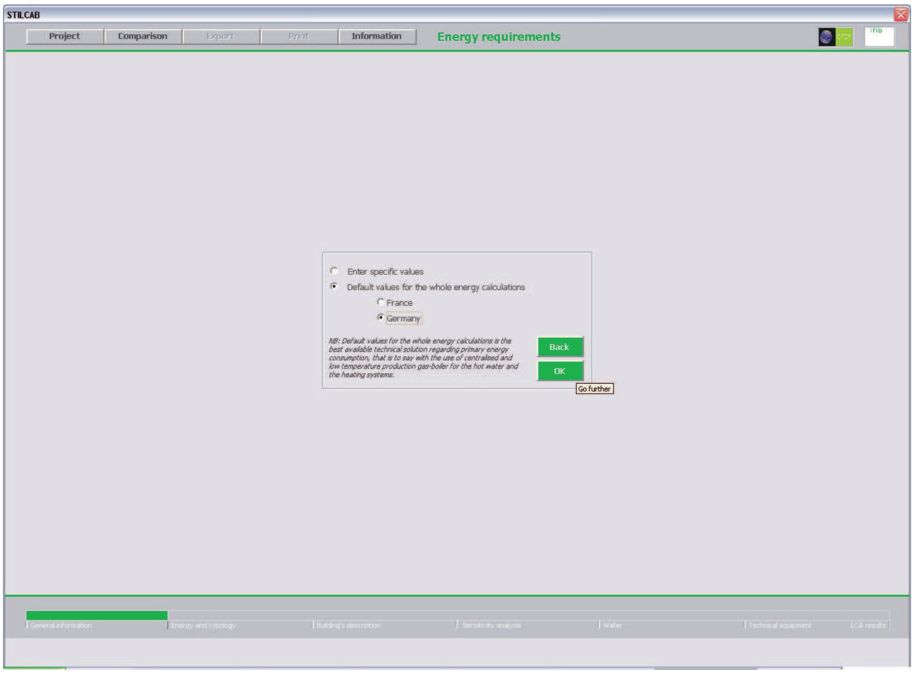


Figure 17

Default value selection for the energy requirements – case 1

Then, another screen appears which is already filled in. For each energy post, a default value is suggested, and the best solution is selected (best solution in terms of efficiencies).

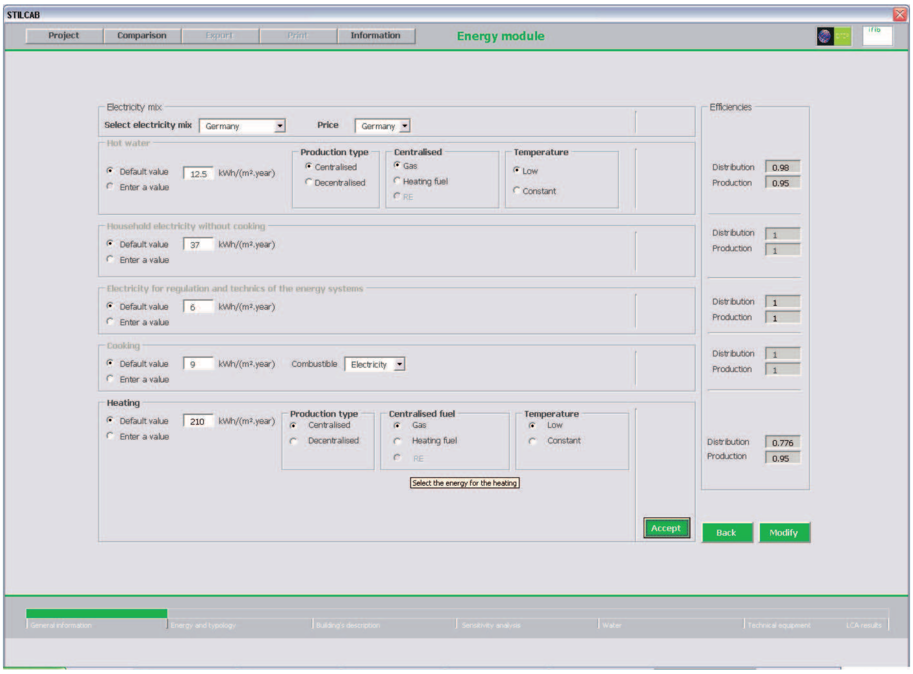


Figure 18

Default values appear for the energy requirements

The user can either accept all those values or modify them.

VII.4. Energy requirements – Energy case 1 Give a value

The user is now asked to enter information about the building's energy requirements.
It is possible to choose between France, German or European electricity mixes, and between German and French costs for the supply of the various fuels.

The energy calculation is divided into five parts:

- Energy for hot water
- Household (or appliance) electricity
- Electricity for the regulation of the several energy systems
- Production of electricity with photovoltaic and/or cogeneration
- Energy for space heating

The principle of available and default information is the same as for the other parameters (water, construction…).

VII.4.1. Hot Water

You must either select a default consumption of energy for hot water preparation or enter the associated end energy consumption.
The fuel used also has to be determined.
Then, you must determine if it is a centralised or a decentralised production system. Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.4.2. Household electricity

You must either select a default consumption of energy for household electricity or enter the associated end energy consumption.
Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.4.3. Electricity for regulation and techniques of the energy systems

You must either select a default consumption of energy for household electricity or enter the associated end energy consumption.
Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.4.4. Cooking energy

You must either select a default consumption of energy for cooking or enter the associated end energy consumption. You can select between cooking with gas or cooking with electricity.
Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.4.5. Heating

You must either select a default consumption of energy for the heating or enter the associated end energy consumption.
The fuel used also has to be determined.
Then, you must determine if it is a centralised or a decentralised production system. Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.5. Energy case 2 - Typology of the building

When the user selects the second available energy option, he is asked to describe the typology of the building.

Several typologies are available for the selection:

- Square
- Rectangle
- L-form
- U-form
- Comb-form

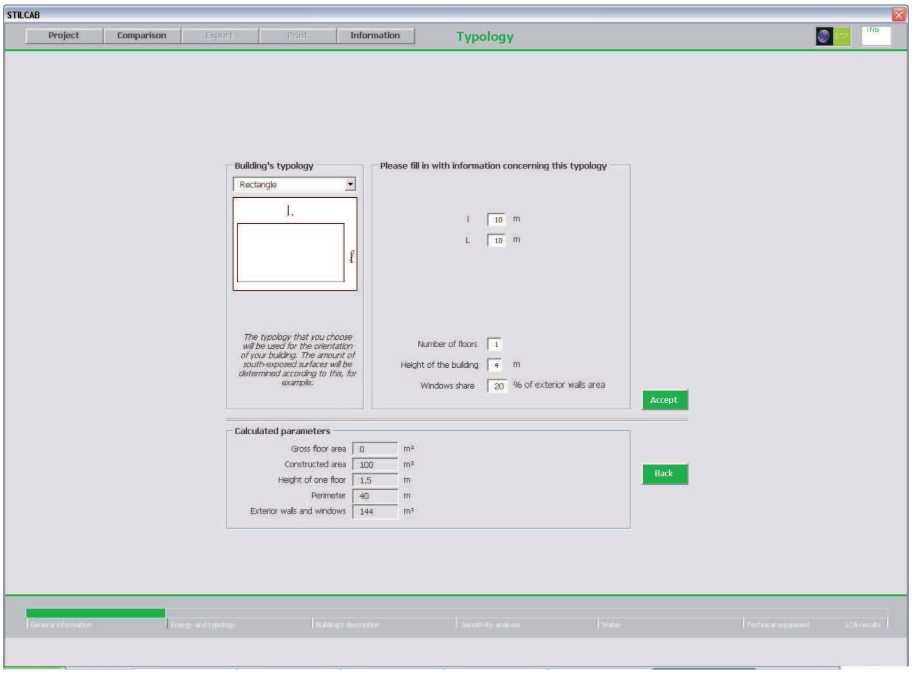


Figure 19

Typology of the building for the energy requirements - case 2

VII.5.1. Other characteristics

Other information will be requested about, such as the height of the building and the number of floors.
The percentage of windows is also necessary to realise the EnEV calculations. For this regulation, the percentage of windows in the exterior walls must be less than 30%.

VII.5.2. Calculated characteristics

At the bottom of the screen, the grey boxes give the results of some calculations done with the previous input: the corresponding gross floor area BGF, ground floor area BF, the height of one floor, the corresponding exterior walls area and the perimeter of the building with this typology and those geometrical characteristics.

VII.6. Energy module EnEV - Energy case 2

VII.6.1. Default values

A screen appears which asks the user if he wants to use default values for the energy calculations, or if he knows more about the energy requirements of the building and therefore can give information such as centralised/decentralised hot water production system, the end energy for lighting, and so on.

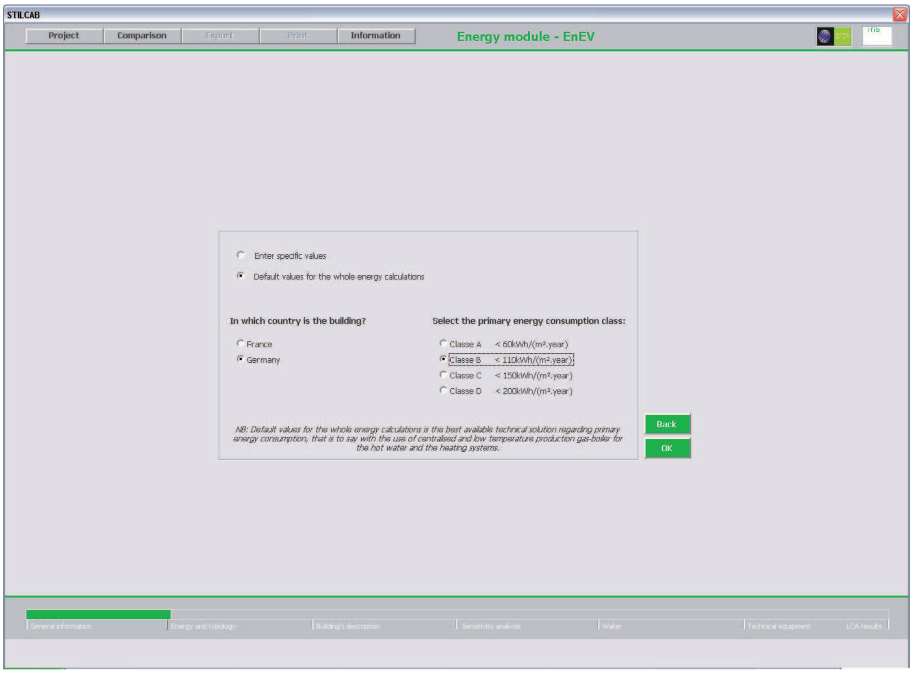


Figure 20

Default values definition

If the user selects “default value”, he is then asked to enter “France” or “Germany.” This information is used to determine the electricity mix and the cost of energy. Moreover, the user must select the class of primary energy consumption that the building should attain, according to the EPBD.

When selecting “default values,” the following screen appears, already filled with the default values. Those values can be either accepted (by clicking on “OK”) or modified (by clicking on “Modify the Value”).

Moreover, on the bottom of the display there is an indication about the EnEV. It says whether the building with those energy consumptions respects the EnEV restrictions when this EPBD’s class is selected. If not, it also displays the principal reason for the non-conformity to the EnEV.

On the right side of the display are the primary energy consumption associated with specific uses of the energy.

Example:

When class C is selected, the maximum primary energy consumption allowed for the building is 110 kWh/(m².year);

- 12,5 kWh/(m².year) end-energy are allocated to hot water preparation, which corresponds to 13 kWh/(m².year) of primary energy, when considering the production and distribution efficiencies as well as the selected fuel;
- 5 kWh/(m².year) end-energy are allocated to lighting, which corresponds to a primary energy consumption of 13 kWh/(m².year) as the lighting is electrical;
- there is no electricity produced on site;
- 6 kWh/(m².year) end-energy are allocated to ventilation, which corresponds to a primary energy consumption of 15 kWh/(m².year) as the ventilation is electrical;
- as the maximum authorised primary energy consumption is 110 kWh/(m².year), only (110-13-13-15)=69 kWh/(m².year) is allocated to heating needs.
- a small darker blue screen appears which indicates which heating systems should be selected in order to respect the EnEV.

The building answers the EPBD's conformities. However, as can be seen at the bottom of the display, the building does not fulfil the conditions of the EnEV (the reason is shown below; there is too much energy for heating).

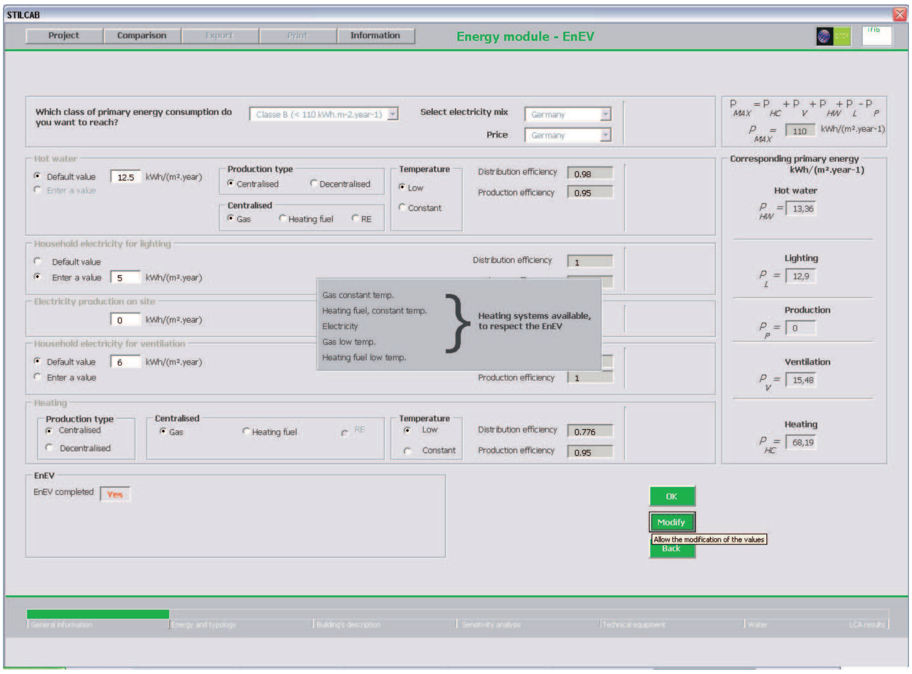


Figure 21

EnEV and EPBD

VII.6.2. Enter values

When the “default values“ option has not been selected, the user must fill in the screen as shown in Figure 21.

The user is now asked to enter information about the energy requirements of the building.
It is possible to choose between France, German or European electricity mixes, and between German and French costs for the supply of the various fuels.
The energy calculation is divided into five parts:

- Energy for hot water;
- Lighting electricity;
- Electricity for ventilation;
- Production of electricity on site;
- Energy for space heating.

The principle of available and default information is the same as for the other parameters (water, construction, etc.).

VII.6.2.a. Hot water

You must either select a default consumption of energy for hot water preparation or enter the associated end energy consumption.
The fuel used also has to be determined.
Then, you must determine if it is a centralised or a decentralised production system. Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.6.2.b. Lighting electricity

You must either select a default consumption of energy for the lighting electricity or enter the associated end energy consumption for it.
Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.6.2.c. Electricity for ventilation

You must either select a default consumption of energy for the ventilation electricity or enter the associated end energy consumption for it.
Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.6.2.d. Production of electricity on site

You must enter the production of energy on site.

VII.6.2.e. Heating

You must either select a default consumption of energy for the heating or enter the associated end energy consumption.
The fuel used also has to be determinded.
Then, you must determine if it is a centralised or a decentralised production system. Both distribution and production efficiencies will be given by the program, and can be changed any time to other values.

VII.7. Energy Performance in Buildings Directive (EPBD) - Standard orientation of the building

When selecting a standard orientation of the building ("Default orientation and surfaces"), an average maximal U-value is calculated by the program and displayed. It is then distributed in U-Value maximum for the exterior walls and roof and U-Value maximum for the windows.
Those U-values are determined taking into consideration the typology of the building, which the user already selected, as well as the percentage of windows.
The hypotheses completed are:

- surfaces and orientations of the exterior walls are those introduced in the typological model;
- the south-exposed side is the one with the biggest area ;
- the percentage of windows that the user indicated is equally distributed in all sides of the building.

You will notice that several "U-values" were calculated: the average maximum U-Value, as well as the maximum for the windows, and the maximum for the walls.

These coefficients represent the maximum values for the thermal transmission coefficients U which the building must have for the walls and windows, if the user wishes the primary consumption of energy to be limited to the class he selected in the "Energy module-EnEV".

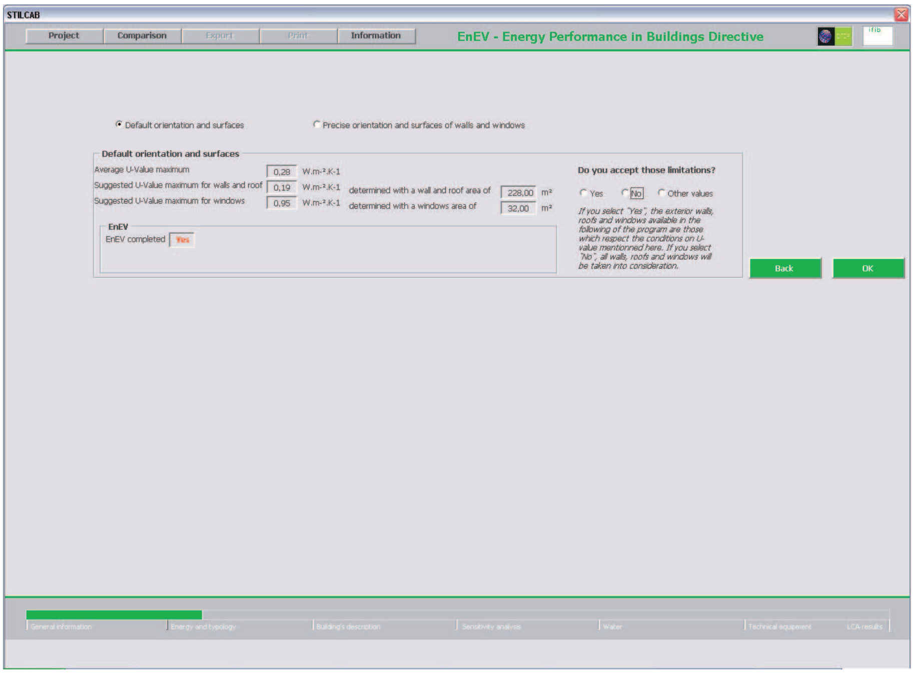


Figure 22

Standard orientation of the building

Limitations on the U-values for the material choice
The user now has three options:

- either he limits the choice of material to those which fulfil the condition on the U-value: the user clicks "YES" - and in this case the continuation of calculations will take into account only the walls and windows whose coefficient U is lower than the calculated maximum values;
- either he does not want to accept this condition - he clicks "NO" - and calculations will take into account all the walls and windows of the construction elements catalogue without any exception (i.e. without conditions on the U-value of the construction element);
- or the user decides to give his own limit on the U-values.

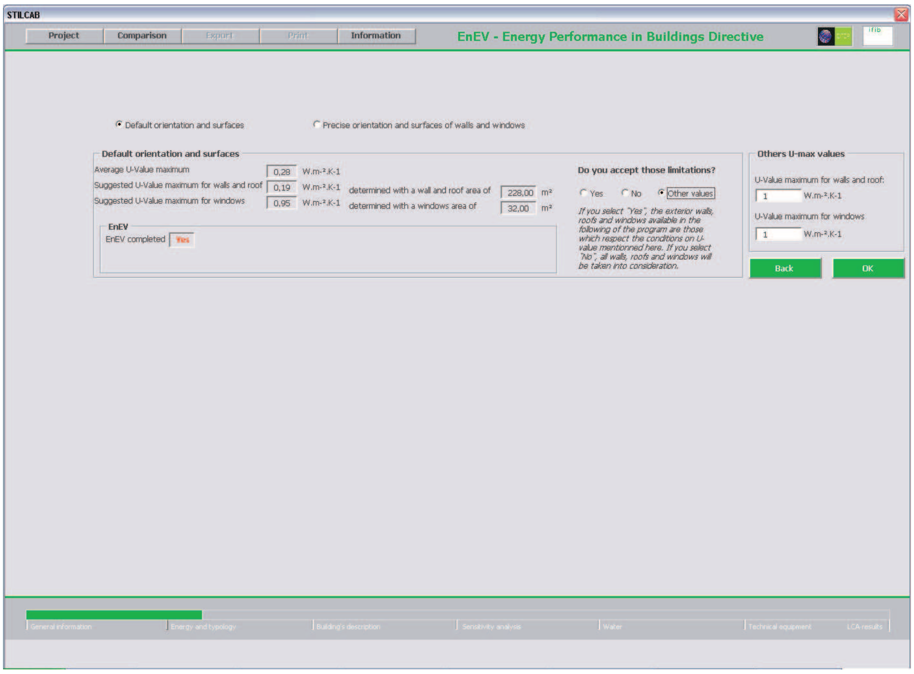


Figure 23

Standart orientation of the building - Limitations on the U-values

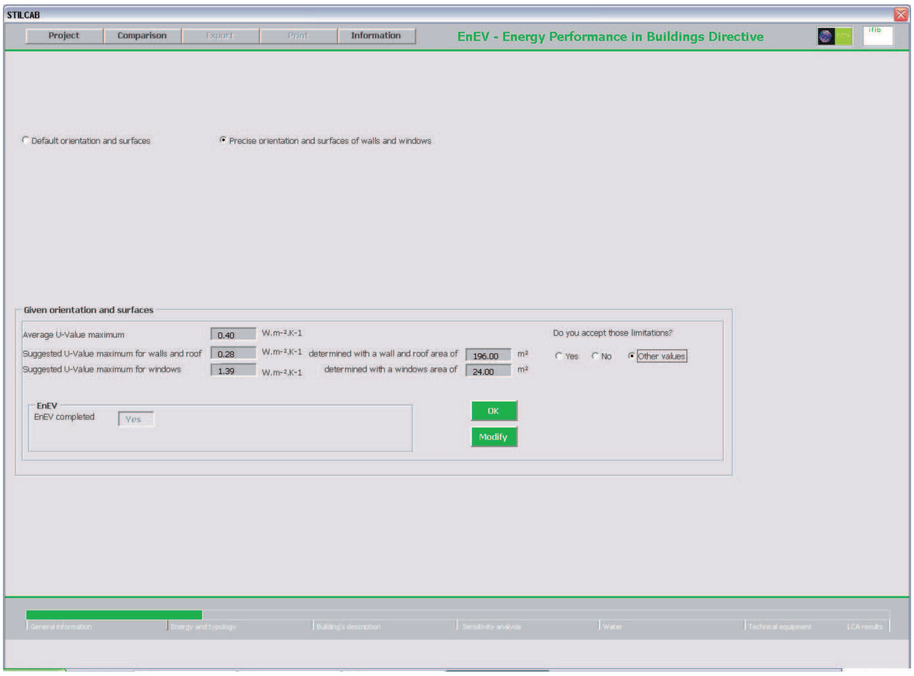


Figure 24

Precise orientation of the building

First of all, the user is asked to enter the following information (in m²):

- Surface of the exterior walls;
- Surface of the windows facing south-east and south-west;
- Surface of the windows facing the north-east and north-west ;
- Surface of the windows facing other directions ;
- Projected surface of the roof, which for the majority of the cases will be roughly equivalent to built area BF.

After having introduced these data, the software will automatically check that the sum of windows areas corresponds roughly to the percentage of windows introduced into the first stage of the analysis, and that the projected surface of the roof does not differ too much from the surface BF indicated in the previous steps.

Once these parameters are indicated, the user can click on the button "Accept".
The results of the exact calculation of the thermal transmission coefficient U are displayed in W/(m².K).

You will notice that several "U-values" were calculated: the average maximum U-Value, as well as the maximum for the windows and the maximum for the walls.
These coefficients represent the maximum values for the thermal transmission coefficients U which the building must have for the walls and windows if the user wishes a primary consumption of energy limited to the class he selected in the "Energy module-EnEV".

Limitations on the U-values for the material choice
The user has now three options:

- either he limits the choice of material to those which fulfil the condition on the U-value: the user clicks "YES" - and in this case the continuation of calculations will take into account only the walls and windows whose coefficient U is lower than the calculated maximum values;
- either he does not want to accept this condition - he clicks "NO" - and calculations will take into account all the walls and windows of the construction elements catalogue without any exception (i.e. without conditions on the U-value of the construction element);
- or the user decides to give his own limit on the U-values.

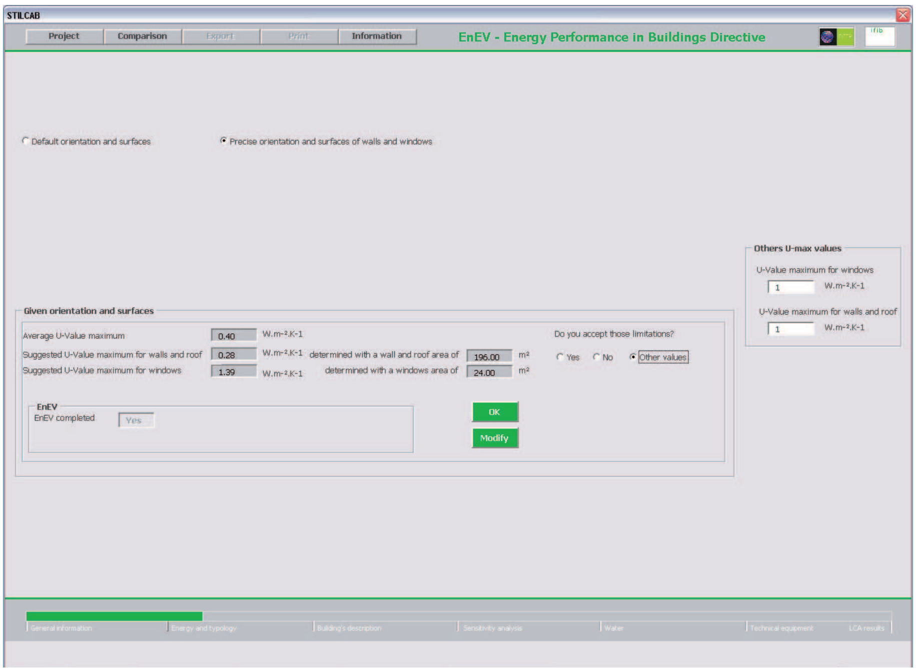


Figure 25

Precise orientation of the building - Limitations on the U-values

VIII. Technical Equipment

The technical equipment refers to installations for:

- heating;
- electro-installation;
- ventilation;
- boiler;
- sanitary.

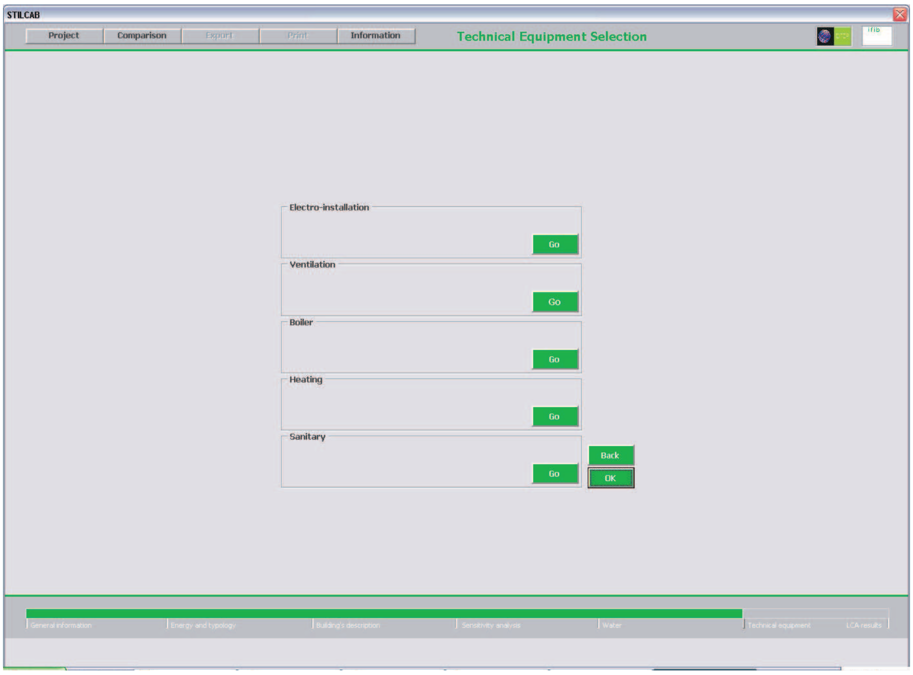


Figure 26

Definition of the technical equipment

VIII.1. Sanitary

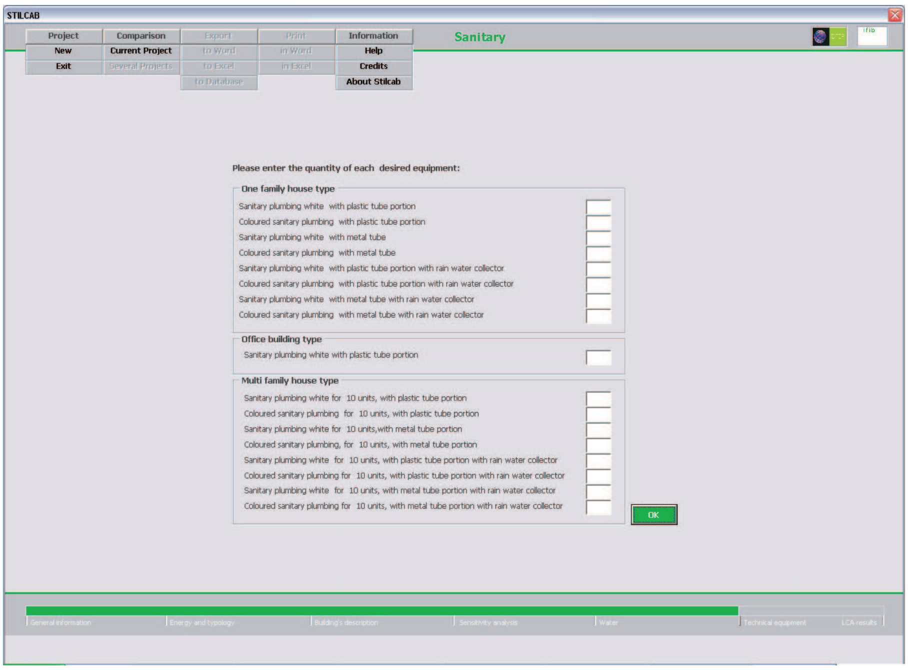


Figure 27

Sanitary selection

VIII.2. Electro-installation

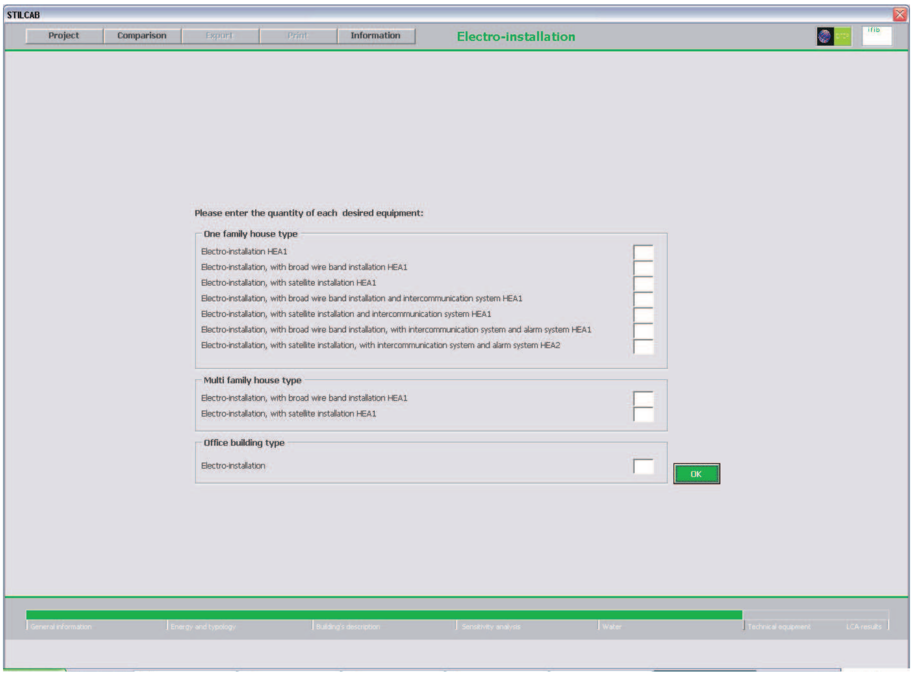


Figure 28

Electro-installation selection

VIII.3. Ventilation

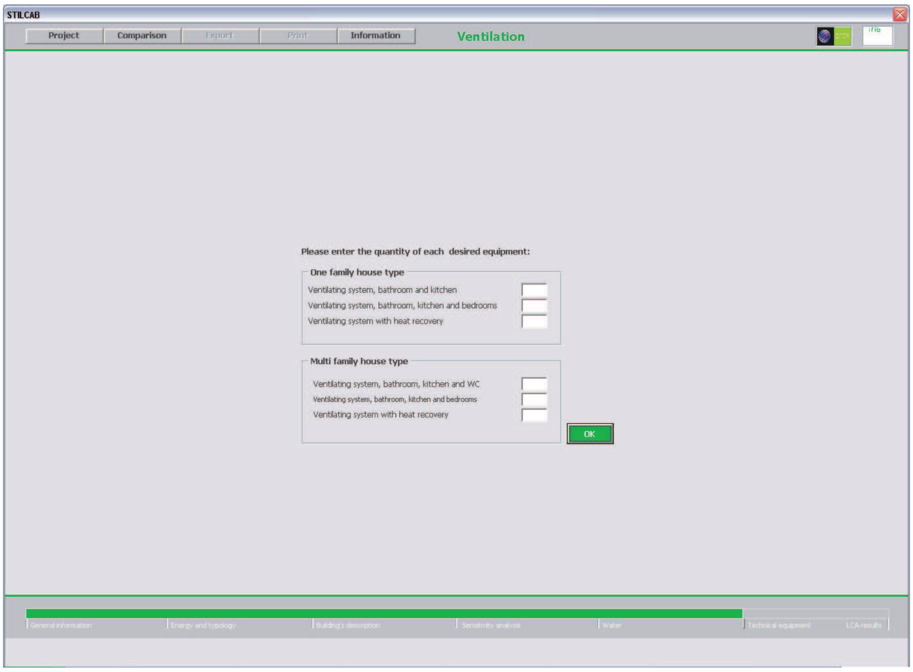


Figure 29

Ventilation equipment selection

VIII.4. Boiler

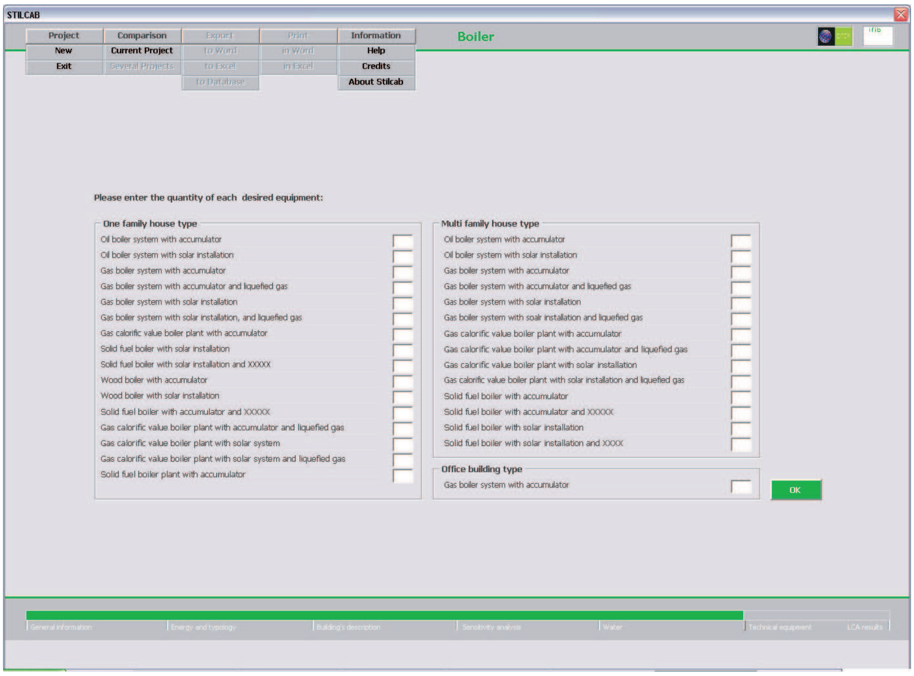


Figure 30

Boiler selection

VIII.5. Heating

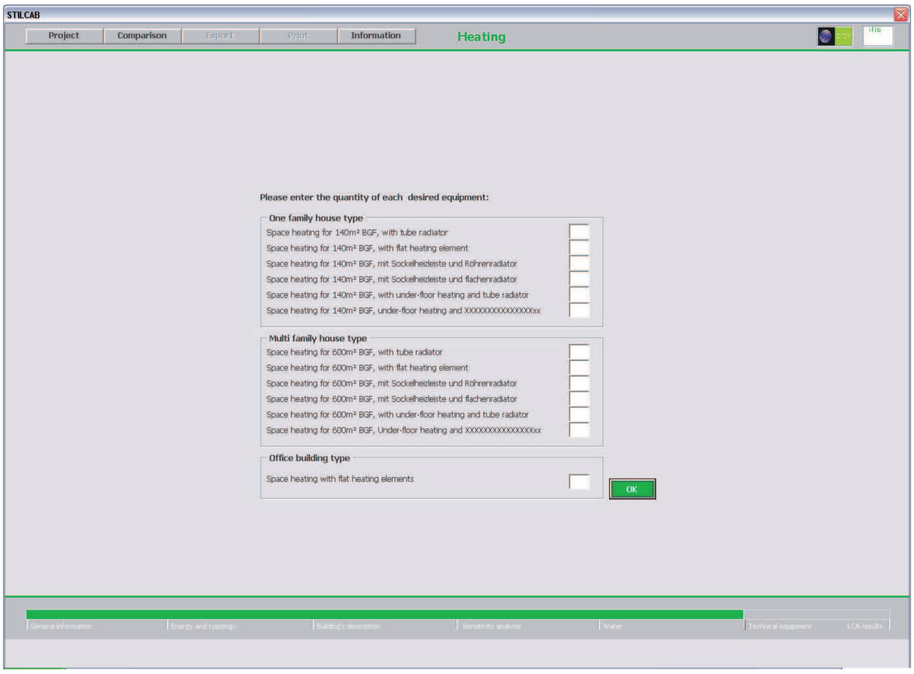


Figure 31

Heating system selection

IX. Prototype – Results

The following figure (Figure 32) is a screenshot of the results obtained.
All results as well as graphs (Figure 33), and a summary of the user inputs can be saved in an Excel file for further analysis.

This screen allows the user to visualize the results of the program sorted by category:

- CO_2,
- Costs,
- Ozone depletion potential,
- Primary energy non renewable,
- Primary energy renewable,
- Acidification potential,
- Photochemical Ozone Creation Potential,
- Abiotic resources consumption,
- Mass Flow,
- Ecopoints,
- Radioactivity,
- Water requirements,
- Energy.

For the first 11 categories mentioned, the results are presented per year, for the total lifetime, for the construction of the building only, for the renovation only, and for the cleaning and the maintenance only. On the vertical scale, the results are sorted out according to the building construction part which is considered.

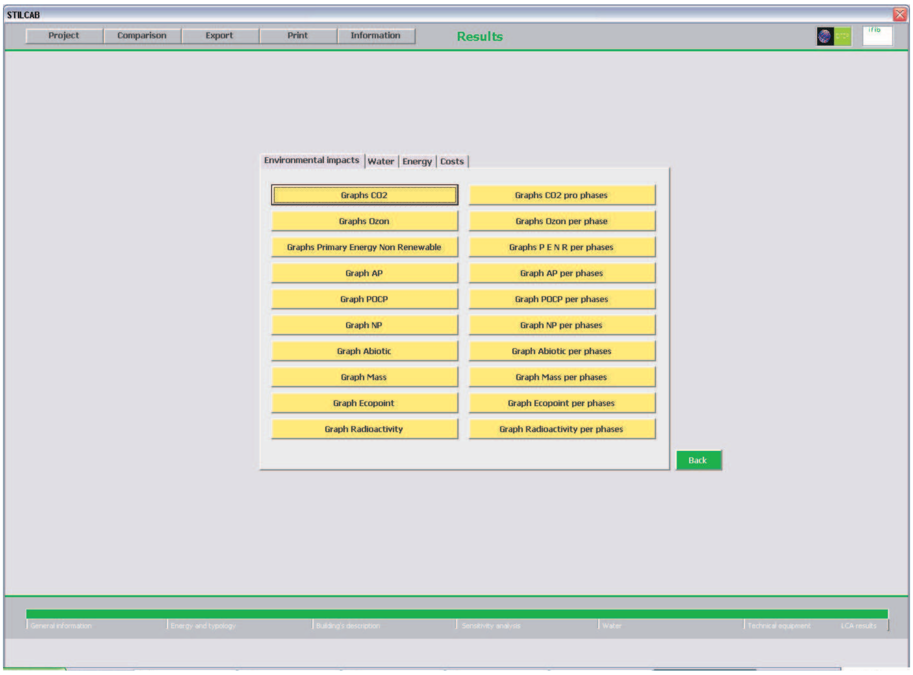


Figure 32

Results

For the last two categories, the presentation of the results is different. However, the results are shown with clear indications which help the user to identify what he reads.

By clicking on the desired button, the corresponding graph appears. All detailed values can be read in Excel and Word files as well as in the database.

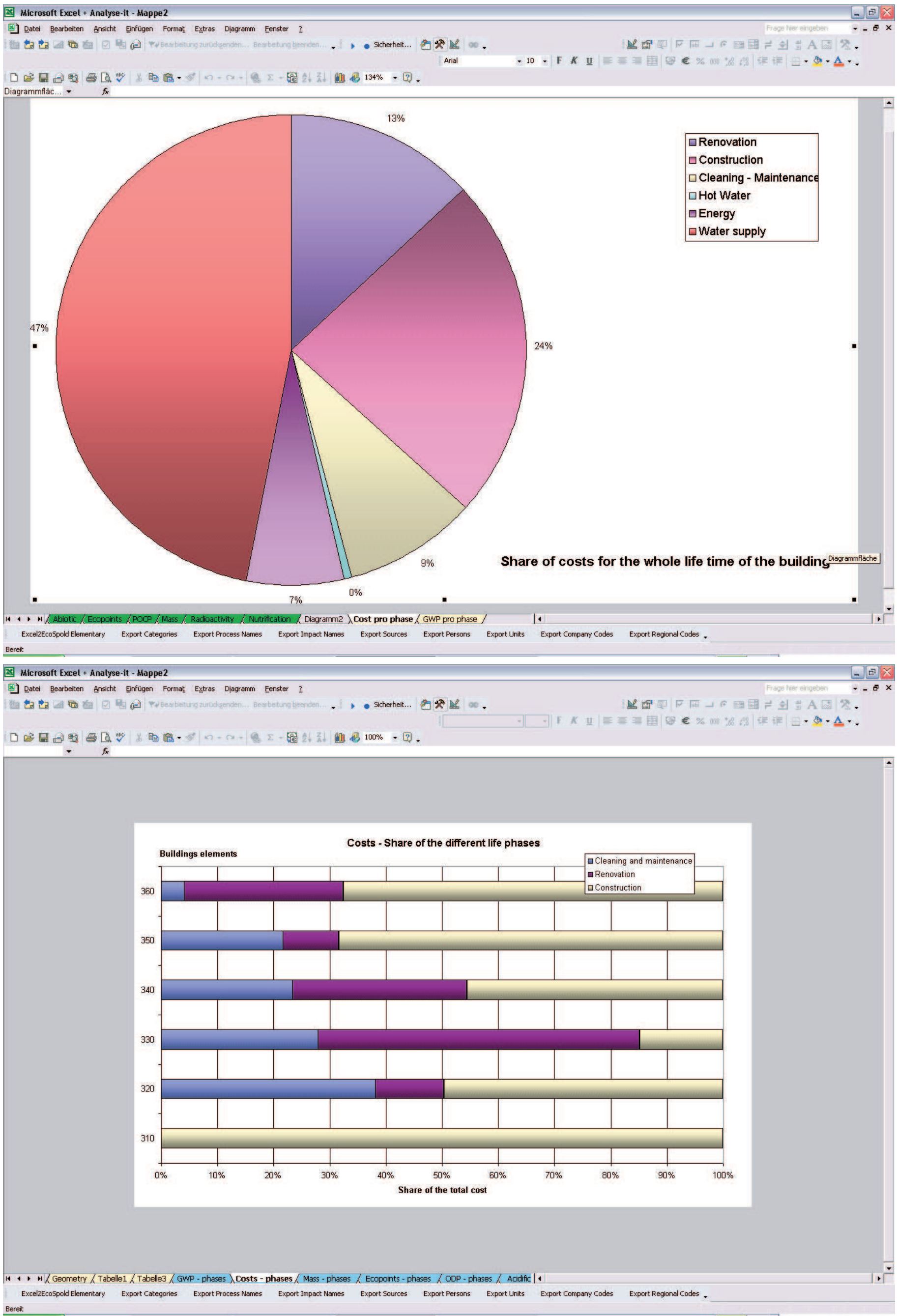


Figure 33

Screenshot of graphs in an Excel file

X. Prototype – Comparison of results

In a further analysis, it is possible with the help of the „comparison function“ to compare the results given for different case studies (several buildings, or several variants of the same building). You can see an example in Figure 35.

X.1. Selection of buildings

The user can select the reference file which corresponds to the file associated with a particular building. It will then be considered as the reference for comparison with the other selected buildings.

X.2. Comparison points

The user can select the results which he wants to compare with the others.

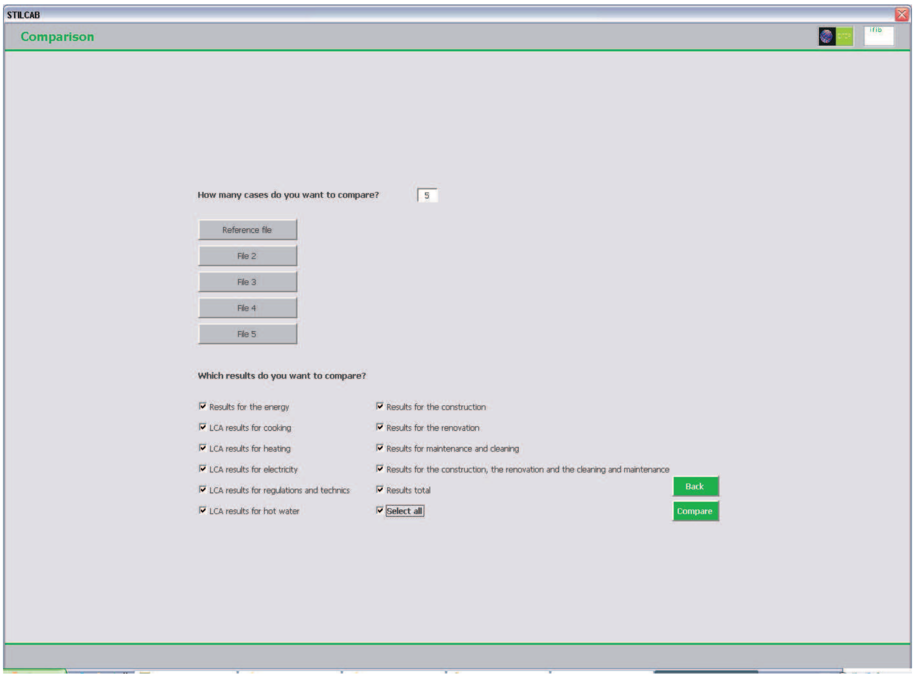


Figure 34

Comparison of results

X.3. Comparison graphs

The comparison results in the creation of a new Excel file which contains graphics such as the one below.

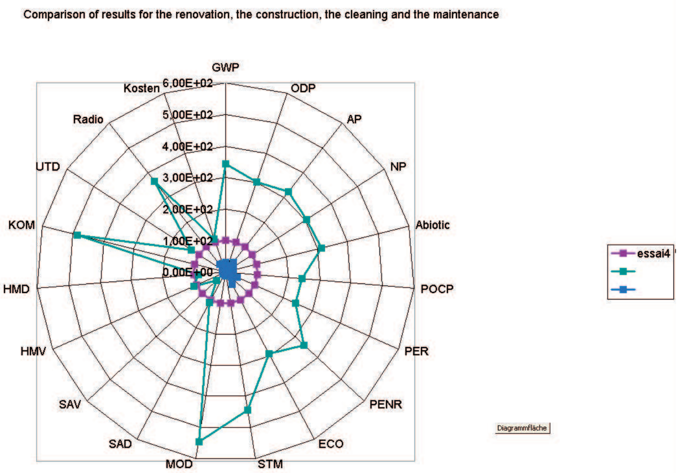


Figure 35

Comparison of the buidling's variants in the prototype

XI. Export in an Excel file

An Excel file is generated when clicking on this option. The user must enter the location and the name of the Excel file.
Graphics are automatically generated when exporting into an Excel file. Below is an example of such a graphic.

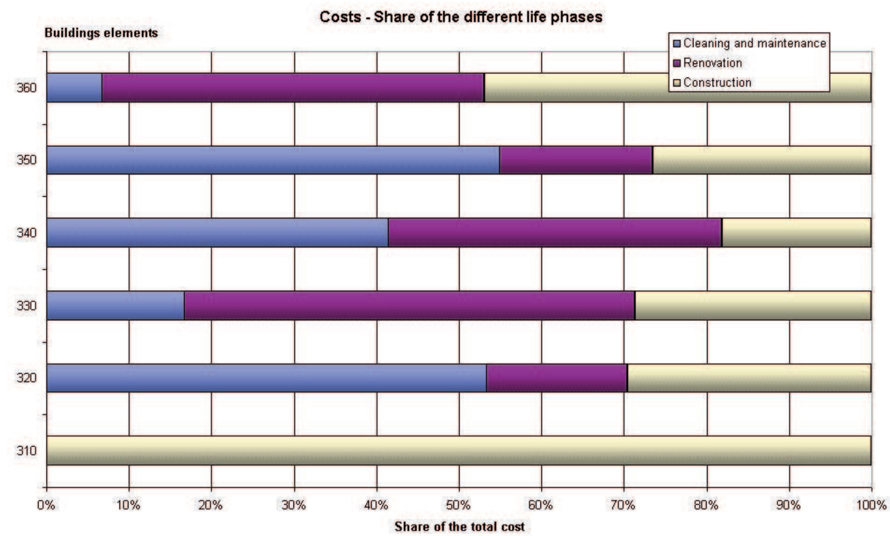


Figure 36
Graph in Excel

XII. Export in a Word file

A Word file is generated when clicking on this option. The user must enter the location and the name of the Word file.
Below is an extract of the automatically generated report in Word when selecting the option "Export in a Word file".

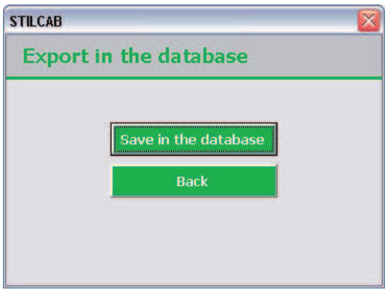
Building's reference	projet 1
Building's name	0
Building's use	Hostel, students habitation
Location	0
Annotations	0
Building's life time (years)	80
BGF (m2)	200
BF (m2)	100
Electricity mix	Germany

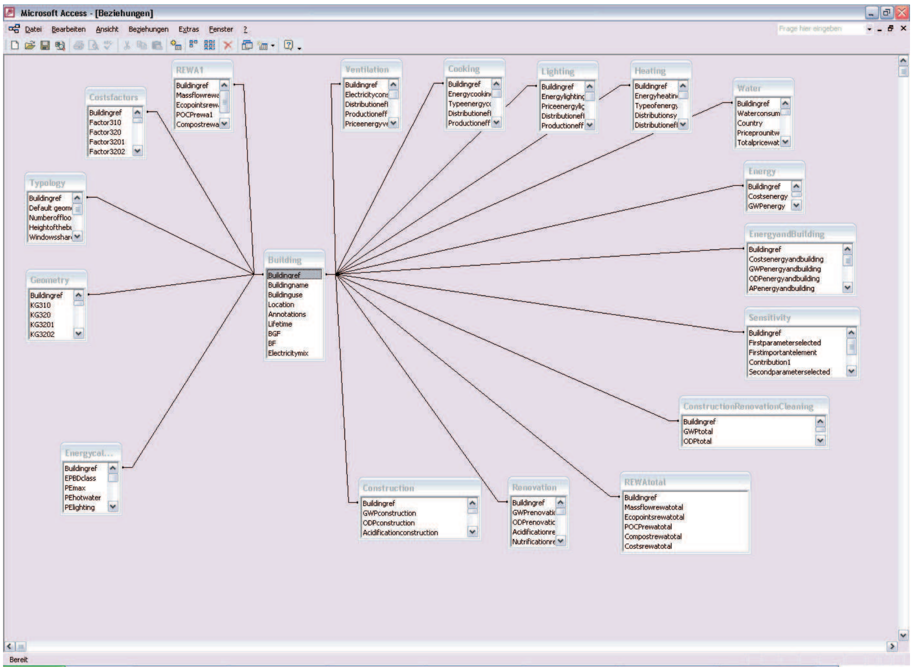
Figure 37
Extract of the automatically generated report in Word

XIII. Export in the database

When clicking on "Save in the database," the inputs and outputs of the current building's project are exported to the database and stored there as a "set of data".

There is only one set of data for each project. All pieces of information are sorted out in different tables in the database, in order to keep a good overview on the building.



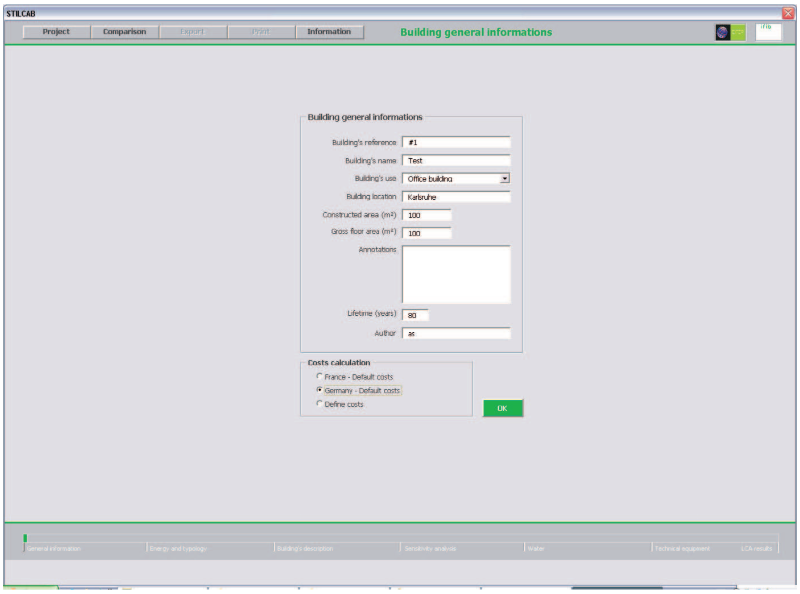


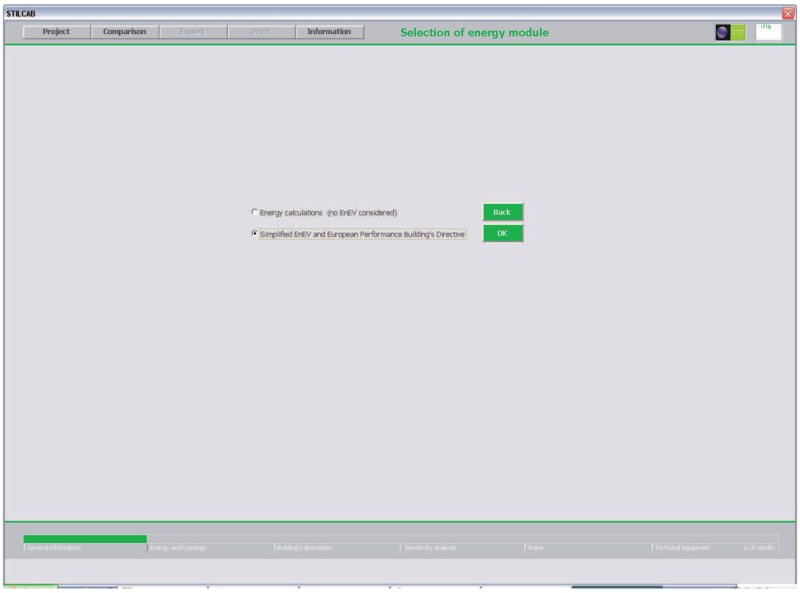
XIV. Case study

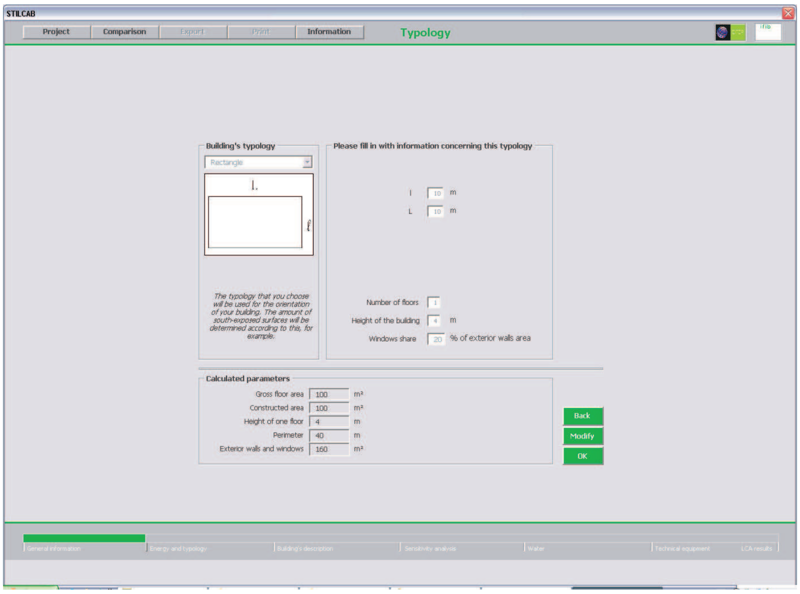
The following building was considered as an application example for Stilcab.

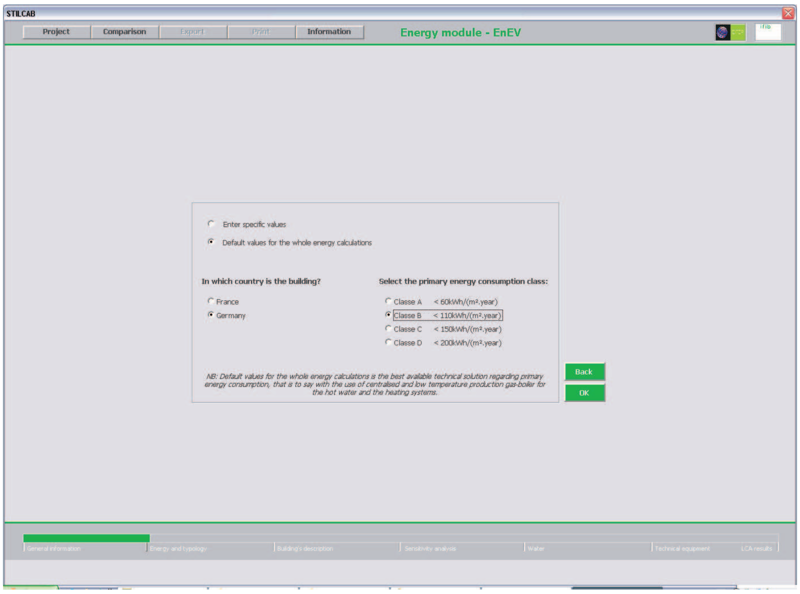
- The building is assimilated to a rectangle form of 28m*22m with one floor only and a height of 3,5m.
- It is a school for small children with 50 persons using the building.
- The school is located in France, therefore, French default costs are considered.
- The technical equipment is not considered in this example.
- In reality the building has 116m² of window space. This is too much to be in accordance with the EnEV (the maximum percentage of windows to fulfil the EnEV is 30%). Therefore a 30 % share was considered.
- Version 1: Class B (110) was first selected for the EPBD, with all default values and a central gas low temperature heating system.

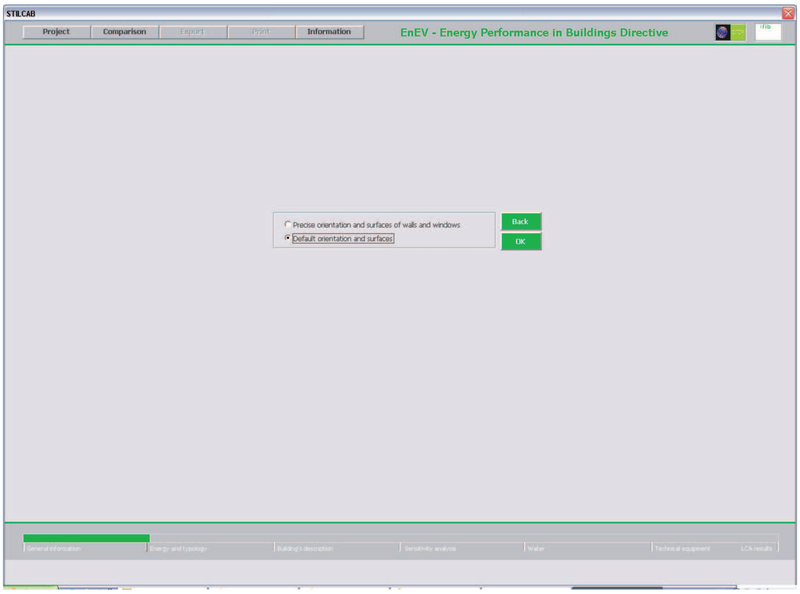
The following figures show the several screens which the user should fill in.

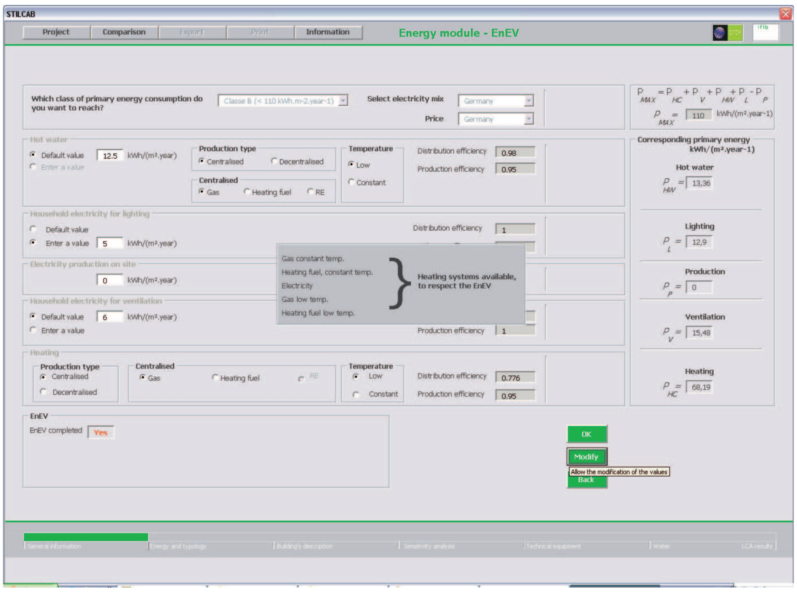

STILCAB
Project
Comparison
Information
Building general informations
Building general informations
Building's reference
Building's name
Building's use
Building location
Constructed area (m²)
Gross floor area (m²)
Annotations
Lifetime (years)
Author
Costs calculation
France - Default costs
Germany - Default costs
Define costs
OK

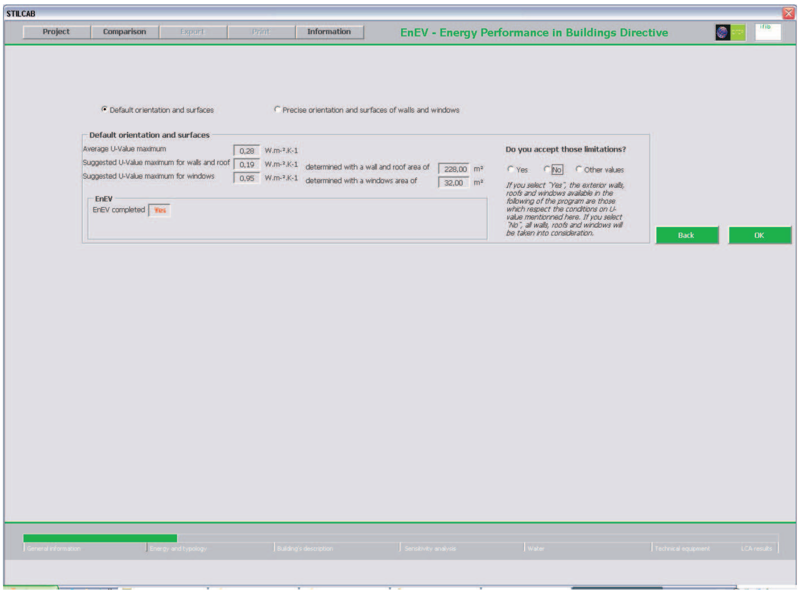

STILCAB
Project
Comparison
Information
Selection of energy module
Energy calculations (no EnEV considered)
Simplified EnEV and European Performance Building's Directive
Back
OK

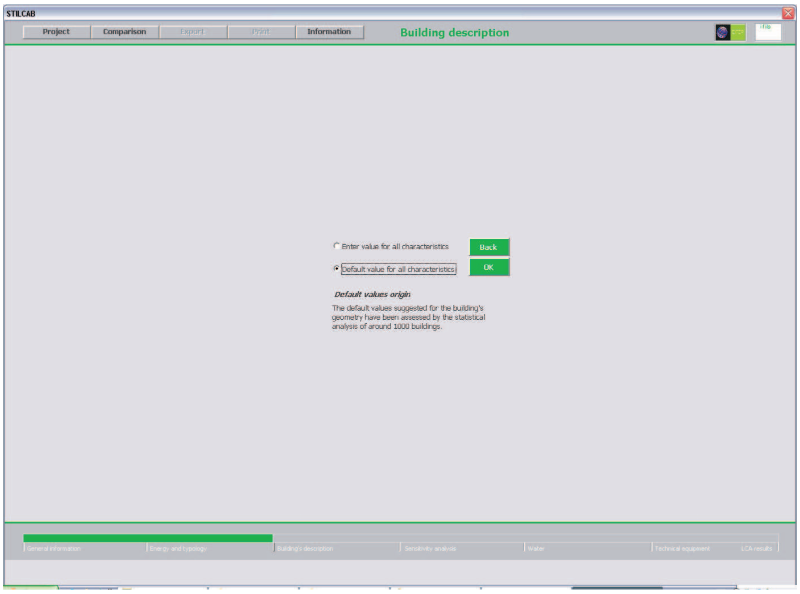

STILCAB
Project
Comparison
Information
Typology
Building's typology
Please fill in with information concerning this typology
Number of floors
Height of the building
Windows share
% of exterior walls area
Calculated parameters
Gross floor area
Constructed area
Height of one floor
Perimeter
Exterior walls and windows
Back
Modify
OK

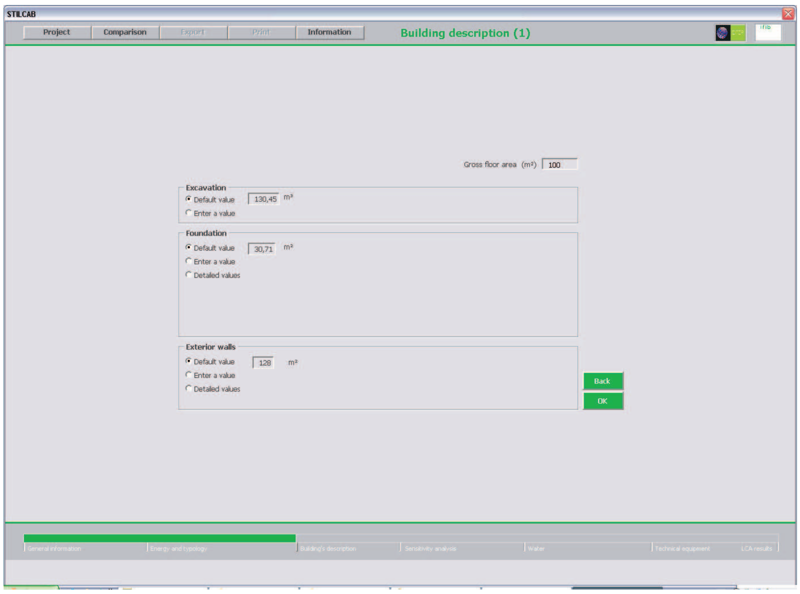

STILCAB
Project
Comparison
Export
Print
Information
Energy module - EnEV
Enter specific values
Default values for the whole energy calculations
In which country is the building?
France
Germany
Select the primary energy consumption class:
Classe A < 60kWh/(m².year)
Classe B < 110kWh/(m².year)
Classe C < 150kWh/(m².year)
Classe D < 200kWh/(m².year)
NB: Default values for the whole energy calculations is the best available technical solution regarding primary energy consumption, that is to say with the use of centralised and low temperature production gas-boiler for the hot water and the heating systems.
Back
OK

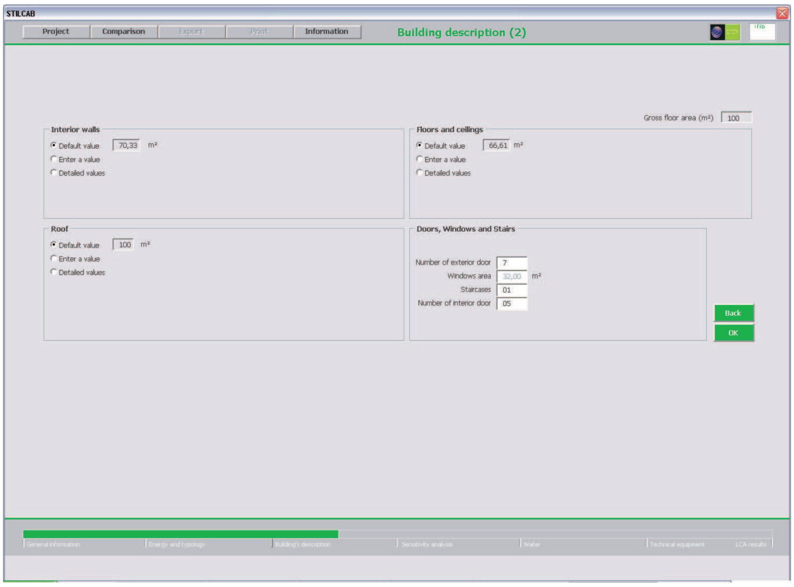

STILCAB
Project
Comparison
Export
Print
Information
EnEV - Energy Performance in Buildings Directive
Precise orientation and surfaces of walls and windows
Default orientation and surfaces
Back
OK

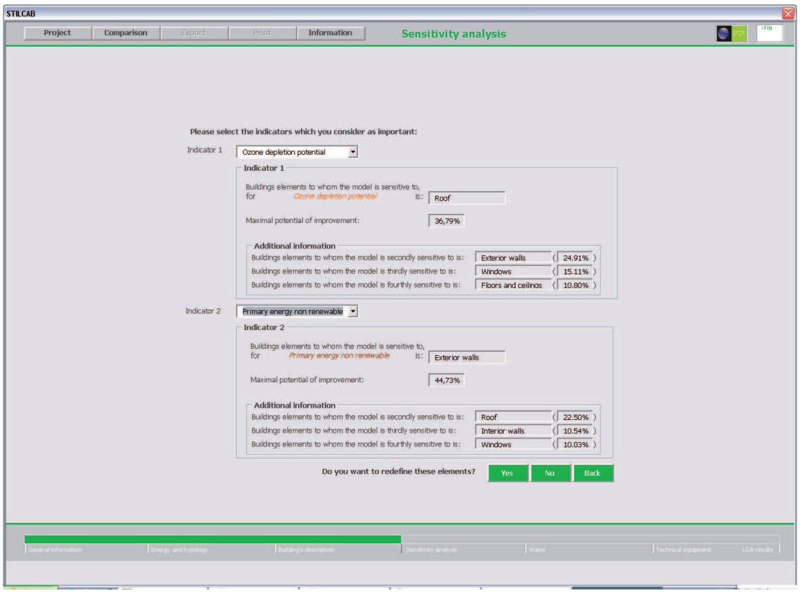

STILCAB
Project
Comparison
Export
Print
Information
Energy module - EnEV
Which class of primary energy consumption do you want to reach?
Select electricity mix
Price
Hot water
Default value
12.5
kWh/(m².year)
Production type
Centralised
Decentralised
Temperature
Low
Constant
Distribution efficiency
0.98
Production efficiency
0.95
Household electricity for lighting
Enter a value
5
Electricity production on site
0
Household electricity for ventilation
6
Gas constant temp.
Heating fuel, constant temp.
Electricity
Gas low temp.
Heating fuel low temp.
Heating systems available, to respect the EnEV
Heating
0.776
EnEV
EnEV completed
Yes
Corresponding primary energy kWh/(m².year-1)
110
Hot water
13,36
Lighting
12,9
Production
0
Ventilation
15,48
Heating
68,19
OK
Modify
Allow the modification of the values
Back

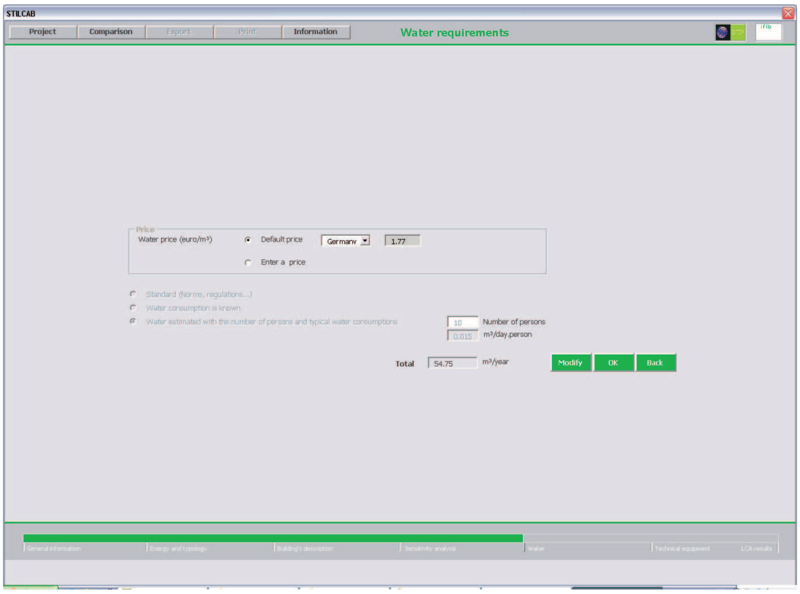

STILCAB
Project
Comparison
Information
EnEV - Energy Performance in Buildings Directive
Default orientation and surfaces
Precise orientation and surfaces of walls and windows
Do you accept those limitations?
Back
OK

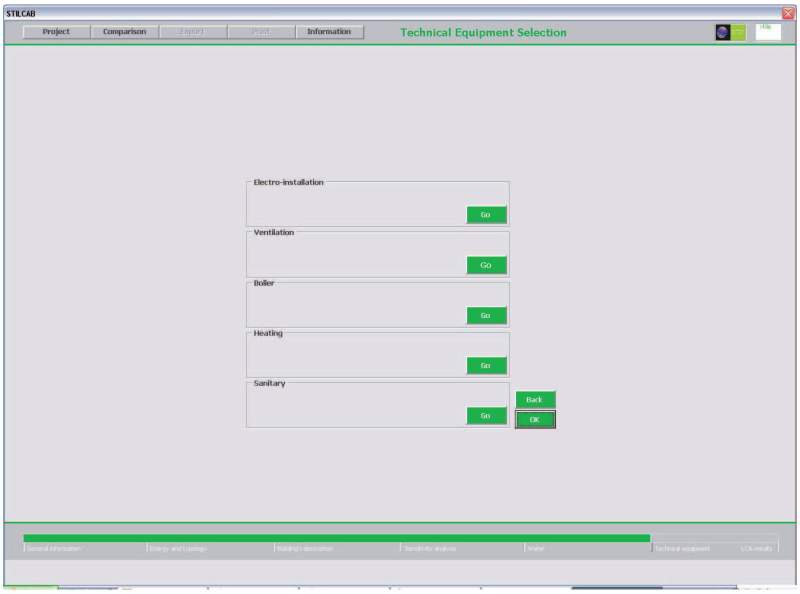

STILCAB
Project
Comparison
Information
Building description
Enter value for all characteristics
Default value for all characteristics
Back
OK
Default values origin
The default values suggested for the building's geometry have been assessed by the statistical analysis of around 1000 buildings.

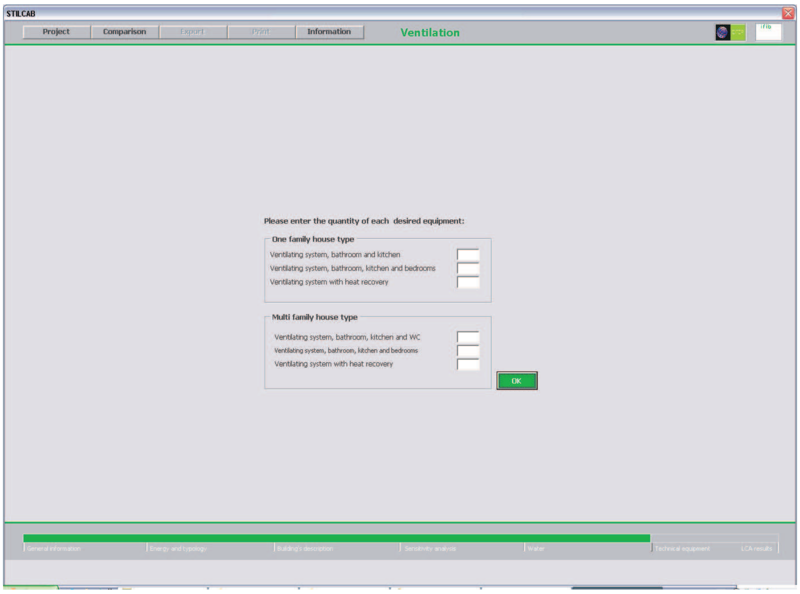

STILCAB
Project
Comparison
Information
Building description (1)
Excavation
Foundation
Exterior walls
Back
OK

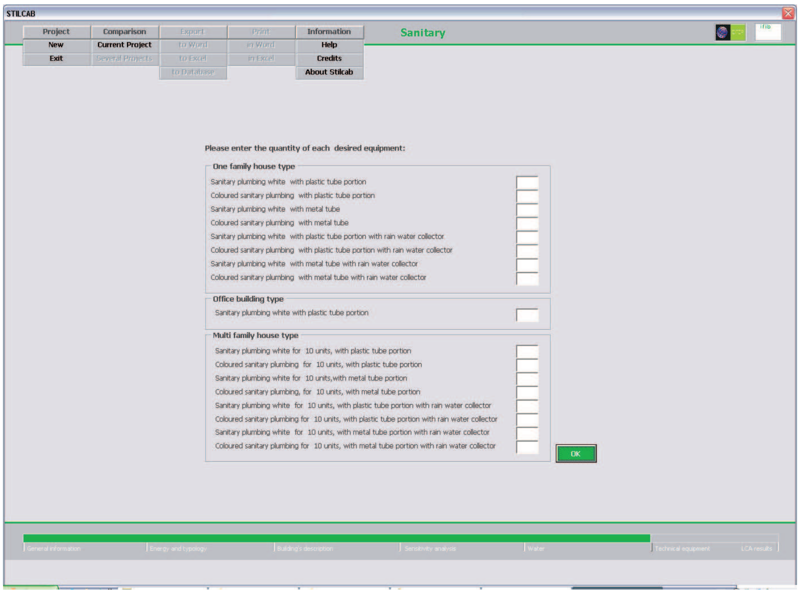

STILCAB
Project
Comparison
Information
Building description (2)
Gross floor area (m²) 100
Interior walls
Default value 70,33 m²
Enter a value
Detailed values
Floors and ceilings
Default value 66,61 m²
Enter a value
Detailed values
Roof
Default value 100 m²
Enter a value
Detailed values
Doors, Windows and Stairs
Number of exterior door 7
Windows area 30,00 m²
Staircases 01
Number of interior door 05
Back
OK

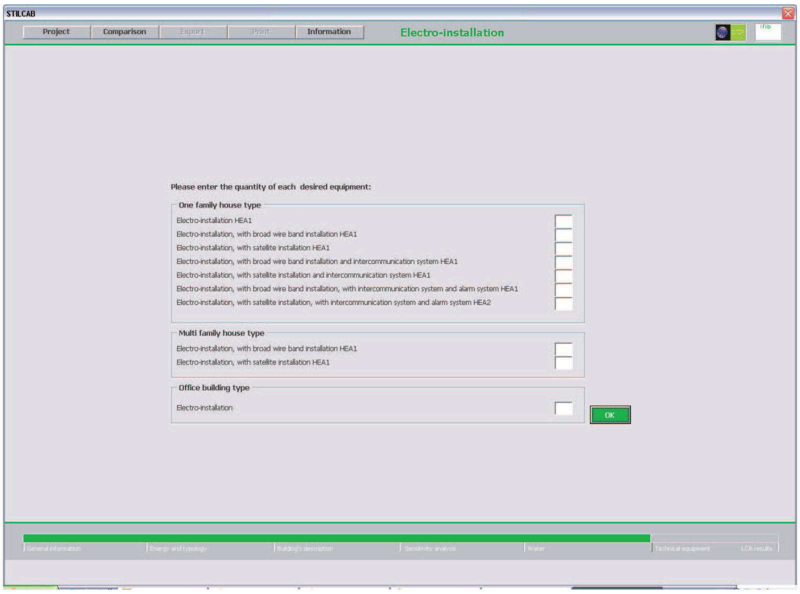

STILCAB
Project
Comparison
Information
Sensitivity analysis
Please select the indicators which you consider as important:
Indicator 1 Ozone depletion potential
Indicator 1
Buildings elements to whom the model is sensitive to, for Ozone depletion potential is: Roof
Maximal potential of improvement: 36,79%
Additional information
Buildings elements to whom the model is secondly sensitive to is: Exterior walls (24.91%)
Buildings elements to whom the model is thirdly sensitive to is: Windows (15.11%)
Buildings elements to whom the model is fourthly sensitive to is: Floors and ceilings (10.80%)
Indicator 2 Primary energy non renewable
Indicator 2
Buildings elements to whom the model is sensitive to, for Primary energy non renewable is: Exterior walls
Maximal potential of improvement: 44,73%
Additional information
Buildings elements to whom the model is secondly sensitive to is: Roof (22.50%)
Buildings elements to whom the model is thirdly sensitive to is: Interior walls (10.54%)
Buildings elements to whom the model is fourthly sensitive to is: Windows (10.03%)
Do you want to redefine these elements?
Yes
No
Back

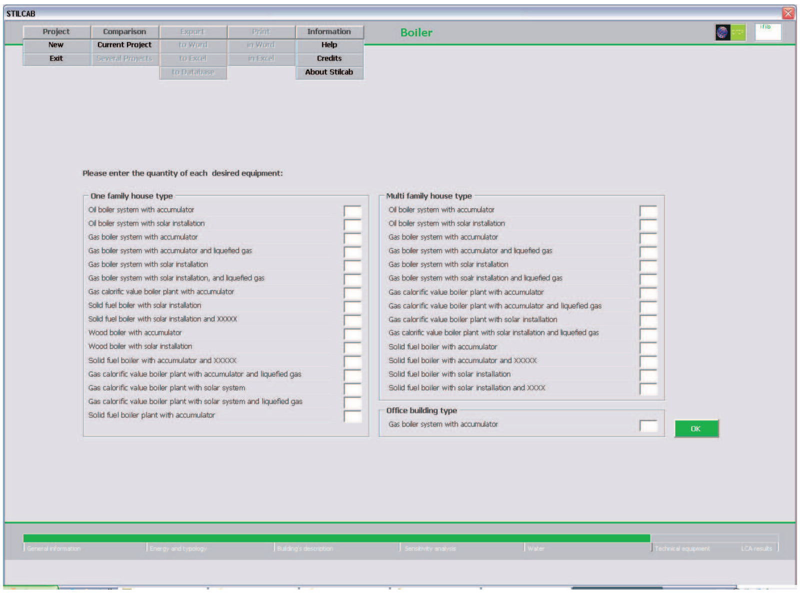

STILCAB
Project
Comparison
Information
Water requirements
Price
Water price (euro/m³)
Default price
Germany
1.77
Enter a price
Number of persons
m³/day.person
Total 54.75 m³/year
Modify
OK
Back

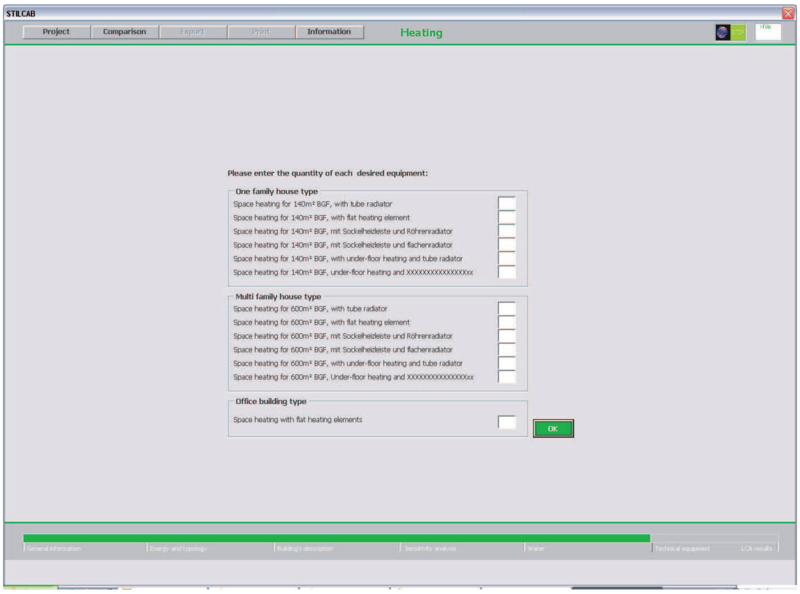

STILCAB
Project
Comparison
Export
Print
Information
Technical Equipment Selection
Electro-installation
Go
Ventilation
Go
Boiler
Go
Heating
Go
Sanitary
Go
Back
OK
General information
Energy and typology
Building's description
Sensitivity analysis
Water
Technical equipment
LCA results

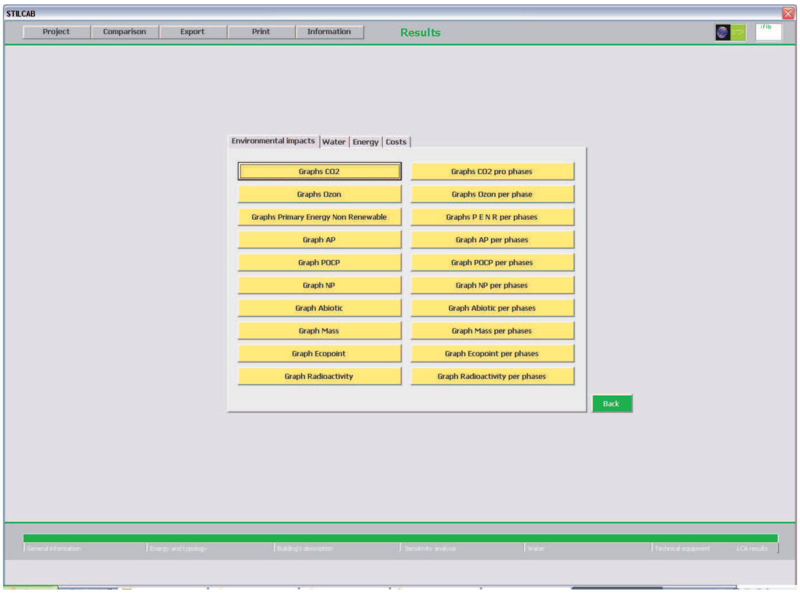

STILCAB
Project
Comparison
Export
Print
Information
Ventilation
Please enter the quantity of each desired equipment:
One family house type
Ventilating system, bathroom and kitchen
Ventilating system, bathroom, kitchen and bedrooms
Ventilating system with heat recovery
Multi family house type
Ventilating system, bathroom, kitchen and WC
Ventilating system, bathroom, kitchen and bedrooms
Ventilating system with heat recovery
OK

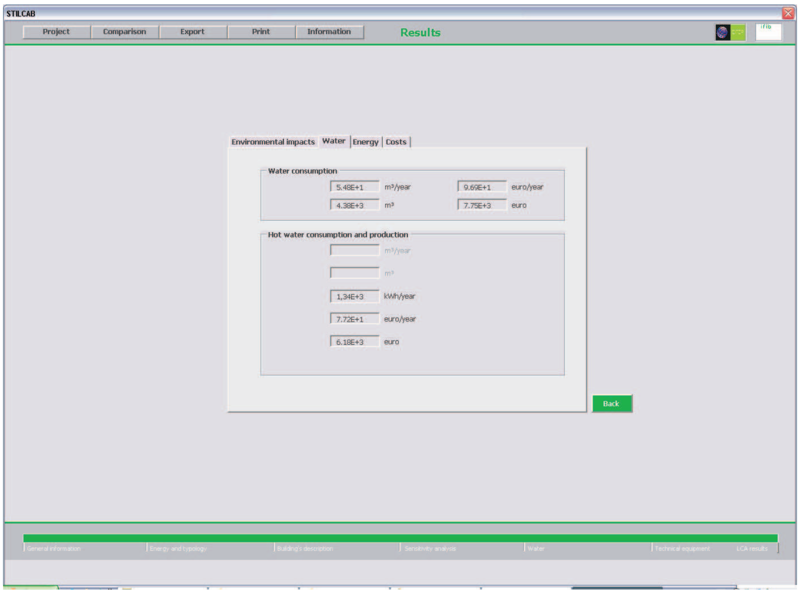

STILCAB
Project
Comparison
Export
Print
Information
New
Current Project
to Word
in Word
Help
Exit
Several Projects
to Excel
in Excel
Credits
to Database
About Stilcab
Sanitary
Please enter the quantity of each desired equipment:
One family house type
Sanitary plumbing white with plastic tube portion
Coloured sanitary plumbing with plastic tube portion
Sanitary plumbing white with metal tube
Coloured sanitary plumbing with metal tube
Sanitary plumbing white with plastic tube portion with rain water collector
Coloured sanitary plumbing with plastic tube portion with rain water collector
Sanitary plumbing white with metal tube with rain water collector
Coloured sanitary plumbing with metal tube with rain water collector
Office building type
Sanitary plumbing white with plastic tube portion
Multi family house type
Sanitary plumbing white for 10 units, with plastic tube portion
Coloured sanitary plumbing for 10 units, with plastic tube portion
Sanitary plumbing white for 10 units,with metal tube portion
Coloured sanitary plumbing, for 10 units, with metal tube portion
Sanitary plumbing white for 10 units, with plastic tube portion with rain water collector
Coloured sanitary plumbing for 10 units, with plastic tube portion with rain water collector
Sanitary plumbing white for 10 units, with metal tube portion with rain water collector
Coloured sanitary plumbing for 10 units, with metal tube portion with rain water collector
OK
General information
Energy and typology
Building's description
Sensitivity analysis
Water

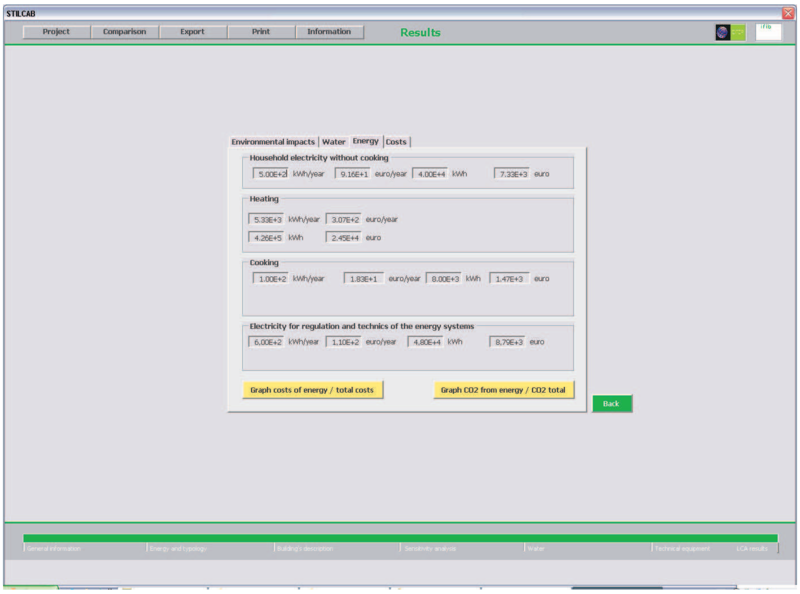

STILCAB
Project
Comparison
Export
Print
Information
Electro-installation
Please enter the quantity of each desired equipment:
One family house type
Electro-installation HEA1
Electro-installation, with broad wire band installation HEA1
Electro-installation, with satellite installation HEA1
Electro-installation, with broad wire band installation and intercommunication system HEA1
Electro-installation, with satellite installation and intercommunication system HEA1
Electro-installation, with broad wire band installation, with intercommunication system and alarm system HEA1
Electro-installation, with satellite installation, with intercommunication system and alarm system HEA2
Multi family house type
Electro-installation, with broad wire band installation HEA1
Electro-installation, with satellite installation HEA1
Office building type
Electro-installation
OK

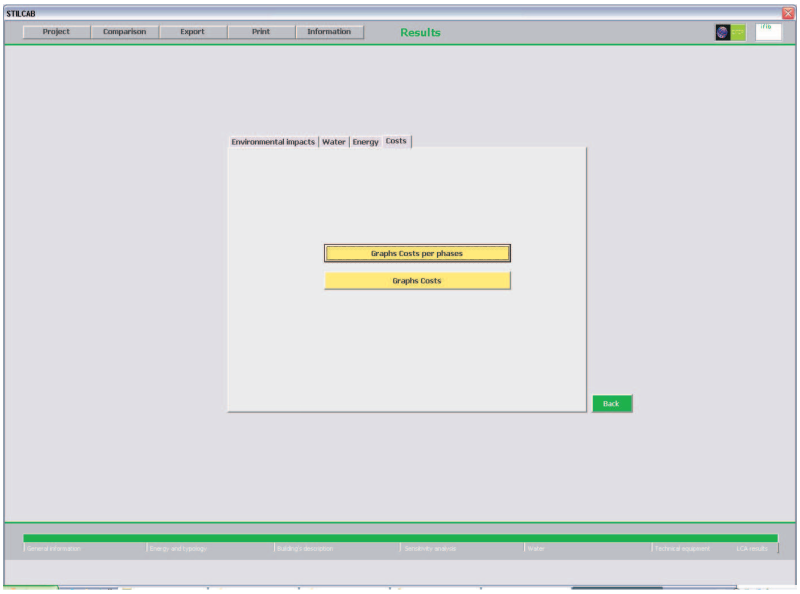

STILCAB
Project
Comparison
Export
Print
Information
New
Current Project
to Word
in Word
Help
Exit
Several Projects
to Excel
in Excel
Credits
to Database
About Stilcab
Boiler
Please enter the quantity of each desired equipment:
One family house type
Oil boiler system with accumulator
Oil boiler system with solar installation
Gas boiler system with accumulator
Gas boiler system with accumulator and liquefied gas
Gas boiler system with solar installation
Gas boiler system with solar installation, and liquefied gas
Gas calorific value boiler plant with accumulator
Solid fuel boiler with solar installation
Solid fuel boiler with solar installation and XXXXX
Wood boiler with accumulator
Wood boiler with solar installation
Solid fuel boiler with accumulator and XXXXX
Gas calorific value boiler plant with accumulator and liquefied gas
Gas calorific value boiler plant with solar system
Gas calorific value boiler plant with solar system and liquefied gas
Solid fuel boiler plant with accumulator
Multi family house type
Oil boiler system with accumulator
Oil boiler system with solar installation
Gas boiler system with accumulator
Gas boiler system with accumulator and liquefied gas
Gas boiler system with solar installation
Gas boiler system with soar installation and liquefied gas
Gas calorific value boiler plant with accumulator
Gas calorific value boiler plant with accumulator and liquefied gas
Gas calorific value boiler plant with solar installation
Gas calorific value boiler plant with solar installation and liquefied gas
Solid fuel boiler with accumulator
Solid fuel boiler with accumulator and XXXXX
Solid fuel boiler with solar installation
Solid fuel boiler with solar installation and XXXX
Office building type
Gas boiler system with accumulator
OK

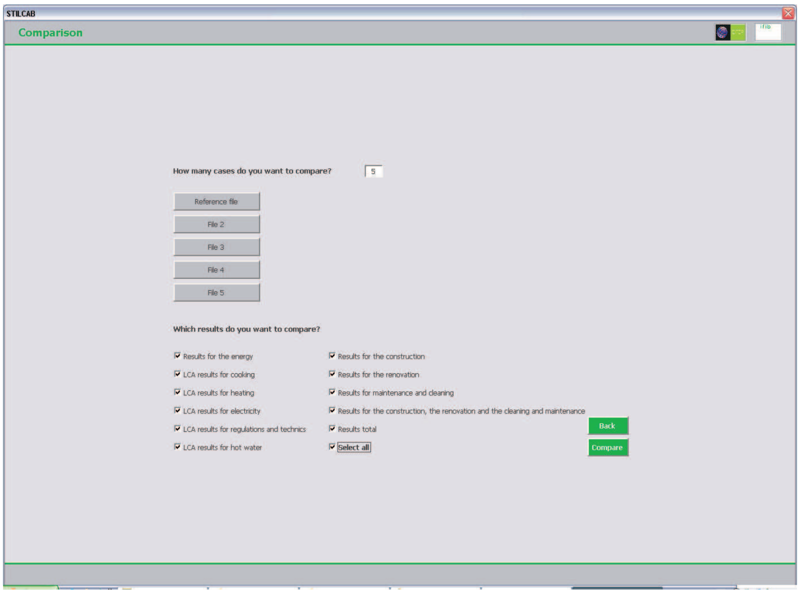

STILCAB
Project
Comparison
Export
Print
Information
Heating
Please enter the quantity of each desired equipment:
One family house type
Space heating for 140m² BGF, with tube radiator
Space heating for 140m² BGF, with flat heating element
Space heating for 140m² BGF, mit Sockelheizleiste und Rohrenradiator
Space heating for 140m² BGF, mit Sockelheizleiste und flachenradiator
Space heating for 140m² BGF, with under-floor heating and tube radiator
Space heating for 140m² BGF, under-floor heating and XXXXXXXXXXXXXXXxx
Multi family house type
Space heating for 600m² BGF, with tube radiator
Space heating for 600m² BGF, with flat heating element
Space heating for 600m² BGF, mit Sockelheizleiste und Rohrenradiator
Space heating for 600m² BGF, mit Sockelheizleiste und flachenradiator
Space heating for 600m² BGF, with under-floor heating and tube radiator
Space heating for 600m² BGF, Under-floor heating and XXXXXXXXXXXXXXXxx
Office building type
Space heating with flat heating elements
OK

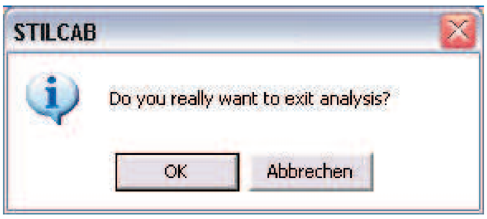

STILCAB
Project
Comparison
Export
Print
Information
Results
Environmental impacts
Water
Energy
Costs
Graphs CO2
Graphs CO2 pro phases
Graphs Ozon
Graphs Ozon per phase
Graphs Primary Energy Non Renewable
Graphs P E N R per phases
Graph AP
Graph AP per phases
Graph POCP
Graph POCP per phases
Graph NP
Graph NP per phases
Graph Abiotic
Graph Abiotic per phases
Graph Mass
Graph Mass per phases
Graph Ecopoint
Graph Ecopoint per phases
Graph Radioactivity
Graph Radioactivity per phases
Back


STILCAB
Project
Comparison
Export
Print
Information
Results
Environmental impacts
Water
Energy
Costs
Water consumption
Hot water consumption and production
Back


STILCAB
Project
Comparison
Export
Print
Information
Results
Environmental impacts
Water
Energy
Costs
Household electricity without cooking
Heating
Cooking
Electricity for regulation and technics of the energy systems
Graph costs of energy / total costs
Graph CO2 from energy / CO2 total
Back







XV. Word document

The following is a copy of the Word document edited directly from the Stilcab Menu and corresponds to the application example.

STILCAB

Simplified Tool for Integrated Life Cycle Analysis of Buildings

Date: 19/01/2007
Building's reference: 001
Author: Julie Chouquet

GENERAL INFORMATION

Building's reference	Crèche de Narbonne - version 1
Building's name	Narbonne jardin d'enfants
Building's use	School, university, education
Location	Narbonne - France
Annotations	Version 1 - Class B - No renewable energy - French costs
Building's lifetime (years)	80
Gross floor area (m^2)	616
Built area (m^2)	616
Electricity mix	France

BUILDING'S SELECTED TYPOLOGY

Default Geometry Selected	Rectangle
Number of floors	1
Height of the building	3,5
Window percentage	30
l	22
L	28

BUILDING'S CONSTRUCTION QUANTITY

Cost type	Given values	
310	**803,29**	
320	**342,25**	
320.1	0	Mat foundation with lining - cave
320.2	0	Base plate with lining
320.4	0	Mat foundation with lining
320.5	0	Base plate with lining
320.6	0	Timber construction resoles with lining
320.7	0	Timber construction massif, resoles with lining
320.9	0	Other establishment surfaces
330	**245**	
330.1	0	Brick-work wall with clothing
330.2	0	Reinforced concrete wall with clothing
330.4	0	Wood wound with clothing
330.6	0	Wood wound with clothing, massif
330.8	0	Windows
340	**449,27**	
340.1	0	Brick-work wall with clothing
340.2	0	Reinforced concrete wall with clothing
340.4	0	Wood stand wall with clothing
340.5	0	Metal stand wall with clothing
340.6	0	Wood board pile wall with clothing
340.7	0	Special construction components
340.8	0	Doors
350	**282,77**	
350.1	0	Brick floor with lining and clothing
350.2	0	Ferroconcrete covers with lining and clothing
350.3	0	Finished unit cover with lining and clothing
350.4	0	Timber ceiling with lining and clothing
350.6	0	Stairs
350.8	0	Composite floor
360	**616**	
360.1	0	Brick flat roof with lining and clothing
360.2	0	Ferroconcrete flat roof with lining and clothing
360.3	0	FT flat roof with lining and clothing
360.4	0	Flat timber roof with lining and clothing
360.7	0	Ferroconcrete - roof gene, with covering and clothing
360.8	0	Wood - roof gene, with covering and clothing
360.9	0	Wood - roof gene, substantial, with covering and clothing
Interior doors	**20**	
Exterior doors	**3**	
Windows	**105,00**	
Staircases	**0**	

COEFFICIENTS FOR THE COSTS CALCULATIONS

310	0,8846
320	1,1
320.1	1,1
320.2	1,1
320.4	1,1
320.5	1,1
320.6	1,1
320.7	1,1
320.9	1,1
330	1
330.1	1
330.2	1
330.4	1
330.6	1
340	1,17
340.1	1,17
340.2	1,17
340.4	1,17
340.5	1,17
340.6	1,17
350	1,31
350.1	1,31
350.2	1,31
350.3	1,31
350.4	1,31
360	0,87
360.1	0,87
360.2	0,87
360.3	0,87
360.4	0,87
360.7	0,87
360.8	0,87
360.9	0,87
Windows	1,51
Exterior doors	1

SENSITIVITY ANALYSIS

First parameter	Ozone depletion potential
First important element	Roof
Contribution of the first element to first parameter	52,06%

Second parameter	Mass flow
Second important element	Foundation
Contribution of the second element to second parameter	25,56%

User redefine the parameters:	0

SELECTED ENERGY CONSUMPTION

PARAMETERS FOR THE ENERGY PASS

Selected class (kWh/m².y)	B
Maximum value for primary energy consumption per year (kWh/m².y)	110
Primary energy for hot water (kWh/m².y)	13,43
Primary energy for lighting (kWh/m².y)	10,32
Primary energy for ventilation (kWh/m².y)	15,48
Avoided primary energy (kWh/m².y)	0,00
Primary energy authorized for heating (kWh/m².y)	70,77

RESULTS

Calculations realised with U value limitations?	Limitations accepted
EnEV completed or not	EnEV Completed
Windows: Windows (south orientation)	29,4
Windows: Windows (north orientation)	29,4
Windows: Windows (other orientations)	46,2
Umax Average	0,43
Umax for walls	0,30
Umax for windows	1,52

RESULTS FOR THE CONSTRUCTION OF THE BUILDING

Global Warming Potential (kg CO2-Eq)	180866,34
Ozone Depletion Potential (kg CFC11-Eq)	0,18
Acidification Potential (kg SO2-Eq)	1252,57
Nutrification Potential (kg P-Eq)	64,05
Consumption of Abiotic Resources (kg Sb-Eq)	34276,53
Photochemical Ozone Creation Potential (kg Ethen-Eq)	187,92
Renewable Primary Energy (MJ)	226375,48
Non-renewable Primary Energy (MJ)	3141673,67
Ecopoints (-)	507,24
Mass Flow (kg)	3263288,74
Sorted Wastes Landfill (kg)	1709015,96
Special Wastes Landfill (kg)	1,66
Special Waste Incineration (kg)	52,90
Domestic Wastes Incineration (kg)	572,58
Domestic Wastes Landfill (kg)	39,81
Compost (kg)	133858,88
Underground Landfill (kg)	0,00
Radioactivity	35117618,93
Costs (€)	561390,81

RESULTS FOR THE RENOVATION OF THE BUILDING FOR ITS LIFETIME

Global Warming Potential (kg CO2-Eq)	94710,38
Ozone Depletion Potential (kg CFC11-Eq)	0,18
Acidification Potential (kg SO2-Eq)	949,02
Nutrification Potential (kg P-Eq)	43,35
Consumption of Abiotic Resources (kg Sb-Eq)	30845,37
Photochemical Ozone Creation Potential (kg Ethen-Eq)	318,29
Renewable Primary Energy (MJ)	159476,95
Non-renewable Primary Energy (MJ)	2207486,56
Ecopoints (-)	456,25
Mass Flow (kg)	148301,05
Sorted Wastes Landfill (kg)	97909,81
Special Wastes Landfill (kg)	2323,85
Special Waste Incineration (kg)	4749,72
Domestic Wastes Incineration (kg)	24060,09
Domestic Wastes Landfill (kg)	4549,13
Compost (kg)	14705,15
Underground Landfill (kg)	0,55
Radioactivity	18484677,71
Costs (€)	1227418,83

RESULTS FOR THE CLEANING AND THE MAINTEANCE OF THE BUILDING FOR ITS LIFETIME

Mass Flow (kg)	492955,08
Ecopoints (-)	0,32
Photochemical Ozone Creation Potential (kg Ethen-Äq)	2,24
Compost (kg)	8,51
Costs (€)	786661,85

RESULTS FOR THE CLEANING, MAINTENANCE, CONSTRUCTION AND RENOVATION OF THE BUILDING OVER ITS LIFETIME

Global Warming Potential (kg CO2-Eq)	275576,73
Ozone Depletion Potential (kg CFC11-Eq)	0,36
Acidification Potential (kg SO2-Eq)	2201,59
Nutrification Potential (kg P-Eq)	107,40
Consumption of Abiotic Resources (kg Sb-Eq)	65121,89
Photochemical Ozone Creation Potential (kg Ethen-Eq)	508,44
Renewable Primary Energy (MJ)	385852,43
Non-renewable Primary Energy (MJ)	5349160,23
Ecopoints (-)	963,80
Mass Flow (kg)	3904544,87
Sorted Wastes Landfill (kg)	1806925,77
Special Wastes Landfill (kg)	2325,52
Special Waste Incineration (kg)	4802,61
Domestic Wastes Incineration (kg)	24632,67
Domestic Wastes Landfill (kg)	4588,94
Compost (kg)	148572,54
Underground Landfill (kg)	0,55
Radioactivity	53602296,63
Costs (€)	2575471,48

ENERGY CONSUMPTION RESULTS

RESULTS FOR THE CONSUMPTION OF FRESH WATER AND THE PREPARATION OF HOT WATER

Water consumption (m³/life time)	21900
Country selected for the price of water	France
Price selected for the supply of water (euro/m²)	23
Total price for the supply of water for the life time	14900
Energy for hot water	12,5
Hot water energy	Gas
Hot water distribution and production system	Centralised
Temperature	Low temperature
Hot water distribution efficiency	0,98
Hot water production efficiency	0,95
Global Warming Potential (kg CO2-Eq)	164211,67
Ozone Depletion Potential (kg CFC11-Eq)	0,02
Acidification Potential (kg SO2-Eq)	162,05
Nutrification Potential (kg P-Eq)	18,32
Consumption of Abiotic Resources (kg Sb-Eq)	49740,65
Photochemical Ozone Creation Potential (kg Ethen-Eq)	63,02
Renewable Primary Energy (MJ)	45419,29
Non-renewable Primary Energy (MJ)	3136406,96
Ecopoints (-)	103,53
Radioactivity	540264,51
Price for the energy for hot water (euro/life time)	38682,95

OVERALL ENERGY RESULTS FOR THE LIFETIME

Global Warming Potential (kg CO2-Eq)	1079571,20
Ozone Depletion Potential (kg CFC11-Eq)	0,14
Acidification Potential (kg SO2-Eq)	1935,47
Nutrification Potential (kg P-Eq)	150,82
Consumption of Abiotic Resources (kg Sb-Eq)	293131,19
Photochemical Ozone Creation Potential (kg Ethen-Eq)	386,19
Renewable Primary Energy (MJ)	1098659,42
Non-renewable Primary Energy (MJ)	29919602,75
Ecopoints (-)	989,76
Radioactivity	3082760,43
Energy cost for the whole life time (€)	284288,89

ENERGY RESULTS FOR LIGHTING

Price for the energy for household electricity (euro/life time)	21525,50
Energy for electrical appliances	4
Distribution efficiency	1
Production efficiency	1
Global Warming Potential (kg CO2-Eq)	30016,00
Ozone Depletion Potential (kg CFC11-Eq)	0,01
Acidification Potential (kg SO2-Eq)	212,80
Nutrification Potential (kg P-Eq)	9,74
Consumption of Abiotic Resources (kg Sb-Eq)	1960,00
Photochemical Ozone Creation Potential (kg Ethen-Eq)	5,60
Renewable Primary Energy (MJ)	176736,00
Non-renewable Primary Energy (MJ)	2531200,00
Ecopoints (-)	84,00
Radioactivity	0,00

ENERGY RESULTS FOR VENTILATION

Electricity for the regulation and techniques of the energy systems	6
Distribution efficiency	1
Production efficiency	1
Price for the energy for regulations and techniques electricity (euro/life time)	32288,26
Global Warming Potential (kg CO2-Eq)	45024,00
Ozone Depletion Potential (kg CFC11-Eq)	0,01
Acidification Potential (kg SO2-Eq)	319,20
Nutrification Potential (kg P-Eq)	14,62
Consumption of Abiotic Resources (kg Sb-Eq)	2940,00
Photochemical Ozone Creation Potential (kg Ethen-Eq)	8,40
Renewable Primary Energy (MJ)	265104,00
Non-renewable Primary Energy (MJ)	3796800,00
Ecopoints (-)	126,00
Radioactivity	0,00

ENERGY RESULTS FOR HEATING

Energy used	Gas
Energy for heating	46,58
Price for the energy for heating (euro/life time)	182042,75
Distribution system selected	Centralised
Distribution efficiency	0,78
Production efficiency	0,95
Global Warming Potential (kg CO2-Eq)	772783,52
Ozone Depletion Potential (kg CFC11-Eq)	0,08
Acidification Potential (kg SO2-Eq)	762,62
Nutrification Potential (kg P-Eq)	86,22
Consumption of Abiotic Resources (kg Sb-Eq)	234080,54
Photochemical Ozone Creation Potential (kg Ethen-Eq)	296,57
Renewable Primary Energy (MJ)	213744,13
Non-renewable Primary Energy (MJ)	14759995,80
Ecopoints (-)	487,23
Radioactivity	2542495,92

RESULTS FOR THE ENERGY SUPPLY AND THE BUILDING ITSELF FOR THE WHOLE LIFETIME

Global Warming Potential (kg CO2-Eq)	1355147,92
Ozone Depletion Potential (kg CFC11-Eq)	0,50
Acidification Potential (kg SO2-Eq)	4137,05
Nutrification Potential (kg P-Eq)	258,22
Consumption of Abiotic Resources (kg Sb-Eq)	358253,08
Photochemical Ozone Creation Potential (kg Ethen-Eq)	894,64
Renewable Primary Energy (MJ)	1484511,85
Non-renewable Primary Energy (MJ)	35268762,99
Ecopoints (-)	1953,56
Radioactivity	56685057,06
Costs all inclusive for the whole lifetime	2859760,37

Annex 6

Analysis of Construction Elements

I. Maximum value of each characteristic for the various element categories

Cost type	Global warming potential [kg $CO_{2\ eq.}$]	Ozone depletion potential [kg CFC11 $_{eq.}$]	Acidification potential [kg $SO_{2\ eq.}$]	Nutrification potential [kg $P_{eq.}$]	Abiotic resources consumption [kg $Sb_{eq.}$]	Photochemical ozone creation potential [kg Ethen $_{eq.}$]	Primary energy renewable [MJ]	Primary energy non-renewable [MJ]	Ecopoints [-]	Radioactivity [kBq]	Costs [€]
310	8,58E-03	0,00E+00	6,20E-05	2,21E-06	7,16E-04	1,99E-06	1,23E-02	1,86E-01	1,73E-05	7,22E+00	1,15E+00
3201	3,27E+00	4,36E-06	1,92E-02	8,73E-04	6,88E-01	2,91E-03	2,26E+00	5,38E+01	5,89E-03	7,29E+02	1,38E+01
3202	2,48E+00	4,36E-06	1,89E-02	8,70E-04	6,86E-01	2,94E-03	2,07E+00	5,38E+01	6,92E-03	4,10E+02	2,32E+01
3204	2,13E+00	4,00E-06	1,79E-02	6,48E-04	5,85E-01	2,69E-03	1,15E+00	3,75E+01	4,19E-03	5,09E+02	1,39E+01
3205	3,11E+00	1,73E-06	2,51E-02	9,13E-04	3,79E-01	2,42E-03	3,25E+00	4,54E+01	5,31E-03	6,03E+02	1,53E+01
3206	1,88E+00	1,09E-06	1,15E-02	7,29E-04	2,59E-01	2,36E-03	3,51E+00	2,92E+01	3,51E-03	4,73E+02	1,38E+01
3207	2,06E+00	1,83E-06	1,31E-02	9,72E-04	3,93E-01	1,35E-03	2,58E+00	3,65E+01	4,01E-03	5,12E+02	1,69E+01
3209	8,63E-01	1,11E-06	5,61E-03	3,37E-04	3,02E-01	7,91E-04	6,02E-01	2,36E+01	1,78E-03	2,67E+02	5,52E+00
3301	2,58E+00	2,19E-06	9,61E-03	6,69E-04	4,10E-01	1,70E-02	3,75E+00	2,90E+01	8,54E-03	3,56E+02	9,27E+00
3302	5,07E+00	2,43E-06	2,69E-02	1,63E-03	8,15E-01	2,01E-03	4,38E+00	8,43E+01	8,62E-03	9,48E+02	8,93E+00
3304	3,27E+00	2,88E-06	1,85E-02	1,11E-03	7,08E-01	3,27E-02	7,75E+00	6,28E+01	1,59E-02	8,07E+02	3,38E+01
3306	2,08E+00	1,70E-06	8,12E-03	7,16E-04	3,07E-01	1,83E-02	3,19E+00	2,51E+01	5,33E-03	2,99E+02	7,69E+00
3308	1,18E+01	1,30E-05	8,76E-02	5,92E-03	2,34E+00	4,65E-02	2,48E+01	1,55E+02	2,99E-02	1,17E+03	1,90E+02
3401	1,57E+00	1,34E-06	4,59E-03	4,32E-04	2,78E-01	8,67E-04	2,04E+00	1,80E+01	3,82E-03	1,70E+02	4,65E+00
3402	4,58E+00	1,73E-06	1,71E-02	1,13E-03	3,06E-01	1,15E-03	5,48E+00	5,30E+01	4,73E-03	7,12E+02	9,57E+00
3404	8,79E-01	2,19E-06	6,28E-03	5,20E-04	3,75E-01	1,64E-02	2,50E+00	2,51E+01	2,69E-03	1,98E+02	6,03E+00
3405	9,62E-01	2,16E-06	6,77E-03	5,13E-04	3,76E-01	1,52E-03	1,46E+00	2,63E+01	3,77E-03	2,14E+02	5,99E+00
3406	1,14E+00	1,33E-06	4,52E-03	4,78E-04	2,03E-01	6,00E-03	2,75E+00	1,57E+01	1,97E-03	1,68E+02	6,68E+00

Cost type	Global warming potential [kg $CO_{2\ eq.}$]	Ozone depletion potential [kg CFC11 $_{eq.}$]	Acidification potential [kg $SO_{2\ eq.}$]	Nutrification potential [kg $P_{eq.}$]	Abiotic resources consumption [kg $Sb_{eq.}$]	Photochemical ozone creation potential [kg Ethen $_{eq.}$]	Primary energy renewable [MJ]	Primary energy non-renewable [MJ]	Ecopoints [-]	Radioactivity [kBq]	Costs [€]
3407	1,08E+01	4,03E-06	4,56E-02	3,61E-03	1,30E+00	3,36E-03	7,24E+00	1,22E+02	2,49E-02	1,36E+03	1,02E+02
3408	1,51E+01	9,81E-06	9,01E-02	4,55E-03	2,03E+00	6,37E-03	4,32E+01	2,34E+02	8,77E-02	3,91E+03	6,11E+01
3501	2,10E+00	1,96E-06	1,72E-02	7,63E-04	3,80E-01	1,36E-02	1,71E+00	3,00E+01	4,48E-03	3,12E+02	1,40E+01
3502	1,99E+00	4,35E-06	1,76E-02	7,71E-04	6,70E-01	6,74E-03	5,76E+00	4,80E+01	5,44E-03	3,51E+02	2,43E+01
3503	2,76E+00	4,46E-06	4,70E-02	1,27E-03	7,02E-01	5,94E-03	6,34E+00	5,23E+01	1,18E-02	5,71E+02	5,82E+01
3504	1,26E+00	3,74E-06	1,26E-02	6,87E-04	5,61E-01	1,37E-02	7,88E+00	3,76E+01	6,90E-03	3,45E+02	1,46E+01
3506	3,46E+01	4,85E-05	7,28E-01	1,26E-02	8,36E+00	3,33E-02	3,11E+01	7,86E+02	1,90E-01	1,07E+04	1,29E+02
3508	7,06E-01	3,75E-07	3,91E-03	3,63E-04	1,28E-01	2,72E-03	1,60E+00	1,28E+01	1,56E-03	1,41E+02	1,30E+01
3601	4,72E+00	8,91E-06	4,04E-02	2,11E-03	1,43E+00	9,24E-03	3,00E+00	1,03E+02	1,52E-02	1,21E+03	1,00E+01
3602	2,89E+00	4,76E-06	2,88E-02	1,05E-03	8,08E-01	4,94E-03	6,10E+00	6,36E+01	8,94E-03	5,39E+02	4,66E+00
3603	3,95E+00	8,74E-06	4,95E-02	1,71E-03	1,43E+00	9,14E-03	3,76E+00	9,82E+01	1,60E-02	8,04E+02	1,09E+01
3604	3,78E+00	1,01E-05	3,86E-02	1,54E-03	1,51E+00	1,13E-02	8,26E+00	9,88E+01	1,55E-02	1,12E+03	1,02E+01
3607	1,32E+00	1,06E-06	7,36E-03	4,38E-04	1,89E-01	8,42E-04	1,20E+00	2,40E+01	9,78E-03	2,28E+02	5,71E+00
3608	1,94E+00	3,86E-06	3,21E-02	1,11E-03	9,52E-01	3,06E-03	7,08E+00	5,95E+01	1,40E-02	4,69E+02	7,72E+00
3609	9,85E-01	1,00E-06	1,29E-02	3,12E-04	1,99E-01	3,25E-03	2,12E+00	1,81E+01	9,64E-03	2,38E+02	5,43E+00
3701	5,35E-01	3,15E-06	1,83E-02	1,63E-03	4,84E-01	4,61E-03	1,82E+01	3,90E+01	9,53E-03	4,99E+02	2,41E+02
Overall	3,46E+01	4,85E-05	7,28E-01	1,26E-02	8,36E+00	4,65E-02	4,32E+01	7,86E+02	1,90E-01	1,07E+04	2,41E+02

NB: Data calculated for a lifetime of 80 years. Data for one year

II. Minimum value of each characteristic for the various element categories

Cost type	Global warming potential [kg $CO_{2\ eq.}$]	Ozone depletion potential [kg CFC11 $_{eq.}$]	Acidification potential [kg $SO_{2\ eq.}$]	Nutrification potential [kg $P_{eq.}$]	Abiotic resources consumption [kg $Sb_{eq.}$]	Photochemical ozone creation potential [kg Ethen $_{eq.}$]	Primary energy renewable [MJ]	Primary energy non-renewable [MJ]	Ecopoints [-]	Mass flow [kg]	Radioactivity [kBq]	Costs [€]
310	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,97E+01	0,00E+00	2,13E-01
3201	9,61E-01	4,00E-07	5,72E-03	3,40E-04	1,05E-01	3,09E-04	6,30E-01	1,82E+01	1,63E-03	9,14E+00	2,75E+02	3,80E+00
3202	5,80E-01	3,38E-07	3,57E-03	1,45E-04	9,02E-02	2,44E-04	2,91E-01	9,74E+00	1,30E-03	7,69E+00	1,32E+02	2,52E+00
3204	1,41E-01	3,00E-07	1,52E-03	6,71E-05	6,84E-02	2,70E-04	1,62E-01	4,38E+00	8,17E-04	9,08E-01	2,14E+01	2,28E+00
3205	1,88E+00	6,00E-07	8,56E-03	4,59E-04	1,48E-01	4,97E-04	7,45E-01	2,45E+01	2,53E-03	4,55E+01	3,40E+02	1,14E+01
3206	1,30E+00	6,25E-07	6,53E-03	3,54E-04	1,53E-01	6,36E-04	9,13E-01	1,93E+01	2,24E-03	3,65E+01	2,69E+02	1,13E+01
3207	1,16E+00	3,63E-07	6,37E-03	3,70E-04	8,77E-02	2,91E-04	9,36E-01	1,27E+01	1,60E-03	1,61E+01	1,84E+02	9,03E+00
3209	8,63E-01	1,11E-06	5,61E-03	3,37E-04	3,02E-01	7,91E-04	6,02E-01	2,36E+01	1,78E-03	9,19E+00	2,67E+02	5,52E+00
3301	9,78E-01	5,00E-07	3,64E-03	3,30E-04	9,70E-02	4,12E-04	3,53E-01	1,18E+01	1,48E-03	4,22E+00	6,85E+01	2,34E+00
3302	2,84E-01	2,75E-07	3,63E-03	1,21E-04	6,93E-02	2,03E-04	5,96E-01	6,00E+00	9,97E-04	5,17E-01	3,45E+01	1,94E+00
3304	-1,82E-01	7,50E-08	9,22E-04	8,44E-05	1,82E-02	5,06E-04	7,97E-01	1,72E+00	1,07E-03	8,28E-01	1,80E+01	4,34E+00
3306	7,08E-03	3,88E-07	2,22E-03	1,64E-04	5,89E-02	7,56E-04	8,87E-01	4,95E+00	1,33E-03	1,13E+00	7,45E+01	4,14E+00
3308	8,78E-01	2,50E-07	4,55E-03	3,32E-04	7,48E-02	6,22E-04	3,76E-01	1,62E+01	3,18E-03	1,32E+00	1,59E+01	1,47E+01
3401	1,45E-01	2,25E-07	1,10E-03	9,14E-05	4,52E-02	1,81E-04	1,85E-01	3,83E+00	4,00E-04	6,36E-01	3,04E+01	1,39E+00
3402	4,45E-02	1,25E-07	4,46E-04	3,41E-05	2,13E-02	8,64E-05	3,74E-01	1,60E+00	1,67E-04	1,14E-01	1,22E+01	6,69E-01
3404	-9,69E-02	2,50E-08	3,63E-04	3,34E-05	2,38E-02	3,04E-04	1,57E-01	1,98E+00	3,43E-04	7,90E-01	2,11E+00	2,68E+00
3405	3,64E-01	5,63E-07	2,38E-03	2,45E-04	1,02E-01	4,45E-04	5,65E-01	8,01E+00	1,69E-03	7,13E-01	9,26E+01	2,91E+00
3406	1,67E-02	1,25E-07	3,56E-04	2,25E-05	1,79E-02	5,76E-04	4,39E-01	1,15E+00	7,44E-04	6,47E-01	6,92E+00	1,85E+00

Cost type	Global warming potential [kg $CO_{2\ eq.}$]	Ozone depletion potential [kg CFC11 $_{eq.}$]	Acidification potential [kg $SO_{2\ eq.}$]	Nutrification potential [kg P $_{eq.}$]	Abiotic resources consumption [kg Sb $_{eq.}$]	Photochemical ozone creation potential [kg Ethen $_{eq.}$]	Primary energy renewable [MJ]	Primary energy non-renewable [MJ]	Ecopoints [-]	Mass flow [kg]	Radioactivity [kBq]	Costs [€]
3407	2,24E-01	3,25E-07	1,46E-03	1,35E-04	6,37E-02	3,39E-04	3,93E-01	5,46E+00	1,42E-03	5,98E-01	5,43E+01	1,77E+00
3408	1,71E-01	9,00E-07	3,72E-03	2,53E-04	1,46E-01	7,90E-04	1,86E+00	1,19E+01	2,52E-03	2,00E+00	1,46E+02	4,10E+01
3501	1,01E+00	6,00E-07	2,74E-03	2,45E-04	1,12E-01	4,94E-04	7,12E-01	9,28E+00	1,19E-03	4,94E+00	1,06E+02	2,78E+00
3502	6,31E-01	2,50E-07	2,99E-03	1,78E-04	5,63E-02	2,24E-04	4,10E-01	8,87E+00	1,18E-03	6,68E+00	1,47E+02	1,67E+00
3503	8,55E-01	3,25E-07	4,62E-03	2,26E-04	7,81E-02	2,28E-04	9,33E-01	1,21E+01	1,19E-03	3,55E+00	1,39E+02	1,71E+00
3504	-3,40E-01	8,75E-08	1,25E-03	1,11E-04	1,65E-02	3,13E-04	6,56E-01	4,01E+00	9,10E-04	1,43E+00	2,59E+01	2,31E+00
3506	1,42E-01	1,25E-07	1,08E-03	6,44E-05	2,29E-02	8,75E-05	2,98E-01	2,19E+00	5,65E-04	2,48E+00	1,51E+01	4,99E+01
3508	5,76E-01	2,63E-07	2,96E-03	2,39E-04	5,92E-02	2,60E-03	1,04E+00	7,64E+00	1,22E-03	2,99E+01	9,71E+01	1,27E+01
3601	4,08E+00	7,15E-06	3,80E-02	1,60E-03	1,40E+00	7,97E-03	2,89E+00	9,55E+01	1,34E-02	6,54E+00	5,55E+02	6,45E+00
3602	1,12E+00	6,38E-07	6,13E-03	3,70E-04	1,26E-01	5,29E-04	6,02E-01	1,84E+01	2,75E-03	6,94E+00	1,78E+02	2,07E+00
3603	2,67E+00	4,39E-06	2,59E-02	1,16E-03	7,27E-01	2,99E-03	2,41E+00	5,47E+01	9,00E-03	8,69E+00	3,81E+02	6,31E+00
3604	9,07E-01	3,16E-06	1,64E-02	6,81E-04	4,95E-01	4,80E-03	2,35E+00	3,50E+01	6,54E-03	2,68E+00	2,24E+02	6,08E+00
3607	1,31E+00	1,03E-06	7,14E-03	4,08E-04	1,79E-01	7,97E-04	8,25E-01	2,33E+01	9,70E-03	5,84E+00	2,24E+02	5,49E+00
3608	-3,51E-01	1,38E-07	1,38E-03	1,15E-04	2,85E-02	2,73E-04	2,38E-01	3,47E+00	8,32E-04	6,44E-01	7,18E+01	1,77E+00
3609	8,11E-01	1,00E-06	5,40E-03	3,08E-04	1,67E-01	3,11E-03	8,91E-01	1,67E+01	5,92E-03	1,97E+00	1,24E+02	5,14E+00
3701	-6,32E-02	1,59E-06	1,32E-02	8,45E-04	2,78E-01	1,25E-03	1,24E+01	2,97E+01	8,61E-03	6,75E+00	4,84E+02	5,27E+01
Overall	-3,51E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,14E-01	0,00E+00	2,13E-01

NB: Data calculated for a lifetime of 80 years. Data for one year

Annex 7

Geometrical Matrix

Y=a * gross floor area	One and two family houses (Gross floor area < 1000m²)	Multiple family houses	Multiple family houses (Gross floor area < 4000m²)	Factory buildings	Factory buildings (Gross floor area < 4000m²)	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings (Gross floor area < 2500m²)	Educational buildings	Educational buildings (Gross floor area < 2000m²)
Excavation	0,99	0,60	0,71	0,93	1,12	1,42	1,15	1,24	1,37	1,38	1,30	1,01	1,30
Foundation	0,42	0,20	0,24	0,52	0,72	0,00	0,36	0,22	0,47	0,24	0,31	0,35	0,56
Exterior walls	0,82	0,68	0,62	0,51	0,64	0,64	0,52	0,48	0,65	0,55	0,68	0,57	0,73
Interior walls	0,82	0,93	0,84	0,57	0,44	0,88	0,47	1,01	0,53	0,75	0,70	0,66	0,73
Floors and ceilings	0,60	0,76	0,76	0,47	0,31	0,66	0,67	0,69	0,50	0,71	0,67	0,51	0,46
Roof					0,76	0,31	0,39	0,25	0,55	0,26			0,70
Net floor area	0,68	0,71	0,70	0,76	0,85	0,67	0,70	0,59	0,74	0,64	0,67	0,60	0,67
Gross net floor area	0,82	0,86	0,83	0,93	0,93	0,85	0,89	0,87	0,88	0,88	0,85	0,86	0,85
Main function area	0,50	0,57	0,54	0,68	0,79	0,56	0,61	0,47	0,47	0,48	0,56	0,50	0,55
Traffic area	0,11	0,14	0,13	0,00	0,06	0,15		0,23	0,11	0,18	0,16	0,20	0,16
Function area	0,04	0,01	0,01	0,05		0,03	0,03	0,04	0,03	0,05	0,03	0,03	0,02
Construction area	0,18	0,14	0,17	0,06	0,07	0,15	0,10	0,13	0,12	0,12	0,15	0,12	0,15
Volume	2,93	2,89	2,94	5,52	5,73	3,23	3,70	3,23	3,93	3,58	3,48	3,87	3,78
Y=a * constructed area													
Excavation	2,22	3,25	2,66	1,62	1,16	5,90	3,09			2,26	3,07		
Foundation	0,97	1,02	0,93	0,97	0,84	1,06	0,99	0,99	0,96	1,00	0,95	0,80	0,95
Roof	1,13	1,16	1,23	1,02	0,99	1,28	1,03	1,07	0,70	1,08	1,07	0,96	1,19
Gross floor area	1,85	4,43	3,40	1,36	1,10	2,74		3,18	1,33	2,99	1,45	1,84	1,25
Y=a * main function area													
Interior walls	1,42	1,57	1,49	0,77	0,54	1,64	0,94	2,10	1,90	1,41	1,19	1,36	1,25
Y=a * construction area													
Interior walls	4,57	6,21	4,97	8,91	6,85	6,41	5,57	7,81	4,39	6,81	4,99	5,37	5,24
Y=a * gross net floor area													
Net floor area	0,83				0,91	0,78	0,78	0,68	0,85		0,78	0,71	0,79
Gross floor area = f(unit)	236,98	121,93	72,64			42,74							

unit: room for the category hostels and student habitations and one family habitation for "multiple family housing" and "one family house"

Minimum value	One and two family houses (Gross floor area < 1000m²)	Multiple family houses	Multiple family houses (Gross floor area < 4000m²)	Factory buildings	Factory buildings (Gross floor area < 4000m²)	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings (Gross floor area < 2500m²)	Educational buildings	Educational buildings (Gross floor area < 2000m²)
Excavation	3,19	60,00	60,00	20,15	20,15	1509,72	403,63	1496,44	80,00	140,00	140,00	48,44	54,00
Foundation	61,30	106,00	106,00	218,37	218,37	197,89	125,41	536,62	122,67	197,00	197,00	97,18	97,18
Exterior walls	170,44	297,00	297,00	225,74	225,74	660,00	93,91	554,95	369,13	185,33	185,33	121,00	121,00
Interior walls	108,31	227,57	227,57	90,00	90,00	520,77	95,97	577,41	153,00	260,60	260,60	27,99	27,99
Floors and ceilings	45,94	316,00	316,00	13,00	13,00	675,57	37,00	130,46	134,00	288,00	288,00	18,00	18,00
Roof	95,58	146,00	146,00	233,00	233,00	314,45	20,15	601,49	210,00	262,00	283,26	31,33	31,33
Net floor area	64,11	67,18	67,18	9,00	9,00	457,00	83,74	182,00	59,00	87,00	87,00	99,34	99,34
Gross net floor area	64,11	69,39	69,39	9,00	9,00	591,00	89,76	277,00	62,00	124,00	124,00	104,19	104,19
Main function area	30,51	59,30	59,30	165,66	165,66	298,58	83,74	156,00	14,00	69,50	69,50	85,35	85,35
Traffic area	11,00	2,21	2,21	10,00	10,00	76,84	2,00	76,20	3,00	15,00	15,00	4,85	4,85
Function area	1,00	1,50	1,50	4,00	4,00	2,72	7,92	13,00	3,81	3,72	3,72	2,00	2,00
Construction area	13,95	12,92	12,92	3,00	3,00	88,00	16,37	63,00	18,00	10,00	10,00	23,00	23,00
Gross floor area	78,06	82,31	82,31	12,00	12,00	679,00	106,13	340,00	80,00	134,00	134,00	137,19	137,19
Volume	168,86	300,43	300,43	130,00	130,00	2322,17	389,42	1051,00	478,00	412,00	412,00	383,93	383,93

Maximum value	One and two family houses Gross floor area < 1000m^2	Multiple family houses	Multiple family houses Gross floor area < 4000m^2	Factory buildings	Factory buildings Gross floor area < 4000m^2	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings Gross floor area < 2500m^2	Educational buildings	Educational buildings Gross floor area < 2000m^2
Excavation	2268,65	10650,00	4485,08	16268,00	8631,45	11358,66	11253,05	28586,00	6952,40	28098,00	5934,56	12497,75	4755,00
Foundation	871,00	2879,34	953,62	8216,25	3069,76	1852,00	4895,33	4120,17	1874,27	4168,00	826,00	3834,00	1295,00
Exterior walls	726,00	11453,50	2402,83	6548,36	2350,00	5990,08	4169,00	8310,00	2362,82	9076,00	1995,00	5666,18	1259,00
Interior walls	1123,00	11696,00	3729,62	11747,28	2301,50	7151,60	4336,00	17796,00	2873,08	13134,00	1681,38	6945,00	1322,00
Floors and ceilings	570,00	9904,00	3241,64	7921,31	2060,00	5129,80	6999,00	12907,00	1872,02	14011,00	1657,98	5949,61	1592,39
Roof	452,00	2656,47	1444,00	9757,00	3055,80	2229,58	4725,25	4390,94	1874,27	4223,00	1681,00	3771,00	1375,00
Net floor area	635,00	9531,00	2798,00	9231,65	3689,00	5850,37	7446,00	10383,00	2859,74	11166,00	1852,00	5056,07	1187,00
Gross net floor area	763,00	11694,86	3388,82	12134,60	3762,00	7387,46	9434,00	14723,00	2916,70	14870,00	2078,00	7943,00	1613,00
Main function area	597,00	8466,00	2414,00	8620,36	3677,00	4816,72	6591,00	9404,00	1518,43	7128,00	1780,00	4668,00	1175,00
Traffic area	157,00	3264,32	804,42	2695,72	329,00	1483,91	3135,20	4876,35	637,83	2999,00	665,43	2043,00	426,00
Function area	108,00	232,00	79,00	1067,39	184,00	376,29	342,84	885,00	171,71	937,00	183,98	345,25	94,46
Construction area	219,00	2100,00	888,00	950,37	430,20	1070,66	1627,00	2418,00	373,54	2020,00	497,77	1099,00	428,08
Gross floor area	964,00	14300,00	3923,76	13084,97	3856,00	8458,12	10443,00	16774,00	3082,58	16757,00	2395,00	9697,03	1905,00
Volume	3139,00	110706,00	14054,00	68974,00	26211,00	25189,62	39192,00	52674,97	14158,78	64206,00	9643,00	37695,00	8028,00

Average	One and two family houses Gross floor area < 1000m²	Multiple family houses	Multiple family houses Gross floor area < 4000m²	Factory buildings	Factory buildings Gross floor area < 4000m²	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings Gross floor area < 2500m²	Educational buildings	Educational buildings Gross floor area < 2000m²
Excavation	457,27	2105,55	1161,17	3522,23	1729,19	5366,23	3295,81	11582,54	2041,22	5048,15	1682,53	2325,99	1051,54
Foundation	179,02	614,50	362,81	2019,38	1155,22	847,24	1017,88	2207,09	651,03	1122,53	409,51	936,44	487,84
Exterior walls	381,58	1925,97	970,50	1904,85	1101,35	2005,99	1434,68	4567,09	928,91	2504,23	917,51	1421,08	646,68
Interior walls	351,27	2659,14	1265,15	1855,26	745,52	2794,90	1368,28	9275,48	729,44	3109,76	931,19	1571,39	616,29
Floors and ceilings	261,51	2194,32	1133,47	1511,76	521,98	2226,56	1568,15	6484,82	701,75	3058,37	924,41	1083,21	390,10
Roof	223,37	732,49	483,87	2134,78	1213,23	1071,02	1064,36	2450,84	788,38	1260,39	555,58	1045,18	619,12
Net floor area	259,20	1824,37	974,14	2411,44	1490,15	1863,90	1791,46	3964,14	774,95	2279,27	727,86	1088,50	561,98
Gross net floor area	308,63	2195,07	1162,18	2848,19	1654,54	2410,36	2222,00	5809,19	915,34	3083,05	938,57	1535,39	706,70
Main function area	186,26	1476,45	748,48	2217,58	1376,38	1591,53	1521,21	3196,52	382,96	1719,20	596,12	947,51	453,54
Traffic area	41,16	339,45	169,89	366,89	129,13	440,63	370,95	1560,43	114,65	595,36	178,57	332,67	130,34
Function area	12,97	39,78	21,19	140,25	57,21	111,40	82,26	284,62	34,12	153,16	34,57	47,56	19,26
Construction area	68,15	409,03	231,89	188,93	126,74	447,01	275,23	913,98	140,53	432,25	166,06	224,80	121,60
Gross floor area	370,73	2836,66	1572,43	3063,06	1787,37	2861,26	2505,71	6761,00	1055,87	3534,29	1106,35	1874,61	832,36
Volume	1084,70	8849,43	4584,37	17204,17	9968,69	9526,62	9385,18	22033,80	4147,84	12622,90	3827,02	7096,67	3152,88

Standard deviation	One and two family houses Gross floor area < 1000m²	Multiple family houses	Multiple family houses Gross floor area < 4000m²	Factory buildings	Factory buildings Gross floor area < 4000m²	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings Gross floor area < 2500m²	Educational buildings	Educational buildings Gross floor area < 2000m²
Excavation	387,53	2357,96	846,77	3804,86	1724,27	3670,97	2815,70	9032,02	2083,92	5748,49	1298,35	2914,01	1019,21
Foundation	121,37	571,43	222,35	1775,49	797,12	617,06	1147,07	1087,26	461,10	905,59	171,33	851,06	231,98
Exterior walls	118,68	2084,75	518,25	1457,21	512,39	1648,77	1036,88	2219,86	591,56	2081,73	390,18	1342,36	262,75
Interior walls	224,93	2817,93	782,56	2342,63	550,27	2259,00	1064,44	5188,54	627,03	3070,12	413,93	1673,09	321,01
Floors and ceilings	119,22	2237,86	684,54	2026,63	488,15	1434,25	1682,99	3439,74	505,89	2844,09	418,79	1427,92	286,79
Roof	88,81	600,94	299,28	1878,24	797,29	667,17	1138,61	1099,99	468,22	965,38	304,69	857,53	282,38
Net floor area	113,95	1947,34	620,35	2025,22	932,78	1536,64	1694,78	2801,09	644,01	2310,10	460,52	1098,13	238,45
Gross net floor area	140,36	2371,22	748,23	2529,36	978,78	1909,61	2178,64	4022,17	741,54	3193,62	562,12	1713,64	308,95
Main function area	106,26	1649,90	479,94	1847,98	906,85	1398,79	1368,80	2523,86	346,70	1659,02	413,07	992,30	212,71
Traffic area	22,02	479,97	171,92	548,04	91,89	398,31	654,06	1155,08	129,25	692,30	136,15	434,99	89,61
Function area	14,00	45,13	16,61	218,11	53,21	117,52	84,99	264,90	41,64	216,14	32,19	64,47	15,15
Construction area	35,26	416,77	172,00	170,92	93,48	320,98	295,55	572,97	107,71	409,51	104,19	231,56	61,33
Gross floor area	170,44	2775,63	943,04	2711,56	1031,62	2190,15	2413,45	4573,10	831,30	3586,17	640,73	2132,91	354,27
Volume	529,54	11500,61	2941,37	15960,51	7143,44	6928,79	9055,90	14759,26	3440,46	12945,61	2347,09	8123,51	1400,63

Variation coefficient	One and two family houses Gross floor area < 1000m²	Multiple family houses	Multiple family houses Gross floor area < 4000m²	Factory buildings	Factory buildings Gross floor area < 4000m²	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings Gross floor area < 2500m²	Educational buildings	Educational buildings Gross floor area < 2000m²
Excavation	0,85	1,12	0,73	1,08	1,00	0,68	0,85	0,78	1,02	1,14	0,77	1,25	0,97
Foundation	0,68	0,93	0,61	0,88	0,69	0,73	1,13	0,49	0,71	0,81	0,42	0,91	0,48
Exterior walls	0,31	1,08	0,53	0,77	0,47	0,82	0,72	0,49	0,64	0,83	0,43	0,94	0,41
Interior walls	0,64	1,06	0,62	1,26	0,74	0,81	0,78	0,56	0,86	0,99	0,44	1,06	0,52
Floors and ceilings	0,46	1,02	0,60	1,34	0,94	0,64	1,07	0,53	0,72	0,93	0,45	1,32	0,74
Roof	0,40	0,82	0,62	0,88	0,66	0,62	1,07	0,45	0,59	0,77	0,55	0,82	0,46
Net floor area	0,44	1,07	0,64	0,84	0,63	0,82	0,95	0,71	0,83	1,01	0,63	1,01	0,42
Gross net floor area	0,45	1,08	0,64	0,89	0,59	0,79	0,98	0,69	0,81	1,04	0,60	1,12	0,44
Main function area	0,57	1,12	0,64	0,83	0,66	0,88	0,90	0,79	0,91	0,96	0,69	1,05	0,47
Traffic area	0,54	1,41	1,01	1,49	0,71	0,90	1,76	0,74	1,13	1,16	0,76	1,31	0,69
Function area	1,08	1,13	0,78	1,56	0,93	1,05	1,03	0,93	1,22	1,41	0,93	1,36	0,79
Construction area	0,52	1,02	0,74	0,90	0,74	0,72	1,07	0,63	0,77	0,95	0,63	1,03	0,50
Gross floor area	0,46	0,98	0,60	0,89	0,58	0,77	0,96	0,68	0,79	1,01	0,58	1,14	0,43
Volume	0,49	1,30	0,64	0,93	0,72	0,73	0,96	0,67	0,83	1,03	0,61	1,14	0,44

Quantity	One and two family houses Gross floor area < 1000m²	Multiple family houses	Multiple family houses Gross floor area < 4000m²	Factory buildings	Factory buildings Gross floor area < 4000m²	Hostels and student habitations	Industry and trade buildings	Hospitals	Fire stations	Office buildings	Office buildings Gross floor area < 2500m²	Educational buildings	Educational buildings Gross floor area < 2000m²
Excavation	53	60	48	51	35	7	20	16	15	49	25	79	58
Foundation	58	63	51	55	39	9	22	16	18	53	25	85	59
Exterior walls	59	63	51	55	39	9	23	16	18	53	26	89	61
Interior walls	59	63	51	50	34	9	23	16	18	53	26	89	61
Floors and ceilings	59	63	51	47	31	9	22	16	17	51	24	82	56
Roof	59	63	51	55	38	9	23	16	18	53	24	84	61
Net floor area	143	117	105	86	65	20	49	35	34	103	57	197	148
Gross net floor area	149	117	105	86	65	20	49	35	34	104	57	199	148
Main function area	141	111	99	84	63	19	45	27	33	101	56	176	129
Traffic area	137	115	103	76	54	20	48	35	33	101	57	197	146
Function area	120	109	95	69	47	19	40	35	29	98	53	168	124
Construction area	149	119	105	85	65	20	49	35	34	103	57	195	148
Gross floor area	162	156	132	86	65	20	49	35	34	104	57	201	148
Volume	162	157	132	86	65	20	49	35	34	104	57	200	148

Annex 8

STILCAB’s Inputs

Energy

Primary energy consumption class desired (please select):	
• Class A (<60 kWh/m².year) • Class B (<110 kWh/m².year) • Class C (<150 kWh/m².year) • Class D (<200 kWh/m².year)	

Orientation of the building (please fill in):	
Windows area oriented southwest to southeast (m²): Windows area oriented northwest to northeast (m²): Windows area other orientation (m²): Roof area (m²):	

Hot water production (please select):	
Centralised Decentralised	

Hot water energy (please select):	
Electricity Gas Heating fuel	

Hot water production temperature (please select, when necessary):	
Constant temperature Low temperature	

End energy requirements for hot water production (kWh/m².year) (please fill in, or default value):	

Heating system (please select):	
Centralised Decentralised	

Heating energy (please select):	
Electricity Gas Heating fuel	

Hot water production temperature(please select, when necessary):	
Constant temperature Low temperature	

End energy requirements for lighting (kWh/m².year) (please fill in, or default value):	

End energy requirements for ventilation (kWh/m².year) (please fill in, or default value):	

End energy produced on site (kWh/m².year) (please fill in, or default value):	

General information

	Building
Building's reference Building's name Building's use Location Annotations Building's life time (years) Gross floor area (m^2) Ground floor area (m^2) Number of floors Height of the building(m) Window **percentage** (percent of the exterior walls surface) (m²) Electricity mix	

Building's construction quantity

Building description	**Default values (m²)** **(Yes or no)**	**Given values (m²)** **Yes or no (when "yes", please fill in the next 10 inputs)**
Yes or no		
Excavation (m³)	X	
Foundation (m²)	X	
Exterior walls (m²)	X	
Interior walls (m²)	X	
Floors and ceilings (m²)	X	
Staircases (unit)	X	
Roof (m²)	X	
Interior doors	X	
Exterior doors	X	
Windows	X	

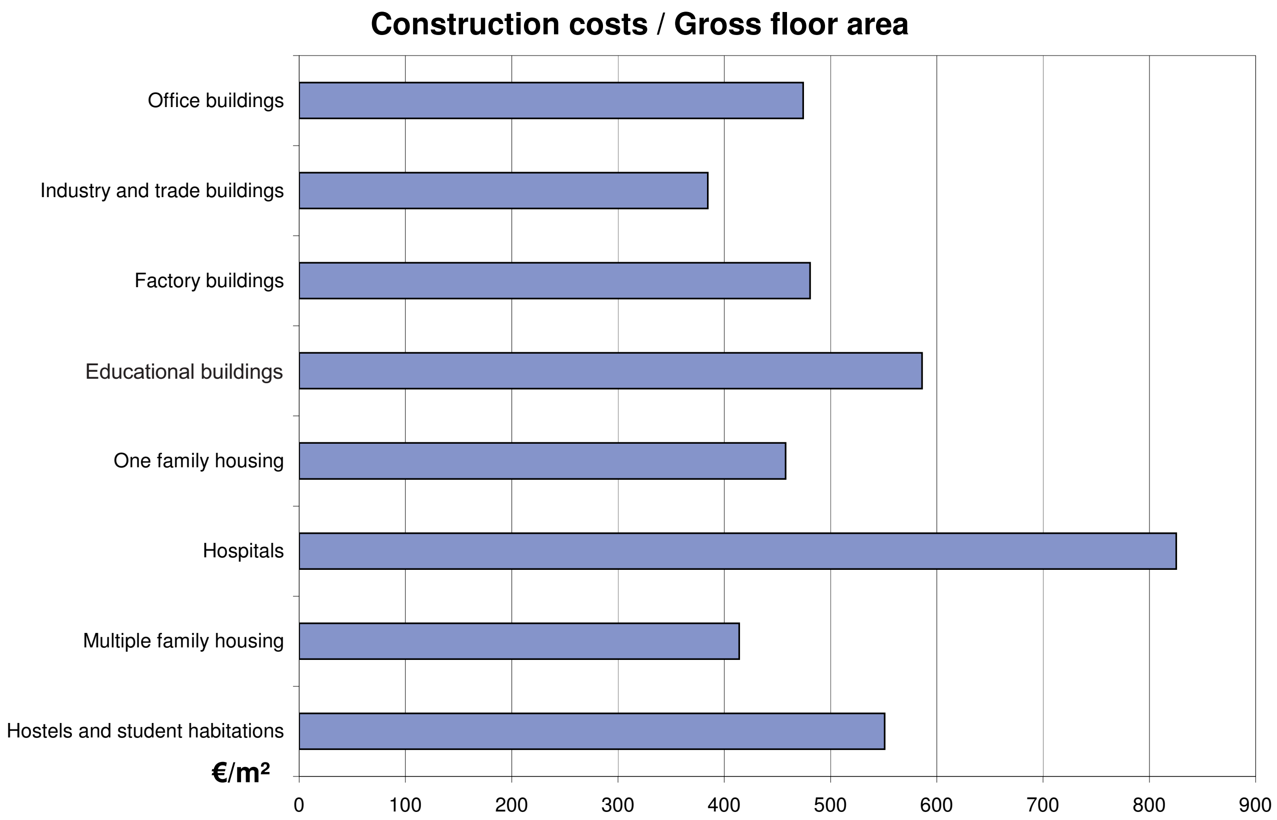
Default typology of the building

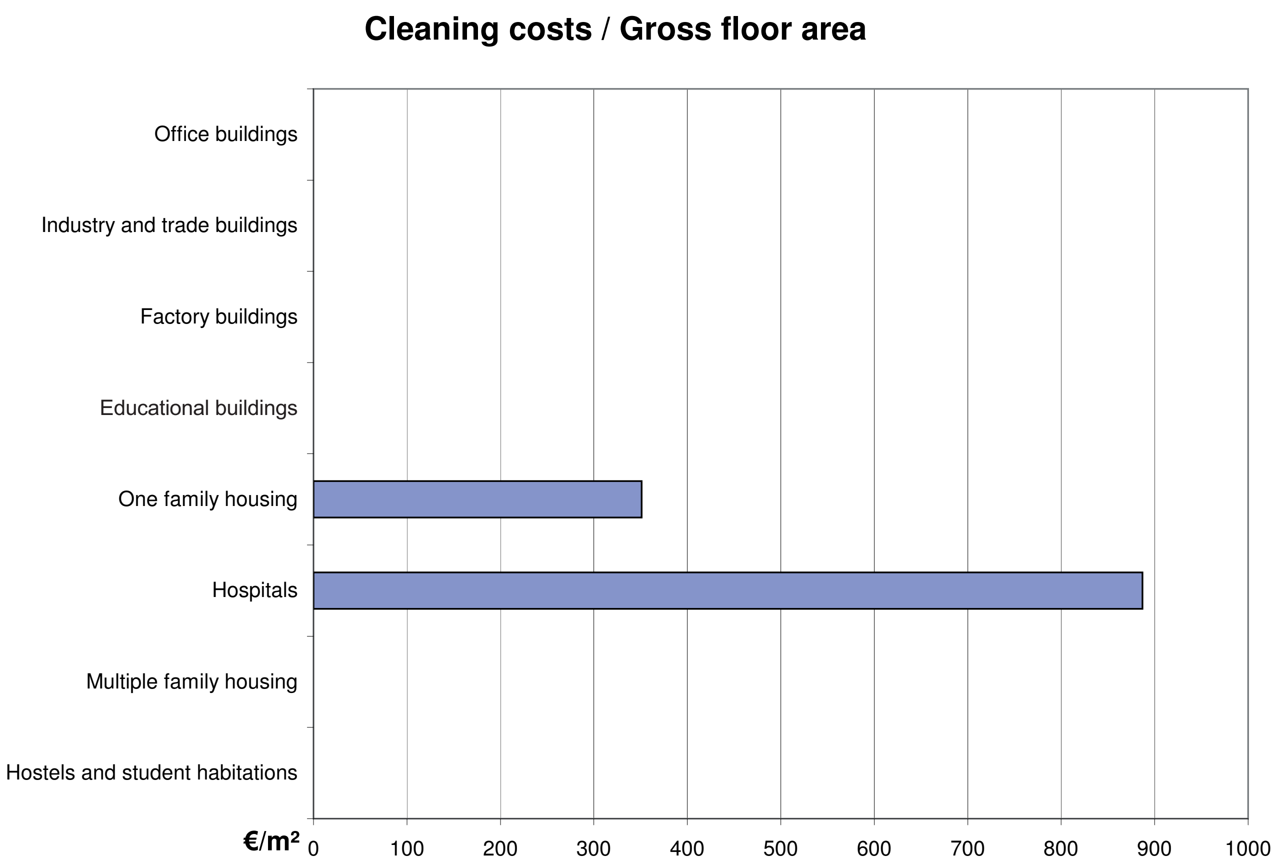
	Please select and fill in
Rectangle	
L (m)	
l (m)	
Square	
l (m)	
U-Form	
L (m)	
l (m)	
a (m)	
b (m)	
L-Form	
a (m)	
b (m)	
c (m)	
d (m)	
Comb form	
L (m)	
l (m)	
a (m)	
b (m)	
c (m)	
d (m)	

Annex 9

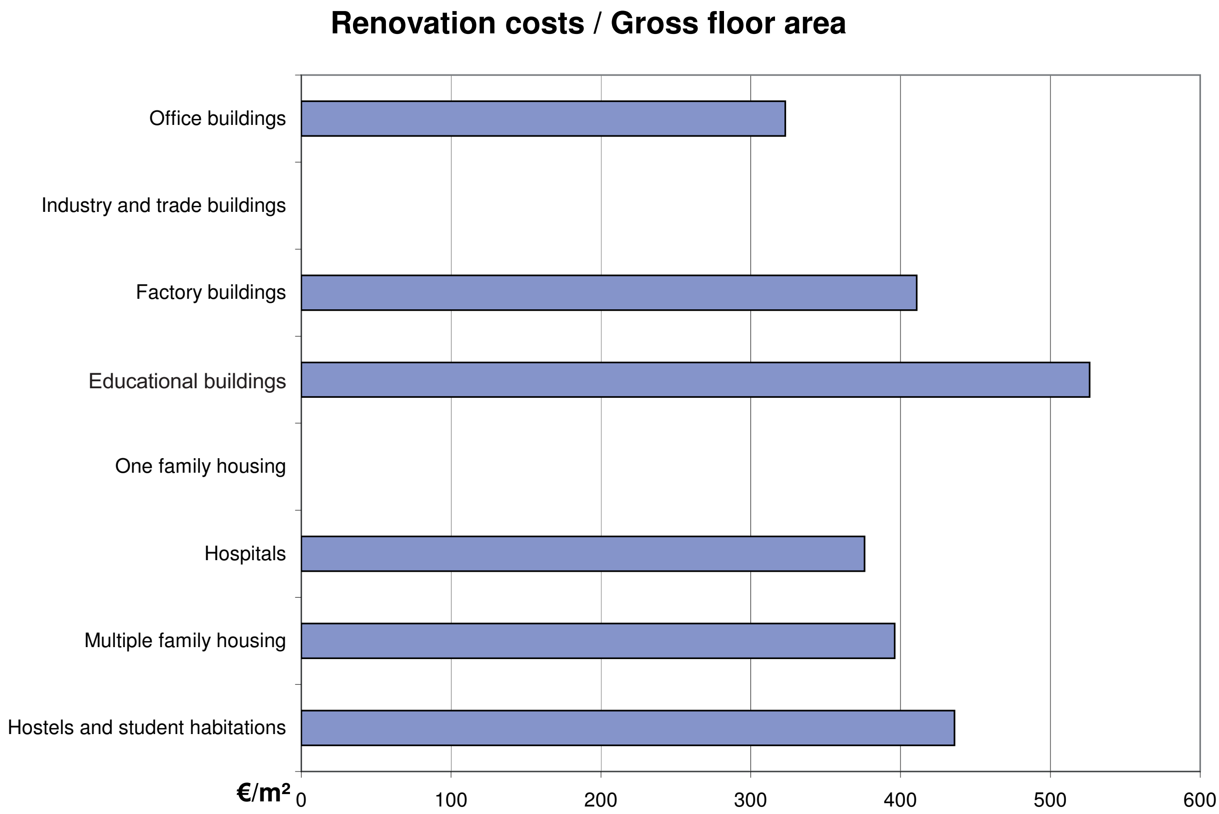
Typical Results of Legep for Several Building Categories

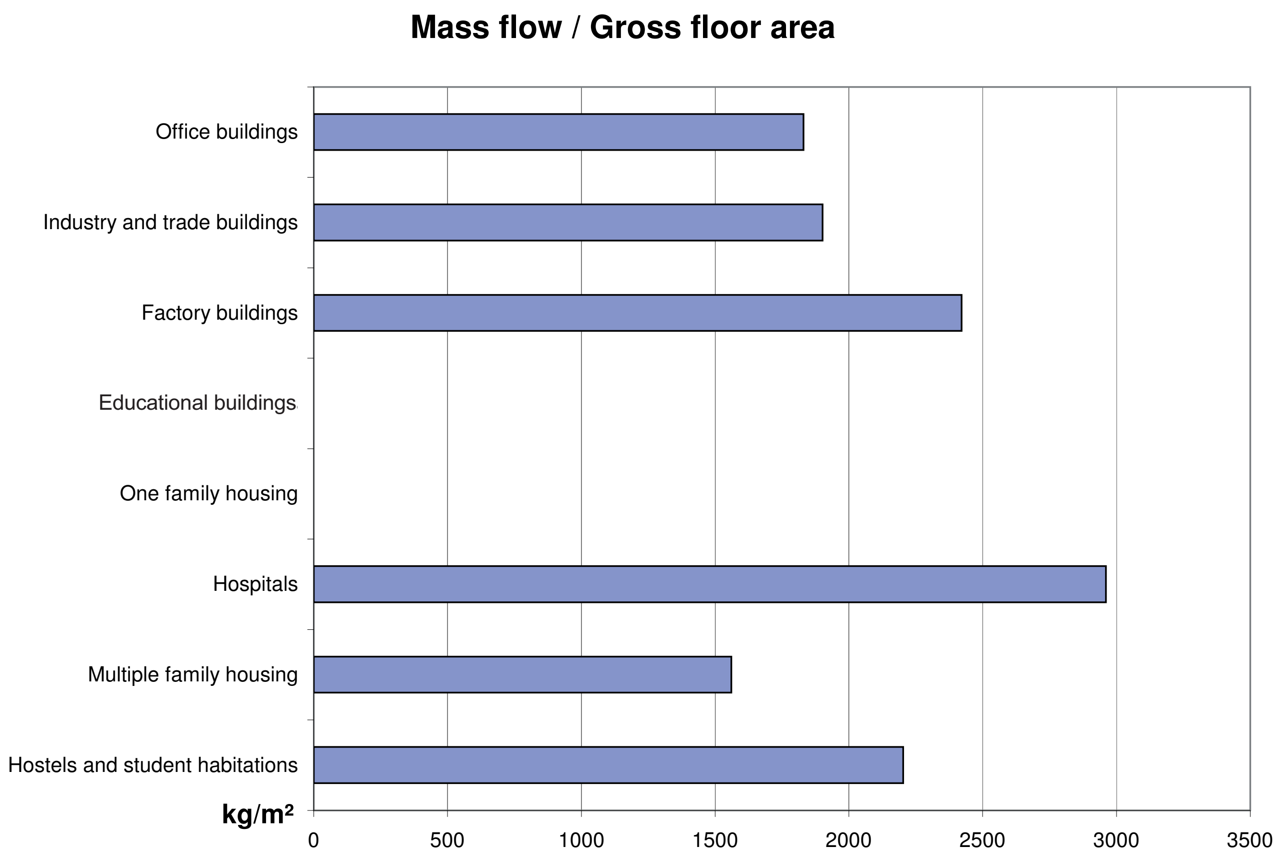
With a variation coefficient < 0,4





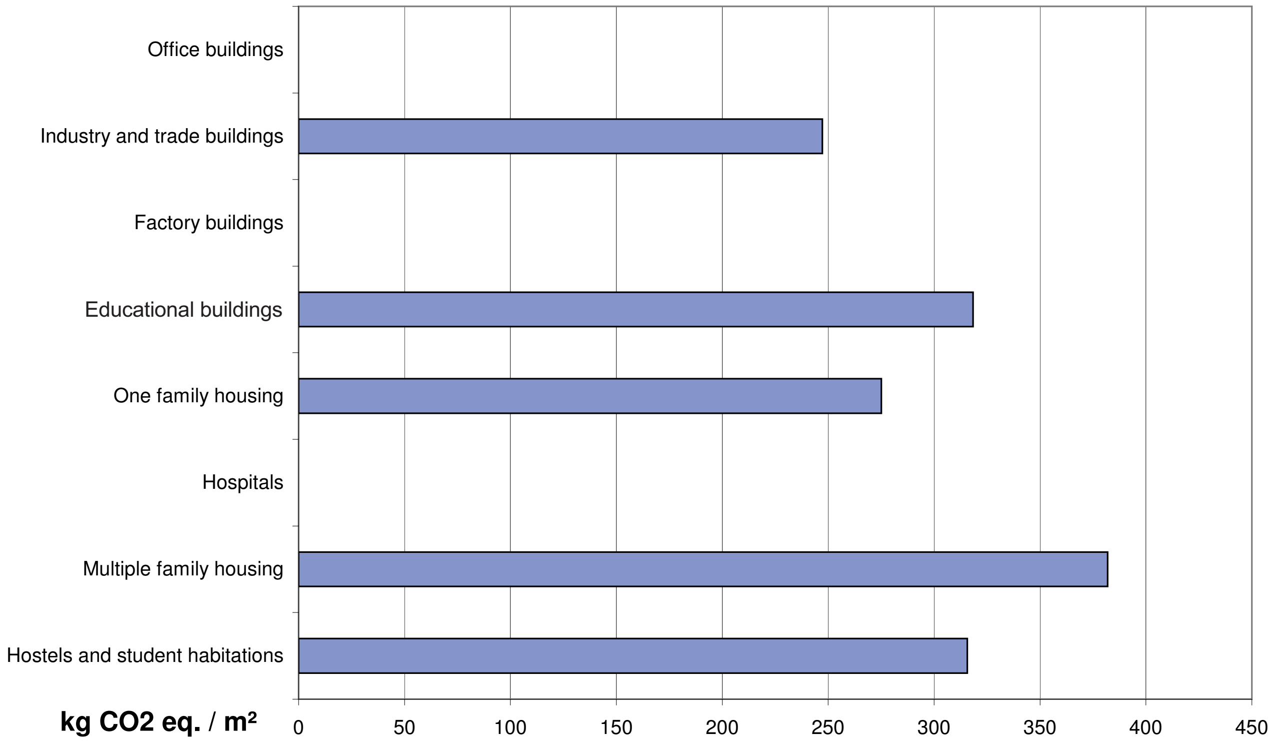
With a variation coefficient < 0,4



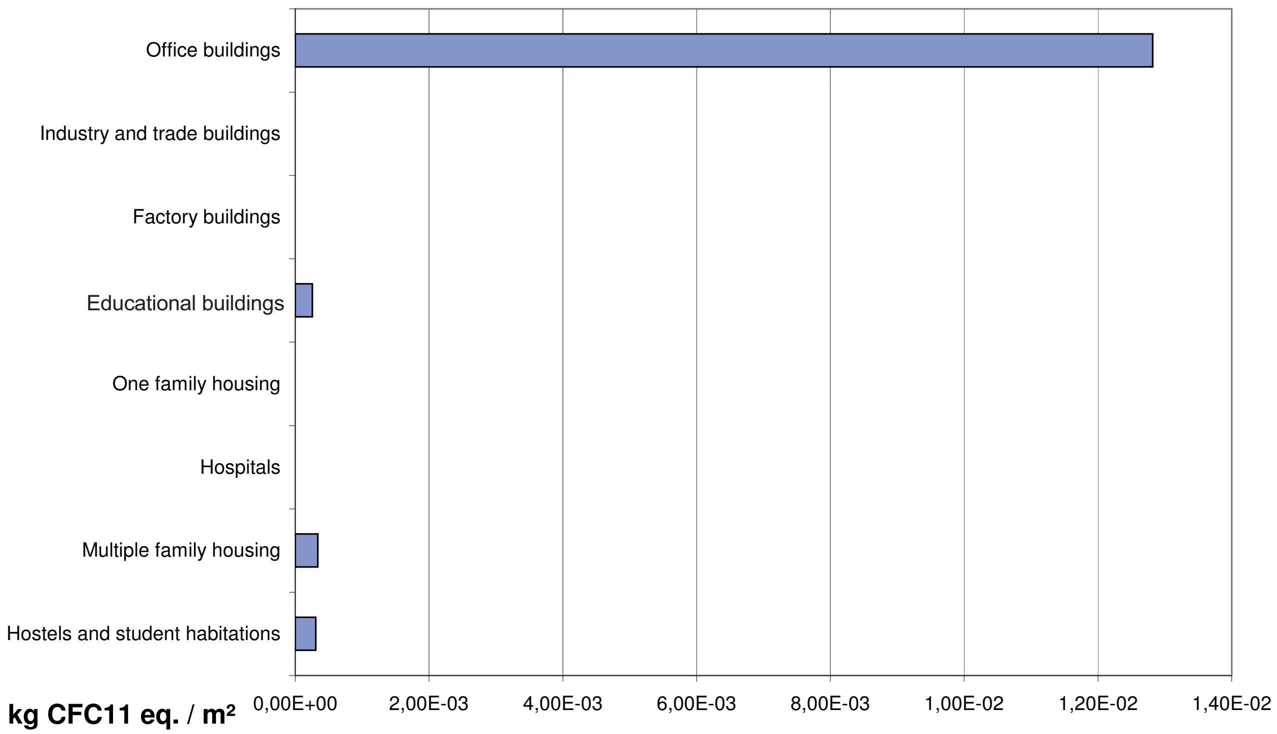


With a variation coefficient < 0,4

Global warming potential / Gross floor area

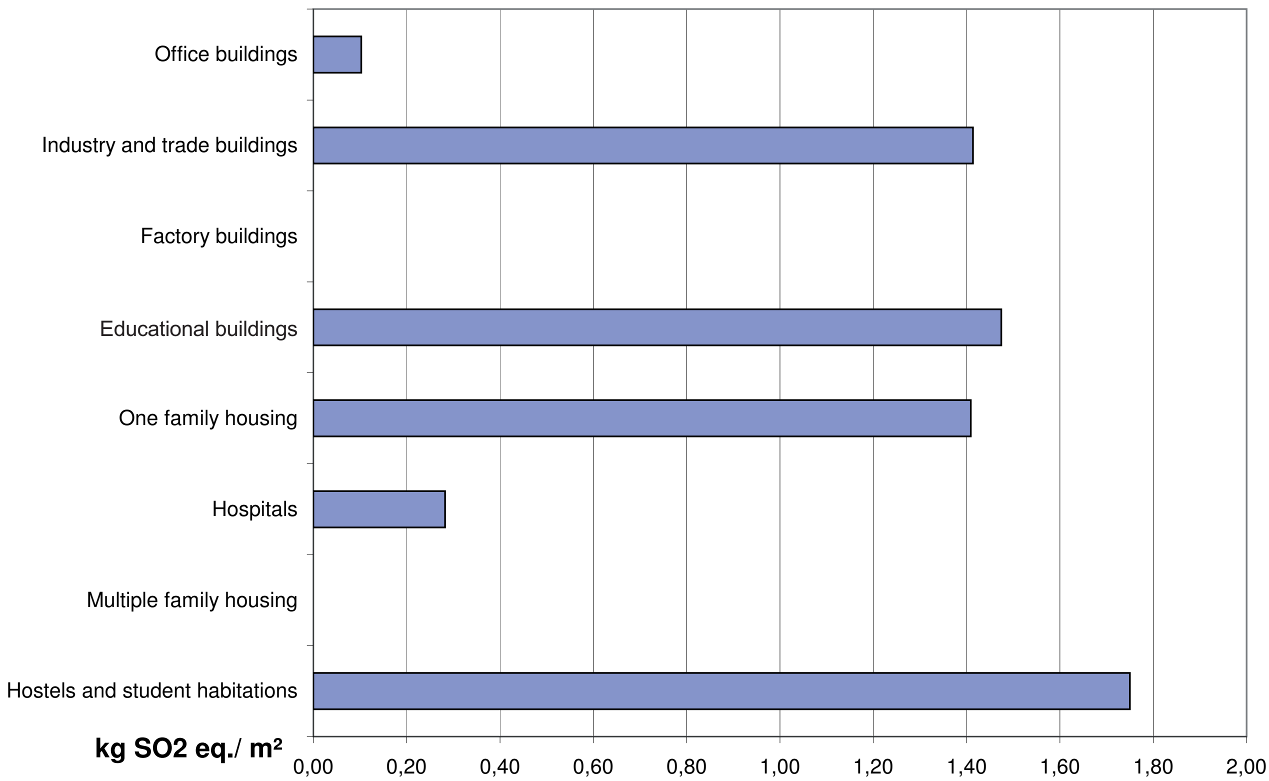


Ozone depletion potential / Gross floor area

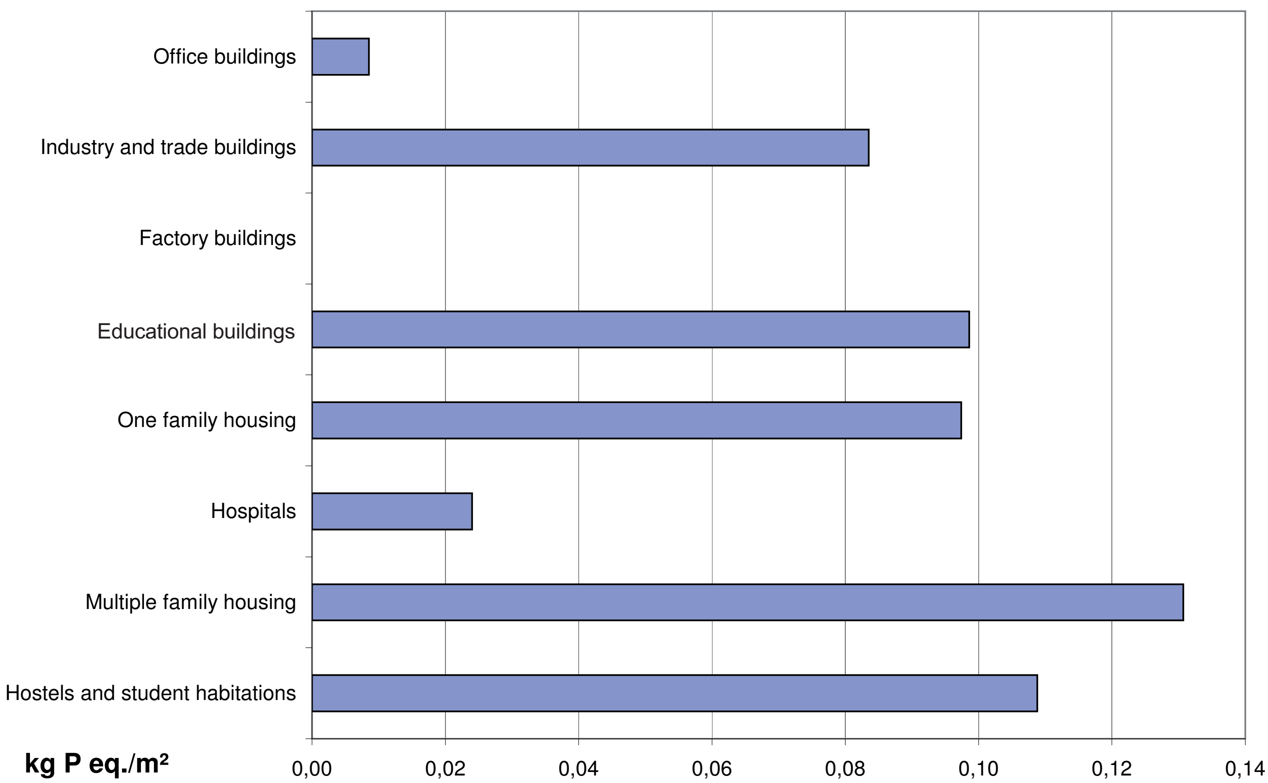


With a variation coefficient < 0,4

Acidification potential / Gross floor area

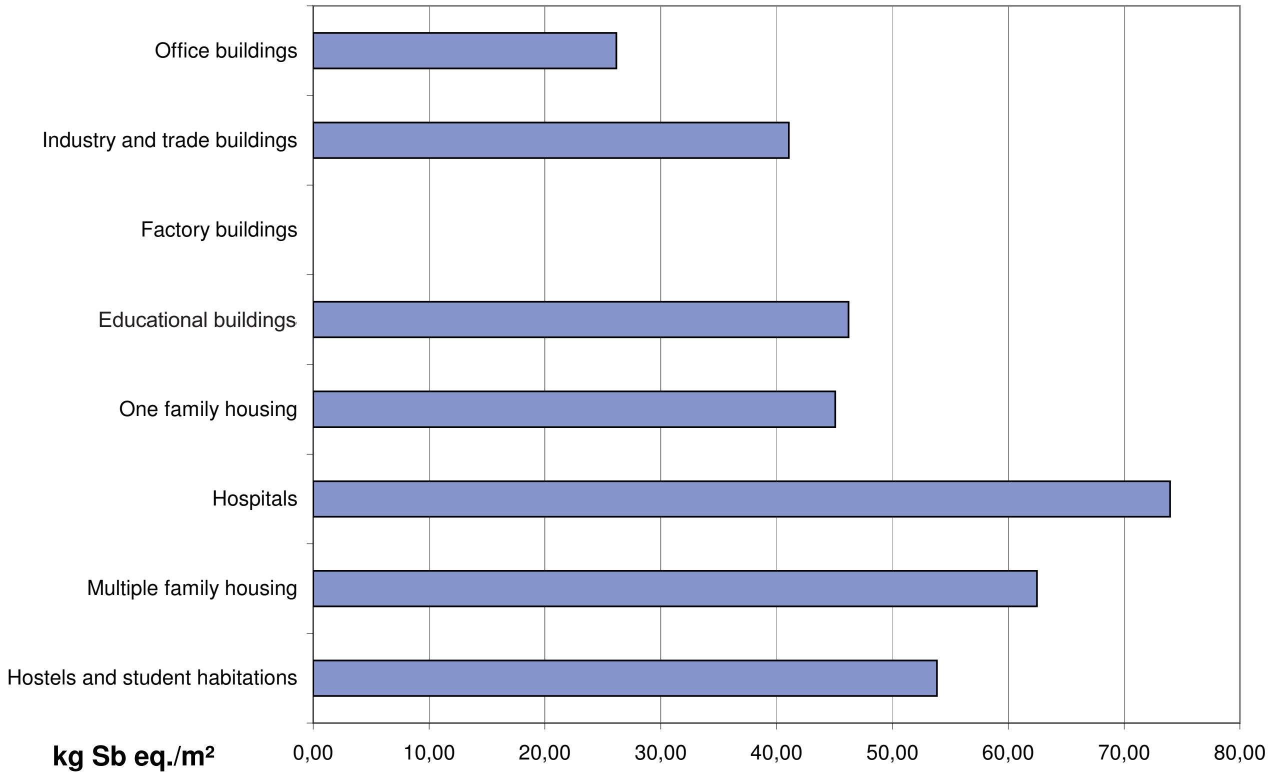


Nutrification potential / Gross floor area

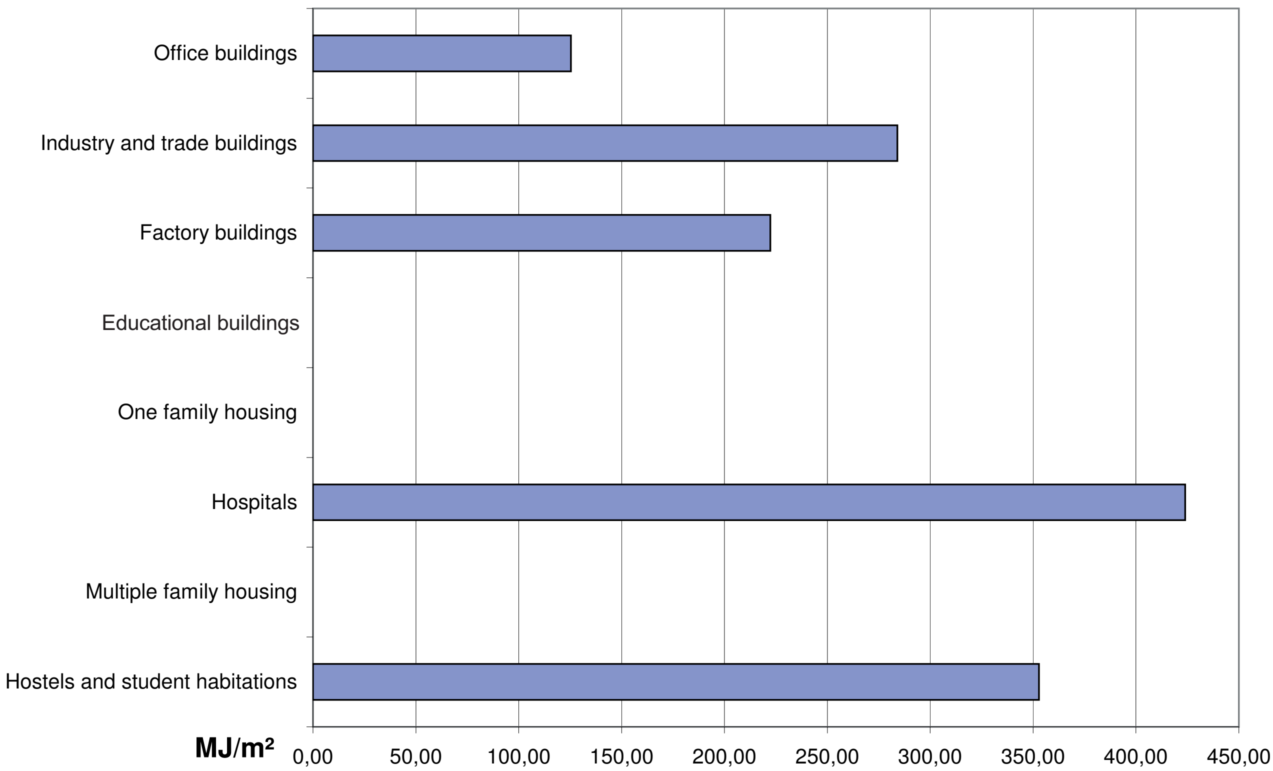


With a variation coefficient < 0,4

Abiotic resources consumption / Gross floor area

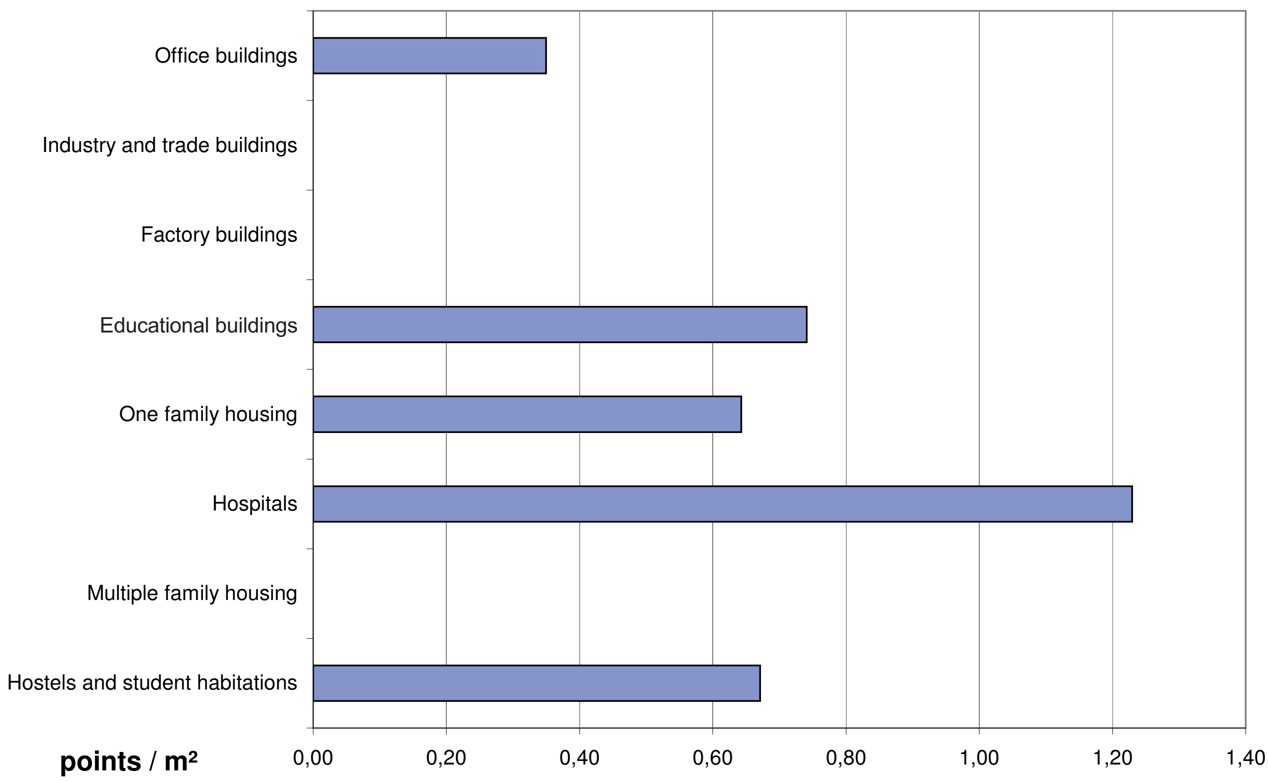


Primary energy renewable / Gross floor area

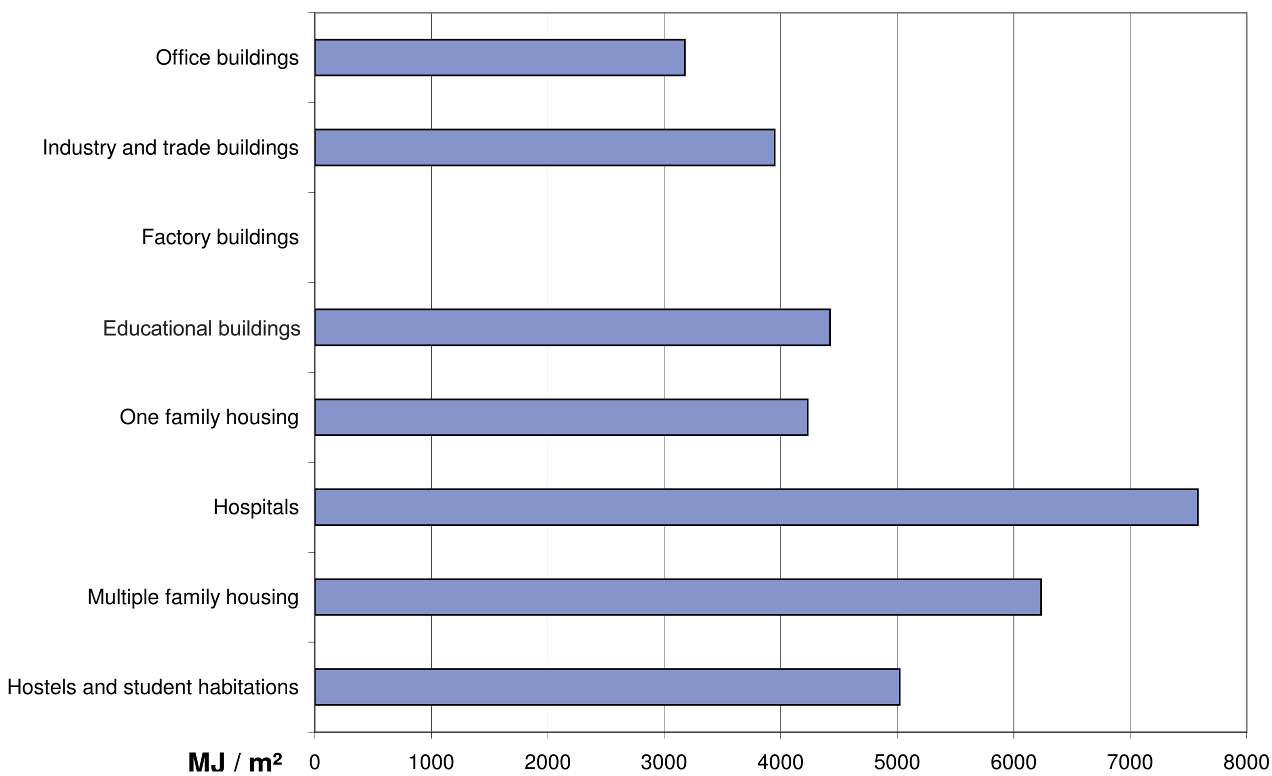


With a variation coefficient < 0,4

Ecopoints/ Gross floor area

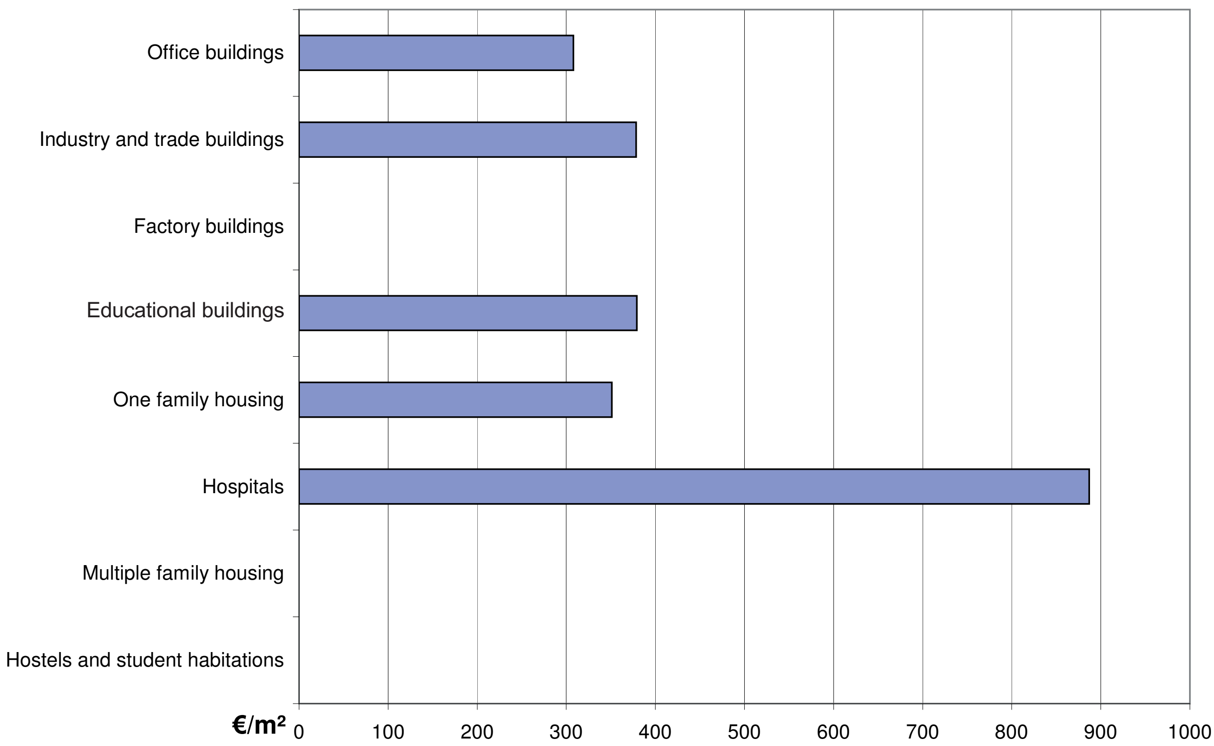


Primary energy non-renewable / Gross floor area

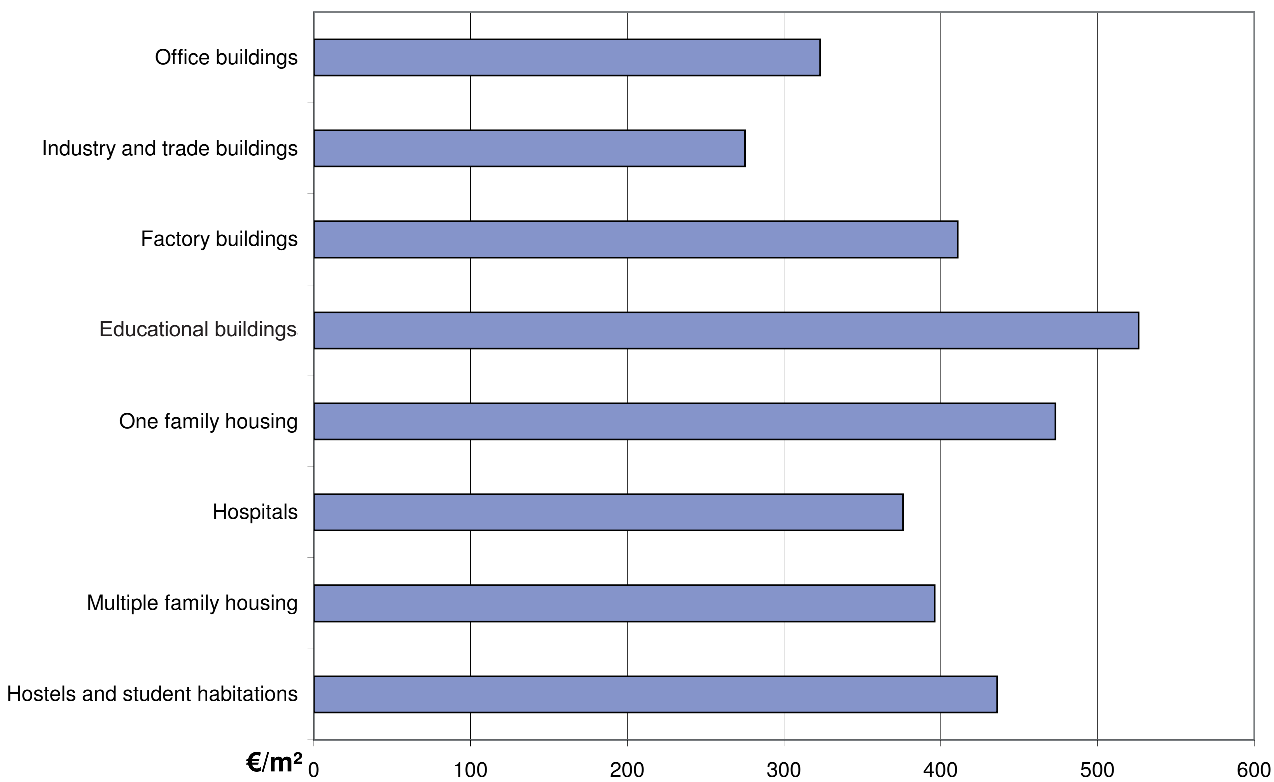


With a variation coefficient < 0,6

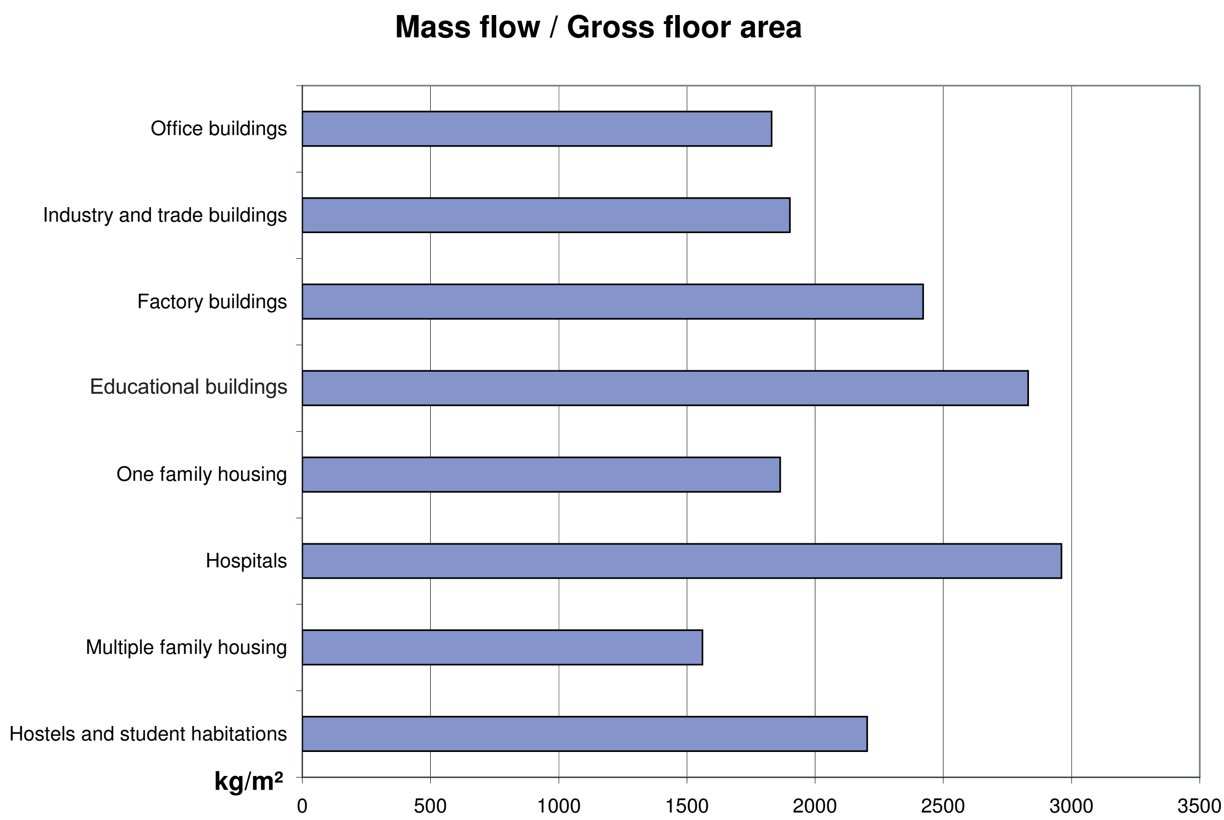
Cleaning costs / Gross floor area

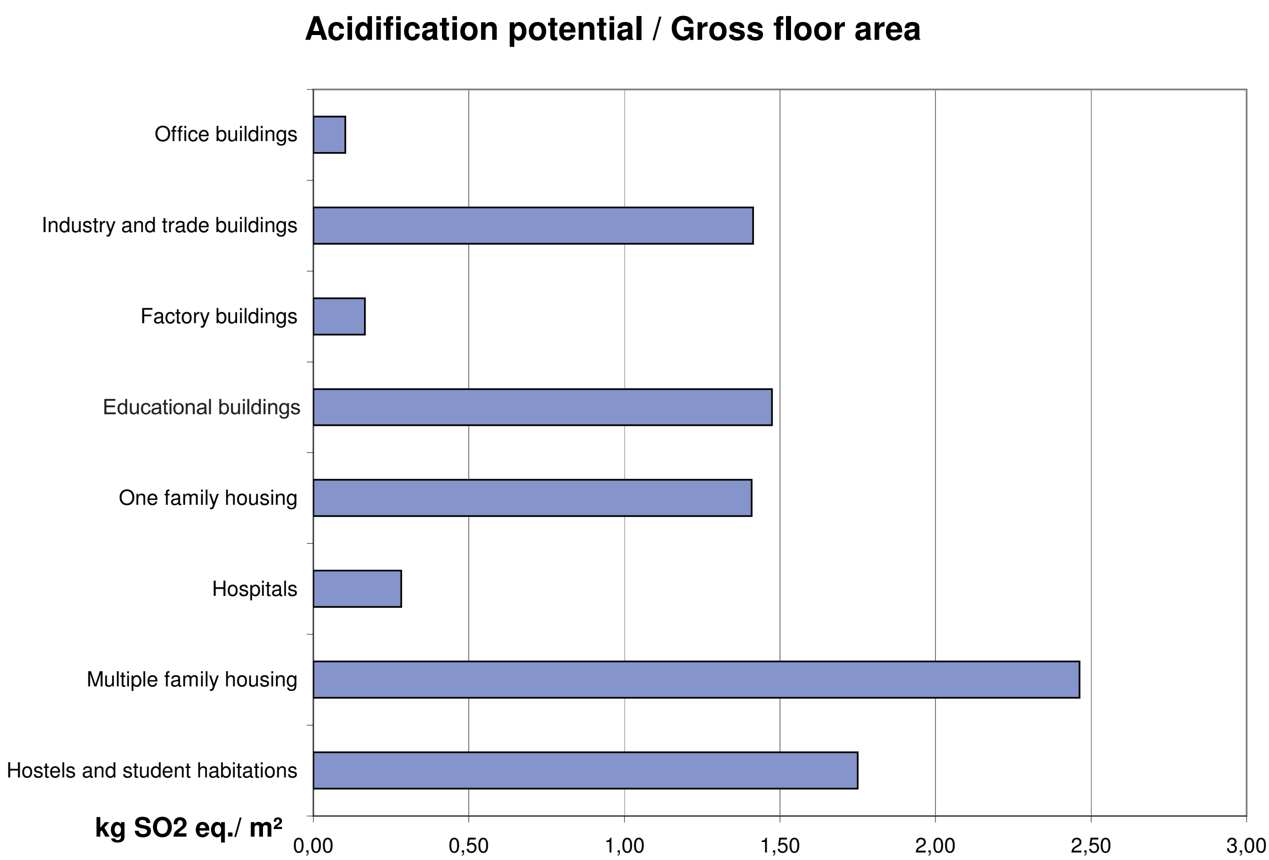


Renovation costs / Gross floor area



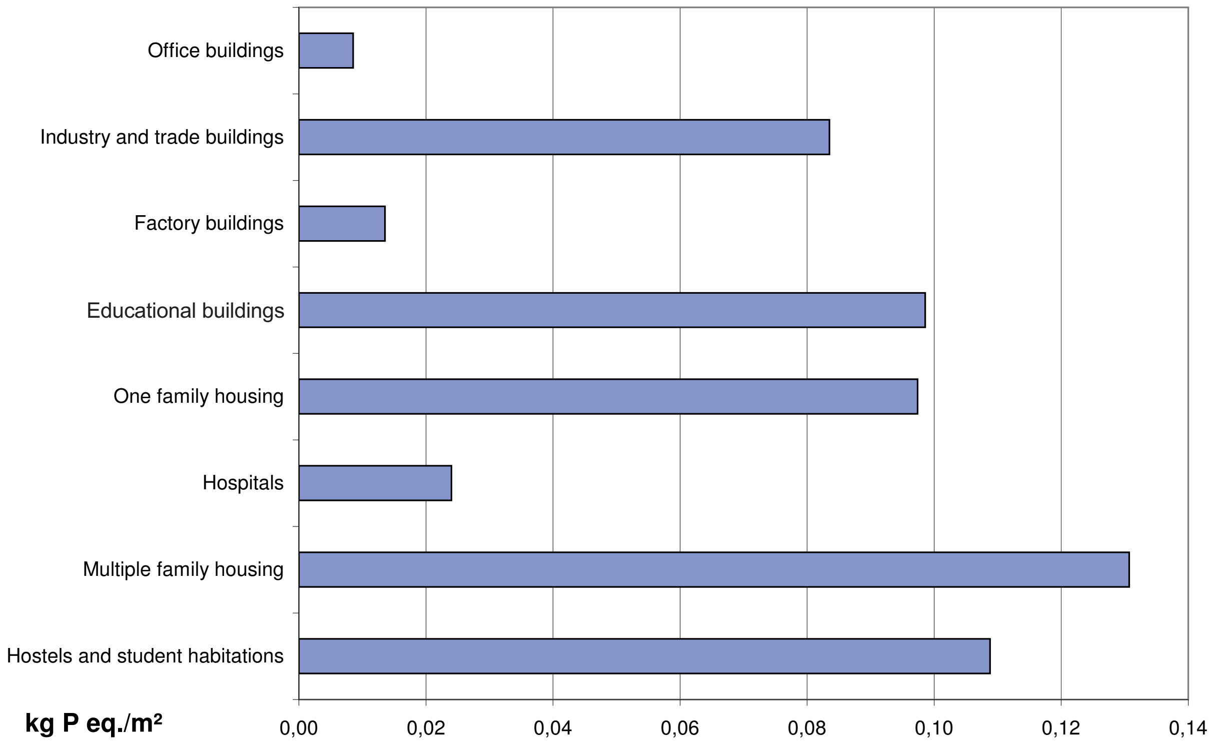
With a variation coefficient < 0,6



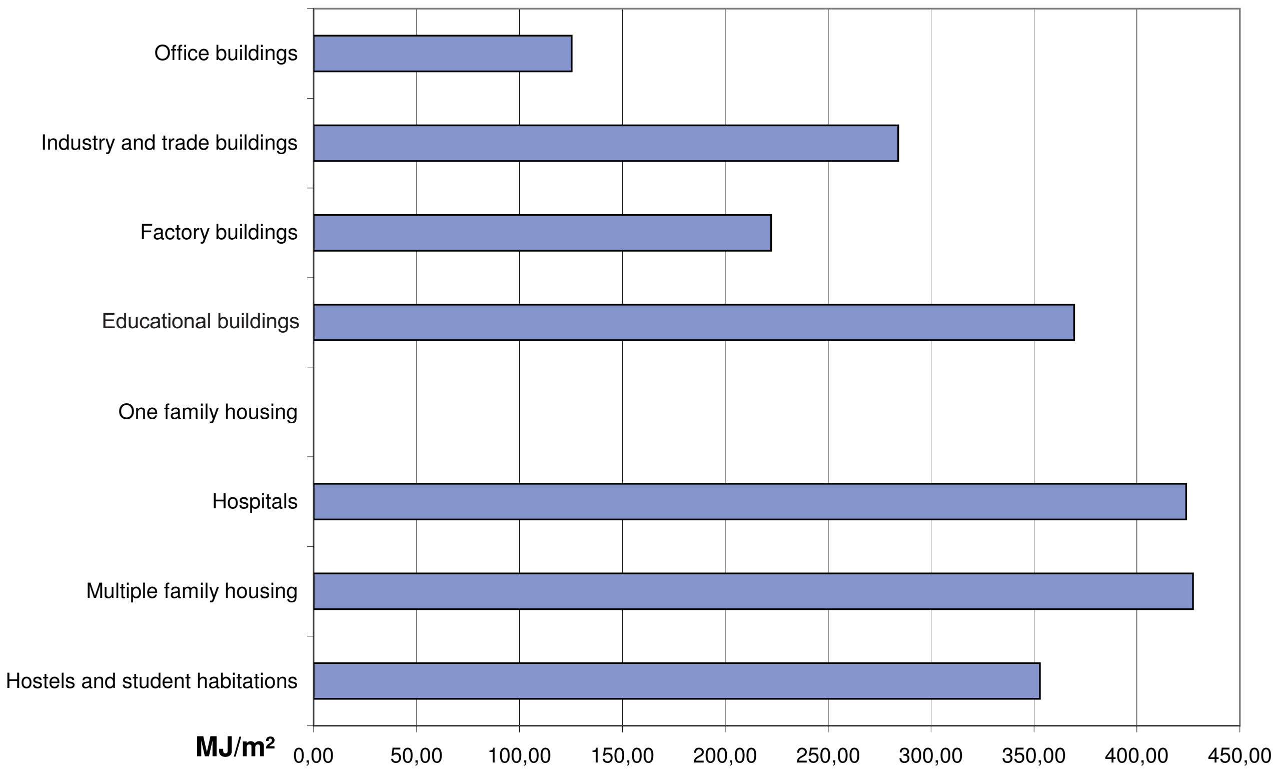


With a variation coefficient < 0,6

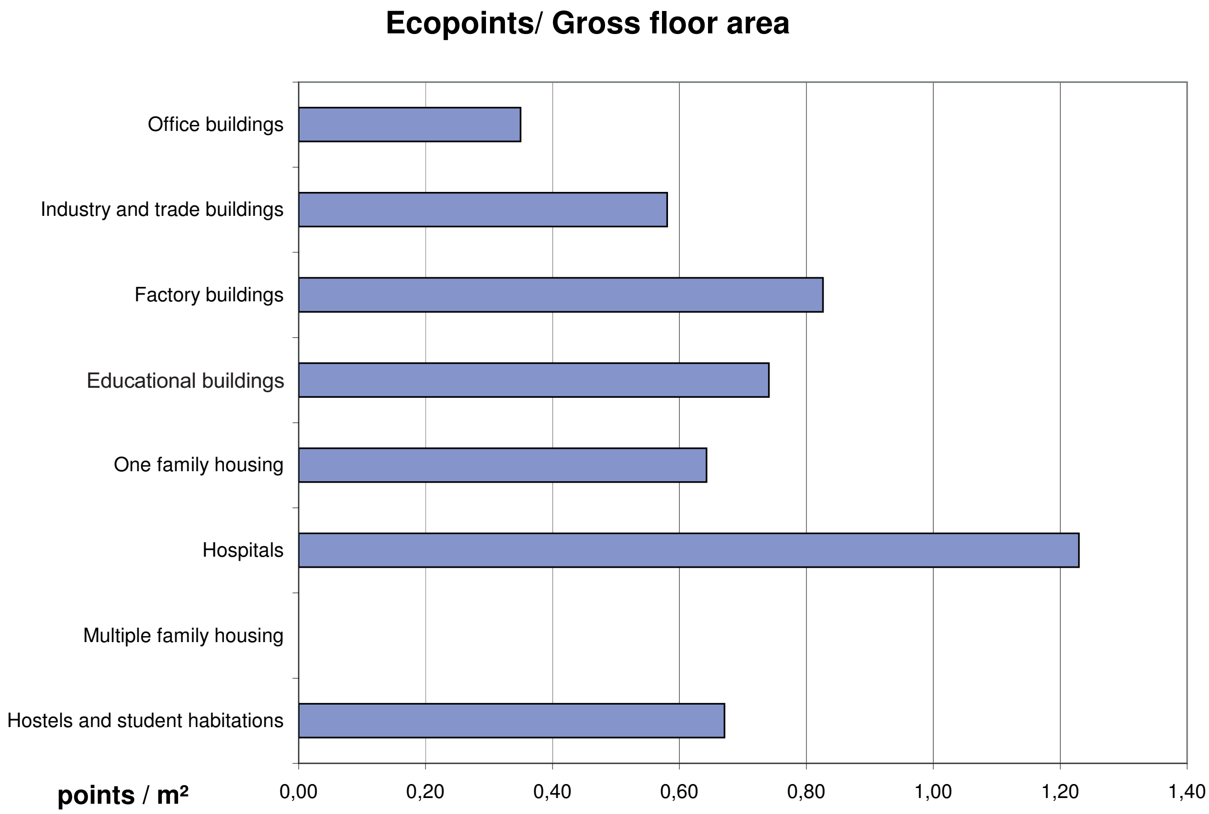
Nutrification potential / Gross floor area

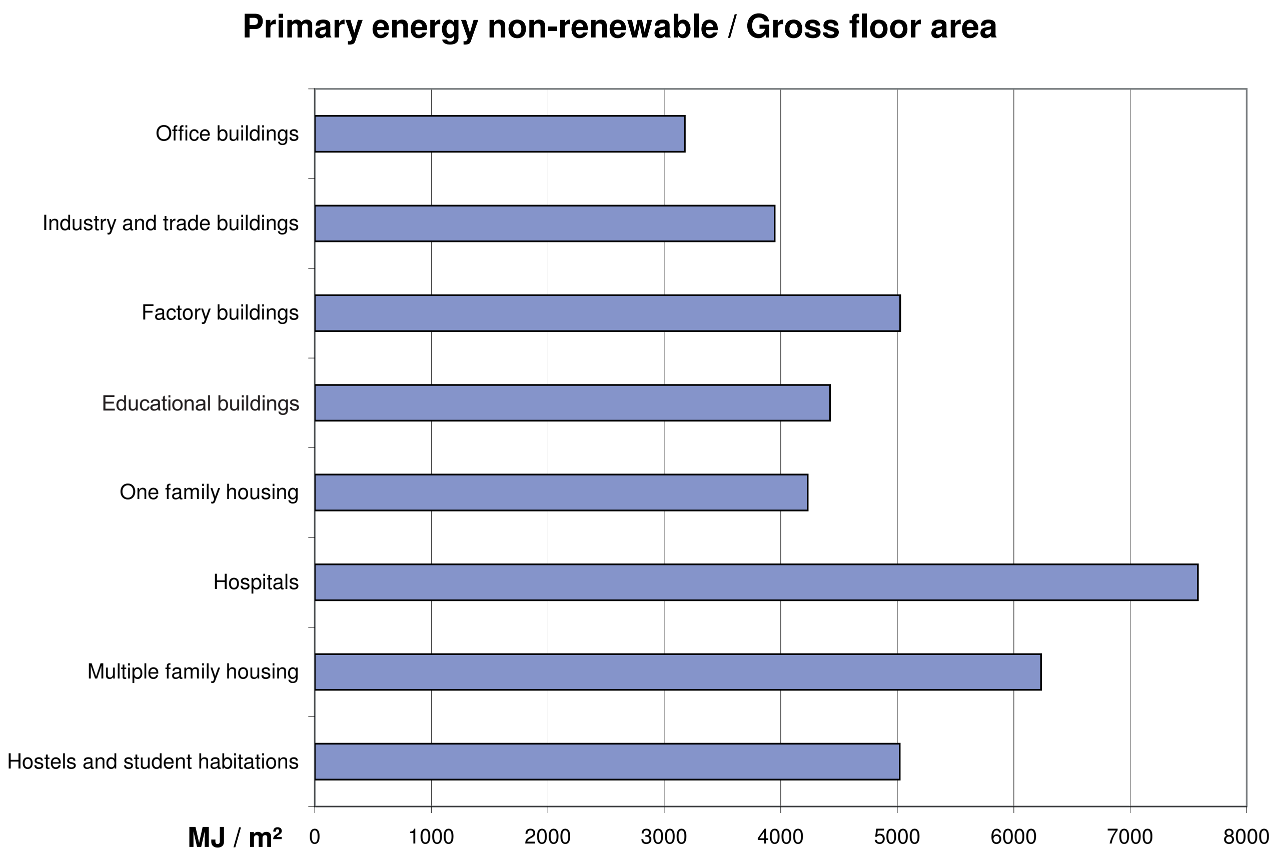


Primary energy renewable / Gross floor area

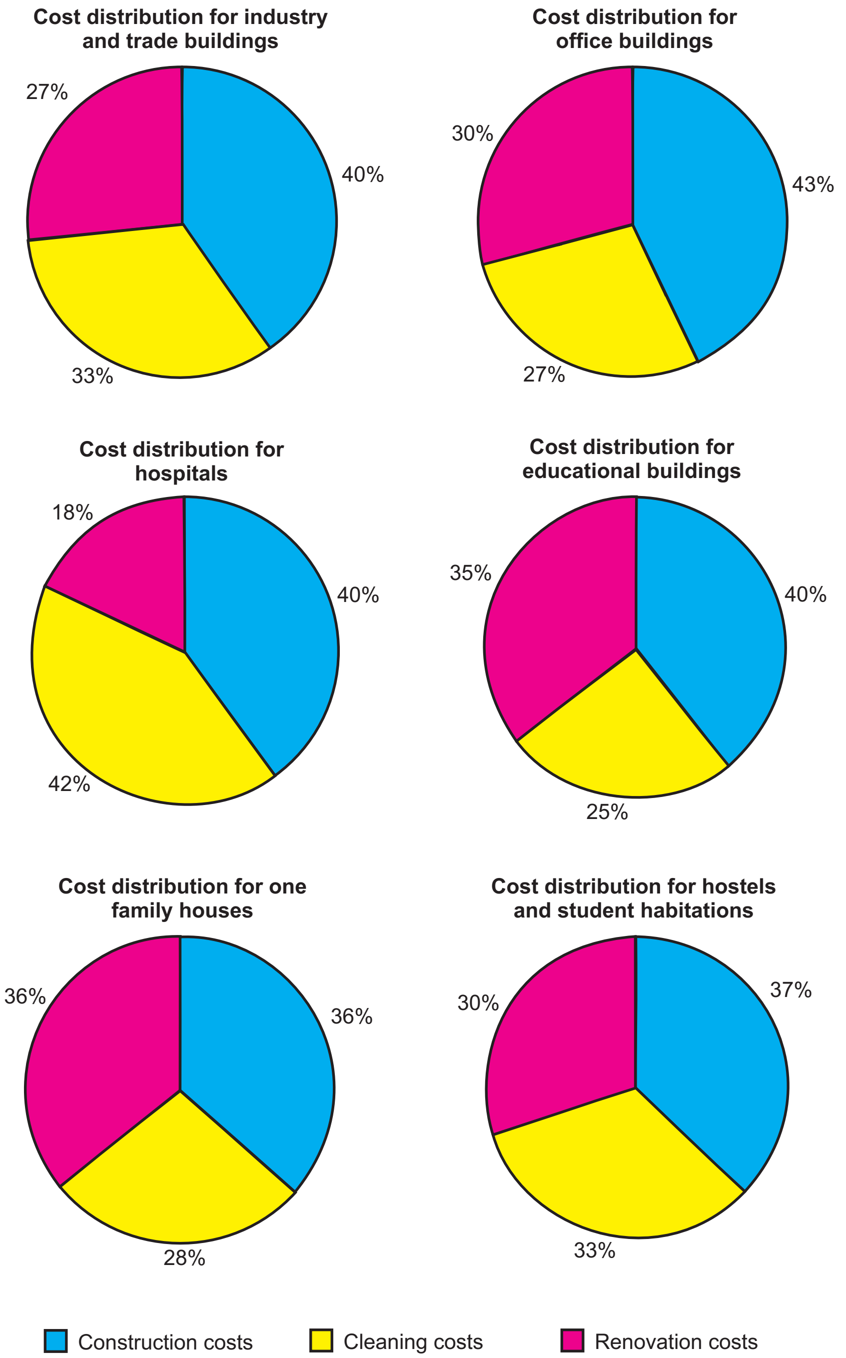


With a variation coefficient < 0,6





Cost distribution for use categories of six buildings



Annex 10

The most commonly used construction materials in Europe

Facade finish

wall construction	brick	concrete	stone	others			
	71%	24%	3%	2%			
facade finish	rendering	prefabricated concrete	exposed masonry	exposed concrete	curtain-wall	wooden elements	artificial stone veneer
	65%	10%	8%	4%	2%	1%	1%
facade rendering	weather resistant	plastic	calk	water color	synthetic coating	other	
	32%	26%	21%	8%	7%	6%	

Balconies and loggias

balcony floor	concrete	tiles	mosaic	stone	marble	aluminium & glass	other
	51%	24%	15%	5%	3%	1%	1%
balcony parapet paint	calk	weather resistant	plastic	non-painted	other		
	56%	23%	7%	7%	7%		
balcony handrail paint	oil	anti-corrosion	non-painted	galvanized	fire painted technique	other	
	51%	39%	4%	3%	2%	1%	

Private cellars

underground wall paint	calk	no paint	oil	lime	plastic	other	
	43%	31%	11%	7%	7%	1%	

Common rooms

underground wall paint	calk	no paint	oil	lime	plastic	other	
	41%	24%	11%	9%	14%	1%	

Distribution of heat (in basement)

heat distribution pipe	iron	cast iron	steal	copper	other	
	34%	34%	23%	8%	1%	

Sewage disposal

sewage pipes	cast iron	plastic	ceramic	asbestos	steel	conrete	other
	59%	26%	6%	3%	2%	1%	3%

Cellar and garage doors

doors paint	oil	anti-corrosion	other	
	64%	27%	9%	

Basement windows

window frames	wood	iron	aluminium	plastic	other	
	53%	43%	2%	2%	0,4%	

Stairways and landings

staircase structure	concrete	stone	wood	metal	other	
	49%	23%	15%	10%	3%	

Entrance area and stairwell wall finish

wall fnish	painted/ plaster	ceramic tiles	wall paper	other	
	97%	1%	1%	1%	
window frame	wood	plastic	iron	aluminium	other
	49%	16%	24%	10%	1%

Main entrance doors

main entrance doors	metal-glazing	wood-glazing	wooden	glazing	other
	58%	28%	12%	1%	1%

Apartment access doors

Apartment access doors	wooden	security	wood-glazing	other
	88%	6%	5%	1%
Apartment doors painted	oil	wood-varnish	plastic	other
	50%	38%	9%	3%

Lift

lift cabine	metal	plastic	wooden
	63%	28%	9%

Roofing

pitched and mansard roof covering	ceramic tiles	brick	slate & zinc	cement fiber	slated roof	concrete tiles	other
	48%	21%	6%	6%	4%	4%	5%
flat roof covering	tar	water resistant layer	insulation layer	mosaic	conrete tiles	ceramic tiles	conret
	31%	21%	21%	12%	8%	2%	1%

Superstructures on roof

external wall paint	weather resistant	not painted	plastic	water color	other
	37%	36%	14%	4%	9%
junctions between superstrucure and roof	copper	lead	steel	paxalu	other
	35%	28%	12%%	12%	13%

Skylights

skylights frame	iron	steel	wood	aluminium	plastic
	38%	36%	13%	9%	4%
junctions between skylights and roof	lead	copper	paxalu	steel	other
	47%	18%	17%	13%	5%

Heating

radiators	cast iron	steel	aluminium	other
	65%	30%	3%	2%

Cold water distribution

cold water pipes	steel	iron-zinc	cast iron	copper	lead	plastic	other
	40%	27%	23%	6%	2%	1%	1%

Hot water distribution

hot water pipes	steel	iron-zinc	cast iron	copper	plastic	other	
	31%	23%	21%	22%	1%	2%	

Gas distribution

gas distribution pipes	iron-zinc	copper	cast-iron	other
	49%	19%	8%	24%

Surface and waste water pipework

waste water pipes	cast-iron	plastic	concrete	ceramic	lead	other	
	60%	29%	6%	2%	1%	2%	

Windows

Window frame	wood	plastic	aluminium	wood and metal	other	
	61%	20%	17%	1%	1%	
window frame paint	oil	weather resistant	anti-corrosion	plastic	other	
	60%	15%	12%	9%	4%	

Shutters

wall shutters	wood	plastic	metal	aluminium			
	41%	35%	14%	10%			
shutters paint	oil	anti-corrosion	weather resistant	wood varnish	plastic	other	
	55%	23%	7%	7%	3%	5%	
roller shutters	plastic	aluminium	wood	metal			
	52%	26%	19%	3%			
roller shutters paint	plastic	anti-corrosion	oil	wood varnish	weather resistant	other	
	38%	36%	15%	7%	3%	1%	
venetian blinds	metal	aluminium	wood	plastic			
	33%	33%	17%	17%			
venetian blinds paint	anti-corrosion	oil					
	80%	20%					

Floor finish

floor finish	wood	plastic and textile lining	tiles	mosaic	marble	other	
	47%	26%	11%	8%	6%	2%	

Source: [DRO]

Annex 11

Comparison of several ILCA tools for buildings

Assessed tool Japan BRI- LCA (Jap)
Athena (Can)
Beaver/ESPII
BEE 1.0 (FIN)
BEES (USA)
BES
Boustead (UK)
BREEAM (UK)
BREGains (UK)
Building design advisor (USA)
BUNYIP (Aus)
Carnegie Melon web based I/O model (USA)
CSIRO embodied energy 3D CAD tool (Aus)
DOE 2.2 (USA)
E2000 (CH)
ECO methods (Fra)
ECOit (NL)
Ecopro (GER)
EcoQuantum (NL)
EcoScan (NL)
Ecotect (Aus)
Energy 10 (USA)
Energy certification for buildings (FIN)
ENER-RATE (Aus)yann
Envest (UK)
EPCMB (UK)
EQUER (Fra)
GaBi (GER)
GBTool (international)
Granlund Energy Tool
Green Building Advisor (USA)
KCL-ECO (FIN)
LCAid (Aus)
LCAiT (SE)
LEED (USA)
Legoe (GER)
LISA (Aus)
NatHERS (Aus)
NIRM (Jap)
OGIP (CH)
Økoprofile (NOR)
Optimize (CAN)
PAPOOSE (Fra)
PEMS (UK)
SBI (DK)
SEDA (Aus)
SIA D0123 (CH)
SimaPro (NL)
TEAM (Fra)

Figure 1

List of the LCA tools which were looked at in the comparative study

1. Detailed LCA modelling tools - material product level

TOOLS		Boustead (UK)	GaBi (GER)	KCL-ECO (FIN)	LCAiT (SE)	PEMS (UK)	Simapro (NL)	TEAM (Fra)
Relevance to building and construction:		low	low	low	low	low	low	low
LCA covers:	materials	yes	yes	yes	yes	yes	yes	yes
	use	yes	yes	yes	yes	yes	yes	yes
	disposal	yes	yes	yes	yes	yes	yes	yes
Impact categories used	Greenhouse	yes	yes	yes	yes	yes	yes	yes
	Energy	yes	yes	yes	yes	yes	yes	yes
	Air Polution	yes	yes	yes	yes	yes	yes	yes
	Ozone	yes	yes	yes	yes	yes	yes	yes
	Toxicity	yes	yes	yes	yes	yes	yes	yes
	water pollution	yes	yes	yes	yes	yes	yes	yes
	Water volume	?	?	?	?	?	possible but no data currently	?
	Solid Waste	yes	yes	yes	yes	yes	yes	yes
	IAQ	no	no	no	no	no	no	no
	Energy consumption during the life time of the building	no, energy consumption is an input value	no, energy consumption is an input value	no, energy consumption is an input value	no, energy consumption is an input value	no, energy consumption is an input value	no, energy consumption is an input value	no, energy consumption is an input value
Database	present	yes	yes	yes	yes	yes	yes	yes
	editable	?	?	?	?	?	yes	?
	name(s)	own	own	KCL EcoData (own)	SPINE (Sustainable Product Information Network for the Environment)		Ecoinvent v1, ETH-ESU 96, BUWAL 250, and others	"Starter Kit" (own)
Life cycle costing	LCC	no	no	no	no	no	possible	yes
Website		www.boustead-consulting.co.uk/	www.environmental-expert.com/software/pr_eng/pr_eng.htm	www.kcl.fi/eco/	www.lcait.com/index.html	www.novxcorp.com/process_environment_monitoring.htm	www.pre.nl/simapro/default.htm	www.ecobilan.com/uk_team.php
Editor / developper		Boustead consulting Ltd.	PE Europe GmbH	KCL	Chalmers Industriteknik / CIT Ekologik	NovX Corporation	PRé Consultants bv	Price Waterhouse Coopers / Ecobilan
Use	Users		Universität Stuttgart, …					Public/controlling authority, researcher, consultant
	Main domain of use	general	general	general	general		general	general
Processing	Methods provided or used		Ecoindicator 95, Ecoindicator 99, UBP, CML 1996 and 2001. Monte-Carlo Analysis, scenario balances, parameter variation.	DAIA-98 (a Finnish method created by the Finnish Environment Institute) and Eco-indicator 95			Eco-indicator 99, Eco-indicator 95, CML 92, CML 2 (2001), EDIP/UMIP, EPS 2000, Ecopoints 97, Cumulative Energy Demand, IPCC Greenhouse gas emission. Monte Carlo analysis.	LCA - classification factors method [Heijungs-1992], Ecological scarcity - Eco-points-method, Critical volumes, Toxicity equivalents, Eco-indicator 95 and 99
	Description of the building (inputs)	Fuels/energy, raw materials						Amounts of building components, annual consumption (electricity, water, heating, etc;) as expected for the use of the building, life time of the components and maintenance assumptions (painting, wallpaper, etc.).
	Results (outputs)	Waste heat, air emissions, water emissions, solid wastes, products	energy, mass, valuated balances and others…					Inventory level: Water consumption, Wood consumption, Particulate emissions, Chlorides emissions, Waste production. Classification level: resource depletion, greenhouse effect, etc. The user can select the environmental impact indicators from the main ones existing in LCA. Evaluation - full aggregation: Critical volumes, EPS, Eco-Indicator 95, etc. The user can select the full aggregation from the main ones existing in LCA.
Prices		24,000 $	7.500 €	3.600 €	3.850 €		1200 to 7600 €	3.000 €
Comments		Boustead has been extensively used by the DPWS, for evaluations for the Olympic games and will be used as a basis for their Australian tool.	GaBi is a German tool which is very process engineering based. It´s not only a LCA tool, it concerns benchmarking, management and social conditions too.	This tool was developed for the Finnish paper board industry. It carries out an LCA based on the mass flow of the inputs and outputs of the product.	This Swedish software has been around since 1992, it works with the SPINE data format and was developed as a tool to aid in product design. It was developed by CIT Ekologik - Consultants in Environmental Management and Product Ecology.	PEMS 4, the current version, is a stand alone tool capable of conducting both life cycle inventory analysis and assessment. It can be used to construct both full and streamlined LCA studies and is suitable for use by either the novice or experienced life cycle assessment practitioner.	Modelling more aimed at product level than building level though used in sectors such as the concrete industry in Europe.	TEAM™ 3.0 (Tool for Environmental Analysis and Management) is a tool for evaluating the life cycle environmental and cost profiles of products and technologies. It has a database of over 600 modules with worldwide coverage. It is developed by the Ecobilan Group. TEAM for building exists too.
	Related to buildings			Environmental assessment				TEAM for building enables the user to perform the environmental evaluation of a building, based on the Life Cycle Assessment methodology. It is a flexible tool which allows the user to select the level of details for the building description, the life cycle stages under study as well as the environmental impact indicators kept for the environmental evaluation.

2. LCA Design tools

TOOLS		Assessed tool Japan BRI- LCA (Jap)	Athena (Can)	BEE 1.0 (FIN)	BES	ECO methods (Fra)	ECOit (NL)	EcoQuantum (NL)	LCAit	LISA (Aus)	Optimize (CAN)	SIA D0123 (CH)
Relevance to building and construction:		high	high	high	high	high	low	high	low	high	high	high
LCA covers[16]	materials	yes	yes	yes	yes	yes	ecopoints	yes	yes	yes	yes	yes
	use	yes	yes	no	no	yes	ecopoints	yes	yes	yes	yes	no
	disposal	yes	yes	yes	yes	no[18]	ecopoints	yes	yes	yes	yes	no
Impact categories used	Greenhouse	yes	yes	yes	yes	yes	ecopoints	yes	ecopoints	yes	yes	yes
	Energy	yes	yes	no	yes	yes	ecopoints	yes	ecopoints	yes	yes	yes
	Air Polution	no	yes	yes	yes	yes	ecopoints	yes	ecopoints	yes[20]	yes	yes
	Ozone	no	no	yes	no	no	ecopoints	yes	ecopoints	no[21]	yes	yes
	Toxicity	no	yes	yes	yes	yes	ecopoints	yes	ecopoints	no[22]	yes	yes
	water pollution	no	yes	yes	yes	no	ecopoints	yes	ecopoints	no[23]	yes	yes
	Water volume	no	no	?	no	?	no	?	no	yes	?	yes
	Solid Waste	no	yes	yes	yes	?	ecopoints	yes	ecopoints	no[24]	yes	yes
	IAQ	no	no	no	no	yes	no	no	no	no	yes	no
	Energy consumption during lifetime of the building	yes, energy consumption is an output	no, consumed energy is an input value (?)	no, consumed energy is an input value (?)		no, consumed energy is an input value (?)		no, consumed energy is an input value (?)			yes (?), energy consumption is an output	yes (?), energy consumption is an output
Database	present	yes	yes	yes	yes	yes	yes - limited	yes	yes	yes	yes	yes?
	editable	?		?	?		no		no ?	no	?	?
	name(s)		own						SPINE (Sustainable Product Information Network for the Environment)	All of the Australian LCI data was obtained from the BHP LCA model EMMA (Eco-model for Materials and Manufacturing Assessment)		
Life cycle costing	LCC	no	no	no	no	no	no	no	no	no	yes	no
Website		www.kenken.go.jp/english/index.html	www.athenasmi.ca/index.html				www.earthshift.com/ecoit.htm	www.ivambv.uva.nl/uk/index.htm	www.lcait.com/index.html	www.lisa.au.com/		
Editor / developper		BRI (= Building Research Institute)	Athena Sustainable Materials Institute	Consortium of consultants for the architectural competition of the Viikki ecological housing area in Helsinki.		Institut für Industrielle Bauproduktion (ifib) ; Universität Karlsruhe	Pre consultant	IVAM	Chalmers Industriteknik / CIT Ekologik	BHP Steel (supplies financial support)	Canada Mortgage and Housing Corporation	SIA (Société Suisse des Ingénieurs et des architectes)
Use	Users			Designer ; Constructor ; Consultant		Planner; Constructor; Researcher	Designers, architects	Architects/designers, public, controlling authority, Researcher, Consultant		Architects/designers		Architects/designers, consultant
	Main domain of use		Building (domestic, office, retail, industrial), building element	Single buildings ; (Groups of buildings). Preliminary stages ; Building products ; Construction ; Operation ; Maintenance of building		Structural members/elements Single buildings ; Groups of buildings. Preliminary stages ; Erection ; (Operation) ; Maintenance; Use ; Demolition ; Disposal		Single buildings and groups of buildings. Stages : Material and energetic preliminary stages, Manufacture of building products, Erection of building, Operation of building, Maintenance of building, Servicing and attendance, Demolition of building, Disposal.	general	Building	Single residential buildings. All stages.	Construction elements, materials. Stages : quantitative from cradle to gate ; qualitative use phase and disposal.
Processing	Methods provided or used					LCA - classification factors method, Ecological scarcity - Environment-loading-points -UBP, Toxicity equivalents, Monetarization (external costs)	Eco-Indicator 95 and 99	CML valuation method, LCA - classification factors method			LCA, full cost accounting	CML impact categories for GWP, Acidification, primary energy use; qualitative assessment based on declaration forms (SIA 493) and general information
	description of the building (inputs)	Building type and scale, building site data, building material/components type and amount, demolition method, life style, heat insulator type, facility type		Energy consumption for heating, electricity consumption in use, amounts of building materials used for initial construction, amounts of building materials for recurring production, reparations, alterations etc.		Climate influences, using parameters, technical standards, mass and energy flows, energy consumption and demand, LC of building components, technical standards (heating system, etc.)		Preliminary design: shape and dimensions, the quantities of a limited number of building components; Definite design: number, quantities and dimensions of building elements; Specifications; Expected energy consumption		Bill of Materials & Quantities, Work Schedule e.g. Fuel consumption by construction equipment, HVAC, Services and Fittings, and utilisation schedules	Quantity Take-off, operating energy, location and distances, construction energy rates	Construction elements, materials
	results (outputs)	Direct values for energy consumption and CO2 emissions	Natural resource, energy and water inputs to processes as well as emissions to air, water and land for the manufacture, transportation and use of the individual building products, embodied energy, resource use, air and water pollution, greenhouse gas effects and total solid wastes produced	Primary energy use, amount of construction waste, GWP, Air Pollution, POCP				Quantities of materials, energy use	Emissions, energy requirements and material flows	resource energy consumption, GGE (greenhouse gas emissions), NOx, SOx, NMVOC (non-methane volatile organic compounds), SPM (suspended particulate matter), and fresh water consumption.	Energy by type, materials by weight, costs, VOCs (volatile organic compounds)	Energy use, water consumption, material use, waste, greenhouse GWP Acidification, comparison between different constructions
Prices			715 $				60 €	350,00 €	One licence : 3850 €	free		
Comments		Based on Energy and CO2 figures allows comparison of options[26]		It is used for accumulating the embodied energy and emissions from the production of building materials, energy consumption and emissions during use and amounts of construction waste from individual building designs.	The building materials Ecological Sustainability Index was developed in 1995 by Harry Partridge and Billa Lawson.it uses value judgements to score materials on a scale of 1 - best practice; to 5 - worst practice, for each choosen issues. There are 16 issues in three categories - resource depletion, Inherent pollution and Embodied energy.	The ECO methods have been derived from research projects in Switzerland and Germany since 1989. This software is a set of excel workbooks which help in analysing each step of the building process, from analysing the need for the building to working out material impacts etc.	This tool is a very simple and quick product analysis tool based on Eco-Indicator scores, that is eco-points per kilo of materials and processes. It is developed by Pre consultants.	Dutch program which is comprehensive and targetted at all levels of the building design. It has been designed to analyse a building in 1 hour.	This Swedish software has been around since 1992, it works with the SPINE data format and was developed as a tool to aid in product design.	LISA (LCA in Sustainable Architecture) is a streamlined LCA decision support tool for construction. It was developed in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design. It allows the modelling of a building by entering the amount of materials used and equipment used, etc.	Estimates the direct and indirect costs, weight, embodied energy and air emissions for buildings as built and over their life cycle.	Assessment catalogue concerning construction elements and construction materials.
	Special for buildings		Athena Environmental Impact Estimator (EIE) takes into account : material manufacturing, including resource extraction and recycled content ; related transportation ; on-site construction ; regional variation in energy use, transportation and other factors ; building type and assumed lifespan ; maintenance, repair and replacement effects ; demolition and disposal ; operating energy emissions and pre-combustion effects. Results about : embodied primary energy use ; global warming potential ; solid waste emissions ; pollutants to air ; pollutants to water ; natural resource use.								Canadian data base and spreadsheet application for estimating the life cycle energy, material flow, environmental impact and cost of residential buildings and assemblies,energy for maintenance, repair and replacement of building components, and the energy to demolish and haul away the structure at the end of its lifetime.	

5. Building Assessment Schemes

TOOLS		Beaver/ESPII	BREEAM (UK)	BREGains (UK)	BUNYIP (Aus)	DOE 2.2 (USA)	E2000 (CH)	Energy certification for buildings (FIN)	LEED (USA)	NatHERS (Aus)	Økoprofile (NOR)	SEDA (Aus)
Relevance to building and construction:		high	high	high	high	high	high	high	high	high	high	high
LCA covers[18]	materials	no	no	no	no	no	yes	no	yes	no	yes	no
	use	energy	no	energy	energy	energy	yes	yes	yes	energy	yes	energy
	disposal	no	no	no	no	no	yes	no	yes	no	no	no
Impact categories used	Greenhouse	no	yes	no	no	no	no	yes	yes	no	yes	yes
	Energy	yes	yes	yes	yes	yes	yes	yes	?	0-5 score	yes	yes
	Air	no	yes	no	no	no	no	no	?	no	yes	no
	Ozone Depl.	no	yes	no	no	no	no	no	yes	no	no	no
	Toxic	no	yes	no	no	no	no	no	?	no	no	no
	Water polution	no	no	no	no	no	no	no	?	no	no	no
	volume water	no	?	no	no	no	yes	no	?	no	yes	no
	Solid waste	no	?	no	no	no	yes	no	?	no	yes	no
	IAQ	no	yes	no	no	no	no	no	yes	no	yes	no
	Energy consumption during lifetime of the building	yes, energy consumption is an output	no		yes	yes	no (?)	yes	no	no	no	no
Database	Present	no?	?	no?	no?	no?	yes?	yes?	?	no?	yes?	no?
	edit DB	no	no	no	no	no	no	no	no	no	no	no
	name(s)											
Life cycle costing	LCC	no	no	no	no	no	no	no	no	no	no	no
	Website	www.members.ozemail.com.au	www.breeam.com/		www.dbce.csiro.au/abcinfo/planners/redev/	www.doe2.com/			www.edcmag.com	www.nathers.com/		www.deus.nsw.gov.au/
	Editor / developper	ACADS-BSG	Building Research Establishment Ltd		CSIRO (Commonwealth Scientific and Industrial Research Organization) division of building	James J. Hirsch & Associates (JJH) in collaboration with Lawrence Berkeley National Laboratory (LBNL)	Basler & Hofmann	VTT Building Technology, Motiva, Finnish Real Estate Federation, Helsinki City Public Works Department, Suomen Talokeskus Oy	US Green Building Council	CSIRO (Commonwealth Scientific and Industrial Research Organization) division of building	The Norwegian Building Research Institute (NBI), GRIP, Storebrand, Gjensidige, NTNU, SINTEF, Entro Energi AS, NVE	SEDA (Sustainable Energy Development Authority) is part of the DEUS (Department of Energy, Utilities and Sustainability) in NSW (New South Wales, Australia)
Use	Users		Public/controlling authority, owners, users, designers, researchers, consultants		Architects, engineers, students	architects, engineers in private A-E firms, energy consultants, building technology researchers, utility companies, state and federal agencies and university schools of architecture and engineering	Building owner/investor, architect/designer, consultant	Public/controlling authority, building owner/investor, building user, architect/designer, constructor, services enterprise during the period of use	Public/controlling authority, building owner/investor, researcher, consultant	Architect, designer, builder of residential work, building assessor, certifier.	Public/controlling authority, building owner/investor, building user, architect/designer, constructor, services enterprise during the period of use	Buildings owners, developpers, tenants, architects and engineers
	Main domain of use	Building energy estimation program	Buildings : offices, homes (known as EcoHomes), industrial units, retail units, schools		Non-residential building	Energy in buildings	Single buildings; Groups of buildings; Stocks of buildings	Single buildings	Design of all buildings	Houses (residential)	Existing office buildings and residentials (With some adjustments, the method can either be used as internal managment and guidance tool or/and a planning tool for new buildings.)	Existing buildings
Processing	Methods provided or used	ASHRAE Response Factor Method	UK ECO-weightings			ASHRAE 90.1, California Title24 and others	point system		Critical volumes, Toxicity equivalents			
	description of the building (inputs)	Hourly climatic data, detailed description of the building construction including shading and occupancy, detailed description of the building services including secondary and unitary air handling plant, chillers, boilers, hot and chilled heater storage tanks, solar collectors, on-site generators...	Information on managment, energy, transport, health and wellbeing, water consumption, materials specification, pollution landuse and site ecology issues, Basic building form/construction and servicing.		Building geometry, building location selection of customised construction details for building elements.	Geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, et), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs.	Predicted energy consumption, main construction materials, building control systems, mobility, finances.	Volumetric information on the subject building; Envelope insulation level; Ventilation system and heat recovery characteristics; Heating system characteristics	Criteria from applications for certification (filed by owner) and construction documents.	Key project details (adress, postcode, etc.), selection of construction details for building elements (up to 3 alternatives each), dimension of each building element entered via tables, infiltration factor. Internal gains due to people, lights and equipments, thermostat settings, schedules for heating and cooling, energy requirements for heating and cooling, internal temperature in each zone during unconditionned hours.	Energy consumption, water consumption. Technical systems. Heating, cooling, ventilation. Lightning, water fittings etc. Indoor climate. Temperatures, emissions, noise. Cleaning, moisture, etc.	Key project details (adress, postcode, etc.), dimensions of building floor area, thermostat settings, schedules for occupancy, energy consumption data for the past year.
	results (outputs)	Energy consuption of building by fuel type, by component and time of day, energy consumption of the building services (chillers, boilers, pumps, fans, cooling towers, on-site generators, etc.) and all other energy consuming devices (domestic hot water, lift, etc.) in the building. Space temperature variation, plant loadings, hourly or daily peak demand.	CO2 emissions (operation); CO2 emissions (transport); NOx emissions; water consumption; specification details; ecological value; ambient noise level		Details of external fixed shading scheme, specification for schedules, including optionnal hourly profiles, selection of energy tariffs from library, details of occupancy, lighting, equipment, infiltration and thermostat for each zone…special for energy	Comprehensive energy modelling, calculation for : natural ventilation capability in all single-duct system types, enhanced residential system with forced ventilation, inside surface temperature caculation, additionnal day lighting controls	Energy use; Water consumption; material use, waste	Energy consumption (kWh/m²/year)	Certification	An energy rating certificate providing a 0 - 5 star rating for houses	Environmental measures, Indoor climate, Energy, water, (materials and land), Temperature, emissions etc.	A rating certificate is provided for each building that has been rated, and the building owner, tenant or other responsible party gains the right to use the Building Greenhouse Rating logo for promotionnal purposes.
Prices					$2, 550					$660		
Comments		It is applied during final design. Assumes buildings have HVAC. BEAVER is a WINDOWS environment for the APEC ESPII Building Energy Estimation Program. It provides for user friendly input of data, processing and viewing of the results. It enables a designer to investigate many alternatives and make energy comparisons quickly and effectively for a very wide range of building configurations and air conditioning systems using actual measured climatic data.	Checklist - The Building Research Establishment Environmental Assessment Method (BREEAM) provides a comprehensive tool for analysing and improving the environmental performance of buildings from design through to management. Conceived as a tool to encourage a market for more environmentally friendly buildings, it is now widely accepted and used both as a property specification tool, a design tool and as an environmental review tool in environmental management strategies. The method covers a range of standard building types with assessment being carried out by a network of registered assessors. BRE are also able to use the methodology to carry out one-off assessments of other buildings.		There are two versions of BUNYIP (Building eNergY Investigation Package) : one aimed at architects interested in evaluating options on the building design and the other aimed at HVAC engineers that adds detailed HVAC modelling and peak load estimation capabilities.	The program contains a module for automatically generating a reference or a prototype building as well as a module that allows the user to change its parameters (to input a reference building corresponding to an existing building). (DOE : Department Of Energy)	Uses a Point system, looking at predicted energy consumption, main construction materials, building control systems, mobility, finances. The input data is: planning parameters concerning energy, materials, building control systems, location of the building; data basis for the assessment: inventories for energy systems, data of building materials. Reports on Resource depletion; Material and energy flow; Environmental loadings, biological criteria for materials. E2000 is not a computer-aided planning tool ; it´s a certification.	Model energy certificates and associated reference consumption levels for single family houses, blocks of flats and office buildings.	LEED (Leadership in Energy and Environmental Design) is a rating process awarding credits for each criteria met. Different levels of certification are awarded according to credits earned. It is a computer-aided assessment tool (not a planning tool) as well as a guideline.	The NatHERS software has been developed by CSIRO to provide quick assessment of house designs in an easy to use format. It is the reference-rating tool for the national House Energy Rating Scheme (HERS). It can be used during conceptual and design development.	It's a top down method used to assess existing office buildings and residential (from 1999). The results can be used in connection with sale and hire of office and residential buildings. With some adjustments, the method can either be used as internal management and guidance tool or/and a planning tool for new buildings. It´s a guideline, not a computer-aided tool. Ökoprofile as a planning tool is now under construction.	The SEDA scheme provides a set of performance benchmarks and a promotionally oriented star rating system that provides a framework within which designers and building operators can evaluate building performance.

4. Green product guides and Checklists

TOOLS		BEPAC (UK)	ECDG (Jap)	EcoSpecifier (Aus)	EPM - check list (NL)	Green housing A-Z (Jap)
Relevance to building and construction:		high	high	high	high	high
LCA covers[8]	materials	no	n/a	n/a	yes	n/a
	use	no	n/a	n/a	yes	n/a
	disposal	no	n/a	n/a	yes	n/a
Impact categories used	Greenhouse	yes	n/a	n/a	yes	n/a
	Energy	yes	n/a	n/a	yes	n/a
	Air	yes	n/a	n/a	yes	yes
	Ozone Depl.	yes	n/a	n/a	yes	n/a
	Toxic	?	n/a	n/a	yes	yes
	Water polution	?	n/a	n/a	yes	n/a
	volume water	?	n/a	n/a	?	n/a
	Solid waste	?	n/a	n/a	?	n/a
	IAQ	no	n/a	n/a	no	n/a
	Energy consumption during lifetime of the building	no	no (?)	no (?)	no (?)	
Database	Present	yes	no	yes	yes	no
	edit DB		no	no		no
	name(s)					
Life cycle costing	LCC	no	no	no	no	no
Website				www.ecospecifier.org/		www.biocity.co.jp/
Editor / developper		University of British Columbia (Canada)	Building Construction Society corporate juridical person (BCS)	Centre of design of the RMIT University in Melbourne, Australia	Woon |Energy	BIO City Co., Ltd.
Use	Users		Architect/designer, constructor, public, investor, user, planner	architects, designers, builders and specifiers		Public/controlling authority, Building owner/investor, User, Planner, Constructor
	Main domain of use	new and existing office buildings	Preliminary stages; Building products; Construction; Operation; Maintenance of building; Demolition of building; Disposal	Planning the construction, taking decisions,		Any stage of any building
Processing	Methods provided or used				CML simplified	
	description of the building (inputs)	criteria				
	results (outputs)		Scores of environmental conscious design about : Attitude for environment problem, Pollution of atmosphere, Reservation of resource, Protection of biosphere, Safety of city, Wastes, Landscape, Amenity		Qualitative assessment of alternatives (with reference to resources, energy, emissions, damage and waste). Allows environmental preferences to be included with other factors in the decision making process - such as costs, aesthetics.	
Prices				$ 3,950		
Comments		Checklist. Building Environmental Performance Assessment Criteria. BEPAC was inspired by BREEAM. It measures the environmental performance of commercial (non-residential) buildings. Its goal is to improve the impacts of building on indoor, local, and global environments. BEPAC looks at five primary criteria in determining a building's environmental performance. These are: Environmental impact of energy use, indoor environmental quality, ozone layer protection, resource conservation, site and transportation.	Each design issue is rated over a range of three: credit 0 for no features; credit 1 for a general response; and 2 for a positive response. The issues addressed include: A: Attitude for environment problem, B: Pollution of atmosphere, C: Reservation of resource, D: Protection of biosphere, E: Safety of city, F: Wastes, G: Landscape, H: Amenity.	It is a web and print based list of products which have shown environmental responsability. Green product guides are based on a group of people deciding a product meets criteria which show it to be more environmentally responsible than other products in its category.	The Environmental Preference Method is developed by Woon.	LCA model is based on input output table.

3. LCA CAD tools

TOOLS		BEES (USA)	Building design advisor (USA)	CSIRO embodied energy 3D CAD tool (Aus)	Ecopro (GER)	Ecotect (Aus)	EPCMB (UK) Environmental Profiles of Construction Materials, Components and Buildings	EQUER (Fra)	Green Building Advisor (USA)	LCAid (Aus)	Legep (GER)	OGIP (CH)	PAPOOSE (F)	SBI (DK)	TEAM (Fra)
Relevance to building and construction		high	high	high	high	high	high	high	high	high	high	high	high	low	high
LCA covers[19]	materials	yes	yes	embodied energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	use	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	disposal	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes?	yes	yes
Impact categories used	Greenhouse	yes	yes	no	yes	yes	yes	yes	no	yes	yes	no	yes eco-indicators	yes	yes
	Energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes eco-indicators	yes	yes
	Air	yes	yes	no	yes	no	yes	yes	no	yes	yes	no	yes eco-indicators	yes	yes
	Ozone Depl.	yes	yes	no	yes	no	yes	yes	no	yes	yes	no	yes eco-indicators	yes	yes
	Toxic	yes	yes	no	yes	no	yes	yes	no	yes	yes	no	yes eco-indicators	yes	yes
	Water polution	yes	yes	no	yes	no	yes	yes	no	yes	yes	no	yes eco-indicators	yes	yes
	volume water	?	?	no	?	?	?	?	?	yes	?	yes	?	no	?
	Solid waste	yes	yes	no	yes	no	yes	?	no	yes	yes	no	yes eco-indicators	yes	yes
	IAQ	no?	yes	no	no	yes	no	no	yes	?	yes	no	yes eco-indicators	no	no
	Energy consumption during lifetime of the building		yes (?)		no	yes (?)		no (?)		yes	yes (?)		yes (?)	yes (?)	no, consumed energy is an input value
Database	Present	yes	yes	?	yes	Yes	yes	yes	yes but hidden	yes	yes	yes	yes	yes	yes[23]
	edit DB			?	?		?				?	?	?	?	
	name(s)	Ecobalance LCA database (own)						database constituted by Karlsruhe Universität		DPWS LCI (Life Cycle Inventory) database and data from Boustead Model	Ökodata Sirados element catalogue	BEK (building-element-catalogue of CRB)	CEREN Data base for building materials-TRIBU		"Starter Kit" (own)
Life cycle costing	LCC	yes	no	no	no	Yes	no	no	no	no	yes	yes	no	no	no
	Website	www.bfrl.nist.gov/oae/software/bees.html	gaia.lbl.gov/bda/	www.csiro.au/	www.ifib.uni-karlsruhe.de/web/	www.squ1.com/	www.bre.co.uk/	www.cenerg-ensmp.fr	www.buildinggreen.com	www.projectweb.gov.com.au	www.fbta.uni-karlsruhe.de	www.crb.ch	www.tributribu.com	www.dbri.dk	www.ecobilan.com
	Editor / developper	NIST (National Institute for Standards and Technology)	Building Technologies Department of the Environmental Energy Technologies Division at Ernest Orlando Lawrence Berkeley National Laboratory	CSIRO (The Commonwealth Scientific and Industrial Research Organisation)	Institut für Industrielle Bauproduktion (ifib) ; Universität Karlsruhe	Welsh School of Architecture at Cardiff University	BRE (Building Research Establishment Ltd)	Ecole des Mines de Paris, Centre d´énergétique	SHAI (software firm in Belmont, California), CREST, BuildingGreen, (publishers of Environmental Building News), Design Harmony	Environmental services of DPWS (Department of Public Works and Services of Australia)	Edition AUM; IEZ AG; Sidoun GmbH; Ascona GbR, IBS Jena ifib Uni Karlsruhe; IREB Uni Weimar Architekturbüro Eble, Architekturbüro Arndt	CRB (Schweizerische Zentralstelle für Baurationalisierung)	TRIBU (Technique Recherche Innovation pour le Bâtiment et l'Urbain)	SBI - Danish Building Research Institute	Price Waterhouse Coopers / Ecobilan
Use	Users	Public/controlling authority, building owner/investor, building user, architect/designer, planner, constructor, researcher, consultant	Designers		Architects, designers, planners, constructors and researchers.	Architects, students of architecture, designers.	Public/controlling authority, building owner/investor, building user, architect/designer, planner, constructor, researcher, consultant	Public/controlling authority, building owner/investor, building user, architect/designer, planner, constructor, researcher, consultant, services	Building owner/investor, building user, architect/designer, constructor	Architects, engineers, students, LCA practicioners and evaluators at all levels of government and private industry.	Architect/designer, researcher, consultant.	Public/controlling authority, planner, architect/designer, constructor, researcher, consultant.	Public/controlling authority, building owner/investor, architect/designer, consultant.	Architect/designer, planner, researcher, consultant.	Public/controlling authority, researcher, consultant.
	Main domain of use	Single building. Preliminary stages; Manufacture of building products; Maintenance of building; Servicing and attendance	Any kind of building		Building elements, single buildings and groups of buildings. All stages of the life-cycle.	Any kind of building. Initial, schematic phases.	Preliminary stages; Manufacture of building products; Maintenance of building; Use; Demolition; Disposal. Building products; Structural members/elements.	Single buildings. Preliminary stages; Building products; Construction; Operation; Disposal	Building products; Building processes; Structural members/elements Single buildings; Services. All stages.	All types of buildings.	Structural members/elements, single buildings. Preliminary stages; building products; construction; operation; disposal.	Structural members/elements, single buildings. Preliminary stages; manufacture of building products and technical systems; erection; operation; maintenance of building; demolition; disposal.	Building products and processes; Structural members/elements. Single buildings, groups of buildings. All stages except construction.	Building products and processes, structural members/elements. Single buildings, groups of buildings. All stages except manufacture of technical systems	Structural members/elements, single buildings; services; groups of buildings. Preliminary stages; building products; manufacture of technical systems; construction; operation; maintenance of building; disposal.
Processing	Methods provided or used	LCA - classification factors method [Heijungs 1992], Critical volumes, Toxicity equivalents, Monetarization (external costs), ASTM life cycle cost LCC, Multiattribute Decision Analysis			Ecological scarcity - environmental loading points, Toxicity equivalents, Monetarization		LCA - classification factors method [Heijungs 1992]	LCA - classification factors method [Heijungs- 1992], mass of solid waste, volume of nuclear waste, water consumption, primary energy	Qualitative, judgement of referenced experts	Eco-indicator 95 and 99	Ecological scarcity - Eco-points method, critical volumes, Eco-indicator 95	Ecological scarcity - Environment-loading-points -UBP, Mass - Intensity per service unit- MIPS, Monetarization (external costs)	Environmental indicators	EDIP-method	LCA - classification factors method, Ecological scarcity - Eco-points-method, Critical volumes, Toxicity equivalents, Eco - Indicator '95
	description of the building (inputs)	Inventory flow items (raw materials, energy,water ...)	Design parameters (e. g. dimensions of spaces, location and orientation of windows, glazing type, etc.) and context parameters (e. g. weather parameters, costs of materials and services, occupant characteristics and preferences)		Climate influences, Using parameters, Technical standards, mass and energy flows, energy consumption and demand, LC of building components	Building geometry and materials, element geometry and materials.	Type of Material and Element	Building site data ; Preliminary design; Detailed design; Use of the building; Occupancy beh.	Basic building description; User determines which areas or systems they want to focus on improving environmentally	Building type, number of occupant, region for climate data, material type and quantity.	Description-stage: - Quantities of volume and areas of the building components and building ground areas - Climate influences, Using parameters - Technical standards (heating system, etc.)	Quantities of construction elements (m² of walls etc.)	Type of building: offices, schools, lodgings,... Situation surface of the site, performances of the environmental impacts wanted: normal performance, outstanding, very outstanding. Dimensions of the buildings Scenarios of the buildings' uses; Specifications of the building components	Details of the mass of each material, its expected life, transport energy requirement and the value of each material for reuse, recycling and ultimately incineration in a power plant.	Amounts of building components, annual consumption (electricity, water, heating, etc;) as expected for the use of the building, life time of the components and maintenance assumptions (painting, wallpaper, etc.).
	results (outputs)	Charts and graphs of production processes, energy requirements, environmental performance (numerical)				Transparent shadow, additionnal overshadowing, shadow profiles, stereographic analysis, sun penetration, solar rays, optimised shading design, solar access, natural and artificial lighting, heating and cooling loads, internal temperature, cumulative frequency, statistical reverberation, sprayed acoustic rays, geometric ray tracing, environment, prevailing wind analysis, material and environment costs, life-cycle embodied energy, life-cycle greenhouse emissions.	Inventory level : Primary Energy; Delivered Energy; Fossil Fuel Depletion; Water Input and Output; Transport; Air Emissions; Emissions to Sewer; Emissions to Surface Water; Emissions to Landfill; Other solid emissions; Inputs; Products/Coproducts Classification level : Effects on : Climate Change; Acid Deposition; Ozone Depletion; Human Toxicity; Ecotoxicity; Fossil Fuel Depletion; Eutrophication; POCP; Dust pollution.	Water consumption; Radioactiste;Other solid waste; Primary energy.	Advice of experts, precedent building cases.	Waste generation, water and energy use. Effects on life-cycle greenhouse gas emissions, embodied energy, ozone depletion, nutriphication, heavy metals, acidification, summer/winter smog, carconogenisis, solid wastes, water consumption, primary fuels analysis.	Energy and mass flow, energy demand, water consumption, waste.	Energy use; Water consumption; material use, waste.	Resources; Energy, Emissions, Waste, Water , Acoustic Level; Daylighting factor.	Energy consumption in use, Life cycle embodied energy, Overall energy consumption figure from 'cradle to grave'.	Inventory level: Water consumption, Wood consumption, Particulate emissions, Chlorides emissions, Waste production. Classification level: resource depletion, greenhouse effect, etc. The user can select the environmental impact indicators from the main ones existing in LCA. Evaluation - full aggregation: Critical volumes, EPS, Eco-Indicator 95, etc. The user can select the full aggregation from the main ones existing in LCA .
Prices		Free				590 €		598 €	$179.00			480 €	software still not commercialized		3000 €.
Comments		(Building for Environmental and Economic Sustainability) The purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance. Developed by the NIST (National Institute of Standards and Technology) the tool is based on consensus, standards and designed to be practical, flexible, and transparent.	This tools has been developed by the Building Technologies Department of the Environmental Energy Technologies Division at Ernest Orlando Lawrence Berkeley National Laboratory. In addition to the Schematic Graphic Editor, the current version of the BDA is linked to DCM (daylighting computation module), ECM (Electric lighting computation module) and DOE-2 (energy analysis module). Future versions of BDA will be linked to additional analysis and visualization tools, such as Radiance (day/lighting and rendering) and ATHENA (lifecycle cost of materials).	Tool calculates the embodied energy for the building components based on a CAD drawing with material specifications.	It's a calculation tool to optimise the material and mass flows, the energy flows and the costs during a early planning process. The building will be described by elements. The elements consists of building components, which are described by materials.	This software couples a 3D design interface with a wide range of performance analysis functions. The tool has been created for use during conceptual design and focuses on environmental impacts related to overall building shape and the materials used. ECOTECT has been developped to interface with LCAid, using building geometry as a bridge to incorporate LCA data into the design tool.	It provides LCA information for building materials, components and complete buildings based on data provided by UK manufactures. It can be used to compare the environmental performance of different specifications for materials.	This model EQUER (Evaluation de la Qualité Environnementale des bâtiments) is developed by Ecole des Mines de Paris, INERIS, DUMEZ-GTM, S'PACE and Pierre Diaz- Pedregal.	It uses artificial intelligence technology to supplement standard decision-making processes in facility design, construction and operations with current environmental data. QUALITATIVE, used the advice of experts to advice of green options on building depending on CAD drawings and function. It helps identify actions to reduce the environmental impacts of a building project, while ensuring healthy and productive indoor spaces - showing specific design strategies that can improve the environmental performance, cost-effectiveness, and healthiness of all phases of a building and its site, from pre-design through occupancy. The strategies are prioritized by the program based on information you give it about your project, such as the location, type and size of the building, and characteristics of the site.	LCAid™ is computer software developed by DPWS Environmental Services with computer programming by Dr. Andrew Marsh of the University of Western Australia's, Department of Architectural Science and LCAidTM input from Murray Hall of Life Cycle Design. Essentially LCAidTM takes LCA information, which until now has been limited to LCA specialists, and makes it more accessible to other practitioners (eg. architects, engineers, and portfolio managers) to make environmental assessments.[25]	Indication of environmental quality of buildings to designers, connection of life cycle assessment and life cycle costing. Looks at Overall building performance.	Software based on the BEK (building-element-catalogue of CRB) which enables the user to compare building projects regarding costs, external costs, UBP and energy. Looks at overall building performance. It uses the Ecological scarcity- Environment-loading-points-UBP; (Mass-Intensity per service unit-MIPS); Monetarization (external costs) methodologies. Modelling of the building as for cost estimates: the building can be subdivided from whole construction groups to construction elements to materials, etc. Results are presented relative compared to another variant after a weighting procedure. OGIP = Optimierung der Gesamtanforderungen (Kosten/Energie/Umwelt).	Needs data from the site; Use of default buildings; Geometry inputs; Main Materials; Use and occupancy schedules. Its database is based on CEREN. Data base for building materials-TRIBU. It looks specifically at Resource depletion; Material and energy flows; Environmental loadings; Effects to the human beings (indoor comfort and health).PAPOOSE (Programmation et Analyse de Projets d'Ouvrages et d'Opérations Soucieux de l'Environnement)	It's a calculating tool on the basis of LCA. It can present list of results as input/output tables or as normalised and weighted potential environmental effects as either detailed or profiles.	TEAM™ 3.0 is a tool for evaluating the life cycle environmental and cost profiles of products and technologies. Build any system easily regardless of its complexity. Benefit from a comprehensive database of over 600 modules with worldwide coverage.
documents related in "docs LCA" files		Tabelle mit viele LCA tools.xls, presentation various tools.htm, report about LCA tools (LCAid, ATHENA, BRE, BEES, Life Cycle Explorer).pdf, Toolsdescription.pdf (p24), ANNEX 31.htm	envtoolevaluation.pdf (p14), BDAbri99.pdf, BDAabn97.pdf		ANNEX 31.htm, envtoolevaluation.pdf (p17), presentation various tools.htm, Tabelle mit viele LCA tools.xls, Toolsdescription.pdf (p20, 51), Report about BREEAM, BEPAC, EcoQuantum, EQUER, etc..dot, Ecopro.xls	ANNEX 31.htm, envtoolevaluation.pdf (p14), Toolsdescription.pdf (p32), ECOTECT.xls	Tabelle mit viele LCA tools.xls, Toolsdescription.pdf (p37)	ANNEX 31.htm, presentation various tools.htm, Report about BREEAM, BEPAC, EcoQuantum, EQUER, etc..dot, Tabelle mit viele LCA tools.xls, Toolsdescription.pdf (p16)	presentation various tools.htm, Tabelle mit viele LCA tools.xls	ANNEX 31.xls, report about LCA tools (LCAid, ATHENA, BRE, BEES, Life Cycle Explorer).pdf (p40), Toolsdescription.pdf (p30), LCAid-brochure.pdf	ANNEX 31.htm, presentation various tools.htm, Toolsdescription.pdf (p35)	ANNEX 31.htm, presentation various tools.htm, Tabelle mit viele LCA tools.xls, Toolsdescription.pdf (p36)	ANNEX 31.htm, presentation various tools.htm, Tabelle mit viele LCA tools.xls, Toolsdescription.pdf (p34)	Introduction to the Information Pack.htm, presentation various tools.htm	ANNEX 31.htm, envtoolevaluation.pdf (p17), presentation various tools.htm,

Annex 12

Validity of the geometrical model

	Excavation	Foundations	Exterior walls	Interior walls	Floors and ceilings	Roof
One family house 3	1	1	1	1	1	1
One family house 5	1	0	1	0	1	1
Multiple family housing 1	1	1	0	1	1	1
Multiple family housing 2	0	0	0	1	0	1
Multiple family housing 3	0	1	1	1	1	1
Multiple family housing 4	1	1	1	0	1	1
Multiple family housing 5	1	1	1	1	1	1
Hostel, student habitation 1	0	1	1	1	1	0
Hostel, student habitation 2	0	1	1	1	1	0
Hostel, student habitation 3	1	1	1	1	1	1
Hostel, student habitation 4	1	1	1	1	1	1
Hostel, student habitation 5	1	1	1	1	1	1
One family house 1	1	1	1	1	1	1
Educational building 1	0	1	1	1	1	1
Educational building 2	1	0	1	1	0	1
Educational building 3	1	1	1	1	0	1
Educational building 4	0	1	1	1	1	0
Educational building 5	0	0	1	1	0	0
Hospital 1	0	1	1	1	1	1
Hospital 2	1	0	1	0	1	0
Hospital 3	0	0	1	0	0	0
Hospital 4	1	1	1	1	1	1
Hospital 5	0	1	1	1	1	1
Factory building 1	0	1	1	1	0	1
Factory building 2	0	0	1	1	1	1
Factory building 3	0	0	1	1	0	0
Factory building 4	1	1	0	1	0	1
Factory building 5	0	1	1	0	0	0
Total	14	20	25	23	19	20
% success	50%	71%	89%	82%	68%	71%

Figure 1: *Validity of the geometrical model.*

“1” means that the calculated geometrical characteristic (excavation volume, exterior wall surface…) and the actual one are considered to be the same (difference is less than 40 %)
“0” means that the calculated geometrical characteristic (excavation volume, exterior wall surface…) and the actual one are not considered to be the same (difference is more than 40 %)

	Excavation	Foundations	Exterior walls	Interior walls	Floors and ceilings	Roof
One family house	100%	67%	100%	67%	100%	100%
Multiple family housing	60%	80%	60%	80%	80%	100%
Hostels, student habitations	60%	100%	100%	100%	100%	60%
Educational buildings	40%	60%	100%	100%	40%	60%
Hospitals	40%	60%	100%	60%	80%	60%
Factory buildings	20%	60%	80%	80%	20%	60%

Figure 2: *Percentage of success per building use category and geometrical characteristics*

Annex 13

Rough Integrated Life Cycle Analysis Tool

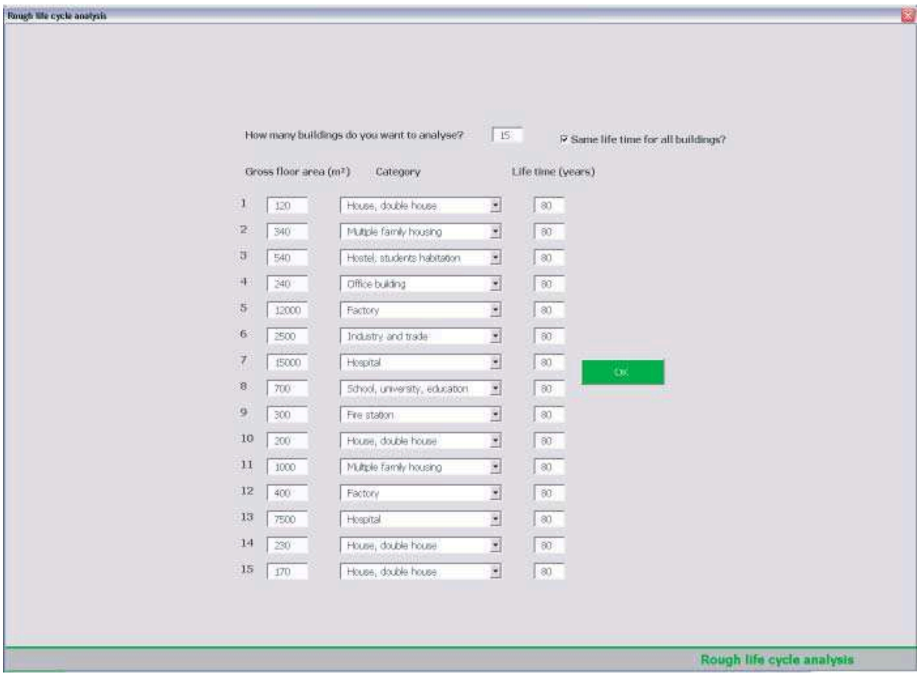
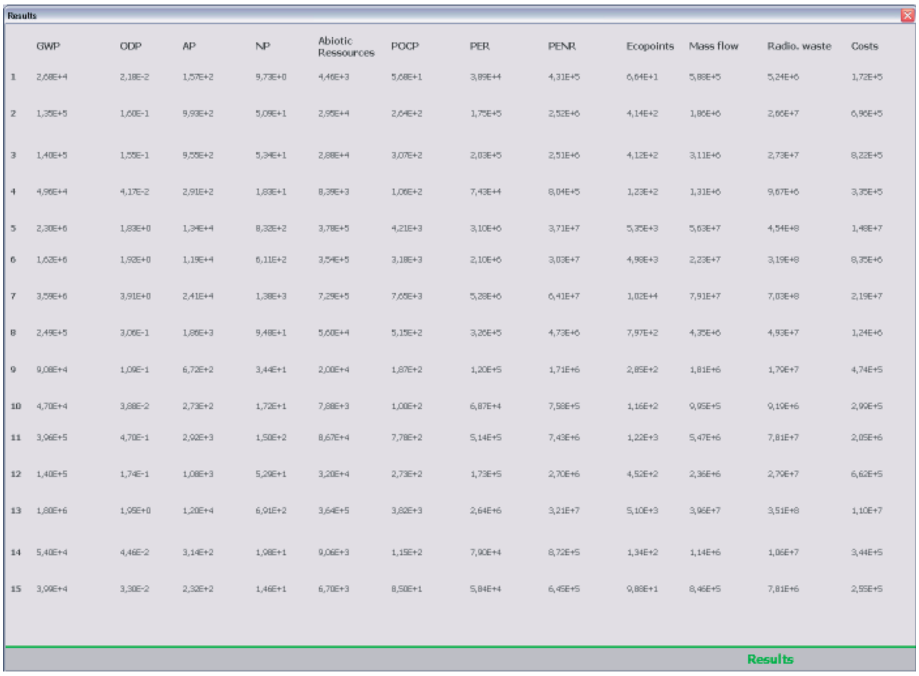


Figure 1

Data input in the gross life cycle evaluation tool



Results

	GWP	ODP	AP	NP	Abiotic Ressources	POCP	PER	PENR	Ecopoints	Mass flow	Radio. waste	Costs
1	2,68E+4	2,18E-2	1,57E+2	9,73E+0	4,46E+3	5,68E+1	3,89E+4	4,31E+5	6,64E+1	5,88E+5	5,24E+6	1,72E+5
2	1,35E+5	1,60E-1	9,93E+2	5,09E+1	2,95E+4	2,64E+2	1,75E+5	2,52E+6	4,14E+2	1,86E+6	2,66E+7	6,96E+5
3	1,40E+5	1,55E-1	9,55E+2	5,34E+1	2,88E+4	3,07E+2	2,03E+5	2,51E+6	4,12E+2	3,11E+6	2,73E+7	8,22E+5
4	4,96E+4	4,17E-2	2,91E+2	1,83E+1	8,39E+3	1,06E+2	7,43E+4	8,04E+5	1,23E+2	1,31E+6	9,67E+6	3,35E+5
5	2,30E+6	1,83E+0	1,34E+4	8,32E+2	3,78E+5	4,21E+3	3,10E+6	3,71E+7	5,35E+3	5,63E+7	4,54E+8	1,48E+7
6	1,62E+6	1,92E+0	1,19E+4	6,11E+2	3,54E+5	3,18E+3	2,10E+6	3,03E+7	4,98E+3	2,23E+7	3,19E+8	8,35E+6
7	3,59E+6	3,91E+0	2,41E+4	1,38E+3	7,29E+5	7,65E+3	5,28E+6	6,41E+7	1,02E+4	7,91E+7	7,03E+8	2,19E+7
8	2,49E+5	3,06E-1	1,86E+3	9,48E+1	5,60E+4	5,15E+2	3,26E+5	4,73E+6	7,97E+2	4,35E+6	4,93E+7	1,24E+6
9	9,08E+4	1,09E-1	6,72E+2	3,44E+1	2,00E+4	1,87E+2	1,20E+5	1,71E+6	2,85E+2	1,81E+6	1,79E+7	4,74E+5
10	4,70E+4	3,88E-2	2,73E+2	1,72E+1	7,88E+3	1,00E+2	6,87E+4	7,58E+5	1,16E+2	9,95E+5	9,19E+6	2,99E+5
11	3,96E+5	4,70E-1	2,92E+3	1,50E+2	8,67E+4	7,78E+2	5,14E+5	7,43E+6	1,22E+3	5,47E+6	7,81E+7	2,05E+6
12	1,40E+5	1,74E-1	1,08E+3	5,29E+1	3,20E+4	2,73E+2	1,73E+5	2,70E+6	4,52E+2	2,36E+6	2,79E+7	6,62E+5
13	1,80E+6	1,95E+0	1,20E+4	6,91E+2	3,64E+5	3,82E+3	2,64E+6	3,21E+7	5,10E+3	3,96E+7	3,51E+8	1,10E+7
14	5,40E+4	4,46E-2	3,14E+2	1,98E+1	9,06E+3	1,15E+2	7,90E+4	8,72E+5	1,34E+2	1,14E+6	1,06E+7	3,44E+5
15	3,99E+4	3,30E-2	2,32E+2	1,46E+1	6,70E+3	8,50E+1	5,84E+4	6,45E+5	9,88E+1	8,46E+5	7,81E+6	2,55E+5

Results

Figure 2

Results of the rough life cycle evaluation tool

Annex 14

Extracts of DIN 276 and DIN 277

DIN 276

4.3 Darstellung der Kostengliederung

Die in der Spalte „Anmerkungen" aufgeführten Güter, Leistungen oder Abgaben sind Beispiele für die jeweilige Kostengruppe; die Aufzählung ist nicht abschließend.

Tabelle 1

Kostengruppe		Anmerkungen
100	**Grundstück**	
110	**Grundstückswert**	
120	**Grundstücksnebenkosten**	Kosten, die im Zusammenhang mit dem Erwerb eines Grundstücks entstehen
121	Vermessungsgebühren	
122	Gerichtsgebühren	
123	Notariatsgebühren	
124	Maklerprovisionen	
125	Grunderwerbssteuer	
126	Wertermittlungen, Untersuchungen	Wertermittlungen, Untersuchungen zu Altlasten und deren Beseitigung, Baugrunduntersuchungen und Untersuchungen über die Bebaubarkeit, soweit sie zur Beurteilung des Grundstückswertes dienen.
127	Genehmigungsgebühren	
128	Bodenordnung, Grenzregulierung	
129	Grundstücksnebenkosten, sonstiges	
130	**Freimachen**	Kosten, die aufzuwenden sind, um ein Grundstück von Belastungen freizumachen
131	Abfindungen	Abfindungen und Entschädigungen für bestehende Nutzungsrechte, z.B. Miet- und Pachtverträge
132	Ablösen dringlicher Rechte	Ablösen von Lasten und Beschränkungen, z.B. Wegerechten
139	Freimachen, sonstiges	
200	**Herrichten und Erschließen**	Kosten aller vorbereitenden Maßnahmen, um das Grundstück bebauen zu können
210	**Herrichten**	Kosten der vorbereitenden Maßnahmen auf dem Baugrundstück
211	Sicherungsmaßnahmen	Schutz von vorhandenen Bauwerken, Bauteilen, Versorgungsleitungen sowie Sichern von Bewuchs und Vegetationsschichten
212	Abbruchmaßnahmen	Abbrechen und beseitigen von vorhandenen Bauwerken, Ver- und Entsorgungsleitungen sowie Verkehrsanlagen
213	Altlastenbeseitigung	Beseitigen von Kampfmitteln und anderen gefährlichen Stoffen, Sanieren belasteter und kontaminierter Böden
214	Herrichten der Geländeoberfläche	Roden von Bewuchs, Planieren, Bodenbewegungen einschließlich Oberbodensicherung
219	Herrichten, sonstiges	
220	**Öffentliche Erschließung**	Anteilige Kosten aufgrund gesetzlicher Vorschriften (Erschließungsbeträge/ Anliegerbeträge) und Kosten aufgrund öffentlich-rechtlicher Verträge für - die Beschaffung oder den Erwerb der Erschließungsflächen gegen Entgelt durch den Träger der öffentlichen Erschließung. - die Herstellung oder Änderung gemeinschaftlich genutzter technischer Anlagen, z.B. zur Ableitung von Abwasser sowie zur Versorgung mit Wasser, Wärme, Gas, Strom und Telekommunikation - die erstmalige Herstellung oder den Ausbau der öffentlichen Verkehrsflächen, der Grünflächen und sonstiger Freiflächen für öffentliche Nutzung. Kostenzuschüsse und Anschlußkosten sollen getrennt ausgewiesen werden.
221	Abwasserentsorgung	Anschlußbeiträge, Anschlußkosten
222	Wasserversorgung	Kostenzuschüsse, Anschlußkosten
223	Gasversorgung	Kostenzuschüsse, Anschlußkosten
224	Fernwärmeversorgung	Kostenzuschüsse, Anschlußkosten
225	Stromversorgung	Kostenzuschüsse, Anschlußkosten
226	Telekommunikation	einmalige Entgelte für die Bereitstellung und Änderung von Netzanschlüssen

DIN 276

Tabelle 1

Kostengruppe	Anmerkungen
227 Verkehrserschließung	Erschließungsbeiträge für die Verkehrs- und Freianlagen einschließlich deren Entwässerung und Beleuchtung
229 Öffentliche Erschließung, sonstiges	
230 Nichtöffentliche Erschließung	Kosten für Verkehrsflächen und technische Anlagen, die ohne öffentlich-rechtliche Verpflichtungen oder Beauftragung mit dem Ziel der späteren Übertragung in den Gebrauch der Allgemeinheit hergestellt und ergänzt werden. Kosten von Anlagen auf dem eigenen Grundstück gehören zu der Kostengruppe 500. Soweit erforderlich, kann die Kostengruppe 230 entsprechend der Kostengruppe 220 untergliedert werden.
240 Ausgleichsaufgaben	Kosten, die aufgrund landesrechtlicher Bestimmungen oder einer Ortssatzung aus Anlaß des geplanten Bauvorhabens einmalig und zusätzlich zu den Erschließungsbeiträgen entstehen. Hierzu gehört insbesondere das Ablösen von Verpflichtungen aus öffentlich-rechtlichen Vorschriften, z.B. für Stellplätze, Baumbestand.
300 Bauwerk - Baukonstruktionen	Kosten von Bauleistungen und Lieferungen zur Herstellung des Bauwerks, jedoch ohne die Technischen Anlagen (Kostengruppe 400). Dazu gehören auch die mit dem Bauwerk fest verbundenen Einbauten, die der besonderen Zweckbestimmung dienen, sowie übergreifende Maßnahmen in Zusammenhang mit der Baukonstruktionen. Bei Umbauten und Modernisierungen zählen hierzu auch die Kosten von Teilabbruch-, Sicherungs- und Demontagearbeiten.
310 Baugrube	Bodenabtrag, Aushub einschließlich Arbeitsräumen und Böschungen, Lagern,
311 Baugrubenherstellung	Hinterherfüllen, Ab- und Anfuhr
312 Baugrubenumschließung	Verbau, z.B. Schlitz-, Pfahl-, Spund-, Trägerbohl-, Injektions- und Spritzbetonwände einschließlich Verankerung, Absteifung
313 Wasserhaltung	Grund- und Schichtenwasserbeseitigung während der Bauzeit
319 Baugrube, sonstiges	
320 Gründung	Die Kostengruppen enthalten die zugehörigen Erdarbeiten und Sauberkeitsschichten.
321 Baugrundverbesserung	Bodenaustausch, Verdichtung, Einpressung
322 Flachgründungen [1])	Einzel-, Streifenfundamente, Fundamentplatten
323 Tiefgründungen [1])	Pfahlgründung einschließlich Roste, Brunnengründungen; Verankerungen
324 Unterböden und Bodenplatten	Unterböden und Bodenplatten, die nicht der Fundamentierung dienen
325 Bodenbeläge [2])	Beläge auf Boden- und Fundamentplatten, z.B. Estriche, Dichtungs-, Dämm-, Schutz-, Nutzschichten
326 Bauwerksabdichtungen	Abdichtungen des Bauwerks einschließlich Filter-, Trenn- und Schutzschichten
327 Dränagen	Leitungen, Schächte, Packungen
329 Gründung, sonstiges	
330 Außenwände	Wände und Stützen, die dem Außenklima ausgesetzt sind bzw. an das Erdreich oder an andere Bauwerke grenzen.
331 Tragende Außenwände [3])	tragende Außenwände einschließlich horizontaler Abdichtungen
332 Nichttragende Außenwände [3])	Außenwände, Brüstungen, Ausfachungen, jedoch ohne Bekleidung
333 Außenstützen [3])	Stützen und Pfeiler mit einem Querschnittverhältnis ? 1:5
334 Außentüren und -fenster	Fenster und Schaufenster, Türen und Tore einschließlich Fensterbänken, Umrahmungen, Beschlägen, Antrieben, Lüftungselementen und sonstigen eingebauten Elementen
335 Außenwandbekleidungen außen	Äußere Bekleidungen einschließlich Putz-, Dichtungs-, Dämm-, Schutzschichten an Außenwänden und -stützen

[1]) Gegebenenfalls können die Kostengruppen 322 und 323 zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[2]) Gegebenenfalls können die Kosten der Bodenbeläge (Kostengruppe KG 325) mit den Kosten Deckenbeläge (KG 352) in einer Kostengruppe zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[3]) Gegebenenfalls können die Kostengruppen 331, 332 und 333 bzw. 341, 342 und 343 zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

DIN 276

Tabelle 1

Kostengruppe		Anmerkungen
336	Außenwandbekleidung innen [4])	Raumseitige Bekleidungen, einschließlich Putz-, Dichtungs-, Dämm-, Schutzschichten an Außenwänden und –stützen
337	Elementierte Außenwände	Elementierte Wände, bestehend aus Außenwand, -fenster, -türen, -bekleidungen
338	Sonnenschutz	Rolläden, Markisen und Jalousien einschließlich Antrieben
339	Außenwände, sonstiges	Gitter, Geländer, Stoßabweiser und Handläufe
340	**Innenwände**	Innenwände und Innenstützen
341	Tragende Innenwände [3])	tragende Innenwände einschließlich horizontaler Abdichtungen
342	Nichttragende Innenwände [3])	Innenwände, Ausfachungen, jedoch ohne Bekleidungen
343	Innenstützen [3])	Stützen und Pfeiler mit einem Querschnittsverhältnis ? 1:5
344	Innentüren und -fenster	Türen und Tore, Fenster und Schaufenster einschließlich Umrahmungen, Beschlägen, Antrieben und sonstigen eingebauten Elementen
345	Innenwandbekleidungen [5])	Bekleidungen einschließlich Putz, Dichtungs-, Dämm-, Schutzschichten an Innenwänden und –stützen
346	Elementierte Innenwände	Elementierte Wände, bestehend aus Innenwänden, -türen, -fenstern, -bekleidungen, z.B. Falt- und Schiebewände, Sanitärtrennwände, Verschläge
349	Innenwände, sonstiges	Gitter, Geländer, Stoßabweiser, Handläufe, Rolläden einschließlich Antrieben
350	**Decken**	Decken, Treppen und Rampen oberhalb der Gründung und unterhalb der Dachfläche
351	Deckenkonstruktionen	Konstruktionen von Decken, Treppen, Rampen, Balkone, Loggien einschließlich Über- und Unterzügen, füllenden Teilen wie Hohlkörper, Blindböden, Schüttungen, jedoch ohne Beläge und Bekleidungen
352	Deckenbeläge [6])	Beläge auf Deckenkonstruktionen einschließlich Estrichen, Dichtungs-, Dämm-, Schutz-, Nutzschichten; Schwing- und Installationsdoppelböden
353	Deckenbekleidungen [7])	Bekleidungen unter Deckenkonstruktionen einschließlich Putz, Dichtungs-, Dämm-, Schutzschichten; Licht- und Kombinationsdecken
359	Decken, sonstiges	Abdeckungen, Schachtdeckel, Roste, Geländer, Stoßabweiser, Handläufe, Leitern, Einschubtreppen
360	**Dächer**	Flache oder geneigte Dächer
361	Dachkonstruktionen	Konstruktionen von Dächern, Dachstühlen, Raumtragwerken und Kuppeln einschließlich Über- und Unterzügen, füllenden Teilen wie Hohlkörper, Blindböden, Schüttungen, jedoch ohne Beläge und Bekleidungen
362	Dachfenster, Dachöffnungen	Fenster, Ausstiege einschließlich Umrahmungen, Beschlägen, Antrieben, Lüftungselementen und sonstigen eingebauten Elementen
363	Dachbeläge	Beläge auf Dachkonstruktionen einschließlich Schalungen, Lattungen, Gefälle-, Dichtungs-, Dämm-, Schutz und Nutzschichten; Entwässerungen der Dachfläche bis zum Anschluß an die Abwasseranlage
364	Dachbekleidungen [8])	Dachbekleidungen unter Dachkonstruktionen einschließlich Putz, Dichtungs-, Dämm-, Schutzschichten; Licht- und Kombinationsdecken unter Dächern
369	Dächer, sonstiges	Geländer, Laufbohlen, Schutzgitter, Schneefänge, Dachleitern, Sonnenschutz
370	**Baukonstruktive Einbauten**	Kosten der mit dem Bauwerk fest verbundenen Einbauten, jedoch ohne die nutzungsspezifischen Anlagen (siehe Kostengruppe 470). Für die Abgrenzung gegenüber der Kostengruppe 610 ist maßgebend, daß die Einbauten durch ihre Beschaffenheit und Befestigung technische und bauplanerische Maßnahmen erforderlich machen, z.B. Anfertigen von Werkplänen, statischen und anderen Berechnungen, Anschließen von Installationen

[3]) siehe Seite 5

[4]) Gegebenenfalls können die Kosten der Außenwandbekleidungen innen (KG 336) mit den Kosten der Innenwandbekleidungen (KG 345) zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[5]) Gegebenenfalls können die Kosten der Innenwandbekleidungen (KG 345) mit den Kosten der Außenwandbekleidungen innen (KG 336) zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[6]) Gegebenenfalls können die Kosten der Deckenbeläge (KG 352) mit den Kosten der Bodenbeläge (KG 325) zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[7]) Gegebenenfalls können die Kosten der Deckenbekleidungen (KG 353) mit den Kosten der Dachbekleidungen (KG 364) zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[8]) siehe Seite 7

DIN 276

Tabelle 1

Kostengruppe		Anmerkungen
371	Allgemeine Erschließung	Einbauten, die einer allgemeinen Zweckbestimmung dienen, z.B. Einbaumöbel wie Sitz- und Liegemöbel, Gestühl, Podien, Tische, Theken, Schränke, Garderoben, Regale
372	Besondere Einbauten	Einbauten, die einer besonderen Zweckbestimmung dienen, z.B. Werkbänke in Werkhallen, Labortische in Labors, Bühnenvorhänge in Theatern, Altäre in Kirchen, Einbausportgeräte in Sporthallen, Operationstische in Krankenhäusern
379	Baukonstruktive Einbauten, sonstiges	
390	**Sonstige Maßnahmen für Baukonstruktionen**	Übergreifende Maßnahmen im Zusammenhang mit den Baukonstruktionen, die nicht einzelnen Kostengruppen der Baukonstruktionen zuzuordnen sind oder nicht in andere Kostengruppen erfaßt werden können.
391	Baustelleneinrichtung	Einrichten, Vorhalten, Betreiben, Räumen der übergeordneten Baustelleneinrichtung, z.B. Material- und Geräteschuppen, Lager-, Wasch-, Toiletten- und Aufenthaltsräume, Bauwagen, Misch- und Transportanlagen, Energie- und Bauwasseranschlüsse, Baustraßen, Lager- und Arbeitsplätze, Verkehrssicherungen, Abdeckungen, Bauschilder, Bau- und Schutzzäune, Baubeleuchtung, Schuttbeseitigung
392	Gerüste	Auf-, Um-, Abbauen, Vorhalten von Gerüsten
393	Sicherungsmaßnahmen	Sicherungsmaßnahmen an bestehenden Bauwerken; z.B. Unterfangungen, Abstützungen
394	Abbruchmaßnahmen	Abbruch- und Demontagearbeiten einschließlich Zwischenlagern wiederverwendbarer Teile, Abfuhr des Abbruchmaterials
395	Instandsetzungen	Maßnahmen zur Wiederherstellung des zum bestimmungsgemäßen Gebrauch geeigneten Zustandes
396	Recycling, Zwischendeponierung und Entsorgung	Maßnahmen zum Recycling, zur Zwischendeponierung und zur Entsorgung von Materialien, die beim Abbruch, bei der Demontage und beim Ausbau von Bauteilen oder bei der Erstellung einer Baustelle anfallen
397	Schlechtwetterbau	Winterbauschutzvorkehrungen wie Notverglasung, Abdeckungen und Umhüllungen, Erwärmung des Bauwerks, Schneeräumung
398	Zusätzliche Maßnahmen	Schutz von Personen, Sachen und Funktionen; Reinigung vor Inbetriebnahme; Maßnahmen aufgrund von Forderungen des Wasser-, Landschafts- und Lärmschutzes während der Bauzeit; Erschütterungsschutz
399	Sonstige Maßnahmen für Baukonstruktionen, sonstiges	Schließanlagen, Schächte, Schornsteine, soweit nicht in anderen Kostengruppen erfaßt
400	**Bauwerk – Technische Anlagen [9])**	Kosten aller im Bauwerk eingebauten, daran angeschlossenen oder damit fest verbundenen technischen Anlagen oder Anlagenteile. Die einzelnen technischen Anlagen enthalten die zugehörigen Gestelle, Befestigungen, Armaturen, Wärme- und Kältedämmung, Schall- und Brandschutzvorkehrungen, Abdeckungen, Verkleidungen, Anstriche, Kennzeichnungen sowie Meß-, Steuer- und Regelanlagen.
410	**Abwasser-, Wasser-, Gasanlagen**	
411	Abwasseranlagen	Abläufe, Abwasserleitungen, Abwassersammelanlagen, Abwasserbehandlungs-anlagen, Hebeanlagen
412	Wasseranlagen	Wassergewinnungs-, Aufbereitungs- und Druckerhöhungsanlagen, Rohrleitungen, dezentrale Wasserwärmer, Sanitärobjekte
413	Gasanlagen	Gasanlagen für Wirtschaftswärme: Gaslagerungs- und Erzeugungsanlagen, Übergabestationen, Druckregelanlagen und Gasleitungen, sowie nicht zu den Kostengruppen 420 oder 470 gehörend
414	Feuerlöschanlagen	Sprinkler-, Co_2-Anlagen, Löschwasserleitungen, Wandhydranten, Feuerlöschgeräte
419	Abwasser-, Wasser-, Gasanlagen, sonstiges	Installationsblöcke, Sanitärzellen

[8]) Gegebenenfalls können die Kosten der Dachbekleidungen (KG 364) mit den Kosten der Deckenbekleidungen (KG 353) zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

[9]) Bei Bedarf können die Kosten der technischen Anlagen in die Installationen und die zentrale Betriebstechnik aufgeteilt werden.

DIN 276

Tabelle 1

Kostengruppe	Anmerkungen
420 Wärmeversorgungsanlagen	
421 Wärmeerzeugsanlagen	Brennstoffversorgung, Wärmeübergabestationen, Wärmeerzeugung auf der Grundlage von Brennstoffen oder unerschöpflichen Energiequellen einschließlich Schornsteinanschlüsse, zentrale Wassererwärmungsanlagen
422 Wärmeverteilnetze	Pumpen, Verteiler; Rohrleitungen für Raumheizflächen, raumlufttechnische Analgen und sonstige Wärmeverbraucher
423 Raumheizflächen	Heizkörper, Flächenheizsysteme
429 Wärmeversorgungsanlagen, sonstiges	Schornsteine, soweit nicht in anderen Kostengruppen erfaßt
430 Lufttechnische Anlagen	Anlagen mit und ohne Lüftungsfunktionen
431 Lüftungsanlagen	Abluftanlagen, Zuluftanlagen, Zuluft- und Abluftanlagen ohne oder mit einer thermodynamischen Luftbehandlungsfunktion, mechanische Entrauchungsanlagen
432 Teilklimaanlagen	Anlagen mit zwei oder drei thermodynamischen Luftbehandlungsfunktionen
433 Klimaanlagen	Analgen mit vier thermodynamischen Luftbehandlungsfunktionen
434 Prozeßlufttechnische Anlagen	Farbnebelabscheideanlagen, Prozeßfortluftsysteme, Absauganlagen
435 Kälteanlagen	Kälteanlagen für lufttechnische Anlagen: Kälteerzeugungs- und Rückkühlanlagen einschließlich Pumpen, Verteiler und Rohrleitungen
439 Lufttechnische Anlagen, sonstiges	Lüftungsdecken, Kühldecken, Abluftfenster; Installationsdoppelböden, soweit nicht in anderen Kostengruppen erfaßt
440 Starkstromanlagen	
411 Hoch- und Mittelspannungs-anlagen	Schaltanlagen, Transformatoren
442 Eigenstromversorgungs-anlagen	Stromerzeugungsanlagen einschließlich Kühlung, Abgasanlagen und Brennstoffversorgung, zentrale Batterie- und unterbrechungsfreie Stromversorgungsanlagen, photovoltaische Anlagen
443 Niedrigspannungsschalt-anlagen	Niedrigspannungshauptverteiler, Blindstromkompensationsanlagen, Maximumüber-wachungsanlagen
444 Niedrigspannungs-installationsanlagen	Kabel, Leitungen, Unterverteiler, Verlegesysteme, Installationsgeräte
445 Beleuchtungsanlagen	Ortsfeste Leuchten, einschließlich Leuchtmittel
446 Blitzschutz- und Erdungsanlagen	Auffangeinrichtungen, Ableitungen, Erdungen
449 Starkstromanlagen, sonstiges	Frequenzumformer
450 Fernmelde- und informationstechnische Anlagen	Die einzelnen Anlagen enthalten die zugehörigen Verteiler, Kabel, Leitungen
451 Telekommunikationsanlagen	
452 Such- und Signalanlagen	Personenrufanlagen, Lichtruf- und Klingelanlagen, Türsprech- und Türöffneranlagen
453 Zeitdienstanlagen	Uhren- und Zeiterfassungsanlagen
454 Elektroakustische Anlagen	Beschallungsanlagen, Konferenz- und Dolmetscheranlagen, Gegen- und Wechsel-sprechanlagen
455 Fernseh- und Antennenanlagen	Fernsehanlagen, soweit nicht in den Such-, Melde-, Signal- und Gefahrenmeldeanlagen erfaßt, einschließlich Sende- und Empfangsantennen-anlagen, Umsetzer
456 Gefahrenmelde- und Alarmanlagen	Brand-, Überfall-, Einbruchmeldeanlagen, Wächterkontrollanlagen, Zugangskontroll- und Raumbeobachtungsanlagen
457 Übertragungsnetze	Kabelnetze zur Übertragung von Daten, Sprache, Text und Bild, soweit nicht in anderen Kostengruppen erfaßt
459 Fernmelde- und informations-technische Anlagen, sonstiges	Verlegesysteme, soweit nicht in Kostengruppe 444 erfaßt; Fernwirkanlagen, Parkleitsysteme
460 Förderanlagen	
461 Aufzugsanlagen	Personenaufzüge, Lastenaufzüge
462 Fahrtreppen, Fahrsteige	
463 Befahranlagen	Fassadenaufzüge und andere Befahranlagen
464 Transportanlagen	Automatische Warentransportanlagen, Aktentransportanlagen, Rohrpostanlagen

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Tabelle 1

Kostengruppe		Anmerkungen
470	**Nutzungsspezifische Anlagen**	Kosten der mit dem Bauwerk fest verbundenen Anlagen, die der besonderen Zweckbestimmung dienen, jedoch ohne die baukonstruktiven Einbauten (Kostengruppe 370). Für die Abgrenzung gegenüber der Kostengruppe 610 ist maßgebend, daß die nutzungsspezifischen Anlagen technische und planerische Maßnahmen erforderlich machen, z.B. Anfertigen von Werkplänen, Berechnungen, Anschließen von anderen technischen Anlagen.
471	Küchentechnische Anlagen	Einrichtungen zur Speisen- und Getränkezubereitung, -ausgabe und –lagerung einschließlich zugehöriger Kälteanlagen
472	Wäscherei- und Reinigungsanlagen	Einschließlich zugehöriger Wasseraufbereitung, Desinfektions- und Sterilisationseinrichtungen
473	Medienversorgungsanlagen	Medizinische und technische Gase, Vakuum, Flüssigchemikalien, Lösungsmittel, vollentsalztes Wasser; einschließlich Lagerung, Erzeugungsanlagen, Übergabestationen, Druckregelanlagen, Leitungen und Entnahmearmaturen
474	Medizintechnische Anlagen	Ortsfeste medizintechnische Anlagen, soweit nicht in Kostengruppe 610 erfaßt
475	Labortechnische Anlagen	Ortsfeste labortechnische Anlagen, soweit nicht in Kostengruppe 610 erfaßt
476	Badetechnische Anlagen	Aufbereitungsanlagen für Schwimmbeckenwasser, soweit nicht in Kostengruppe 410 erfaßt
477	Kälteanlagen	Kälteversorgungsanlagen, soweit nicht in anderen Kostengruppen erfaßt; Eissportflächen
478	Entsorgungsanlagen	Abfall- und Medienentsorgungsanlagen, Staubsauganlagen, soweit nicht in Kostengruppe 610 erfaßt
479	Nutzungsspezifische Anlagen, sonstiges	Bühnentechnische Anlagen, Tankstellen- und Waschanlagen
480	**Gebäudeautomation**	Kosten der anlagenübergreifenden Automation, einschließlich der zugehörigen Verteiler, Kabel, Leitungen
481	Automationssysteme	Automationsanlagen, Bedien- und Beobachtungseinrichtungen, Programmiereinrichtungen, Sensoren und Aktoren, Kommunikationsschnittstellen, Software der Automationsstationen
482	Leistungsteile	Schaltschränke mit Leistungs-, Steuerungs- und Sicherungsbaugruppen
483	Zentrale Einrichtungen	Leitstationen mit Peripherie-Einrichtungen, Einrichtungen für Systemkommunikation zu den Automationsstationen
489	Gebäudeautomation, sonstiges	
490	**Sonstige Maßnahmen für Technische Anlagen**	Übergreifende Maßnahmen im Zusammenhang mit den Technischen Anlagen, die nicht einzelnen Kostengruppen der Technischen Anlagen zuzuordnen sind oder nicht an anderen Kostengruppen erfaßt werden können.
491	Baustelleneinrichtung	Einrichten, Vorhalten, Betreiben, Räumen der übergeordneten Baustelleneinrichtung, z.B. Material- und Geräteschuppen, Lager-, Wasch-, Toiletten- und Aufenthaltsräume, Bauwagen, Misch- und Transportanlagen, Energie- und Bauwasseranschlüsse, Baustraßen, Lager- und Arbeitsplätze, Verkehrssicherung, Abdeckungen, Bauschilder, Bau- und Schutzzäune, Baubeleuchtung, Schuttbeseitigung
492	Gerüste	Auf-, Um-, Abbauen, Vorhalten von Gerüsten
493	Sicherungsmaßnahmen	Sicherungsmaßnahmen an bestehenden Bauwerken; z.B. Unterfangungen, Abstützungen
494	Abbruchmaßnahmen	Abbruch- und Demontagearbeiten einschließlich Zwischenlagern wiederverwendbarer Teile, Abfuhr des Abbruchmaterials
495	Instandsetzungen	Maßnahmen zur Wiederherstellung des zum bestimmungsgemäßen Gebrauch geeigneten Zustandes
496	Recycling, Zwischendeponierung und Entsorgung	Maßnahmen zum Recycling, zur Zwischendeponierung und zur Entsorgung von Materialien, die beim Abbruch, bei der Demontage und beim Ausbau von Bauteilen oder bei der Erstellung einer Baustelle anfallen
497	Schlechtwetterbau	Winterbauschutzvorkehrungen wie Notverglasung, Abdeckungen und Umhüllungen, Erwärmung des Bauwerks, Schneeräumung
498	Zusätzliche Maßnahmen	Schutz von Personen, Sachen und Funktionen; Reinigung vor Inbetriebnahme; Maßnahmen aufgrund von Forderungen des Wasser-, Landschafts- und Lärmschutzes während der Bauzeit; Erschütterungsschutz

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Tabelle 1

Kostengruppe		Anmerkungen
500	**Außenanlagen**	Kosten der Bauleistungen und Lieferungen für die Herstellung aller Gelände- und Verkehrsflächen, Baukonstruktionen und technische Anlagen außerhalb des Bauwerks, soweit nicht in Kostengruppe 200 erfaßt. In den einzelnen Kostengruppen sind die zugehörigen Leistungen, wie z.B. Erdarbeiten, Unterbau und Gründungen, enthalten.
510	**Geländeoberflächen**	
511	Geländebearbeitung	Bodenabtrag und Bodenauftrag; Boden- und Oberbodenarbeiten
512	Vegetationstechnische Bodenbearbeitung	Bodenlockerung, Bodenverbesserung, z.B. Düngung, Bodenhilfsstoffe
513	Sicherungsbauweisen	Vegetationsstücke, Geotextilien, Flechtwerk
514	Pflanzen	Einschließlich Fertigstellungspflege
515	Rasen	Einschließlich Fertigstellungspflege; ohne Sportrasenflächen (siehe Kostengruppe 525)
516	Begrünung unterbauter Flächen	Auf Tiefgaragen, einschließlich Wurzelschutz- und Fertigstellungspflege
517	Wasserflächen	Naturnahe Wasserflächen
519	Geländeflächen, sonstiges	Entwicklungspflege
520	**Befestige Flächen**	
521	Wege [10])	Befestigte Fläche für den Fuß- und Radfahrerverkehr
522	Straße [10])	Flächen für den Leiht- und Schwerverkehr; Fußgängerzonen mit Anlieferungsverkehr
523	Plätze, Höfe [10])	Gestaltete Platzflächen, Innenhöfe
524	Stellplätze [10])	Flächen für den ruhenden Verkehr
525	Sportplatzflächen	Sportrasenflächen, Kunststoffsportflächen
526	Spielplatzflächen	
527	Gleisanlagen	
529	Befestige Flächen, sonstiges	
530	**Baukonstruktionen in Außenanlagen**	
531	Einfriedungen	Zäune, Mauern, Türen, Tore, Schrankenanlagen
532	Schutzkonstruktionen	Lärmschutzwände, Sichtschutzwände, Schutzgitter
533	Mauern, Wände	Stütz-, Schwergewichtsmauern
534	Rampen, Treppen, Tribünen	Kinderwagen- und Behindertentreppen, Block- und Stellstufen, Zuschauertribünen von Sportplätzen
535	Überdachungen	Wetterschutz, Unterstände; Pergolen
536	Brücken, Stege	Holz- und Stahlkonstruktionen
537	Kanal- und Schachtbau-anlagen	Bauliche Anlagen für Medien- oder Verkehrserschließung
538	Wasserbauliche Anlagen	Brunnen, Wasserbecken, Bachregulierungen
539	Baukonstruktionen in Außenanlagen, sonstiges	
540	**Technische Anlagen in Außenanlagen**	Kosten der technischen Anlagen auf dem Grundstück einschließlich der Versatz Ringanker/ Trennwand- und Entsorgung des Bauwerks
541	Abwasseranlagen	Kläranlagen, Oberflächen- und Bauwerksentwässerungsanlagen, Sammelgruben, Abscheider, Hebeanlagen
542	Wasseranlagen	Wassergewinnungsanlagen, Wasserversorgungsnetze, Hydrantenanlagen, Druckerhöhungs- und Beregnungsanlagen
543	Gasanlagen	Gasversorgungsnetze, Flüssiggasanlagen
544	Wärmeversorgungsanlagen	Wärmeerzeugungsanlagen, Wärmeversorgungsnetze, Freiflächen- und Rampenheizungen
545	Lufttechnische Anlagen	Bauteile von lufttechnischen Anlagen, z.B. Außenluftansaugung, Fortluftausblas, Kälteversorgung

[10]) Gegebenenfalls können die Kostengruppen 521, 523 und 524 zusammengefaßt werden; die Zusammenfassung ist kenntlich zu machen.

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Tabelle 1

Kostengruppe		Anmerkungen
546	Starkstromanlagen	Stromversorgungsnetze, Freilufttrafostationen, Eigenstromerzeugungsanlagen, Außenbeleuchtungs- und Flutlichtanlagen einschließlich Maste und Befestigung
547	Fernmelde- und informations-technische Anlagen	Leitungsnetze, Beschallungs-, Zeitdienst- und Verkehrssignalanlagen, elektronische Anzeigetafeln, Objektsicherungsanlagen, Parkleitsysteme
548	Nutzungsspezifische Anlagen	Medienversorgungsanlagen, Tankstellenanlagen, badetechnische Anlagen
549	Technische Anlagen in Außenanlagen, sonstiges	
550	**Einbauten in Außenanlagen**	
551	Allgemeine Einbauten	Wirtschaftsgegenstände, z.B. Möbel, Fahrradständer, Schilder, Pflanzbehälter, Abfallbehälter, Fahnenmaste
552	Besondere Einbauten	Einbauten für Sport- und Spielanlagen, Tiergehege
559	Einbauten in Außenanlagen, sonstiges	
590	**Sonstige Maßnahmen für Außenanlagen**	Übergreifende Maßnahmen im Zusammenhang mit den Außenanlagen, die nicht in einzelnen Kostengruppen der Außenanlagen zuzuordnen sind.
591	Baustelleneinrichtung	einrichten, Vorhalten Betreiben, Räumen der übergeordneten Baustelleneinrichtung, z.B. Material- und Geräteschuppen, Lager-, Wasch-, Toiletten- und Aufenthaltsräume, Bauwagen, Misch- und Transportanlagen, Energie- und Bauwasseranschlüsse, Baustraßen, Lager- und Arbeitsplätze, Verkehrssicherungen, Abdeckungen, Bauschilder, Bau- und Schutzzäune, Baubeleuchtung, Schuttbeseitigung
592	Gerüste	Auf-, Um-, Abbauen, Vorhalten von Gerüsten
593	Sicherungsmaßnahmen	Sicherungsmaßnahmen an bestehenden baulichen Anlagen; z.B. Unterfangungen, Abstützungen
594	Abbruchmaßnahmen	Abbruch- und Demontagearbeiten einschließlich Zwischenlagern wiederverwendbarer Teile, Abfuhr des Abbruchmaterials
595	Instandsetzungen	Maßnahmen zur Wiederherstellung des zum bestimmungsgemäßen Gebrauch geeigneten Zustandes
596	Recycling, Zwischendeponierung und Entsorgung	Maßnahmen zum Recycling, zur Zwischendeponierung und zur Entsorgung von Materialien, die beim Abbruch, bei der Demontage und beim Ausbau von Bauteilen oder bei der Erstellung einer Baustelle anfallen
597	Schlechtwetterbau	Winterbauschutzvorkehrungen wie Notverglasung, Abdeckungen und Umhüllungen, Erwärmung des Bauwerks, Schneeräumung
598	Zusätzliche Maßnahmen	Schutz von Personen, Sachen und Funktionen; Reinigung vor Inbetriebnahme; Maßnahmen aufgrund von Forderungen des Wasser-, Landschafts- und Lärmschutzes während der Bauzeit; Erschütterungsschutz
599	Sonstige Maßnahmen für Außenanlagen, sonstiges	
600	**Ausstattung und Kunstwerke**	Kosten für alle beweglichen oder ohne besondere Maßnahmen zu befestigenden Sachen, die zur Ingebrauchnahme, zur allgemeinen Benutzung oder zur künstlerischen Gestaltung des Bauwerks und der Außenanlagen erforderlich sind. (siehe Anmerkungen zu den Kostengruppen 370 und 470)
610	**Ausstattung**	
611	Allgemeine Ausstattung	Möbel, z.B. Sitz- und Liegemöbel, Schränke, Regale, Tische; Textilien, z.B. Vorhänge, Wandbehänge, lose Teppiche, Wäsche; Haus-, Wirtschafts-, Garten- und Reinigungsgeräte
612	Besondere Ausstattung	Ausstattungsgegenstände, die einer besonderen Zweckbestimmung dienen wie z.B. wissenschaftliche, medizinische, technische Geräte
619	Ausstattung, sonstiges	Wegweiser, Orientierungstafeln, Farbleitsysteme, Werbeanlagen
620	**Kunstwerke**	
621	Kunstobjekte	Kunstwerke zur künstlerischen Ausstattung des Bauwerks und der Außenanlagen einschließlich Tragkonstruktionen, z.B. Skulpturen, Objekte, Gemälde, Möbel, Antiquitäten, Altäre, Taufbecken
622	Künstlerisch gestaltete Bauteile des Bauwerks	Kosten für die künstlerische Gestaltung, z.B. Malereien, Reliefs, Mosaiken, Glas-, Schmiede-, Steinmetzarbeiten

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Tabelle 1

Kostengruppe	Anmerkungen
623 Künstlerisch gestaltete Bauteile der Außenanlagen	Kosten für die künstlerische Gestaltung, z.B. Malereien, Reliefs, Mosaiken, Glas-, Schmiede-, Steinmetzarbeiten
629 Kunstwerke, sonstiges	
700 Baunebenkosten	Kosten, die bei der Planung und Durchführung auf der Grundlage von Honorarordnungen, Gebührenordnungen oder nach weiteren vertraglichen Vereinbarungen entstehen.
710 Bauherrenaufgaben	
711 Projektleitung	Kosten, die der Bauherr zum Zwecke der Überwachung und Vertretung der Bauherreninteressen aufwendet
712 Projektsteuerung	Kosten für Projektsteuerungsleistungen im Sinne der HOAI sowie für andere Leistungen, die sich mit der übergeordneten Steuerung und Kontrolle von Projektorganisation, Terminen, Kosten und Qualitätssicherung befassen
713 Betriebs- und Organisationsberatung	Kosten für die Beratung, z.B. zur betrieblichen Organisation, zur Arbeitsplatzgestaltung, zur Erstellung von Raum- und Funktionsprogrammen, zur betrieblichen Ablaufplanung und zur Inbetriebnahme
719 Bauherrenaufgaben, sonstiges	Baubetreuung
720 Vorbereitung der Objektplanung	
721 Untersuchungen	Standortanalysen, Baugrubengutachten, Gutachten für die Verkehrsanbindung, Bestandsanalysen, z.B. Untersuchungen zum Gebäudebestand bei Umbau- und Modernisierungsmaßnahmen, Umweltverträglichkeitsprüfungen
722 Wertermittlungen	Gutachten zur Ermittlung von Gebäudewerten, soweit nicht in Kostengruppe 126 erfaßt
723 Städtebauliche Leistungen	vorbereitende Bebauungsstudien
724 Landschaftsplanerische Leistungen	vorbereitende Grünplanstudien
725 Wettbewerbe	Kosten für Ideenwettbewerbe und Realisierungswettbewerbe nach den GRW 1977
729 Vorbereitung der Objektplanung, sonstiges	
730 Architekten- und Ingenieurleistungen	Kosten für die Bearbeitung der in der HOAI beschriebenen Leistungen (Honorare fr Grundleistungen und Besondere Leistungen) bzw. nach vertraglicher Vereinbarung
731 Gebäude	
732 Freianlagen	
733 Raumbildende Ausbauten	
734 Ingenieurbauwerke und Verkehrsanlagen	
735 Tragwerksplanung	
736 Technische Ausrüstung	
739 Architekten- und Ingenieur-leistungen, sonstiges	
740 Gutachten und Beratung	Kosten für die Bearbeitung der in der HOAI beschriebenen Leistungen (Honorare für die Grundleistungen und Besondere Leistungen) bzw. nach vertraglicher Vereinbarung
741 Thermische Bauphysik	
742 Schallschutz und Raumakustik	
743 Bodenmechanik, Erd- und Grundbau	
744 Vermessung	Vermessungstechnische Leistungen mit Ausnahme von Leistungen die aufgrund landesrechtlicher Vorschriften für Zwecke der Landvermessung und des Liegenschaftskatasters durchgeführt werden (siehe Kostengruppe 771)
745 Lichttechnik, Tageslichttechnik	
749 Gutachten und Beratung, sonstiges	

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Tabelle 1

Kostengruppe	Anmerkungen
750 Kunst	
751 Kunstwettbewerbe	Kosten für die Durchführung von Wettbewerben zur Erarbeitung eines Konzeptes für Kunstwerke oder künstlerisch gestaltete Bauteile
752 Honorare	Kosten für die geistig-schöpferische Leistung für Kunstwerke oder künstlerisch gestaltete Bauteile, soweit nicht in der Kostengruppe 620 enthalten
759 Kunst, sonstiges	
760 Finanzierung	
761 Finanzierungskosten	Kosten für die Beschaffung der Dauerfinanzierungsmittel, die Bereitstellung des Fremdkapitals, die Beschaffung der Zwischenkredite und für Teilvalutierungen von Dauerfinanzierungsmittel
762 Zinsen vor Nutzungsbeginn	Kosten für alle im Zusammenhang mit der Finanzierung des Projektes anfallenden Zinsen bis zum Zeitpunkt des Nutzungsbeginns
759 Finanzierung, sonstiges	
770 Allgemeine Baunebenkosten	
771 Prüfungen, Genehmigungen, Abnahmen	Kosten im Zusammenhang mit Prüfungen, Genehmigungen und Abnahme, z.B. Prüfung der Tragwerksplanung, Vermessungsgebühren für das Liegenschaftskataster
772 Bewirtschaftungskosten	Baustellenbewachung, Nutzungsschädigungen während der Bauzeit; Gestellung des Bauleitungsbüros auf de Baustelle sowie dessen Beheizung, Beleuchtung und Reinigung
773 Bemusterungskosten	Modellversuche, Musterstücke, Eignungsversuche, Eignungsmessungen
774 Betriebskosten während der Bauzeit	Kosten für den vorläufigen Betrieb insbesondere der Technischen Anlagen bis zur Inbetriebnahme
779 Allgemeine Baunebenkosten, sonstiges	Kosten für Vervielfältigung und Dokumentation, Post- und Fernsprechgebühren, Kosten für Baufeiern, z.B. Grundsteinlegung, Richtfest
790 Sonstige Baunebenkosten	

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4.4 Gliederung in Leistungsbereiche

Als Beispiel für eine ausführungsorientiere Ergänzung der Kostengliederung werden im folgenden die Leistungsbereiche des Standardleistungsbuches für das Bauwesen (StLB) in einer Übersicht dargestellt. Diese Gliederung kann entsprechend der Weiterentwicklung des StLB angepaßt werden.

Tabelle 2: Übersicht über die Leistungsbereiche

000	Baustelleneinrichtung	042	Gas- und Wasserinstallationsarbeiten - Leitungen und Armaturen -
001	Gerüstarbeiten	043	Druckrohrleitungen für Gas, Wasser und Abwasser
002	Erdarbeiten	044	Abwasserinstallationsarbeiten - Leitungen, Abläufe -
003	Landschaftsbauarbeiten	045	Gas-, Wasser- und Abwasserinstallationsarbeiten - Einrichtungsgegenstände -
004	Landschaftsbauarbeiten, Pflanzen	046	Gas-, Wasser- und Abwasserinstallationsarbeiten - Betriebseinrichtungen -
005	Brunnenarbeiten und Aufschlußbohrungen	047	Wärme- und Kältedämmarbeiten an betriebs-technischen Anlagen
006	Verbau-, Ramm- und Einpreßarbeiten	049	Feuerlöschanlagen, Feuerlöschgeräte
007	Untertagebauarbeiten	050	Blitzschutz- und Erdungsanlagen
008	Wasserhaltungsarbeiten	051	Bauleistungen für Kabelanlagen
009	Entwässerungskanalarbeiten	052	Mittelspannungsanlagen
010	Dränarbeiten	053	Niederspannungsanlagen
011	Abscheideranlagen, Kleinkläranlagen	055	Ersatzstromversorgungsanlagen
012	Mauerarbeiten	056	Batterien
013	Beton- und Stahlbetonarbeiten	058	Leuchten und Lampen
014	Naturwerksteinarbeiten, Betonwerksteinarbeiten	060	Elektroakutische Anlagen, Sprechanlagen, Personenrufanlagen
016	Zimmer- und Holzbauarbeiten	061	Fernmeldeleitungsanlagen
017	Stahlbauarbeiten	063	Meldeanlagen
018	Abdichtungsarbeiten gegen Wasser	065	Empfangsantennenanlagen
020	Dachdeckungsarbeiten	067	Zentrale Leittechnik für betriebstechnische Anlagen in Gebäuden (ZLT-G)
021	Dachabdichtungsarbeiten	069	Aufzüge
022	Klempnerarbeiten	070	Regelung und Steuerung für heiz-, raumluft- und sanitärtechnische Anlagen
023	Putz- und Stuckarbeiten	074	Raumlufttechnische Anlagen - Zentralgeräte und deren Bauelemente -
024	Fliesen- und Plattenarbeiten	075 0	Raumlufttechnische Anlagen - Luftverteilsysteme und deren Bauelemente -
025	Estricharbeiten	076	Raumlufttechnische Anlagen - Einzelgeräte -
027	Tischlerarbeiten	077	Raumlufttechnische Anlagen - Schutzräume -
028	Parkettarbeiten, Holzpflasterarbeiten	078	Raumlufttechnische Anlagen
029	Beschlagarbeiten	080	Straßen, Wege, Plätze
030	Rolladenarbeiten; Rollabschlüsse, Sonnenschutz- und Verdunklungsanlagen		
031	Metallbauarbeiten, Schlosserarbeiten		
032	Verglasungsarbeiten		
033	Gebäudereinigungsarbeiten		
034	Maler- und Lackiererarbeiten		
035	Korrosionsschutzarbeiten an Stahl- und Aluminium-baukonstruktionen		
036	Bodenbelagsarbeiten		
037	Tapezierarbeiten		
039	Trockenbauarbeiten		
040	Heizungs- und zentrale Brauchwassererwärmungs-anlagen		

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Brutto-Grundfläche (BGF)

Die Brutto-Grundfläche ist die Summe der Grundflächen aller Grundrißebenen eines Bauwerkes. Nicht dazu gehören die Grundflächen von nicht nutzbaren Dachflächen und von konstruktiv bedingten Hohlrämen, z.B. in belüfteten Dächern oder über abgehängten Decken. Die Brutto-Grundfläche gliedert sich in Konstruktions-Grundfläche und Netto-Grundfläche.

Konstruktions-Grundfläche (KGF)

Die Konstruktions-Grundfläche ist die Summe der Grundflächen der aufgehenden Bauteile aller Grundrißebenen eines Bauwerkes, z.B. von Wänden, Stützen und Pfeilern. Zur Konstruktions-Grundfläche gehören auch die Grundflächen von Schornsteinen, nicht begehbaren Schächten, Türöffnungen, Nischen sowie Schlitzen.

Netto-Grundfläche (NGF)

Die Netto-Grundfläche ist die Summe der nutzbaren, zwischen den aufgehenden Bauteilen befindlichen Grundflächen aller Grundrißebenen eines Bauwerkes. Zur Netto-Grundfläche gehören auch die Grundflächen von freiliegenden Installationen und von fest eingebauten Gegenständen, z.B. von Öfen, Heizkörpern oder Tischplatten. Die Netto-Grundfläche, Funktionsfläche und Verkehrsfläche.

Nutzfläche (NF)

Die Nutzfläche ist derjenige Teil der Netto-Grundfläche, der der Nutzung der Bauwerkes aufgrund seiner Zweckbestimmung dient. Die Nutzfläche gliedert sich Hauptnutzfläche (HNF) und Nebennutzfläche (NNF).

Funktionsfläche (FF)

Die Funktionsfläche ist derjenige Teil der Netto-Grundfläche, der der Unterbringung zentraler betriebstechnischer Anlagen in einem Bauwerk dient. Sofern es die Zweckbestimmung eines Bauwerkes ist, eine oder mehrere betriebstechnische Anlagen unterzubringen, die der Ver- und Entsorgung anderer Bauwerke dienen, z.B. bei einem Heizhaus, sind die dafür erforderlichen Grundflächen jedoch Nutzfläche.

Verkehrsfläche (VF)

Die Verkehrsfläche ist derjenige Teil der Netto-Grundfläche, der dem Zugang zu den Rämen, dem Verkehr innerhalb des Bauwerkes und auch dem Verlassen im Notfall dient. Bewegungsflächen innerhalb von Rämen, die zur Nutz- und Funktionsfläche gehören, z.B. Gänge zwischen Einrichtungsgegenständen, zählen nicht zur Verkehrsfläche.

Brutto-Rauminhalt (BRI)

Der Brutto-Rauminhalt ist der Rauminhalt des Baukörpers, der nach unten von der Unterfläche der konstruktiven Bauwerkssohle und im übringen von den äußeren Begrenzungsflächen des Bauwerkes umschlossen wird. Nicht zum Brutto-Rauminhalt gehören die Rauminhalte von

- Fundamenten
- Bauteilen, soweit sie für den Brutto-Rauminhalt von untergeordneter Bedeutung sind, z.B. Kellerlichtschächte, Außentreppen, Außenrampen, Eingangsüberdachungen und Dachgauben
- untergeordneten Bauteilen wie z.B. konstruktive und gestalterische Vor- und Rücksprünge an den Außenflächen, auskragende Sonnenschutzanlagen, Lichtkuppeln, Schornsteinköpfe, Dachüberstände, soweit sie nicht Überdeckungen für Bereich b sind.

Netto-Rauminhalt (NRI)

Der Netto-Rauminhalt ist die Summe der Rauminhalte aller Räme, deren Grundflächen zur Netto-Grundfläche gehören.

Annex 15

Sensitivity analysis with STILCAB for each building category

One Family House	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	34%	1%
Foundation	15%	19%	16%	13%	22%	13%
Exterior walls	19%	10%	21%	25%	11%	15%
Interior walls	27%	12%	20%	11%	18%	7%
Floors and ceilings	8%	13%	10%	14%	8%	23%
Roof	11%	23%	16%	15%	2%	2%
Windows	18%	19%	15,%	19%	1%	35%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	27%	23%	21%	25%	34%	35%
Parameter	Interior walls	Roof	Exterior walls	Exterior walls	Excavation	Windows

Figure 1 - *Improvement potential for several results of LCA for one family house category*

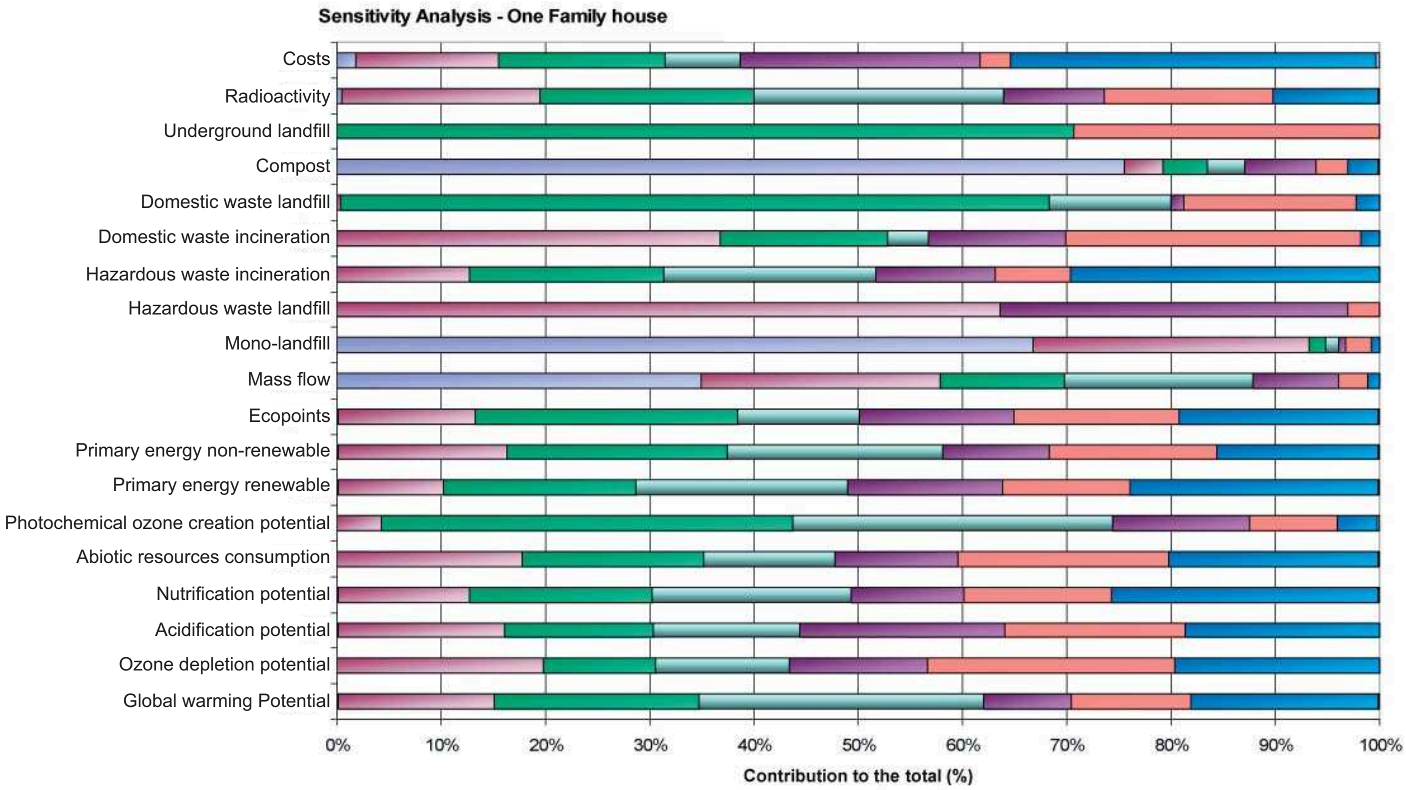


Figure 2 - *Typical results of the building's ILCA sensitivity analysis, for one family house category*

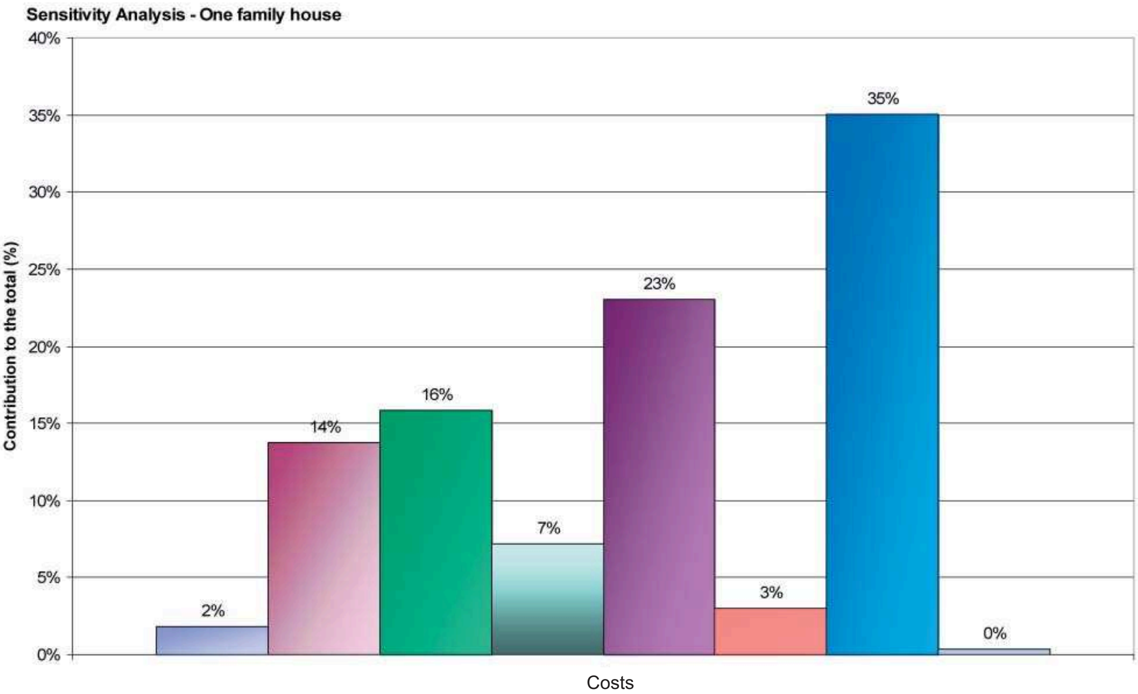
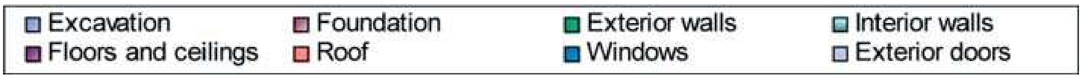


Figure 3 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for one family house category*



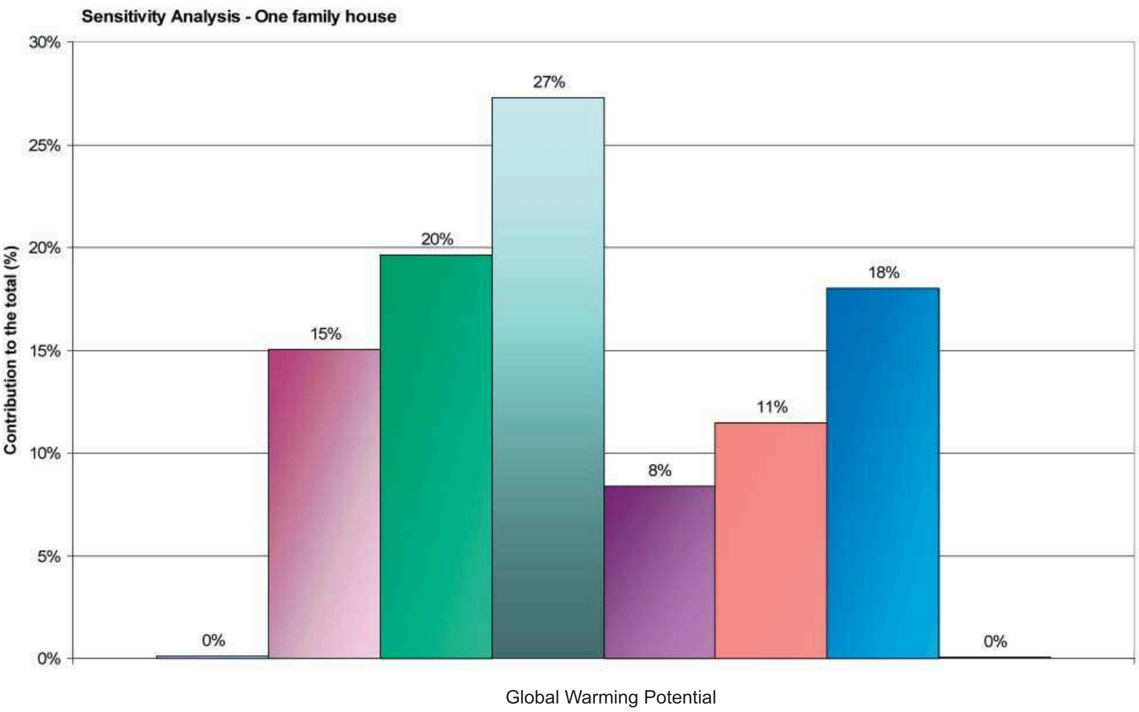


Figure 4 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for one family house category*

Multiple Family House	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	20%	0%
Foundation	4%	6%	4%	3%	9%	3%
Exterior walls	27%	16%	29%	32%	23%	18%
Interior walls	24%	12%	19%	9%	23%	5%
Floors and ceilings	12%	21%	15%	21%	17%	29%
Roof	5%	13%	8%	7%	2%	1%
Windows	25%	29%	21%	24%	2%	40%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	27%	29%	29%	32%	23%	40%
Parameter	**Exterior walls**	**Windows**	**Exterior walls**	**Exterior walls**	**Interior walls**	**Windows**

Figure 5 - *Improvement potential for several results of LCA for multiple family housing category*

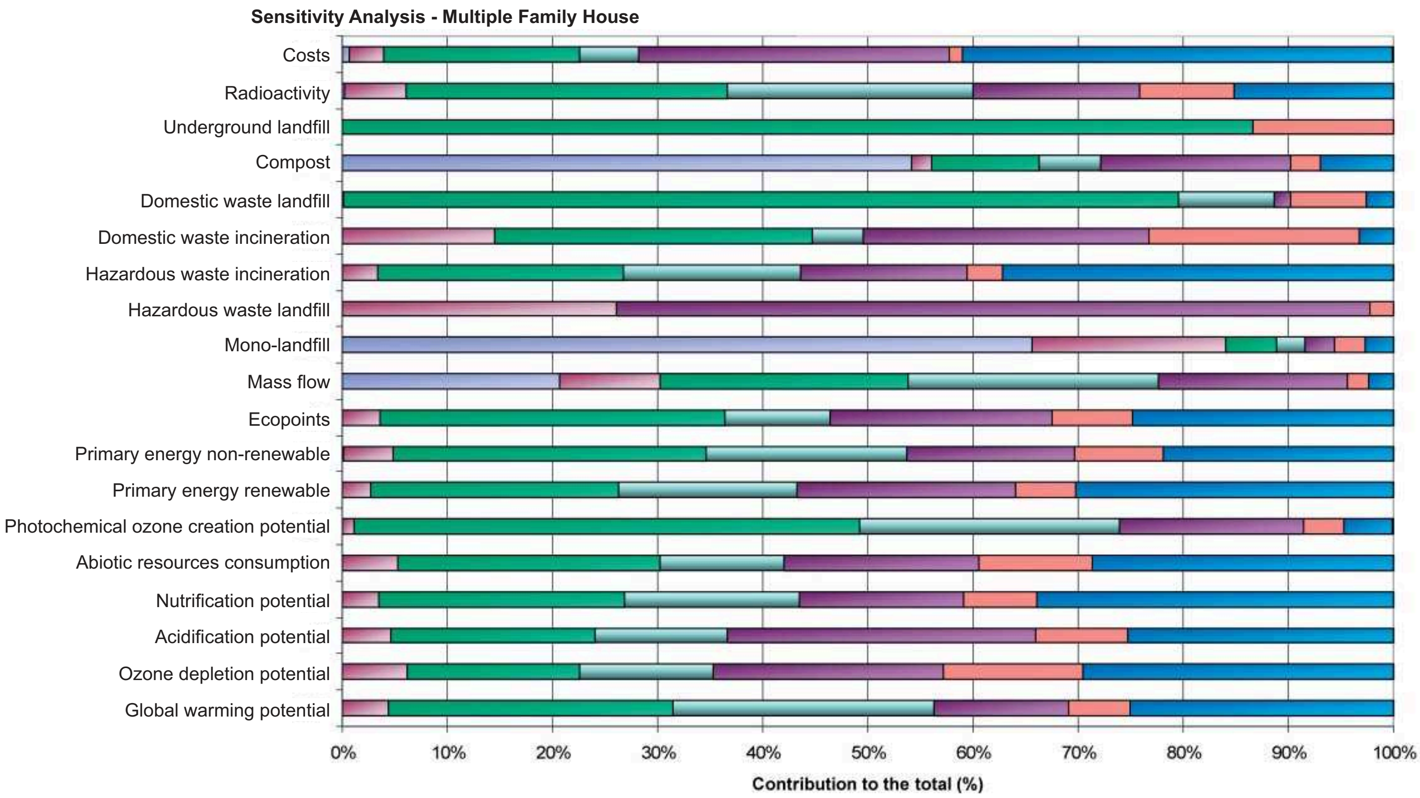


Figure 6 - *Typical results of the building's ILCA sensitivity analysis, for multiple family housing category*

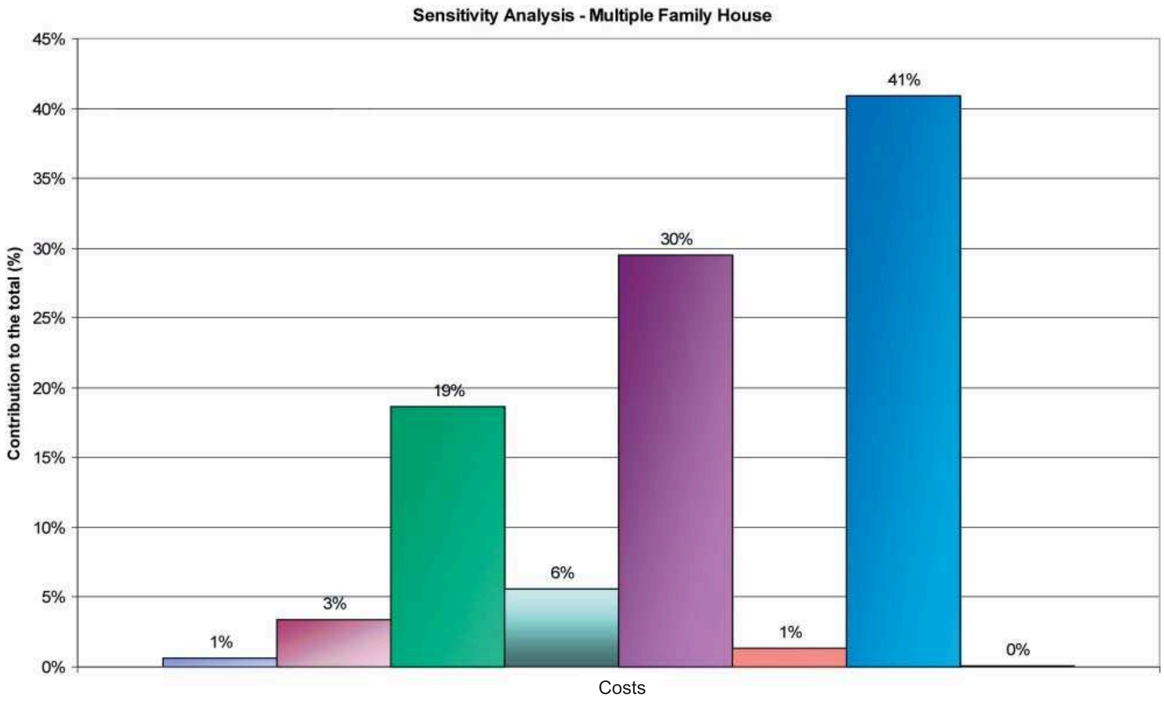
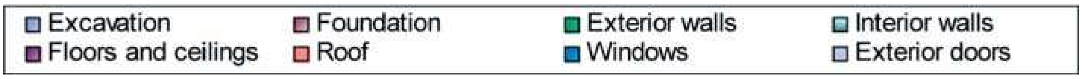


Figure 7 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for multiple family housing category*



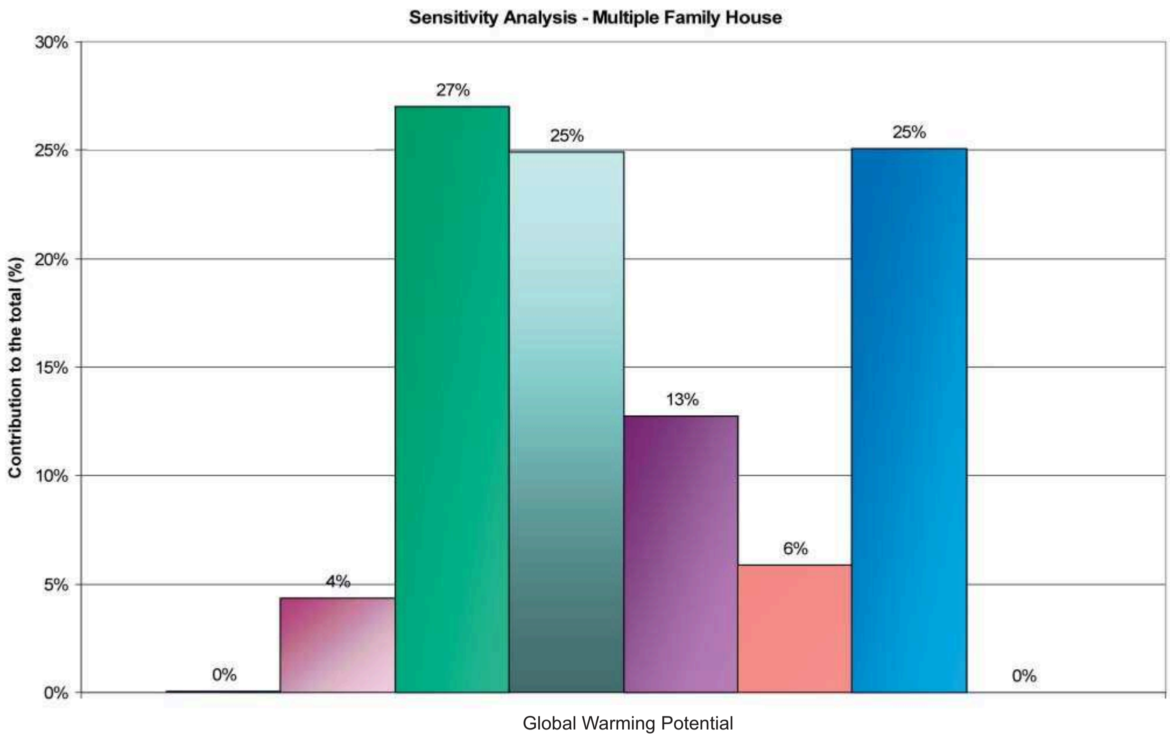


Figure 8 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for multiple family housing category*

Fire Station	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	37%	1%
Foundation	10%	13%	11%	8%	17%	9%
Exterior walls	21%	11%	22%	25%	13%	16%
Interior walls	23%	10%	17%	9%	16%	5%
Floors and ceilings	9%	13%	10%	15%	9%	24%
Roof	15%	31%	21%	20%	4%	4%
Windows	19%	20%	16%	19%	1%	36%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	23%	31%	22%	25%	37%	36%
Parameter	**Interior walls**	**Roof**	**Exterior walls**	**Exterior walls**	**Excavation**	**Windows**

Figure 9 - *Improvement potential for several results of LCA for fire station category*

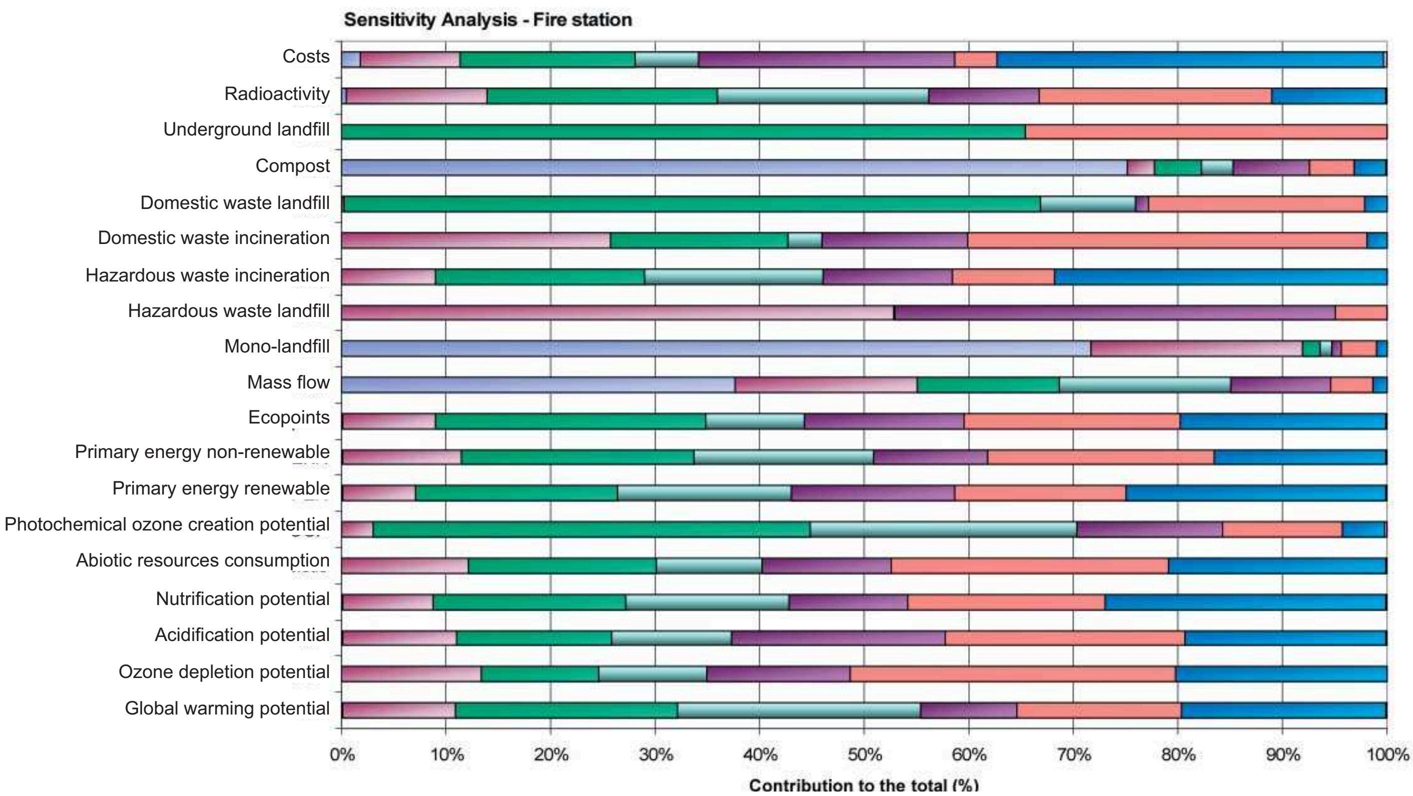


Figure 10 - *Typical results of the building's ILCA sensitivity analysis, for fire station category*

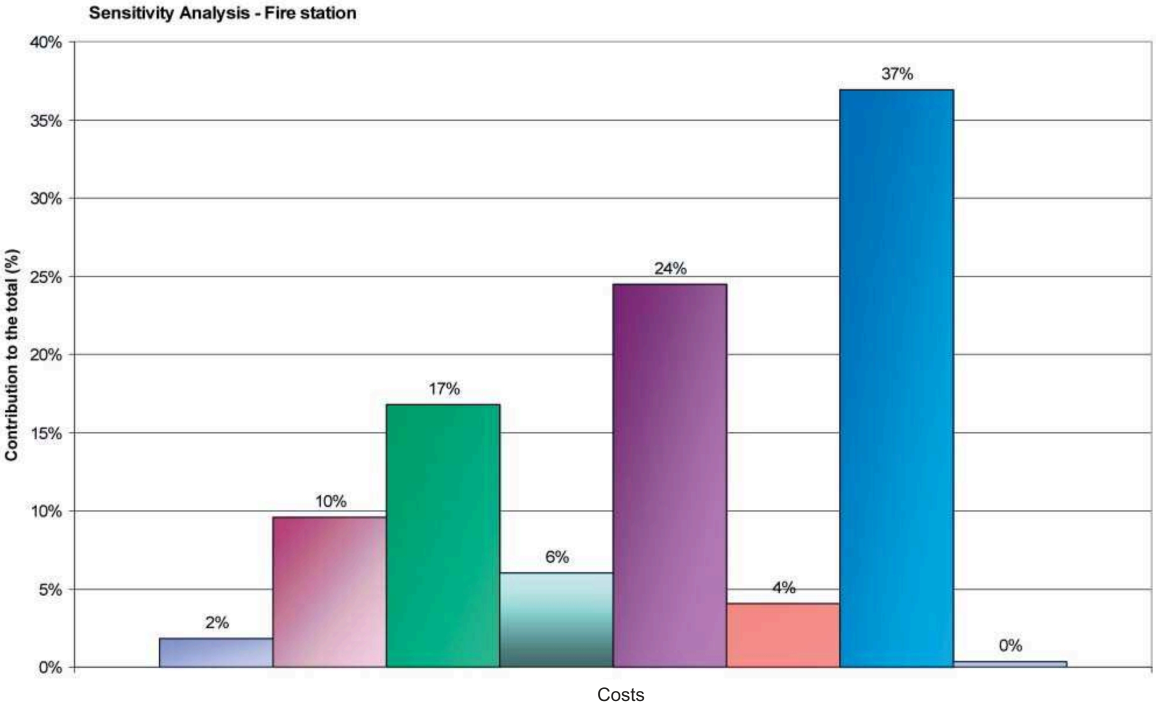
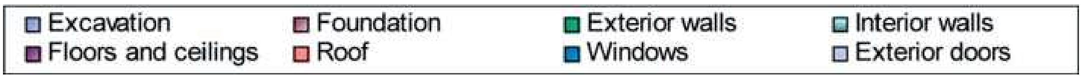


Figure 11 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for fire station category*



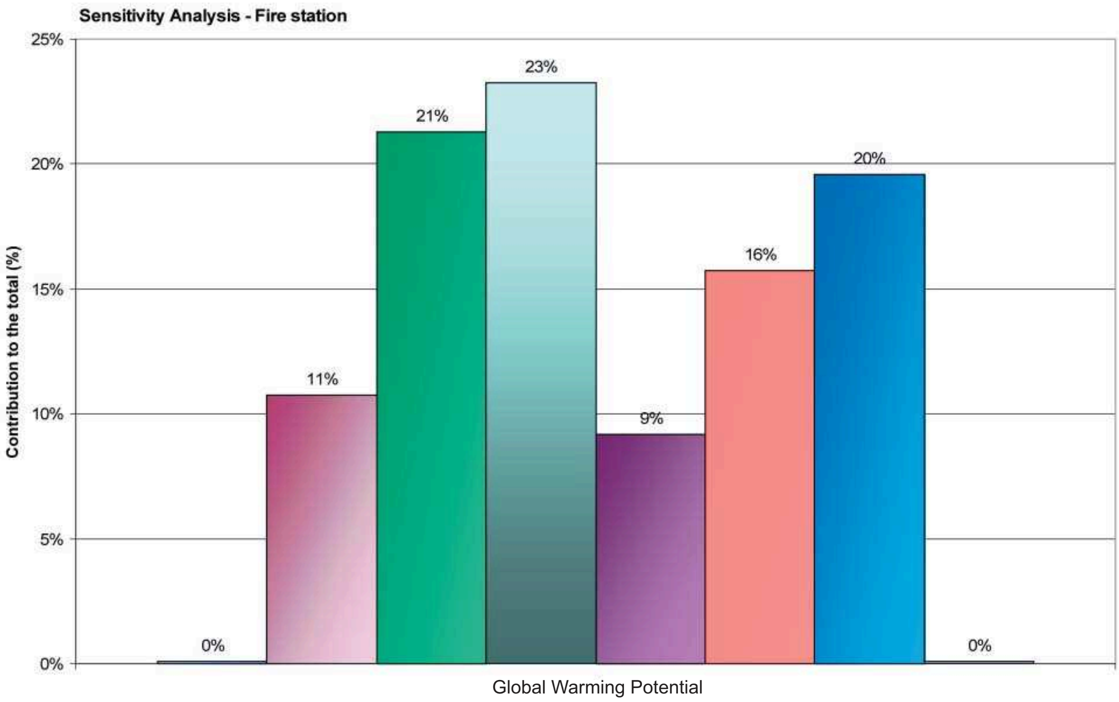


Figure 12 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for fire station category*

Hotel and students habitation	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	31%	1%
Foundation	4%	6%	5%	4%	9%	3%
Exterior walls	24%	14%	27%	30%	18%	18%
Interior walls	26%	13%	20%	10%	22%	6%
Floors and ceilings	11%	19%	14%	19%	14%	28%
Roof	8%	19%	12%	11%	2%	2%
Windows	22%	26%	20%	23%	1%	39%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	26%	26%	27%	30%	31%	39%
Parameter	Interior walls	Windows	Exterior walls	Exterior walls	Excavation	Windows

Figure 13 - *Improvement potential for several results of LCA for hotel and students habitation category*

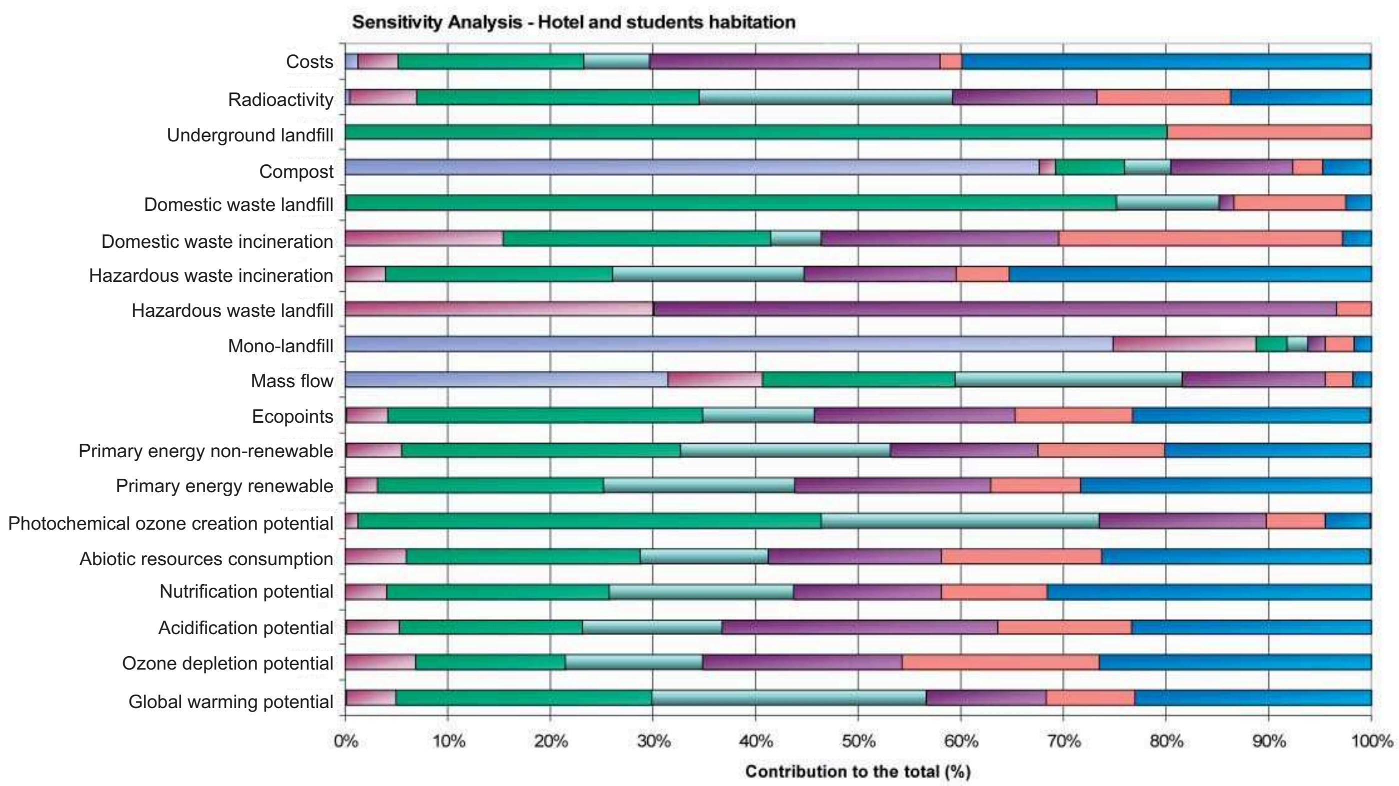


Figure 14 - *Typical results of the building's ILCA sensitivity analysis, for hotel and students habitation category*

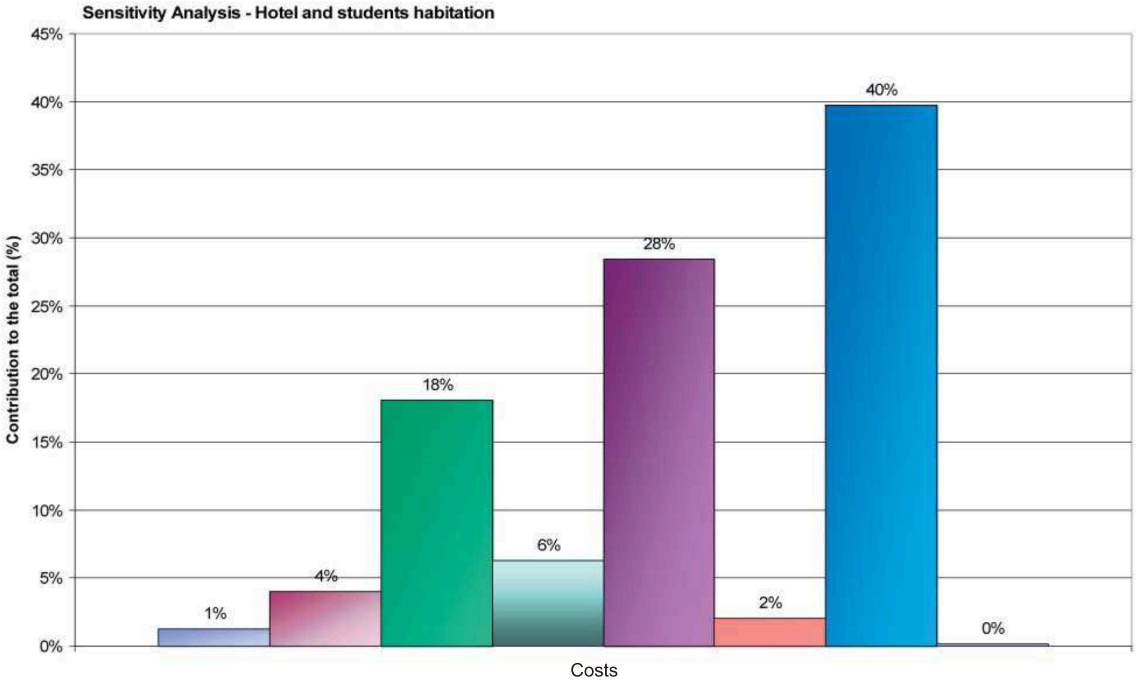
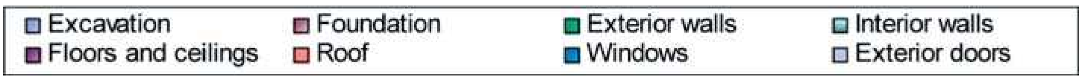


Figure 15 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for hotel and students habitation category*



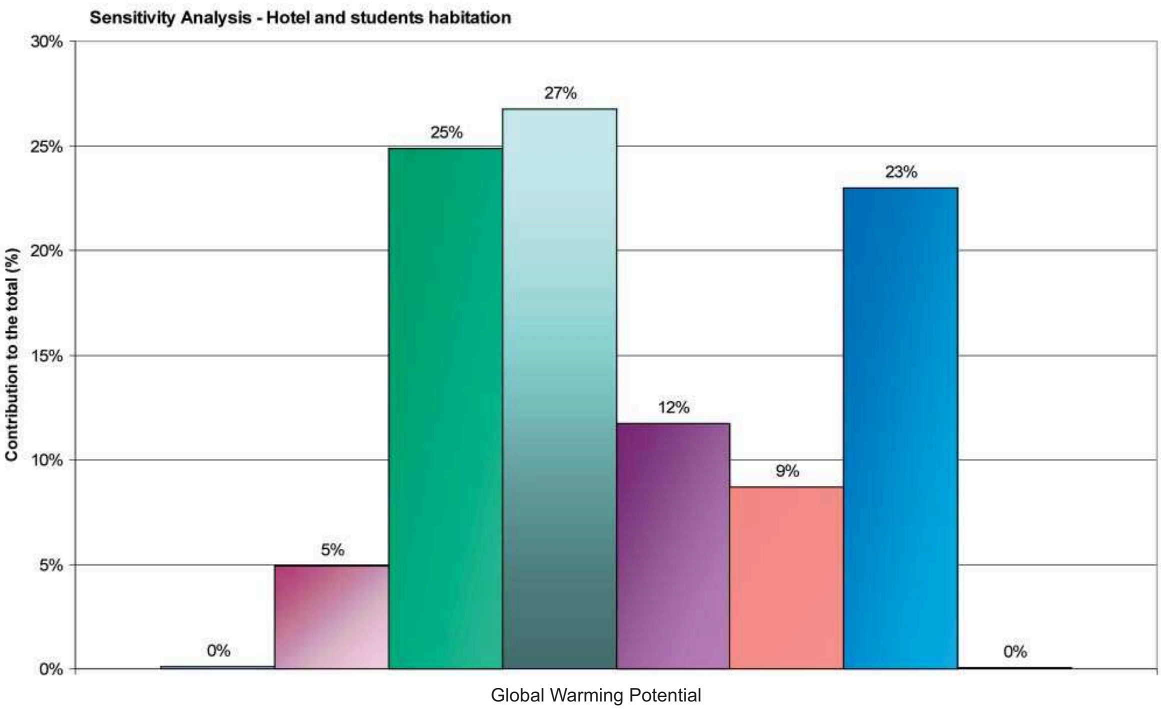
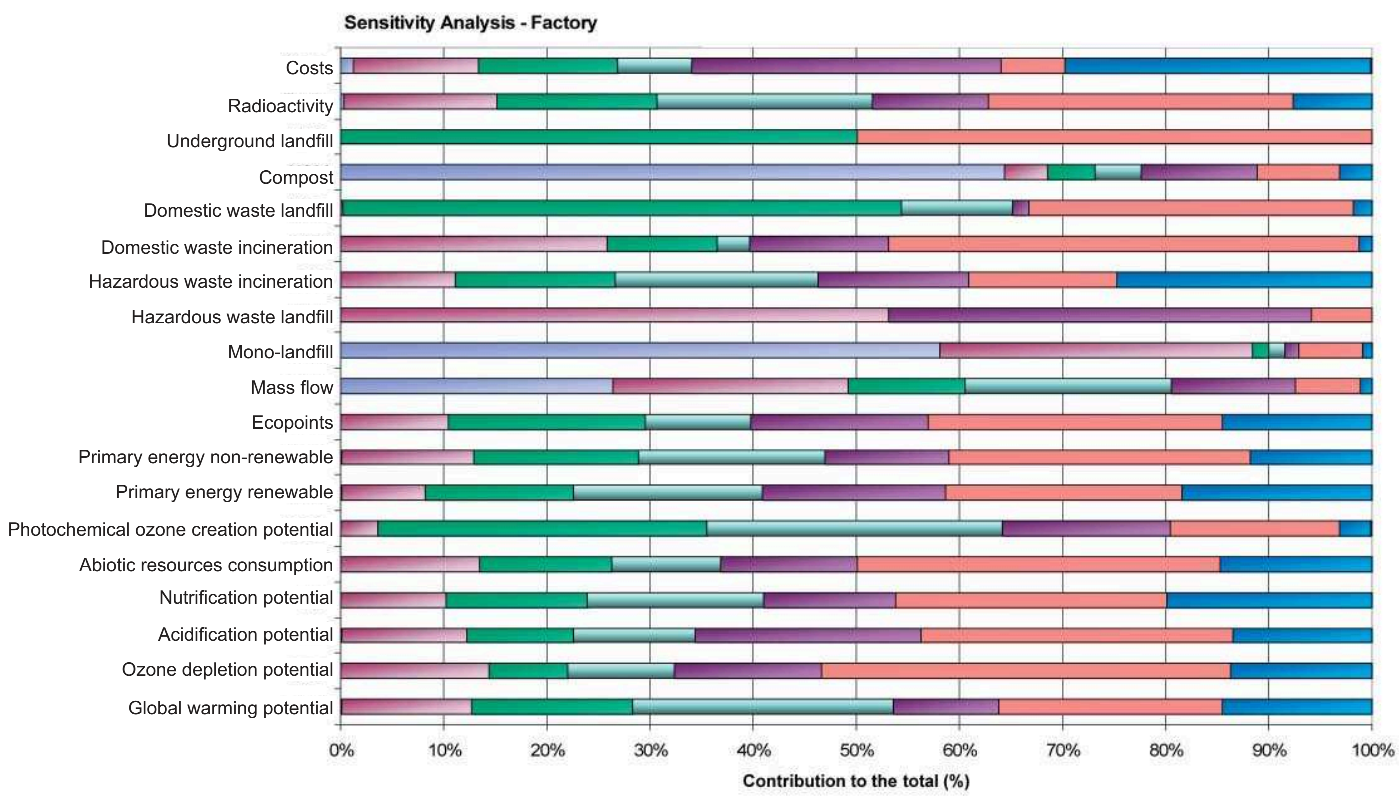


Figure 16- *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for hotel and students habitation category*

Factory Buildings	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	26,%	1%
Foundation	12%	14%	12%	10%	22%	12%
Exterior walls	15%	7%	16%	19%	11%	13%
Interior walls	25%	10%	18,%	10%	20%	7%
Floors and ceilings	10%	14%	12%	17%	12%	30%
Roof	21%	39%	29%	28%	6%	6%
Windows	14%	13%	11%	14%	1%	29%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	25%	39%	29%	28%	26%	30%
Parameter	**Interior walls**	**Roof**	**Roof**	**Roof**	**Excavation**	**Floors and ceilings**

Figure 17 - *Improvement potential for several results of LCA for factory buildings*



Figur 18 - *Typical results of the building's ILCA sensitivity analysis, for factory buildings*

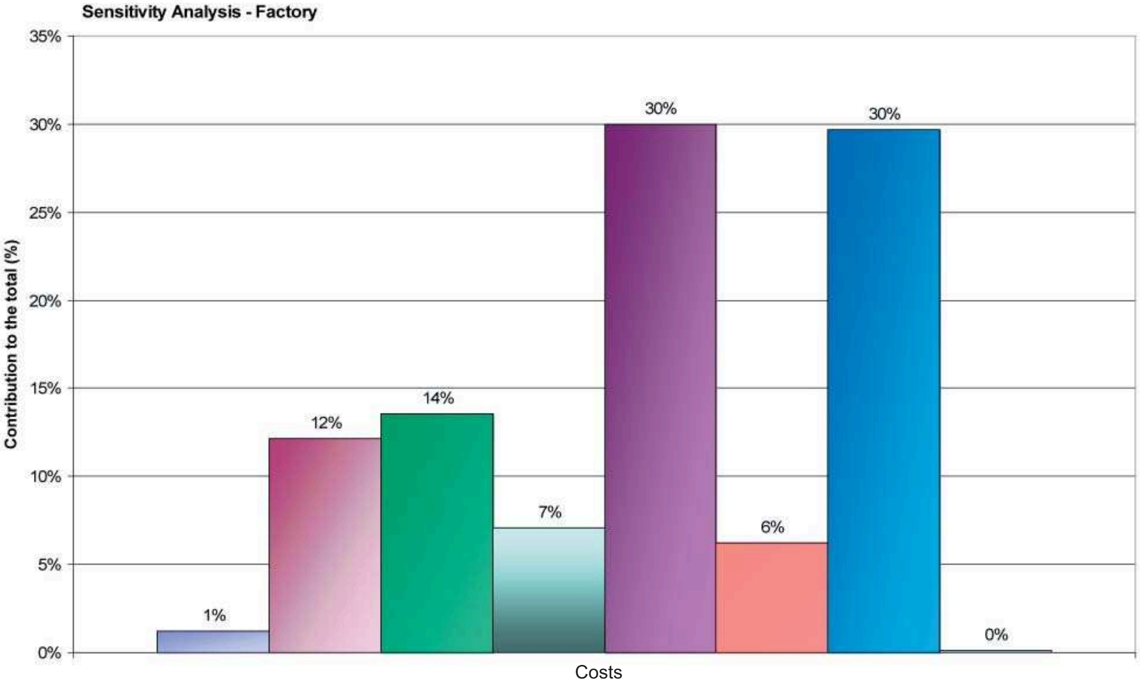
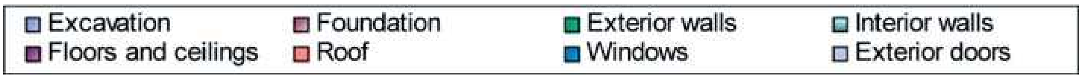


Figure 19 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for factory buildings*



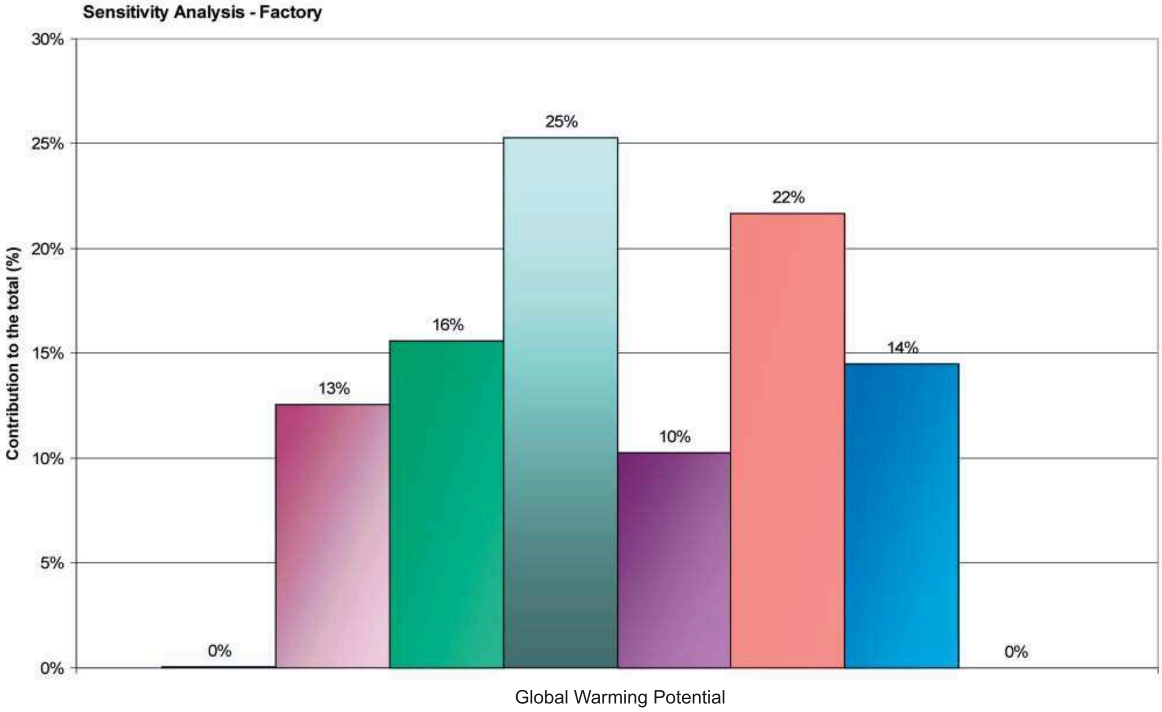


Figure 20 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for factory buildings*

Industry and trade	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	29%	1%
Foundation	13%	14%	13%	10%	22%	10%
Exterior walls	17%	8%	17%	20%	11%	12%
Interior walls	16%	6%	11%	6%	12%	3%
Floors and ceilings	16%	21%	18%	25%	17%	39%
Roof	18%	33%	24,%	22%	5%	4%
Windows	16%	15%	13%	15%	1%	27%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	18%	33%	24%	25%	29%	39%
Parameter	Roof	Roof	Roof	Floors and ceilings	Excavation	Floors and ceilings

Figure 21 - *Improvement potential for several results of LCA for industry and trade buildings*

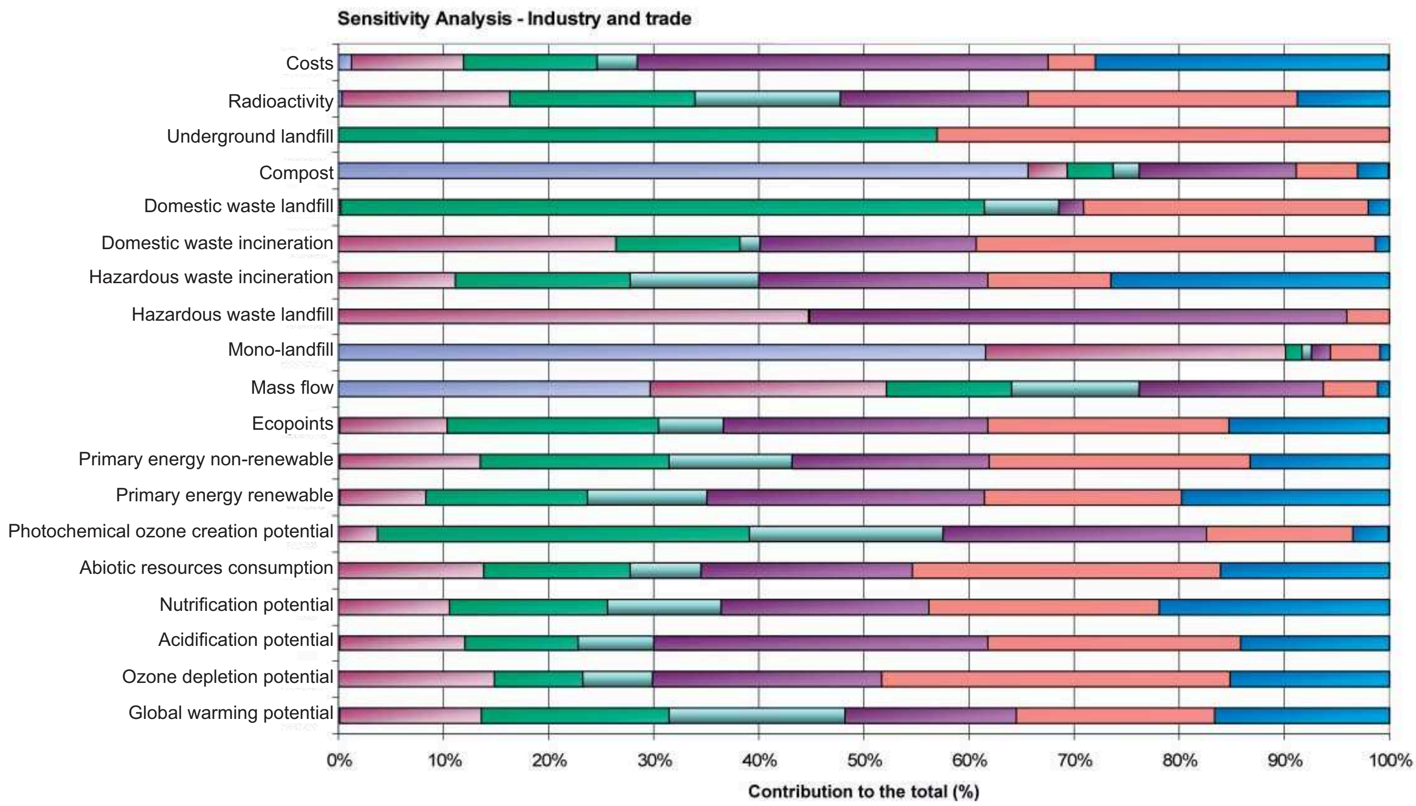


Figure 22 - *Typical results of the building's ILCA sensitivity analysis, for industry and trade buildings*

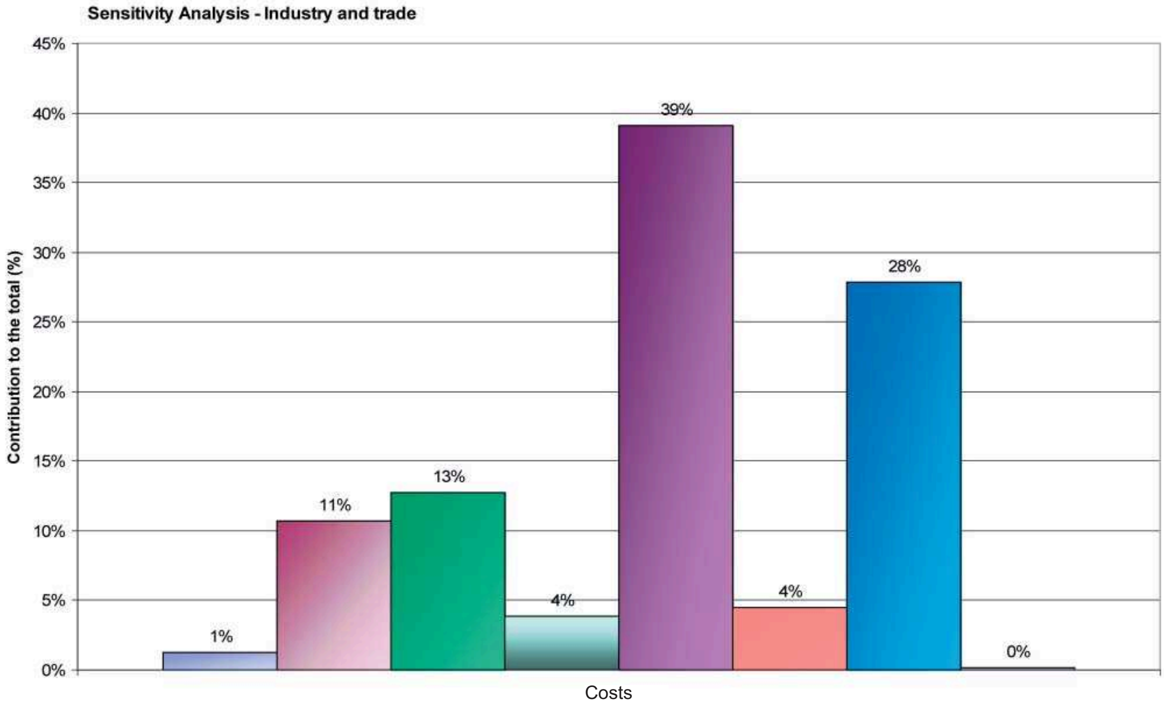
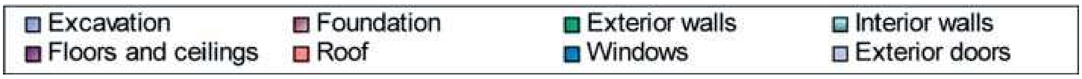


Figure 23 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for industry and trade buildings*



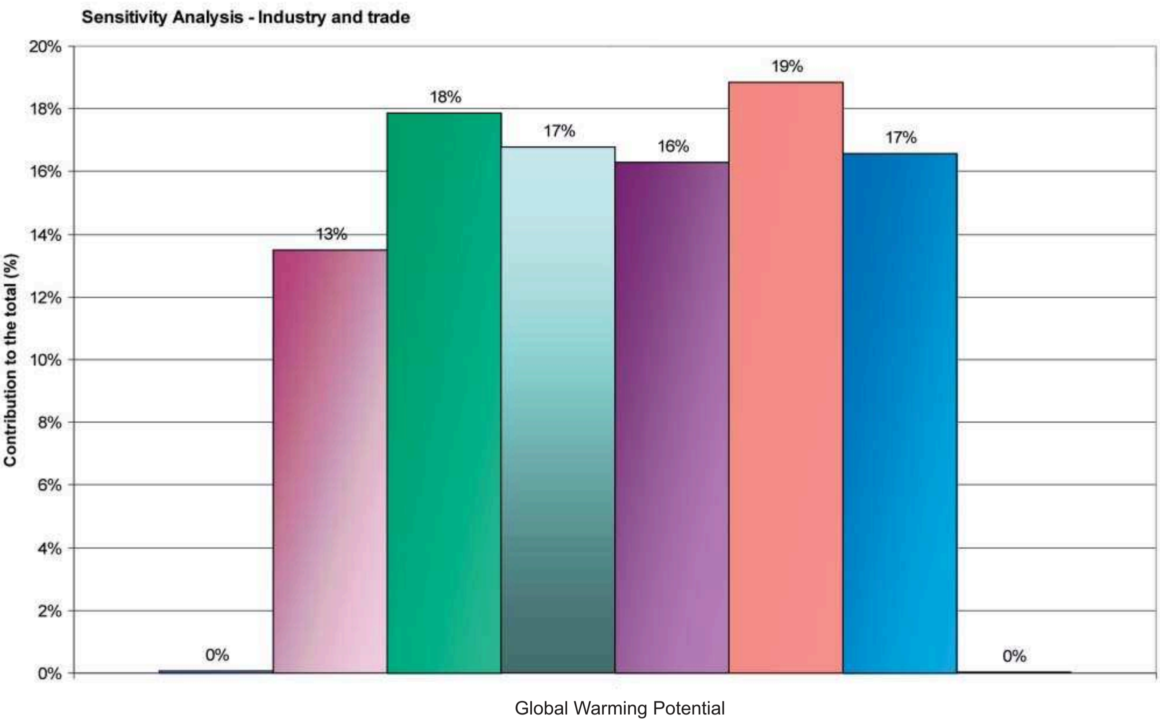
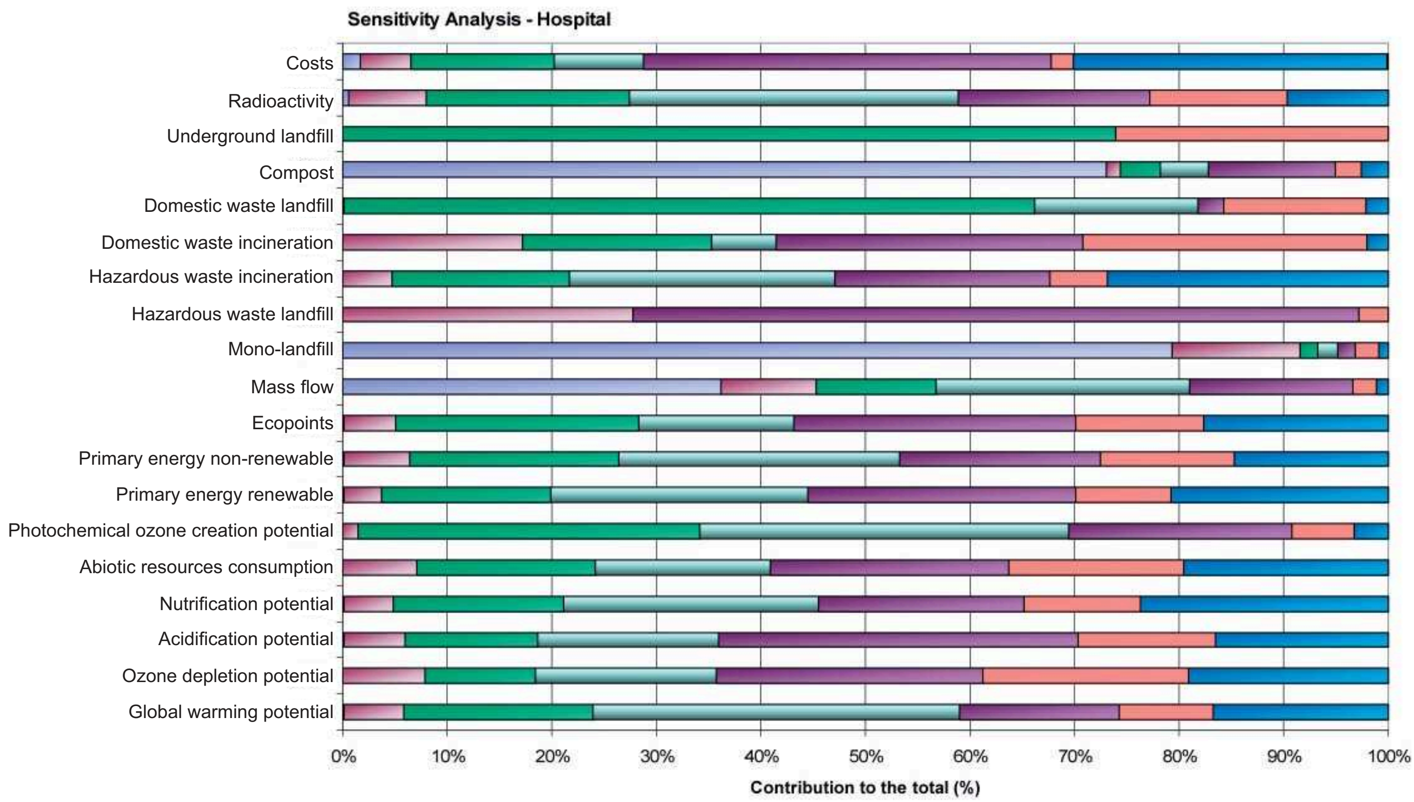


Figure 24 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for industry and trade buildings*

Hospital	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	36%	1%
Foundation	5%	7%	6%	4%	9%	4%
Exterior walls	18%	10%	19%	23%	11%	13%
Interior walls	34%	17%	26%	14%	24%	8%
Floors and ceilings	15%	25%	19%	26%	15%	38%
Roof	8%	19%	12%	12%	2%	2%
Windows	16%	19%	14%	17%	1%	30%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	34%	25%	26%	26%	36%	38%
Parameter	Interior walls	Floors and ceilings	Interior walls	Floors and ceilings	Excavation	Floors and ceilings

Figure 25 - *Improvement potential for several results of LCA for hospital category*



Figur 26 - *Typical results of the building's ILCA sensitivity analysis, for hospital category*

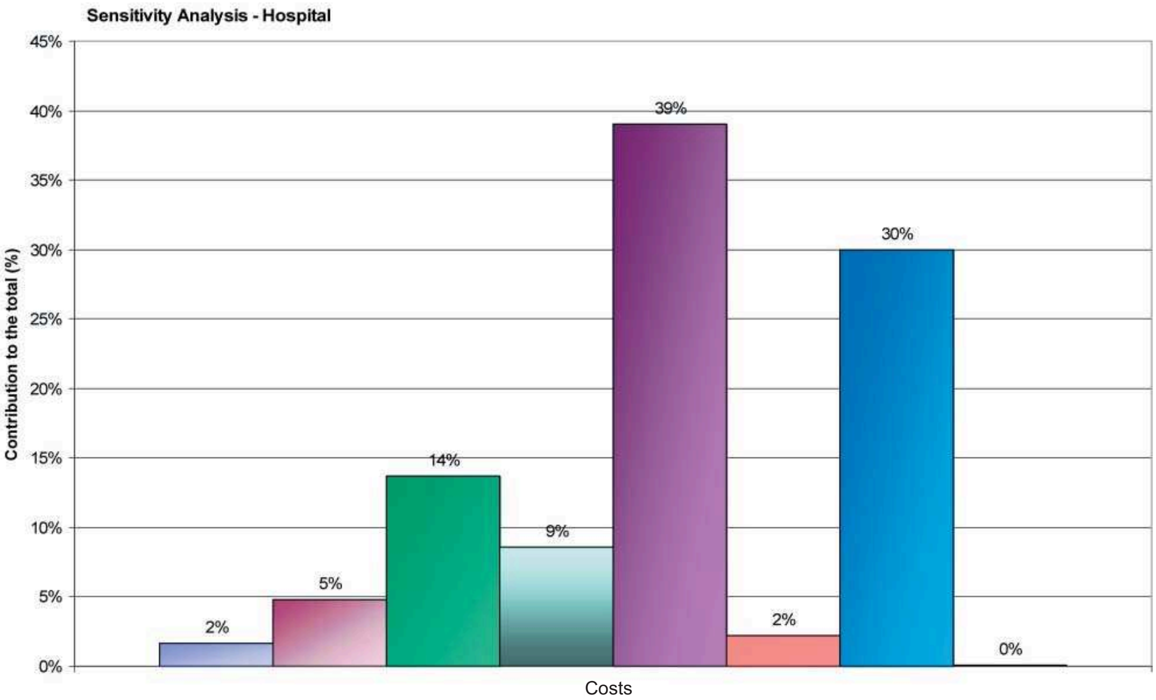
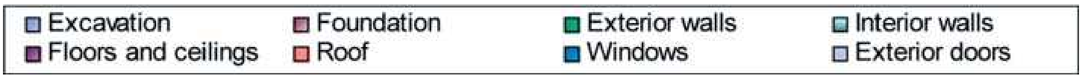


Figure 27 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for hospital category*



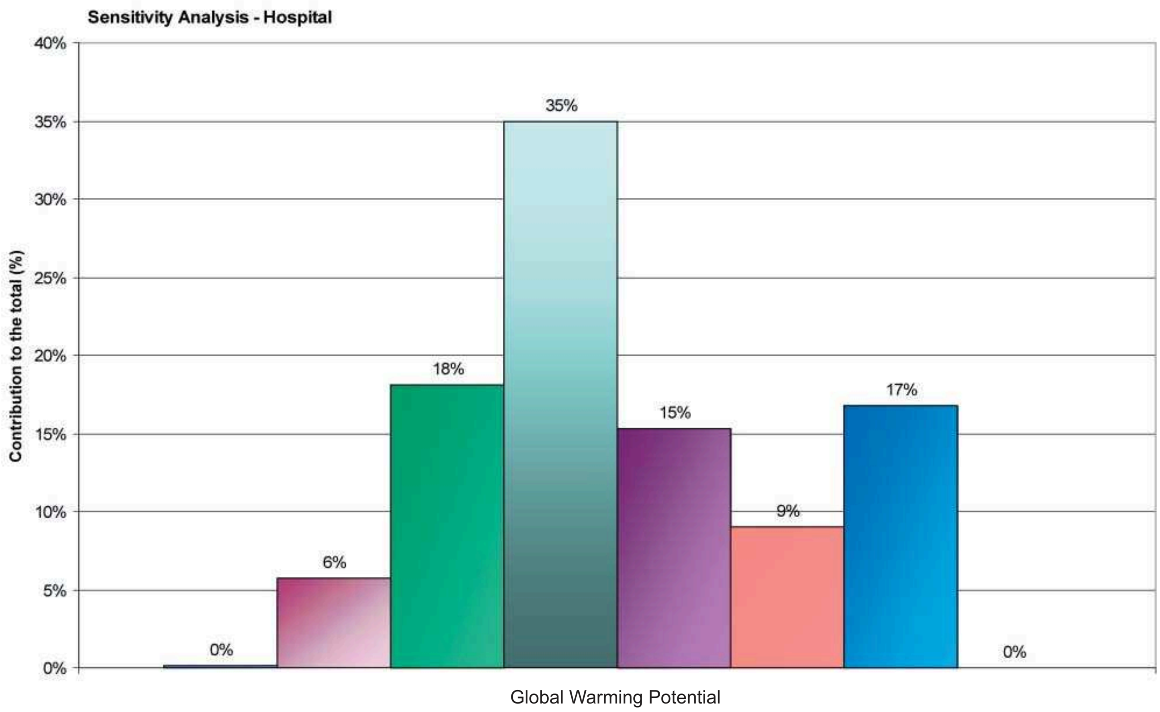


Figure 28 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for hospital category*

Educational buildings	Global warming potential	Ozone depletion potential	Primary energy non-renewable	Ecopoints	Mass flow	Costs
Excavation	0%	0%	0%	0%	31%	1%
Foundation	9%	11%	9%	7%	16%	7%
Exterior walls	21%	11%	22%	25%	15%	16%
Interior walls	23%	10%	17%	9%	18%	5%
Floors and ceilings	12%	18%	14%	20%	13%	30%
Roof	13%	26%	18%	17%	3%	3%
Windows	19%	20%	16%	19%	1%	35%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	23%	26%	22%	25%	31%	35%
Parameter	**Interior walls**	**Roof**	**Exterior walls**	**Exterior walls**	**Excavation**	**Windows**

Figure 29 - *Improvement potential for several results of LCA for educational buildings*

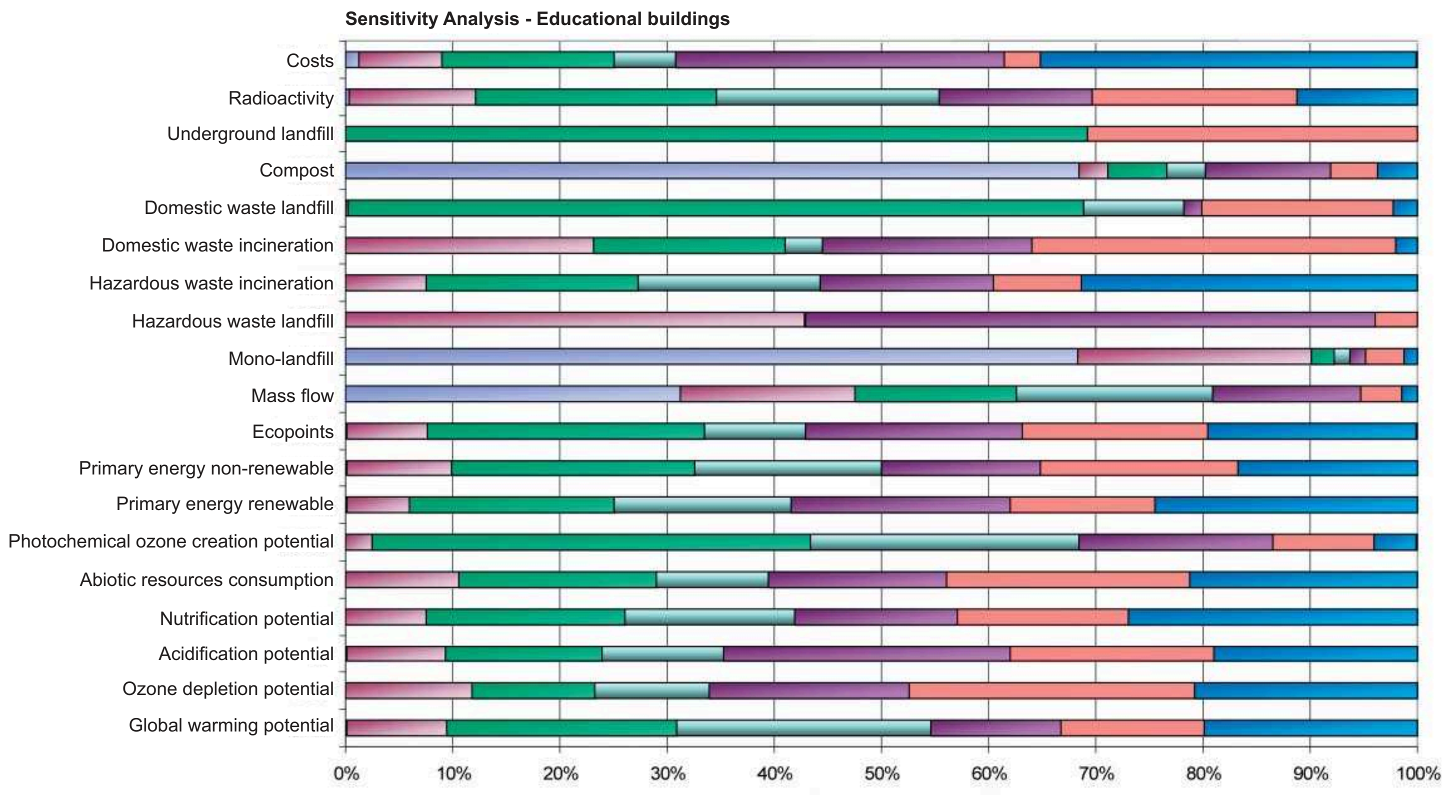


Figure 30 - *Typical results of the building's ILCA sensitivity analysis, for educational buildings*

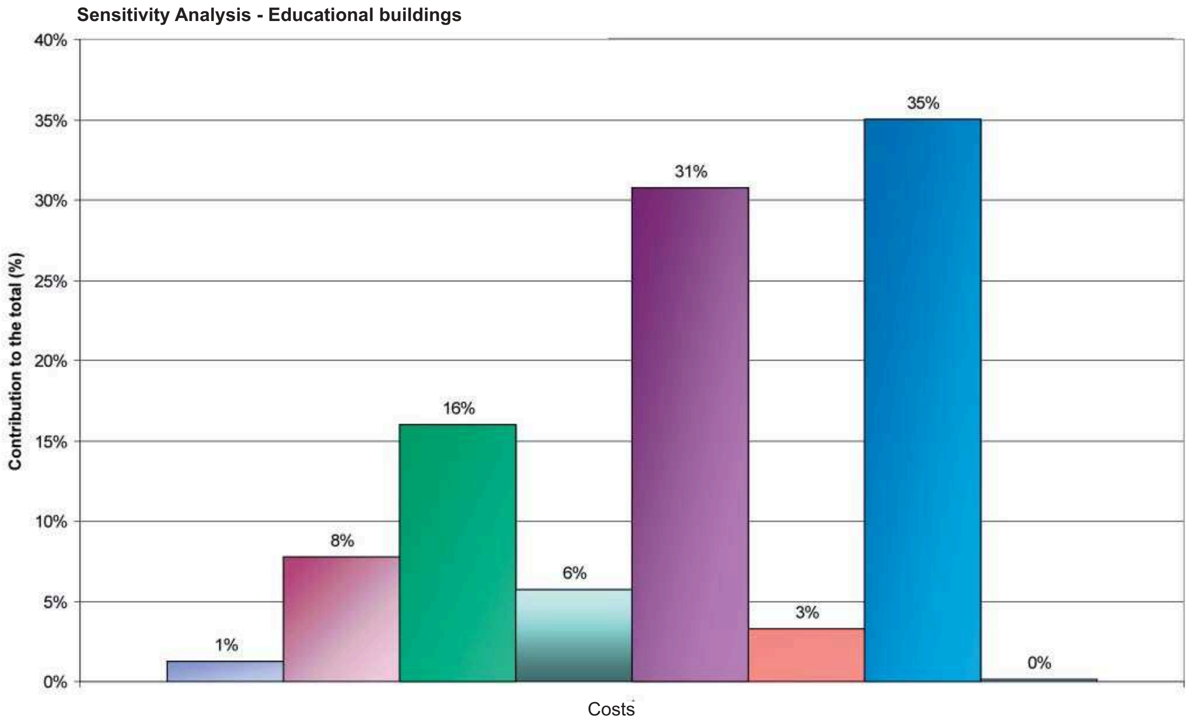
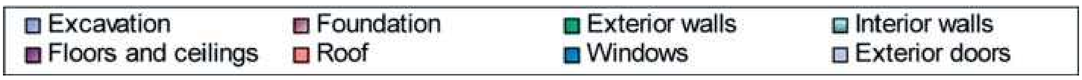


Figure 31 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for educational buildings*



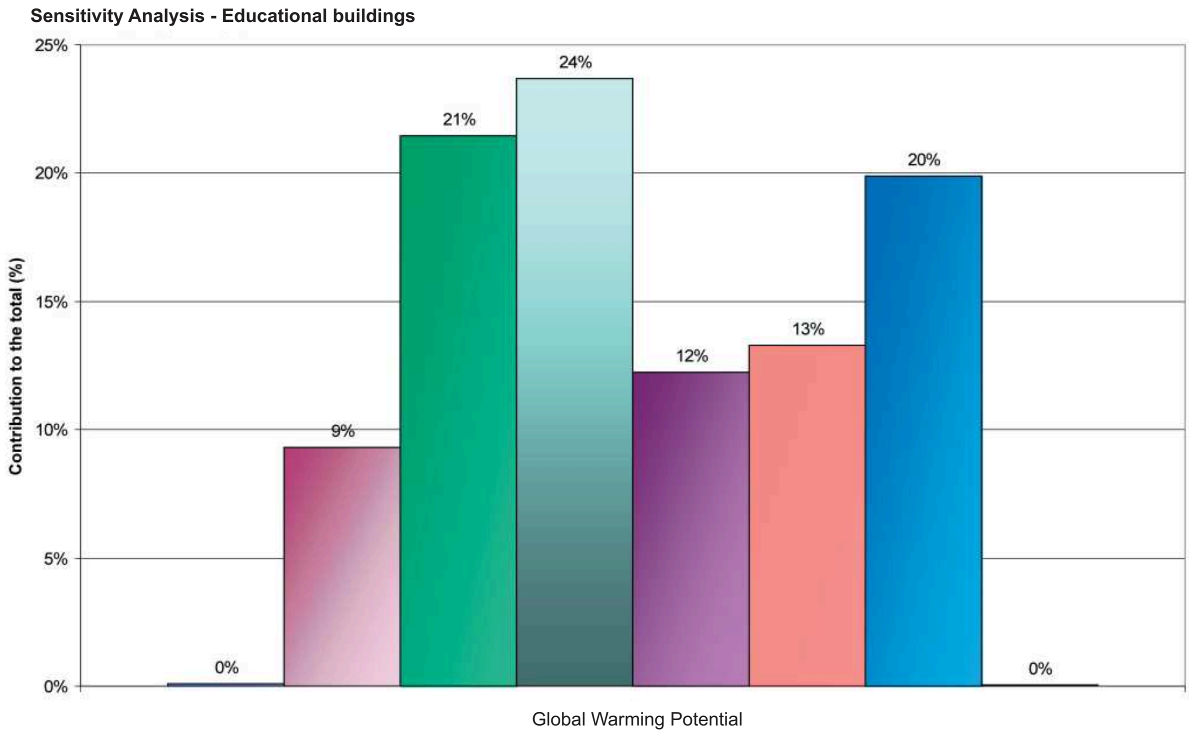


Figure 32 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for educational buildings*

Office buildings	**Global warming potential**	**Ozone depletion potential**	**Primary energy non-renewable**	**Ecopoints**	**Mass flow**	**Costs**
Excavation	0%	0%	0%	0%	37%	1%
Foundation	6%	8%	6%	4%	9%	4%
Exterior walls	20%	11%	22%	24%	12%	14%
Interior walls	27%	12%	20%	10%	18%	6%
Floors and ceilings	17%	27%	21%	28%	17%	40%
Roof	9%	18%	12%	11%	2%	2%
Windows	19%	20%	16%	18%	1%	31%
Exterior doors	0%	0%	0%	0%	0%	0%
Maximum	27%	27%	22%	28%	37,73%	40%
Parameter	**Interior walls**	**Floors and ceilings**	**Exterior walls**	**Floors and ceilings**	**Excavation**	**Floors and ceilings**

Figure 33 - *Improvement potential for several results of LCA for office buildings*

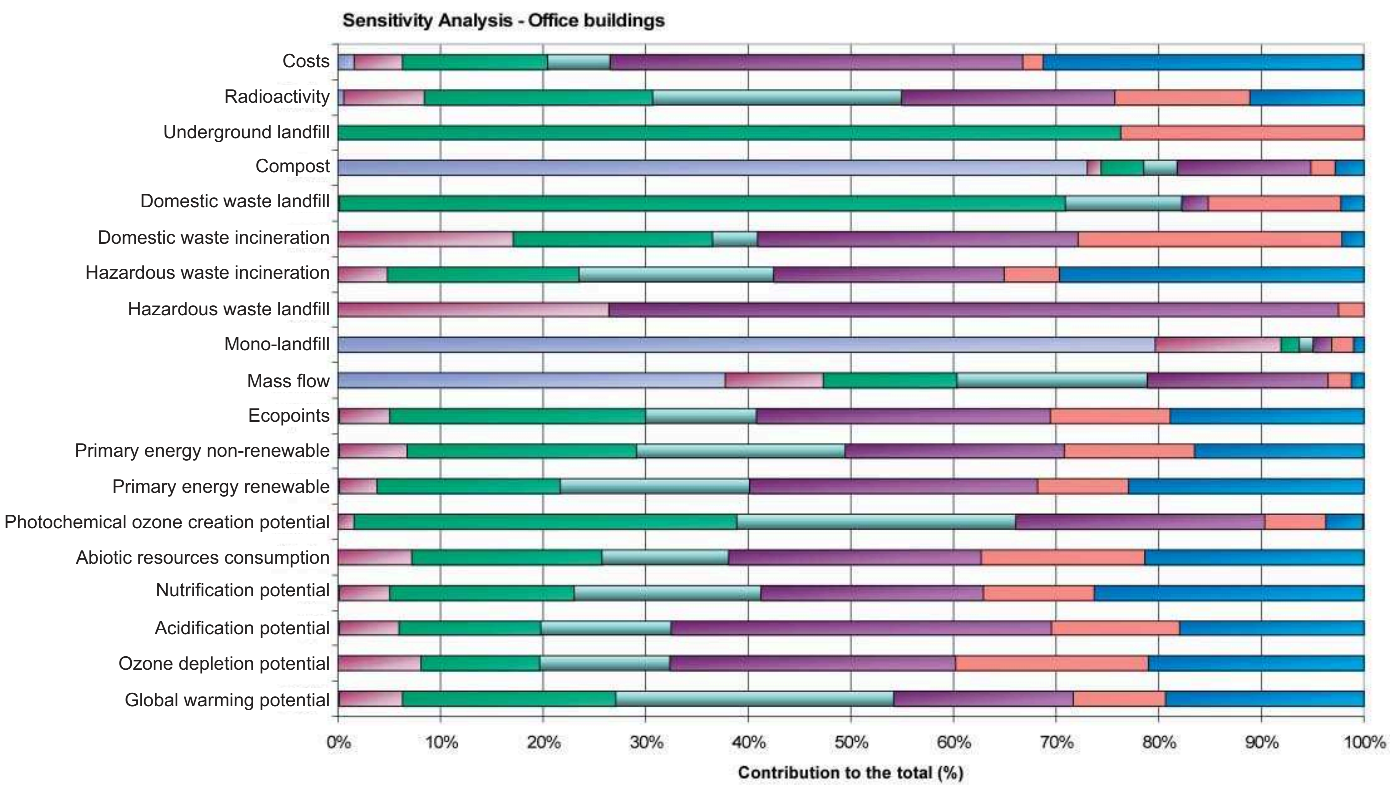


Figure 34 - *Typical results of the building's ILCA sensitivity analysis, for office buildings*

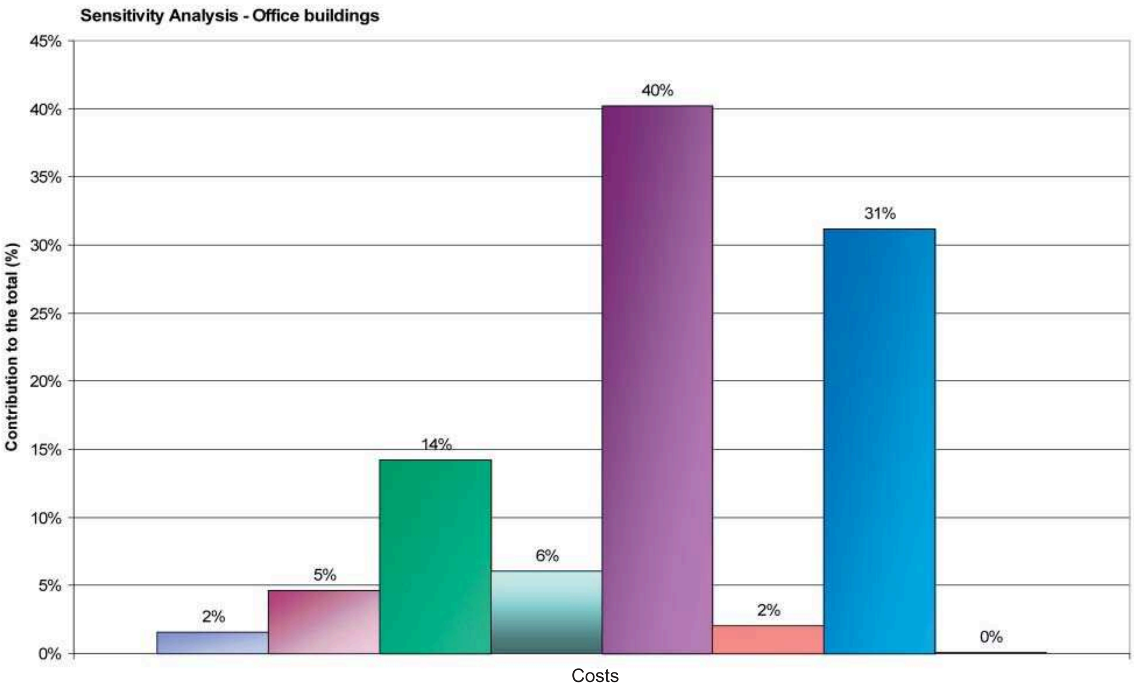
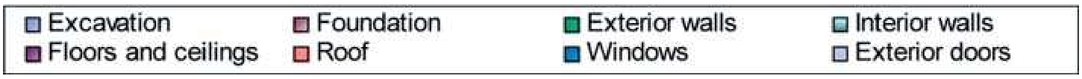


Figure 35 - *Typical results of the building's ILCA sensitivity analysis, for the costs, for office buildings*



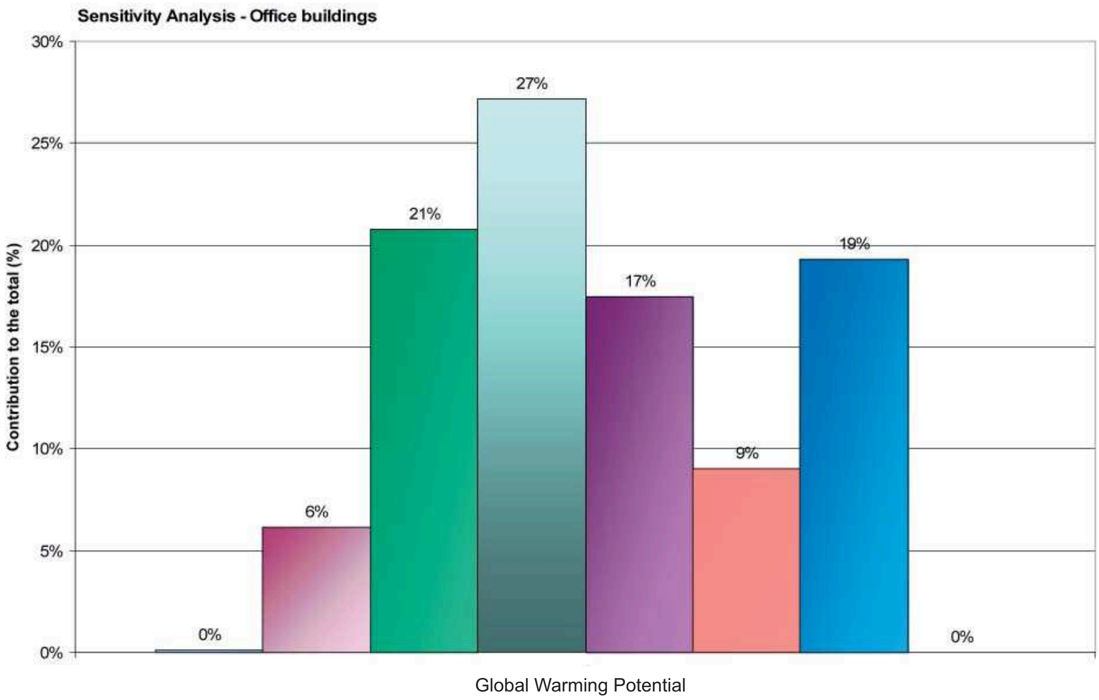


Figure 36 - *Typical results of the building's ILCA sensitivity analysis, for the global warming potential, for office buildings*

Buildings category	**Global warming potential**	**Ozone depletion potential**	**Primary energy non-renewable**	**Ecopoints**	**Mass flow**	**Compost**	**Costs**
Office buildings <2500m²	Exterior walls	Roof	Roof	Exterior walls	Excavation	Excavation	Windows
One family house	Interior walls	Roof	Exterior walls	Exterior walls	Excavation	Excavation	Windows
Multiple family house	Exterior walls	Windows	Exterior walls	Exterior walls	Interior walls	Excavation	Windows
Multiple family house <4000m²	Interior walls	Roof	Exterior walls	Floors and ceilings	Excavation	Excavation	Floors and ceilings
Fire stations	Interior walls	Roof	Exterior walls	Exterior walls	Excavation	Excavation	Windows
Hostels and students habitations	Interior walls	Windows	Exterior walls	Exterior walls	Excavation	Excavation	Windows
Factory buildings	Interior walls	Roof	Roof	Roof	Excavation	Excavation	Floors and ceilings
Factory buildings <4000m²	Roof	Roof	Roof	Roof	Excavation	Excavation	Windows
Industry and trade buildings	Roof	Roof	Roof	Floors and ceilings	Excavation	Excavation	Floors and ceilings
Hospitals	Interior walls	Floors and ceilings	Interior walls	Floors and ceilings	Excavation	Excavation	Floors and ceilings
Educational buildings <2000m²	Roof	Roof	Roof	Roof	Excavation	Excavation	Floors and ceilings
Educational buildings	Interior walls	Roof	Exterior walls	Exterior walls	Excavation	Excavation	Windows
Office buildings	Interior walls	Floors and ceilings	Exterior walls	Floors and ceilings	Excavation	Excavation	Floors and ceilings

Figur 37 - *Improvement potential for several results of LCA of different categories of buildings*

Annex 16

STILCAB uncertainty analysis

Uncertainty of costs calculated after 80 years

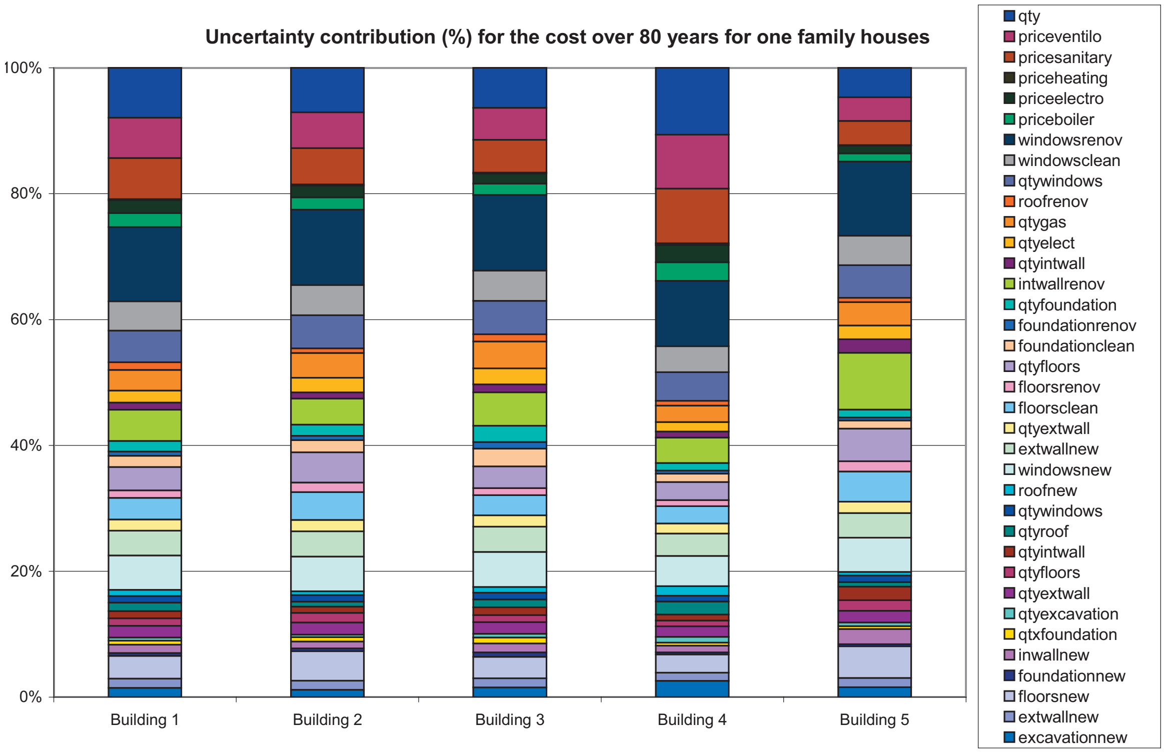


Figure 1 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for one family houses*

Figure 2 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for office buildings*

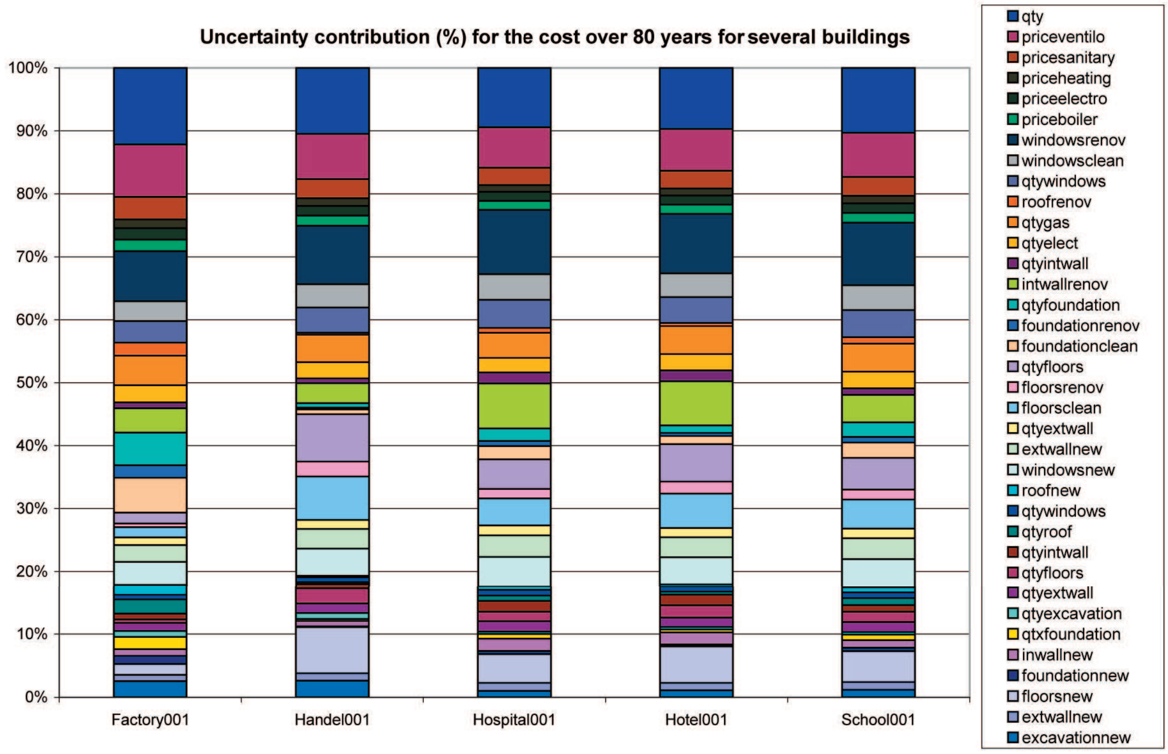


Figure 3 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for five other buildings*

Average one family houses	Average office buildings	Factory buildings	Industry buildings	Hospitals	Hostels, student habitations	Educational buildings	
27%	20%	18%	22%	24%	22%	23%	**Contribution windows**
23%	24%	29%	25%	22%	23%	24%	**Contribution technical equipment**
52%	52%	54%	53%	49%	50%	51%	**Contribution construction**
5%	6%	7%	6%	6%	7%	7%	**Contribution energy part**
42%	40%	38%	39%	43%	42%	41%	**Contribution renovation and maintenance**
2%	3%	3%	3%	1%	1%	1%	**Contribution excavation**
5%	4%	15%	2%	6%	3%	7%	**Contribution foundation**
8%	6%	6%	7%	7%	7%	7%	**Contribution exterior walls**
9%	10%	6%	5%	12%	12%	7%	**Contribution interior walls**
14%	21%	6%	26%	16%	20%	17%	**Contribution floors and ceilings**
3%	2%	5%	0%	2%	1%	2%	**Contribution roof**

Figure 4 - *Contribution of several part of the buildings to the overall uncertainty on the costs calculation for 80 years*

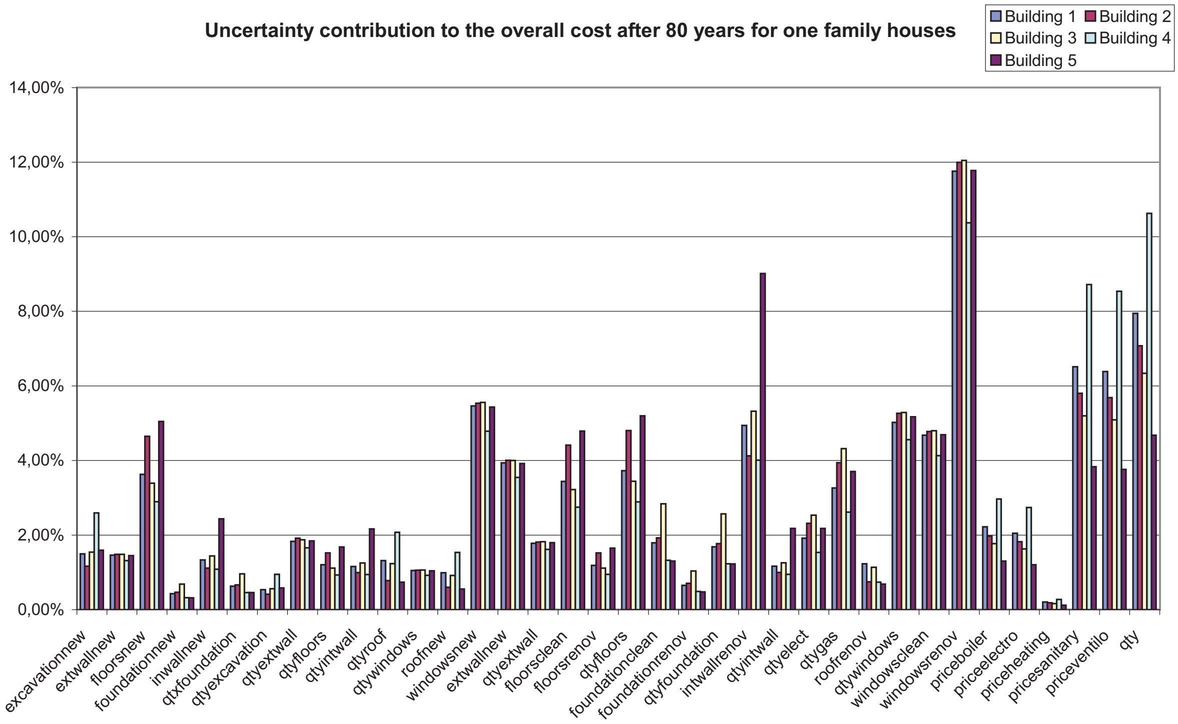


Figure 5 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for one family houses*

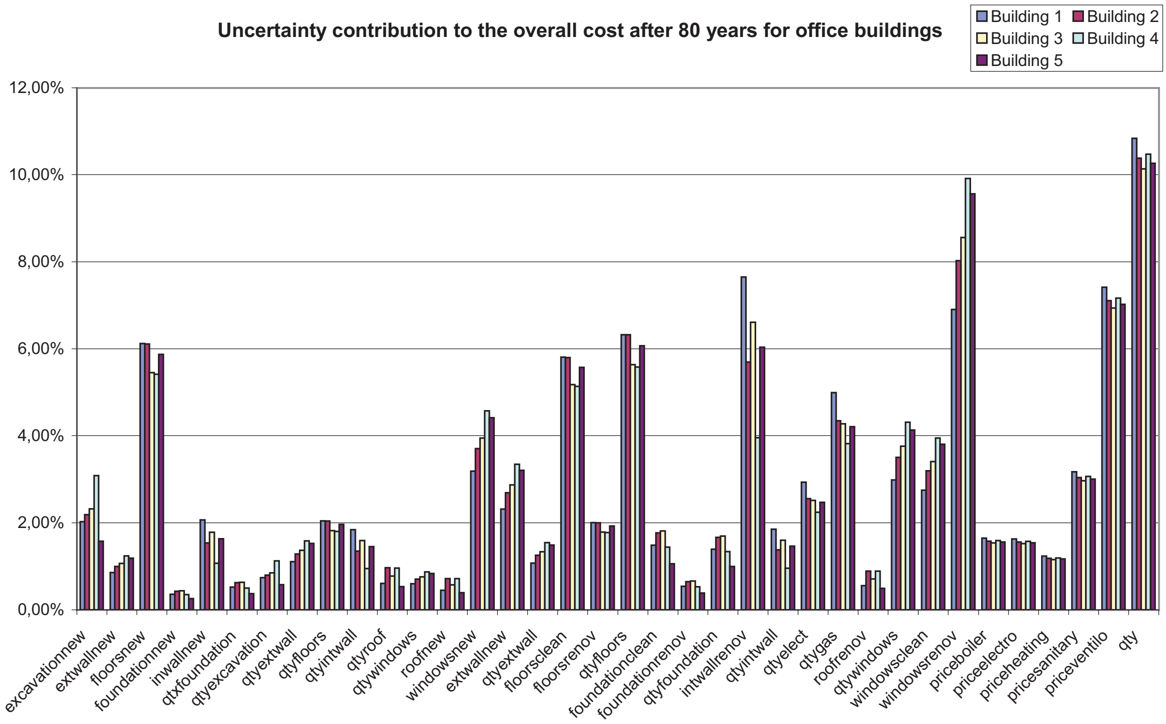


Figure 6 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for office buildings*

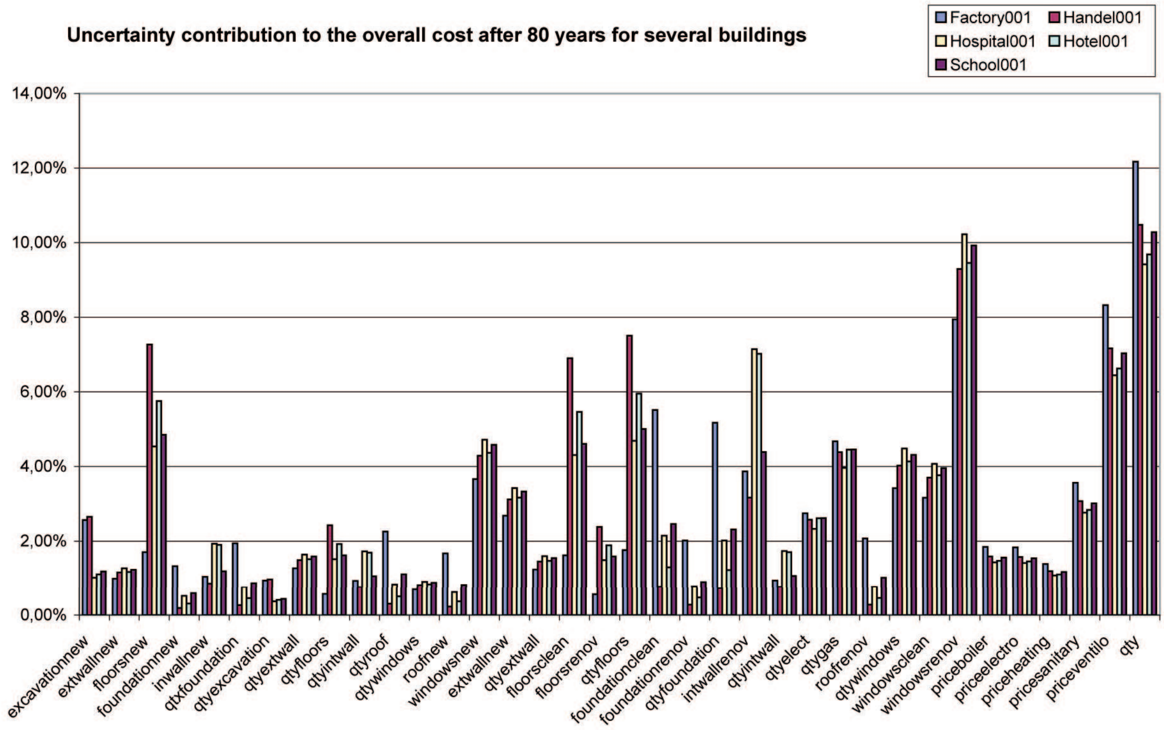


Figure 7 - *Contribution of the different parameters to the overall uncertainty on the costs calculation for 80 years, for five other buildings*

	Building 1	Building 2	Building 3	Building 4	Building 5
Value	1255000	1424100	1632000	913600	2104200
Uncertainty (+/-)	88400	98200	107000	69600	149000
Uncertainty (%)	7,04	6,90	6,56	7,62	7,08

	Building 1	Building 2	Building 3	Building 4	Building 5
Value	41660000	21559000	19553000	6246000	25368000
Uncertainty (+/-)	2600000	1330000	1220000	400000	1660000
Uncertainty (%)	6,24	6,17	6,24	6,40	6,54

	Factory	Industry	Hospital	Hotel	School
Value	7905000	25056000	68810000	44910000	32770000
Uncertainty (+/-)	464000	1670000	4400000	2910000	2010000
Uncertainty (%)	5,87	6,67	6,39	6,48	6,13

Figure 8 - *Uncertainty of costs calculation for 80 years, for office buildings, one family houses and five other buildings*

Uncertainty of CO_2 calculated after 80 years

	One family house 1	One family house 5	Multiple family housing 1
Value	869100	1678100	15391000
Uncertainty (+/-)	63200	131000	1180000
Uncertainty (%)	7,27	7,81	7,67

Figure 9 - *Uncertainty of CO_2 calculation for 80 years, for three buildings*

Average	One family house 1	One family house 5	Multiple family housing 1	
2%	3%	2%	1%	**Contribution windows**
7%	8%	4%	10%	**Contribution technical equipment**
21%	23%	19%	21%	**Contribution construction**
50%	51%	49%	52%	**Contribution energy part**
26%	23%	30%	24%	**Contribution renovation and maintenance**
0%	0%	0%	0%	**Contribution excavation**
1%	2%	1%	1%	**Contribution foundation**
4%	5%	4%	2%	**Contribution exterior walls**
25%	20%	31%	25%	**Contribution interior walls**
3%	2%	3%	3%	**Contribution floors and ceilings**
3%	6%	3%	2%	**Contribution roof**

Figure 10 - *Contribution of several parts of the buildings to the overall uncertainty on CO_2 calculation for 80 years*

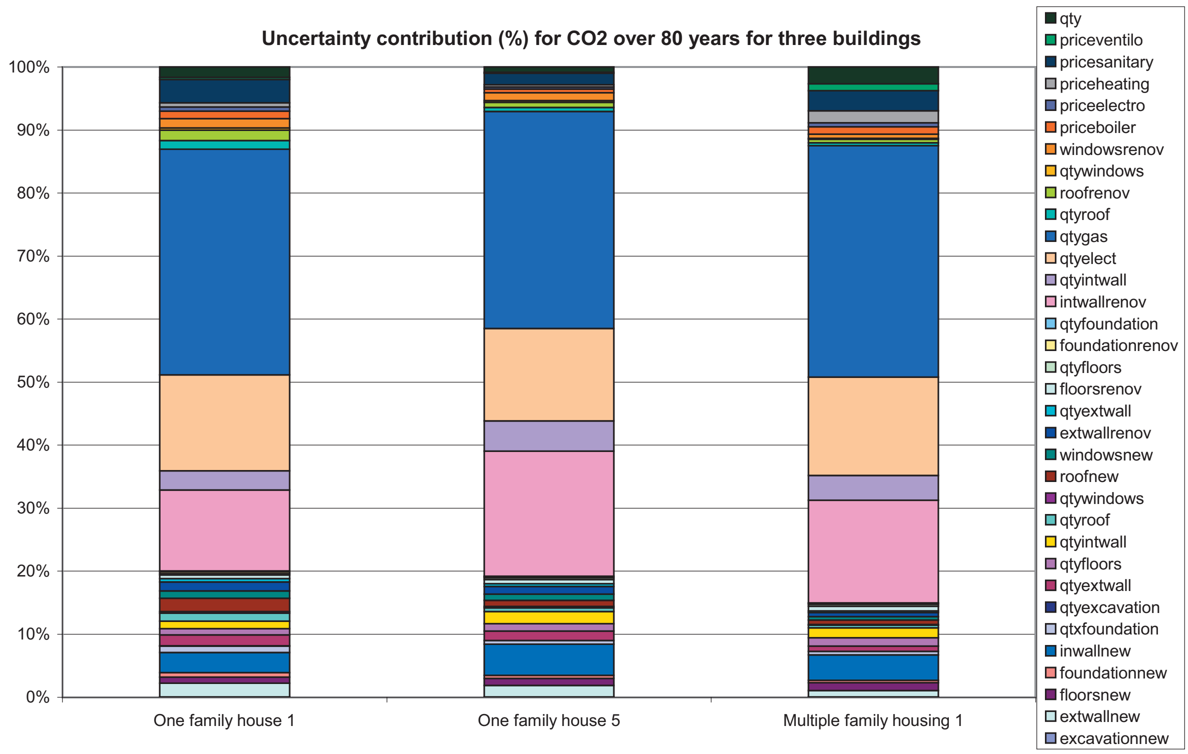


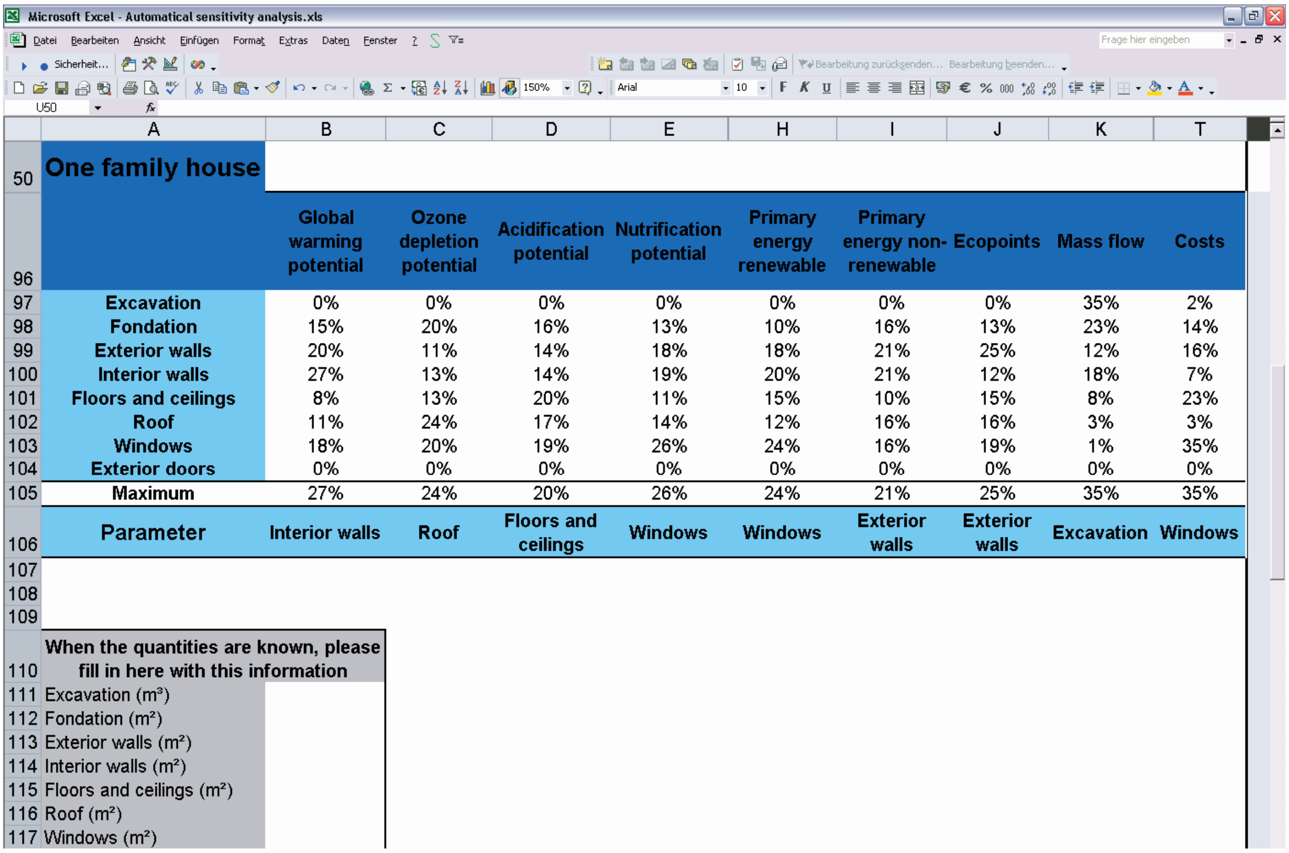
Figure 11 - *Contribution of the different parameters to the overall uncertainty on CO_2 calculation for 80 years, for three buildings*

Annex 17

Instructions for the sensivity analysis

The file concerned is „Automatical sensitivity analysis", it can be found on the CD.

In the A50 case, please write the use category of the building considered.
If the categories hospital, fire station, office building with a gross floor area < 2500m², educational building and educational building with a gross floor area <2500m² are chosen; the second sheet „Sensitivity 2" will be used as intermediary for the calculations.
If the quantities of elements are known, please write them in the cases E111 to E118.
If those cases are empty, the minimum and maximum values of the database concerning those categories of buildings will be considered.
It means that the sensitivity analysis will be realised for the whole building category.
When the quantities are mentioned, the sensitivity is done only for the specific building.
The sensitivity analysis gives an indication of the improvement potential which can be reached in the optimisation of one parameter.
The parameters which can be optimized are the „results" from life cycle analysis: GWP, ODP, Costs…
The line 106 indicates which part of the building (exterior walls, windows…) has the largest improvement potential of the selected parameters (GWP, ODP)
This statement means that by changing the construction elements corresponding to the part of the building indicated in line 106, the parameter indicated in line 96 will be greatly influenced.
All elements together naturally have an improvement potential of 100%. In line 106, the elements with the largest potential are indicated. The percent indicates the share of the improvement contribution of this element out of the whole improvement opportunity.


Microsoft Excel - Automatical sensitivity analysis.xls

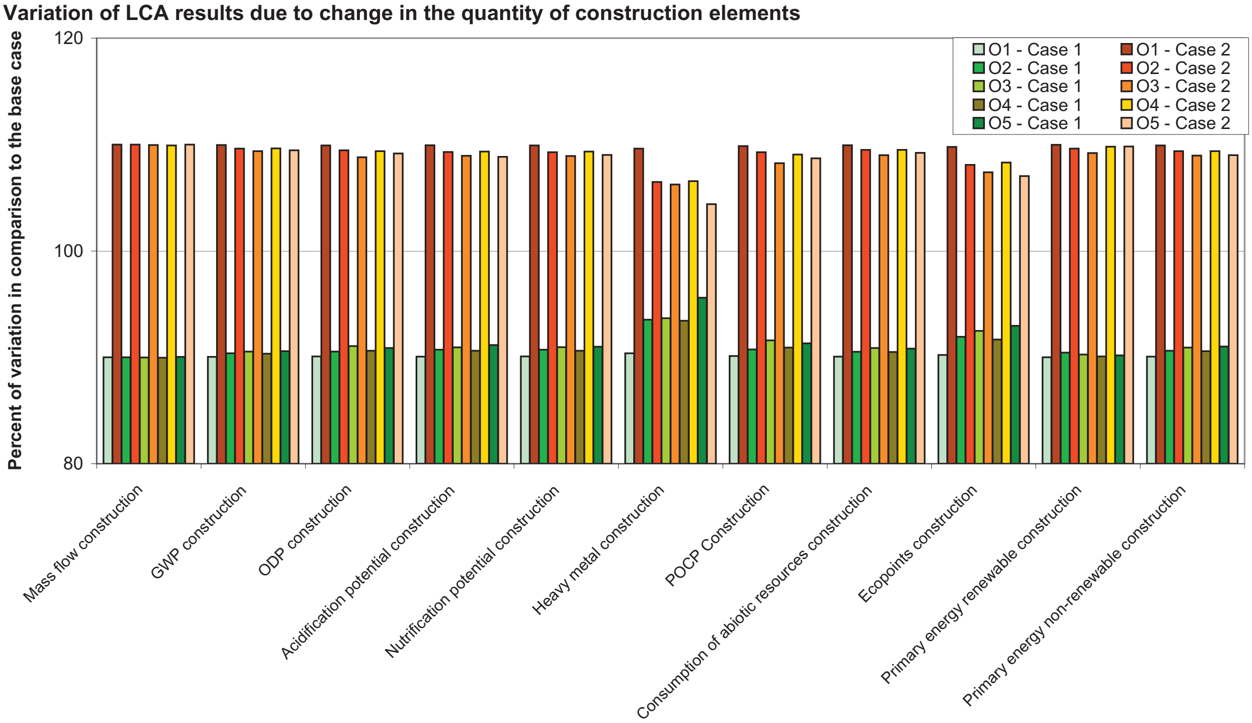
	A	B	C	D	E	H	I	J	K	T
50	One family house									
96		Global warming potential	Ozone depletion potential	Acidification potential	Nutrification potential	Primary energy renewable	Primary energy non-renewable	Ecopoints	Mass flow	Costs
97	Excavation	0%	0%	0%	0%	0%	0%	0%	35%	2%
98	Fondation	15%	20%	16%	13%	10%	16%	13%	23%	14%
99	Exterior walls	20%	11%	14%	18%	18%	21%	25%	12%	16%
100	Interior walls	27%	13%	14%	19%	20%	21%	12%	18%	7%
101	Floors and ceilings	8%	13%	20%	11%	15%	10%	15%	8%	23%
102	Roof	11%	24%	17%	14%	12%	16%	16%	3%	3%
103	Windows	18%	20%	19%	26%	24%	16%	19%	1%	35%
104	Exterior doors	0%	0%	0%	0%	0%	0%	0%	0%	0%
105	Maximum	27%	24%	20%	26%	24%	21%	25%	35%	35%
106	Parameter	Interior walls	Roof	Floors and ceilings	Windows	Windows	Exterior walls	Exterior walls	Excavation	Windows
107										
108										
109										

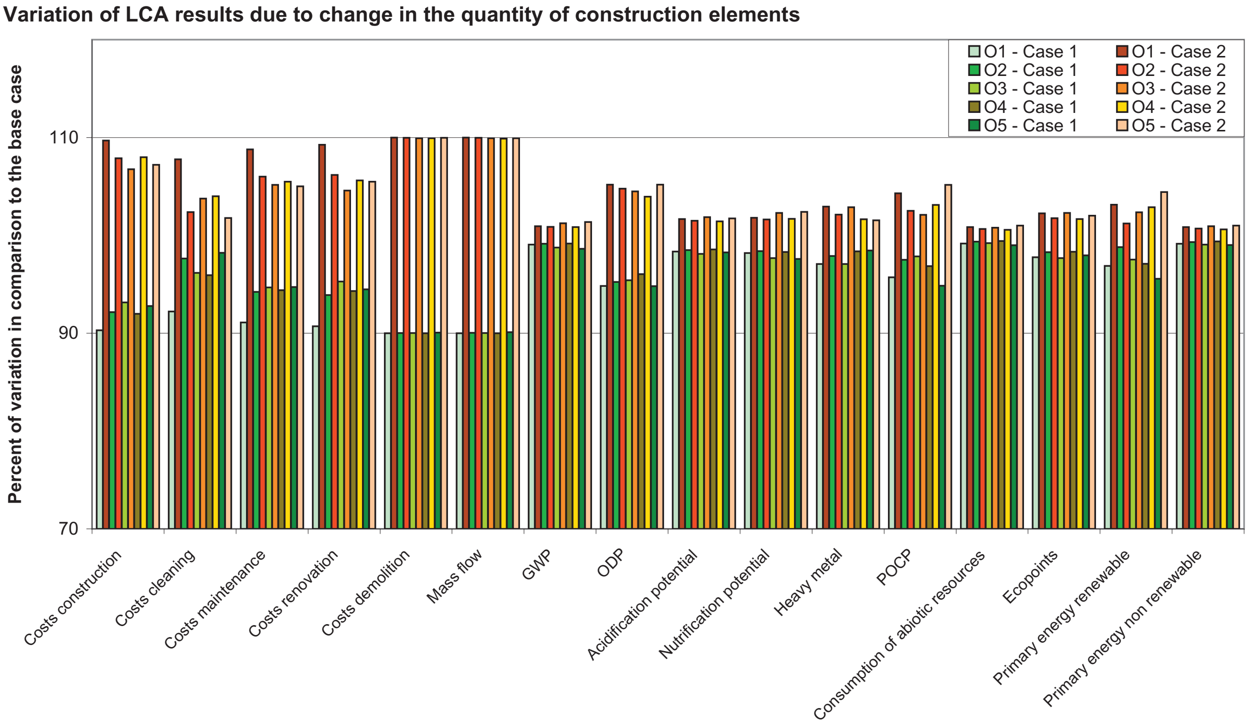
110	When the quantities are known, please fill in here with this information
111	Excavation (m³)
112	Fondation (m²)
113	Exterior walls (m²)
114	Interior walls (m²)
115	Floors and ceilings (m²)
116	Roof (m²)
117	Windows (m²)

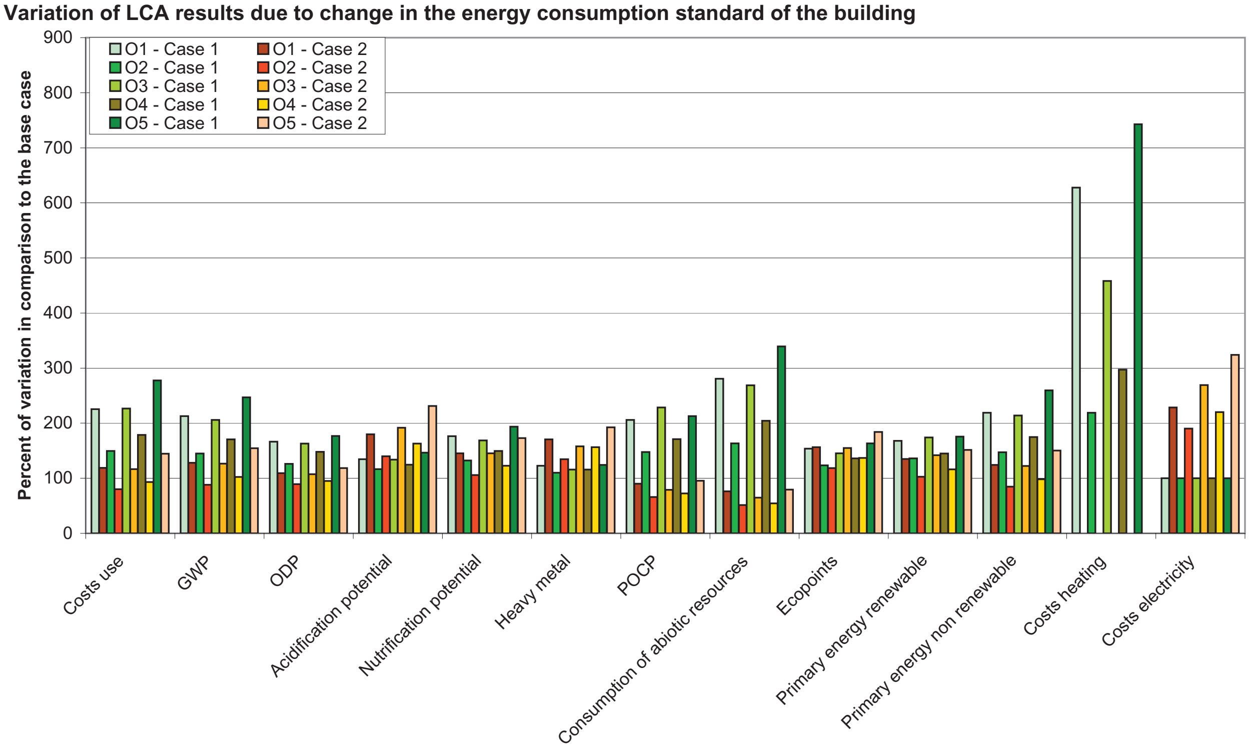
Annex 18

Uncertainty analysis in Legep

Educational buildings

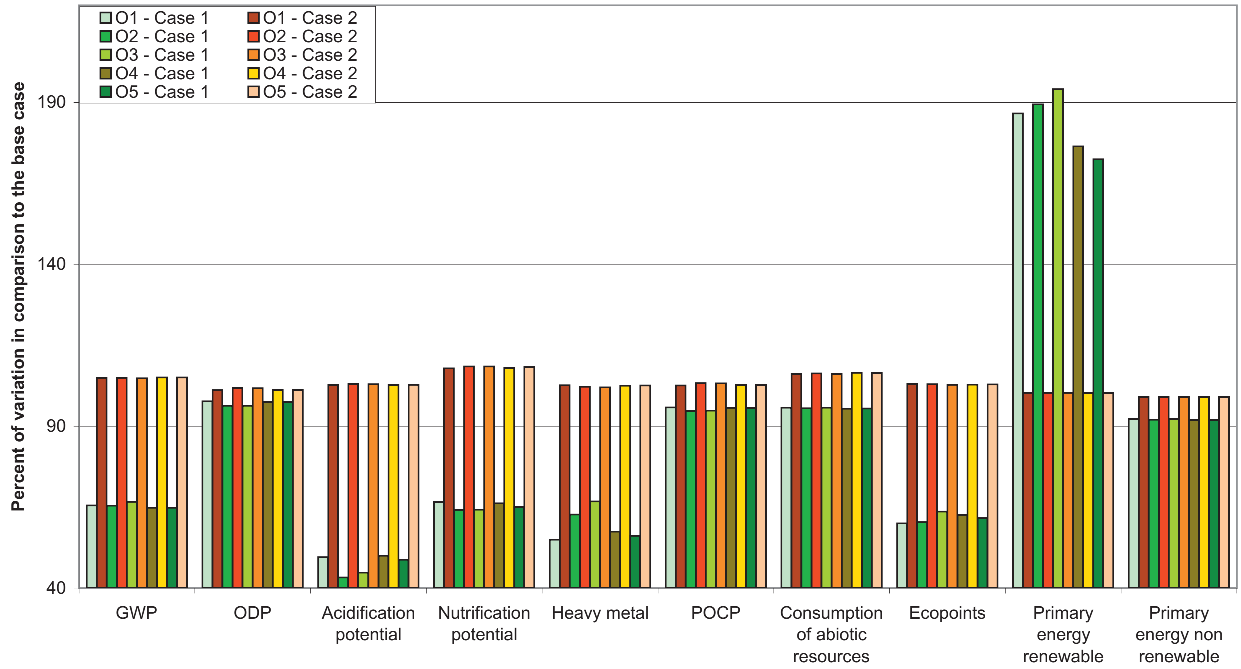




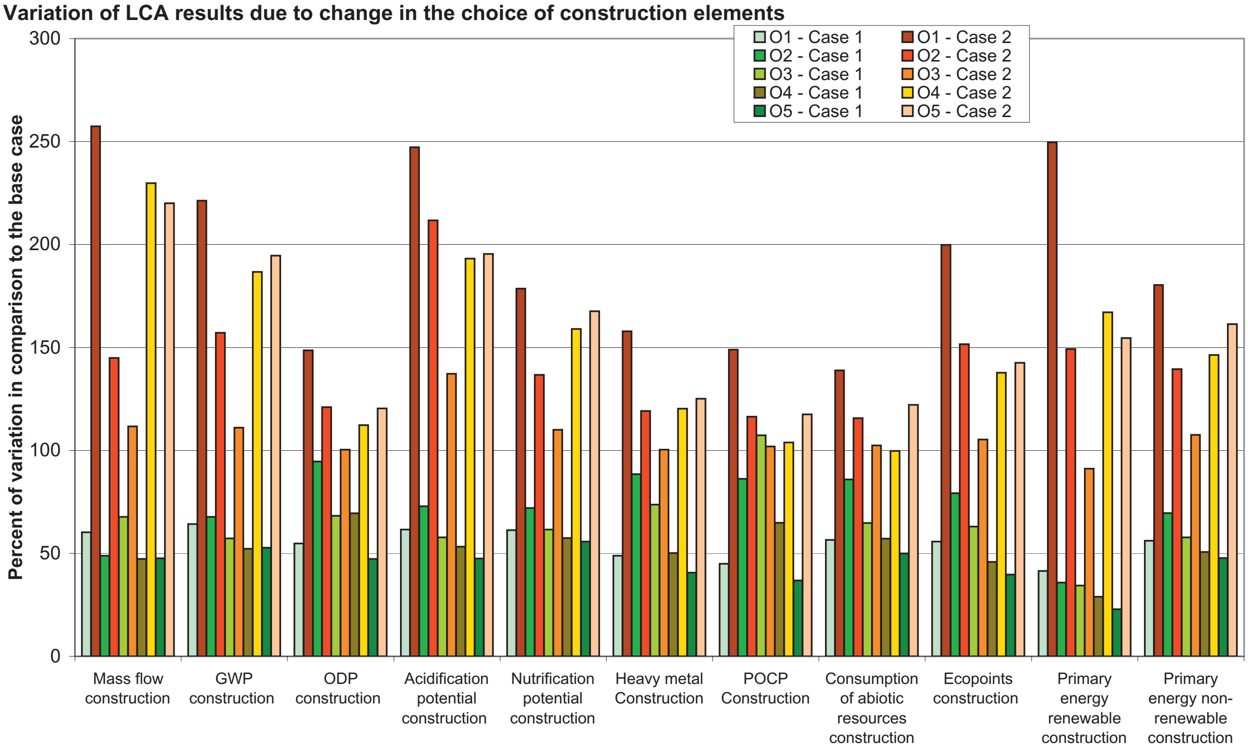

Variation of LCA results due to change in the energy consumption standard of the building
Percent of variation in comparison to the base case
900
800
700
600
500
400
300
200
100
0
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs use
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable
Costs heating
Costs electricity

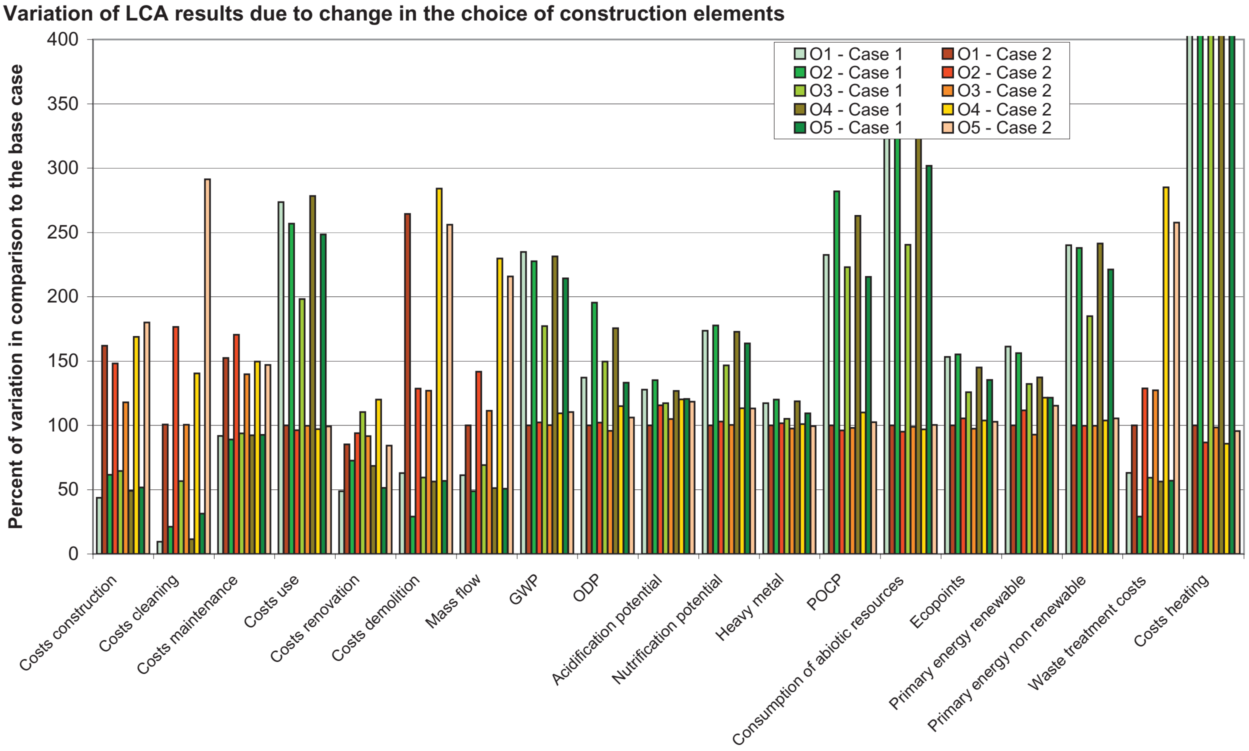
Hospitals

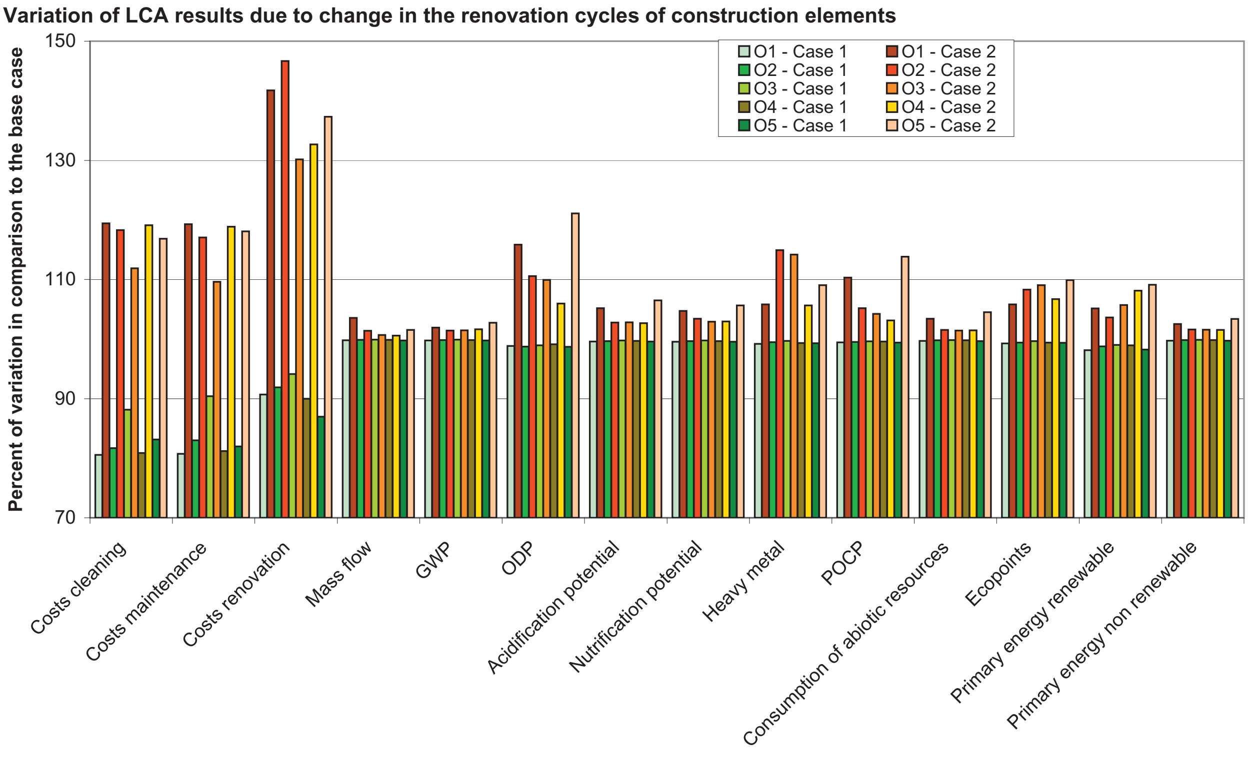
Variation of LCA results due to variation of the electricity mix



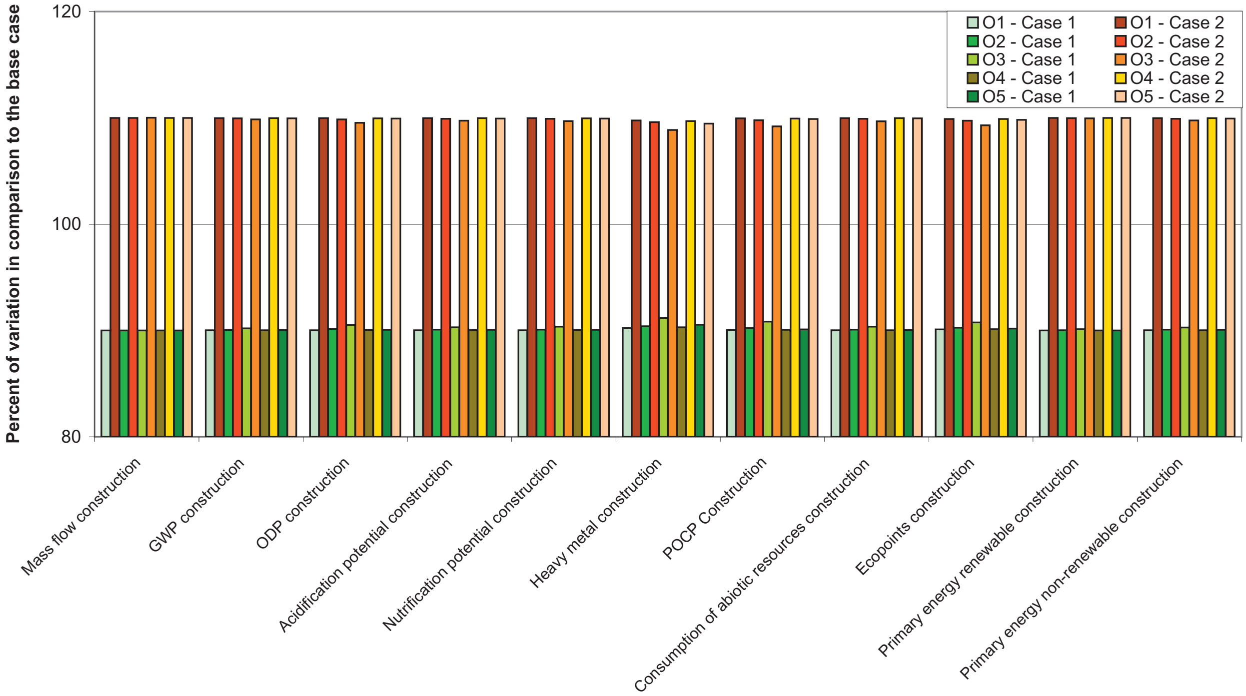
Variation of LCA results due to change in the choice of construction elements



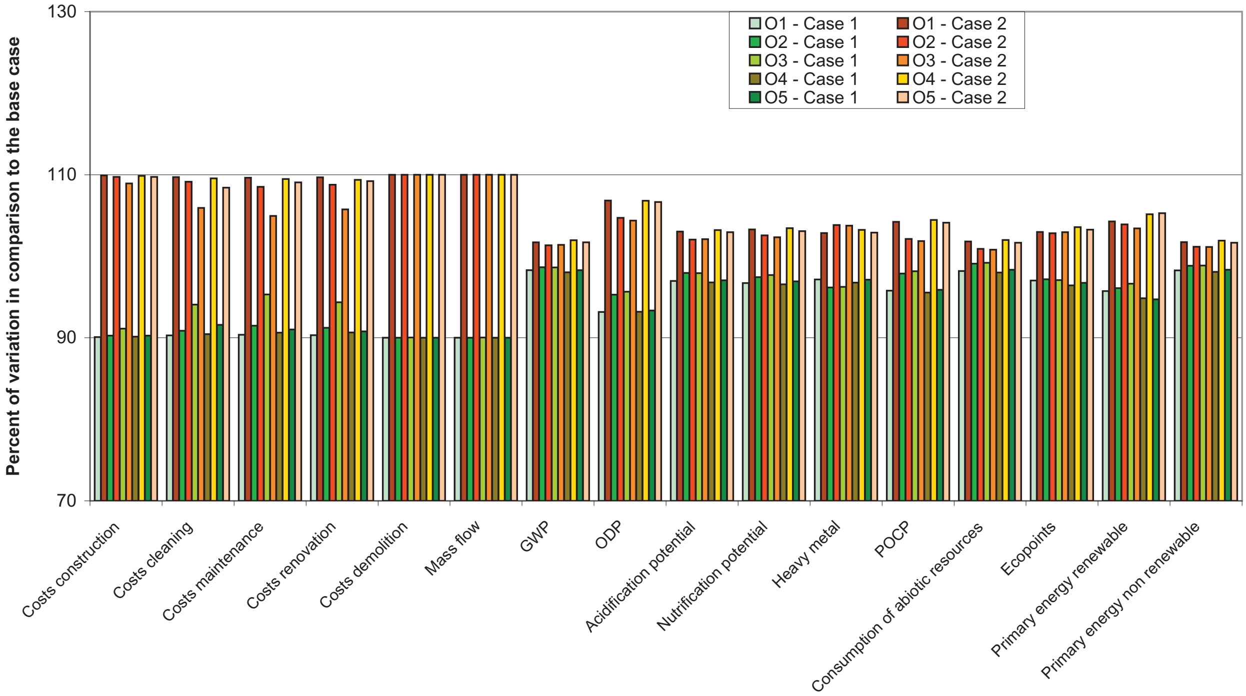

Variation of LCA results due to change in the choice of construction elements
Percent of variation in comparison to the base case
0
50
100
150
200
250
300
350
400
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs construction
Costs cleaning
Costs maintenance
Costs use
Costs renovation
Costs demolition
Mass flow
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable
Waste treatment costs
Costs heating

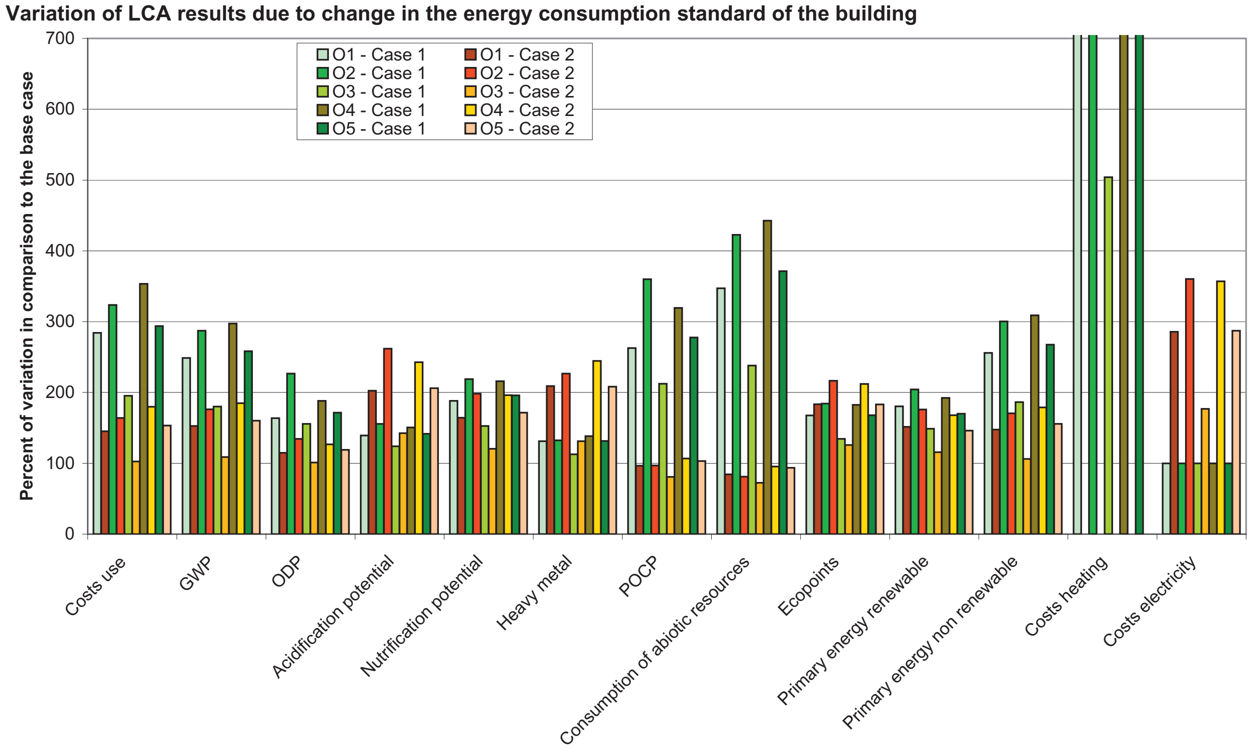

Variation of LCA results due to change in the renovation cycles of construction elements
Percent of variation in comparison to the base case
70
90
110
130
150
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs cleaning
Costs maintenance
Costs renovation
Mass flow
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable

Variation of LCA results due to change in the quantity of construction elements

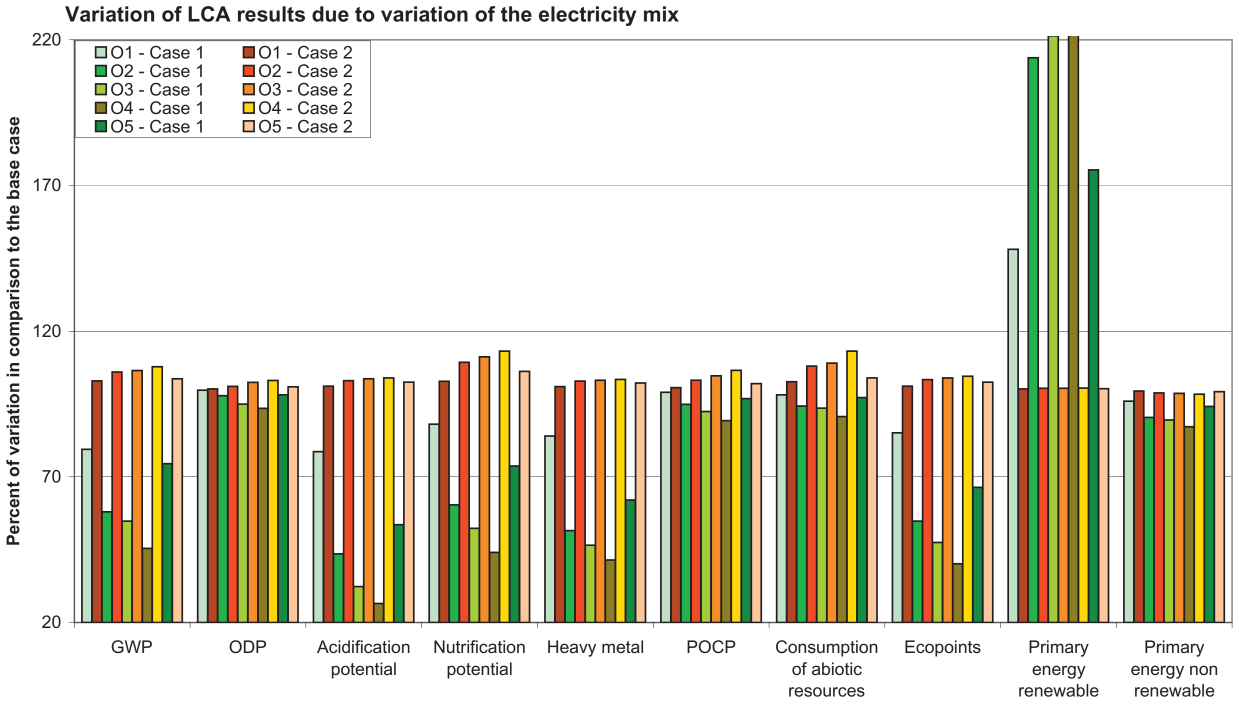


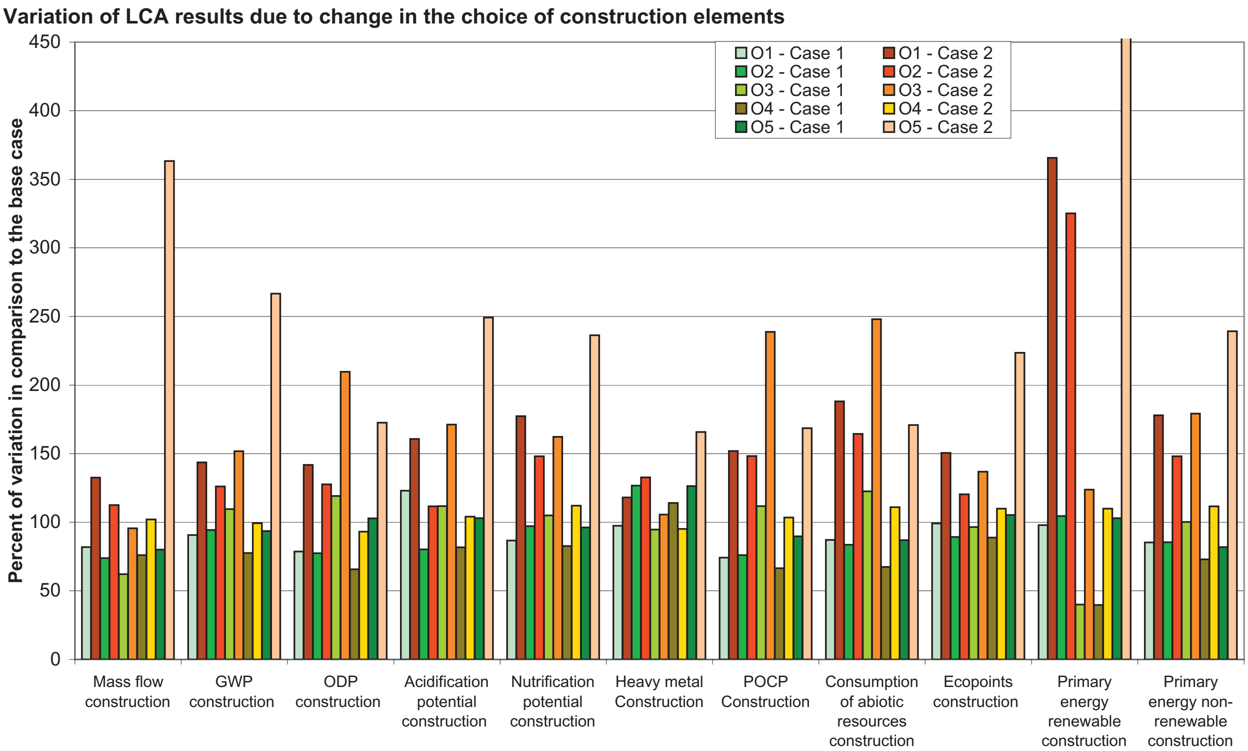
Variation of LCA results due to change in the quantity of construction elements



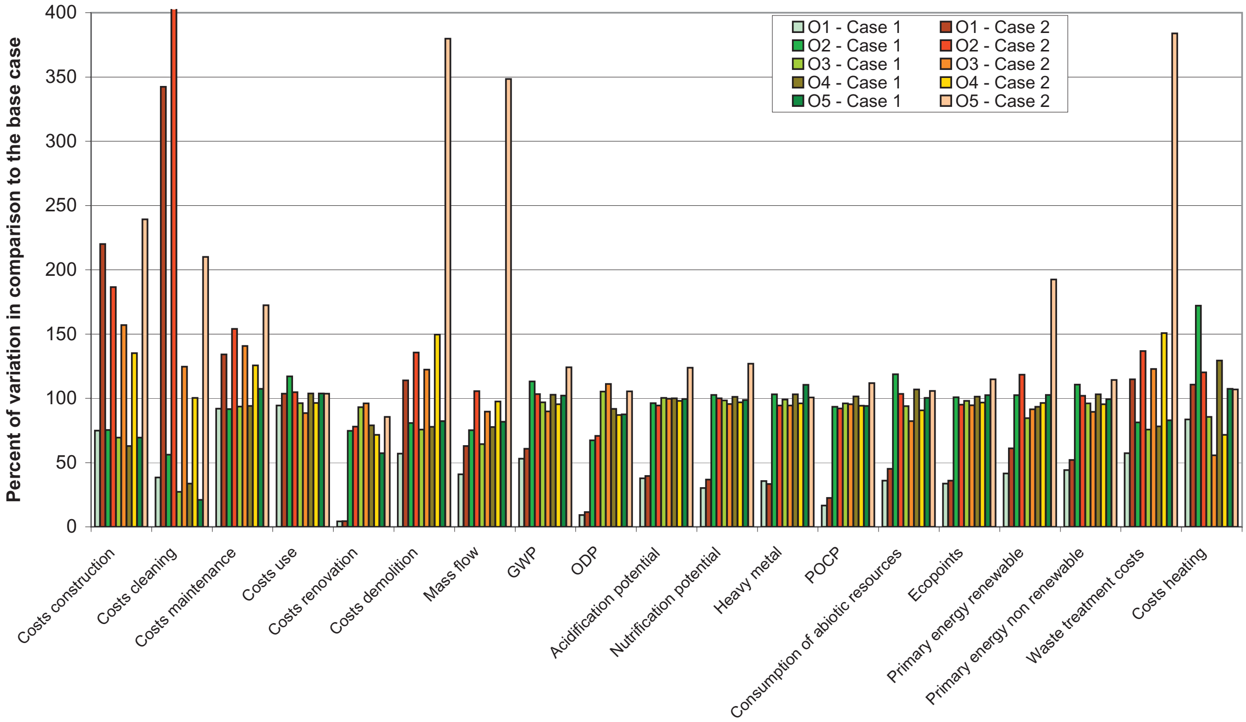

Variation of LCA results due to change in the energy consumption standard of the building
Percent of variation in comparison to the base case
0
100
200
300
400
500
600
700
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs use
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable
Costs heating
Costs electricity

Multiple family housing

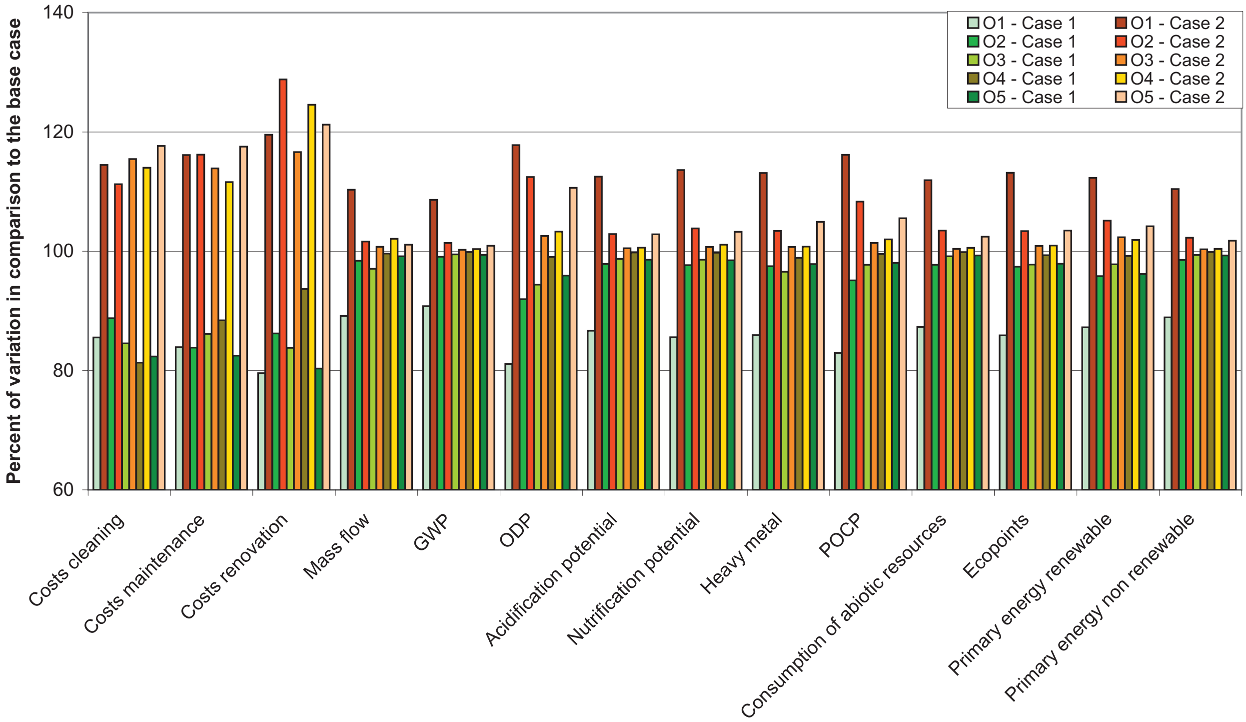




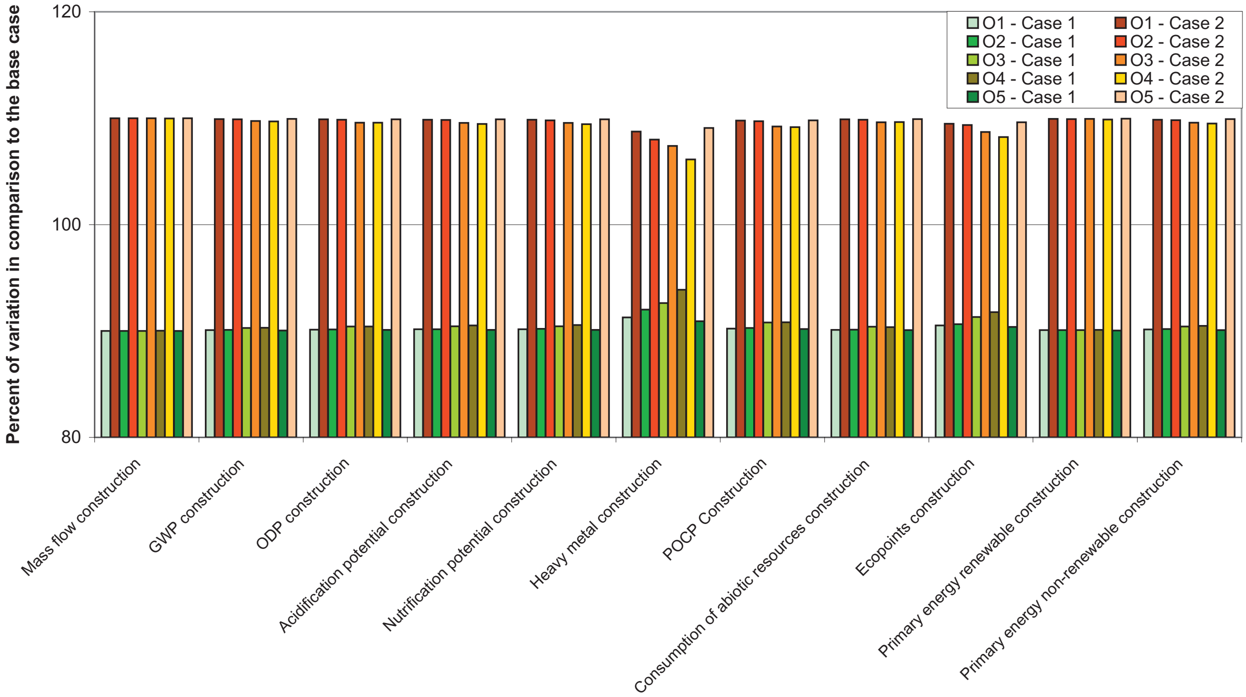
Variation of LCA results due to change in the choice of construction elements



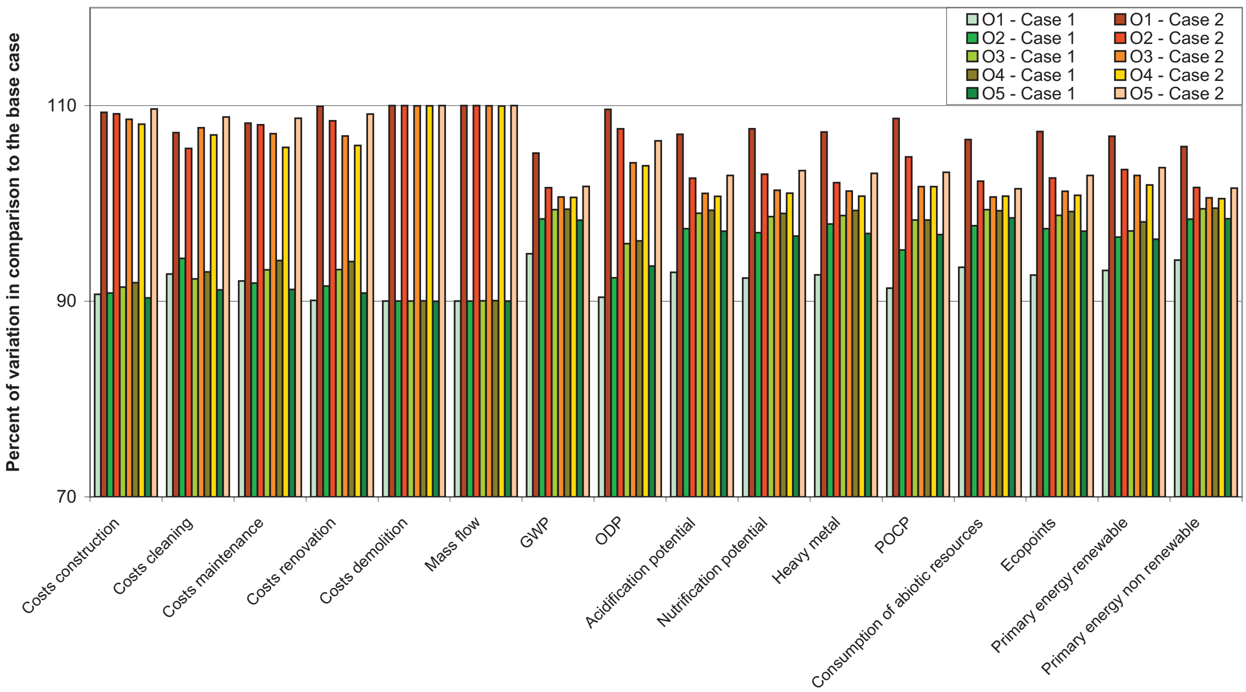
Variation of LCA results due to change in the renovation cycles of construction elements

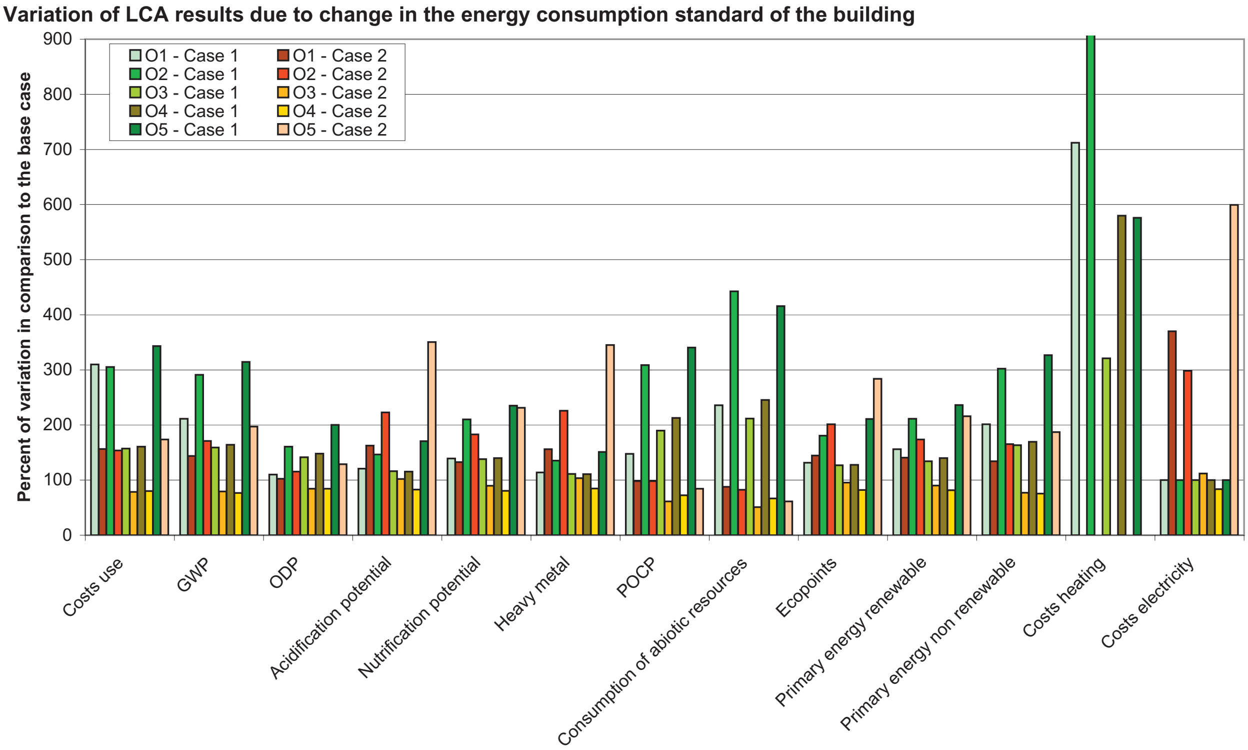


Variation of LCA results due to change in the quantity of construction elements



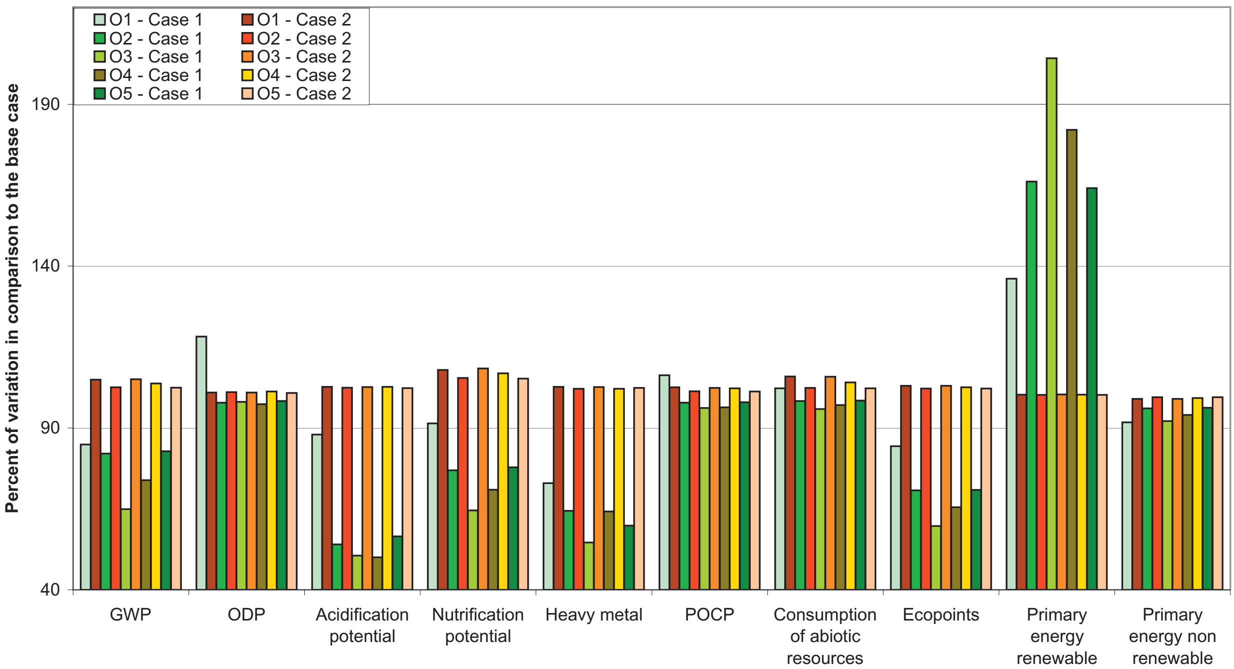
Variation of LCA results due to change in the quantity of construction elements

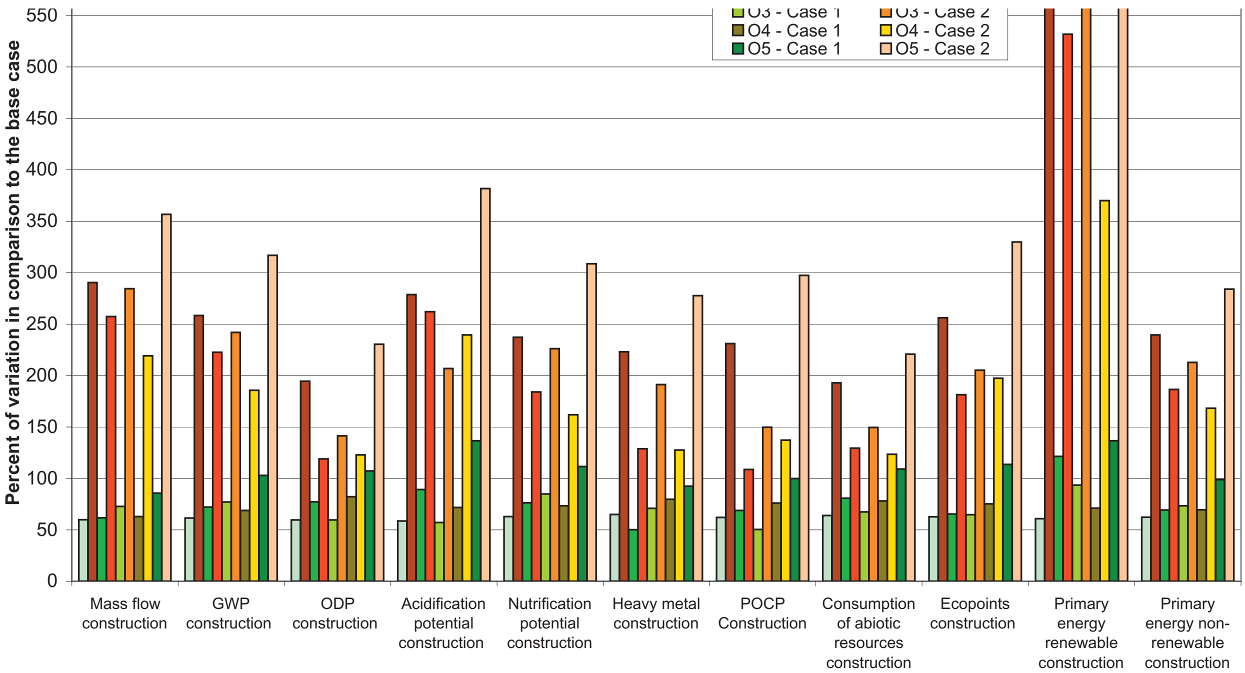


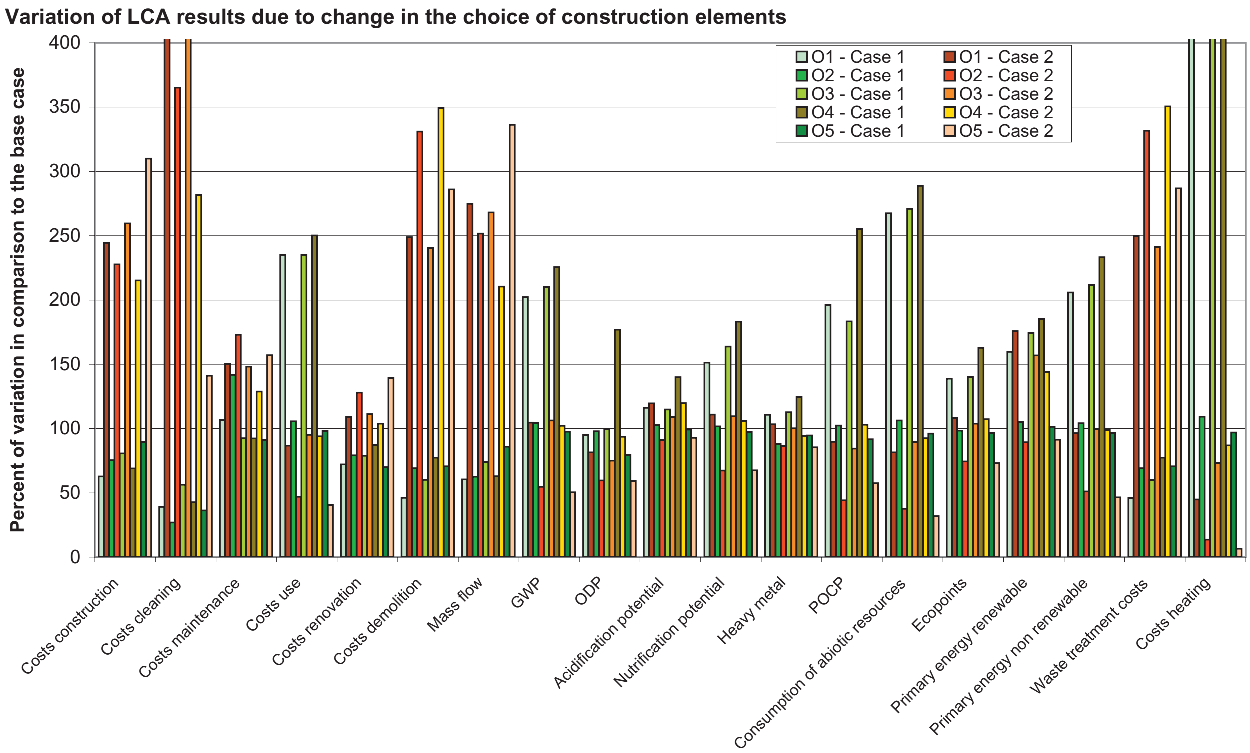

Variation of LCA results due to change in the energy consumption standard of the building
Percent of variation in comparison to the base case
0
100
200
300
400
500
600
700
800
900
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs use
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable
Costs heating
Costs electricity

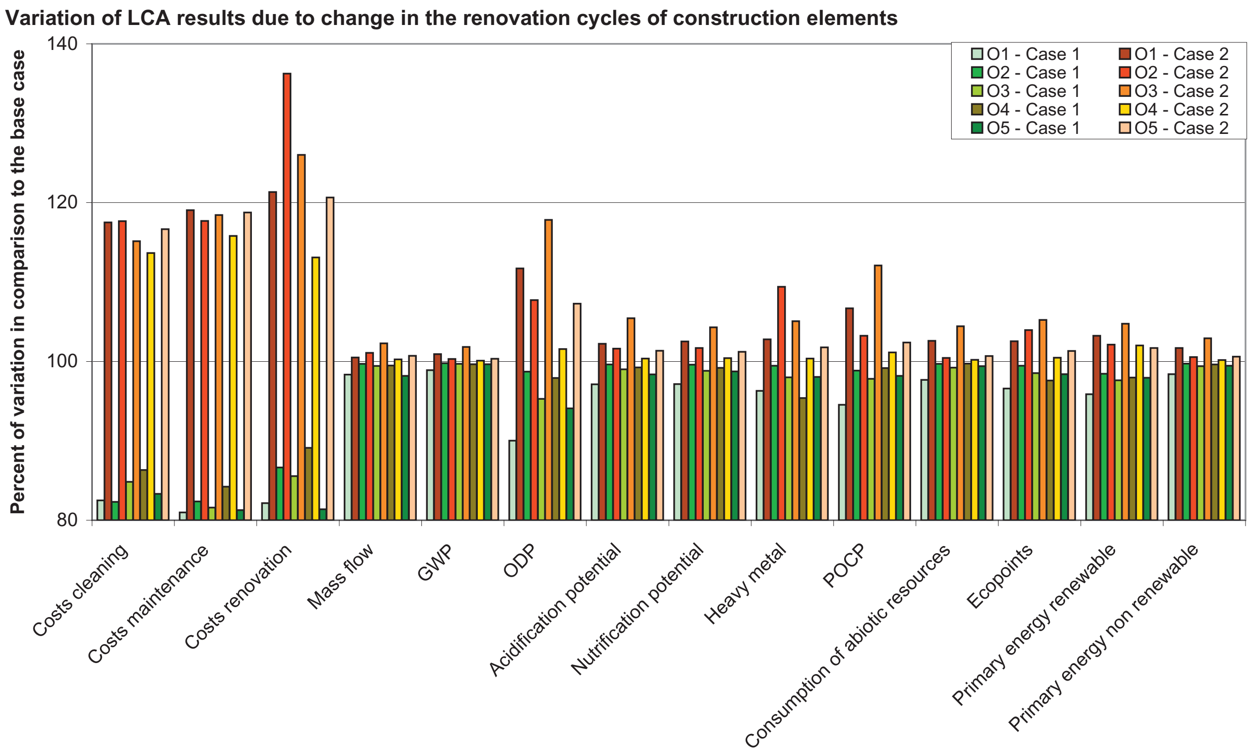
Office buildings

Variation of LCA results due to variation of the electricity mix

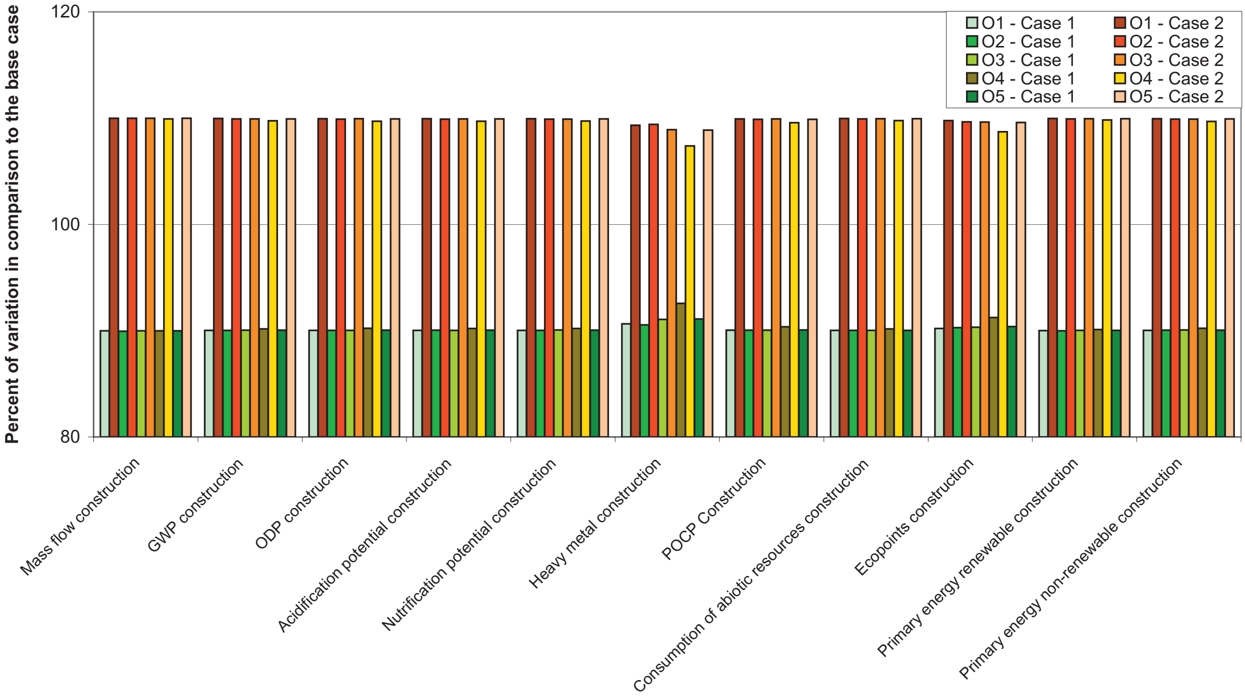




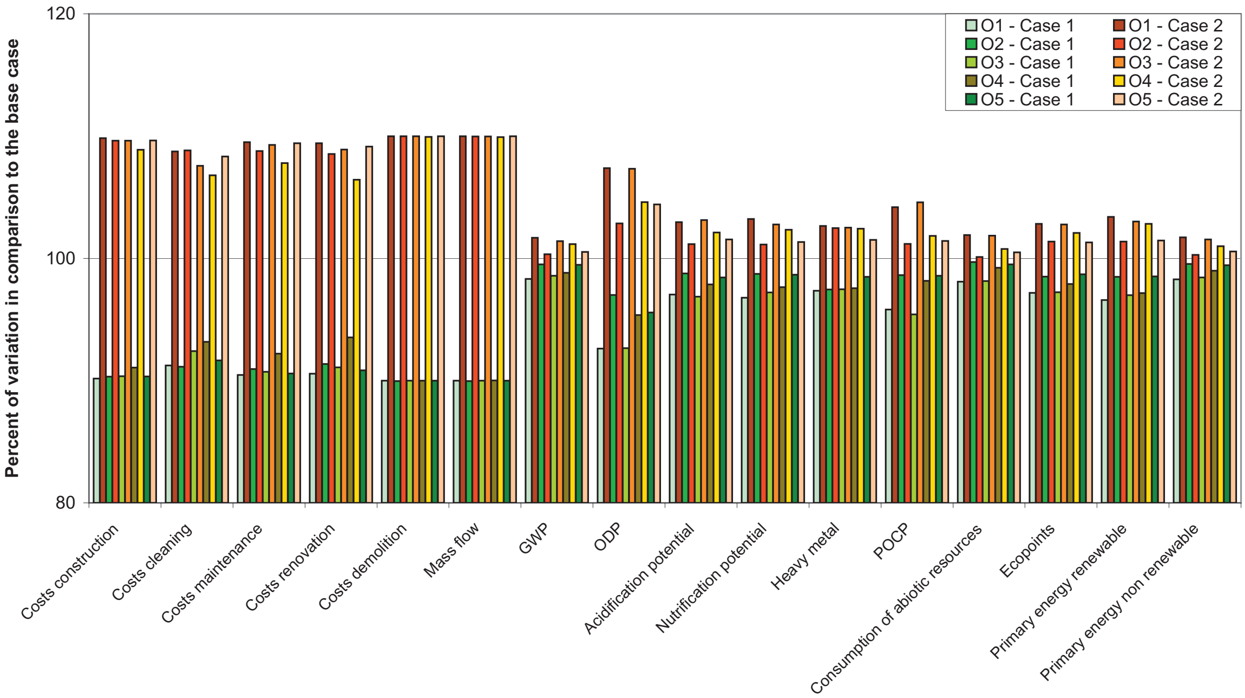

Variation of LCA results due to change in the choice of construction elements
Percent of variation in comparison to the base case
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs construction
Costs cleaning
Costs maintenance
Costs use
Costs renovation
Costs demolition
Mass flow
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable
Waste treatment costs
Costs heating


Variation of LCA results due to change in the renovation cycles of construction elements
Percent of variation in comparison to the base case
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs cleaning
Costs maintenance
Costs renovation
Mass flow
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable

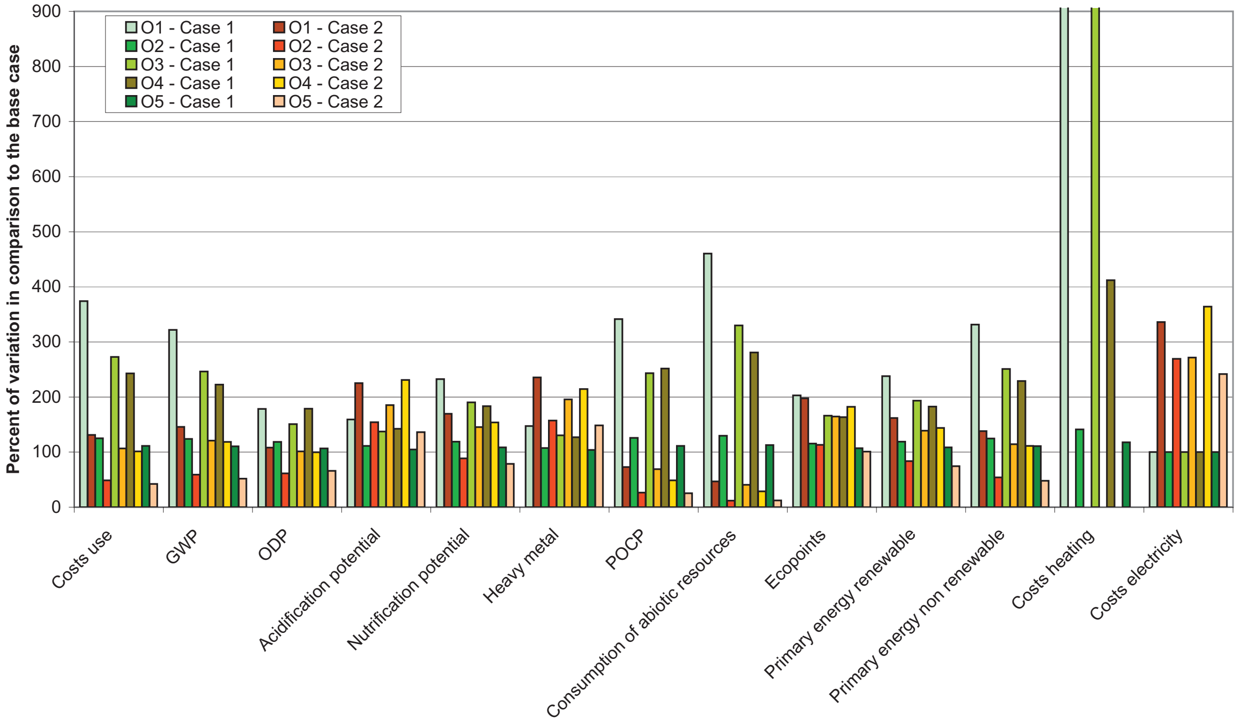
Variation of LCA results due to change in the quantity of construction elements



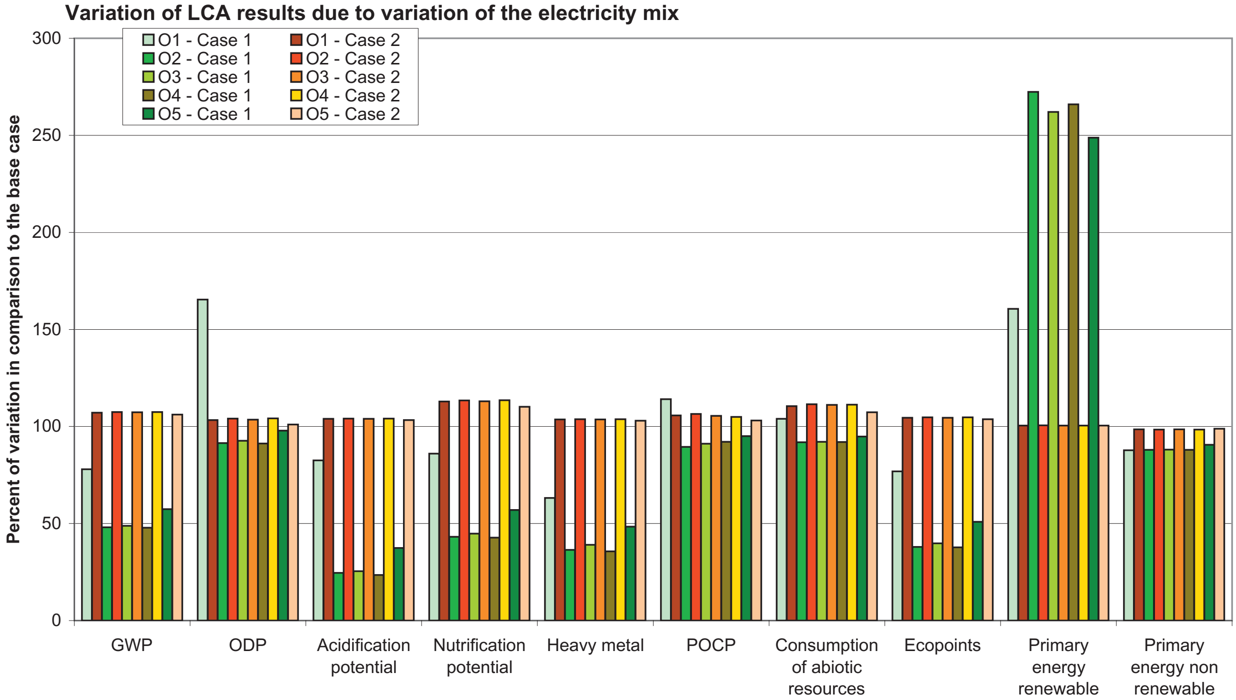
Variation of LCA results due to change in the quantity of construction elements

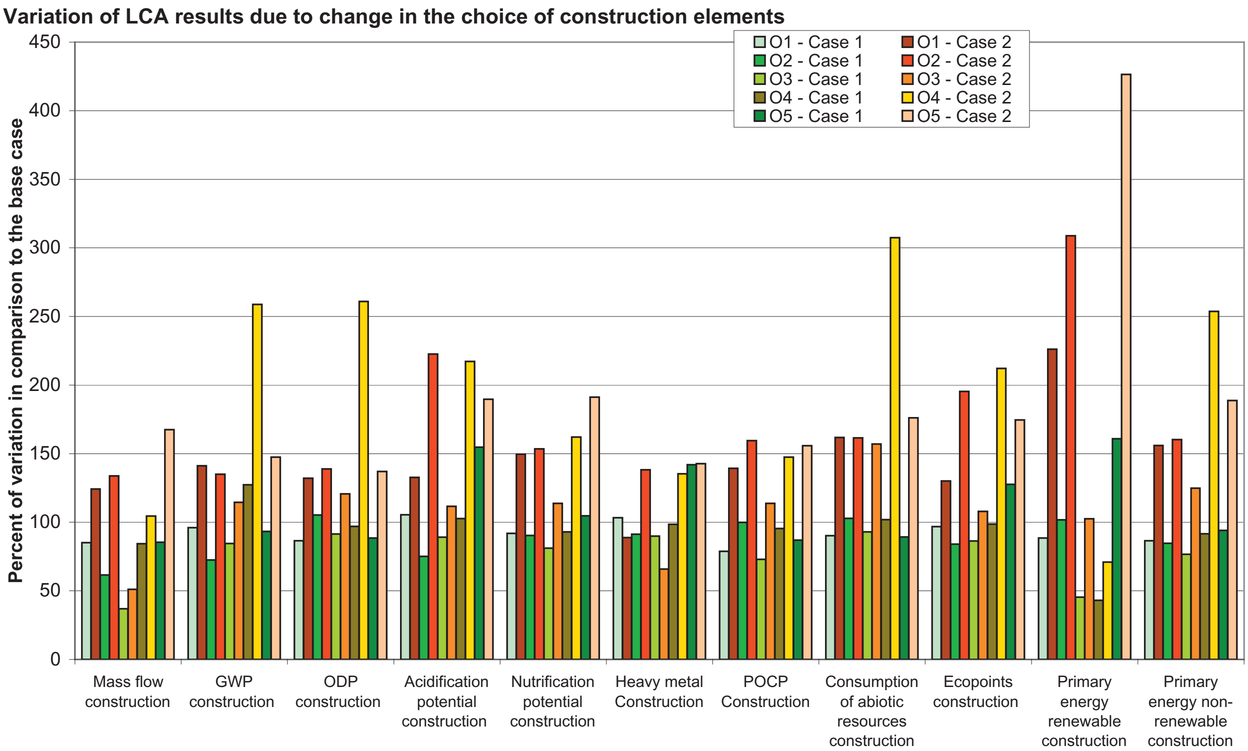


Variation of LCA results due to change in the energy consumption standard of the building

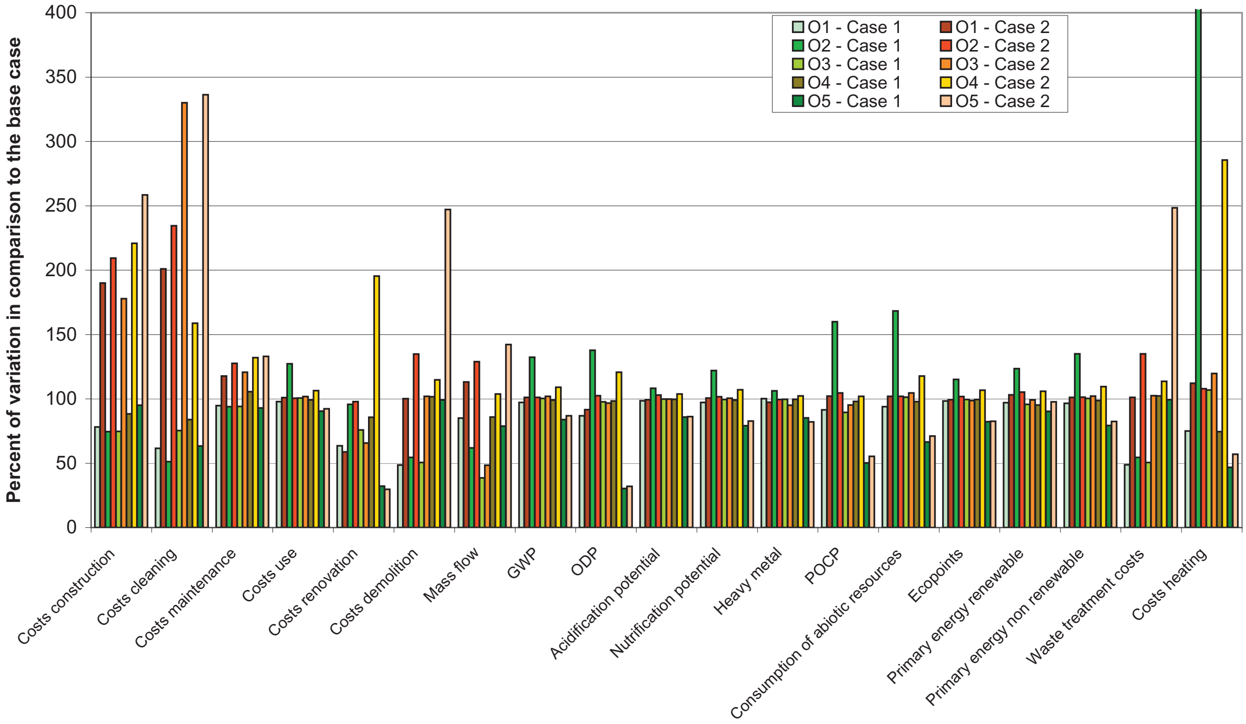


One family houses

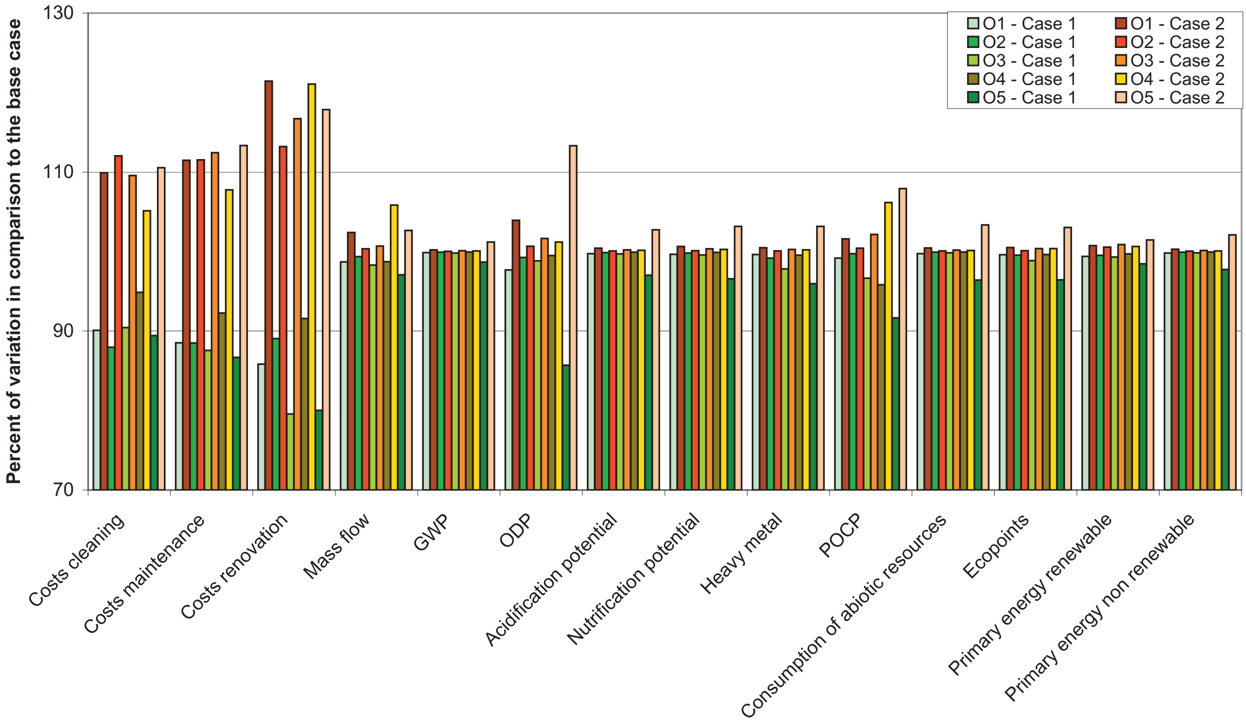


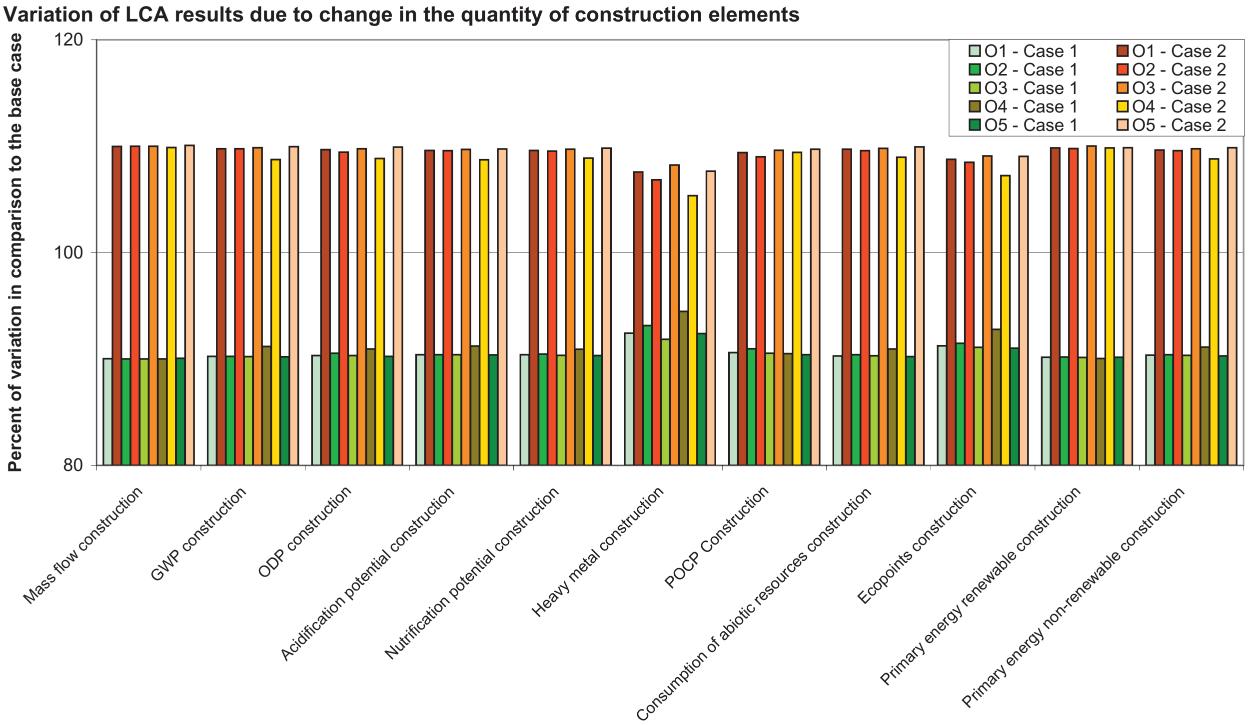


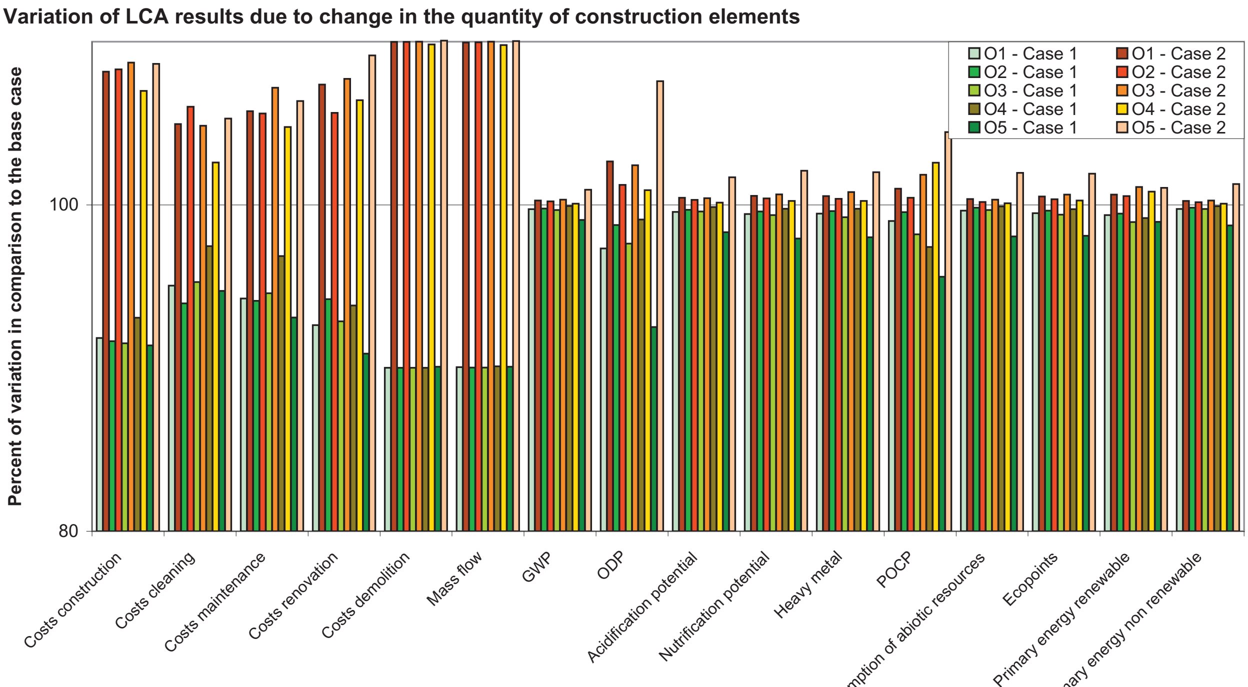
Variation of LCA results due to change in the choice of construction elements



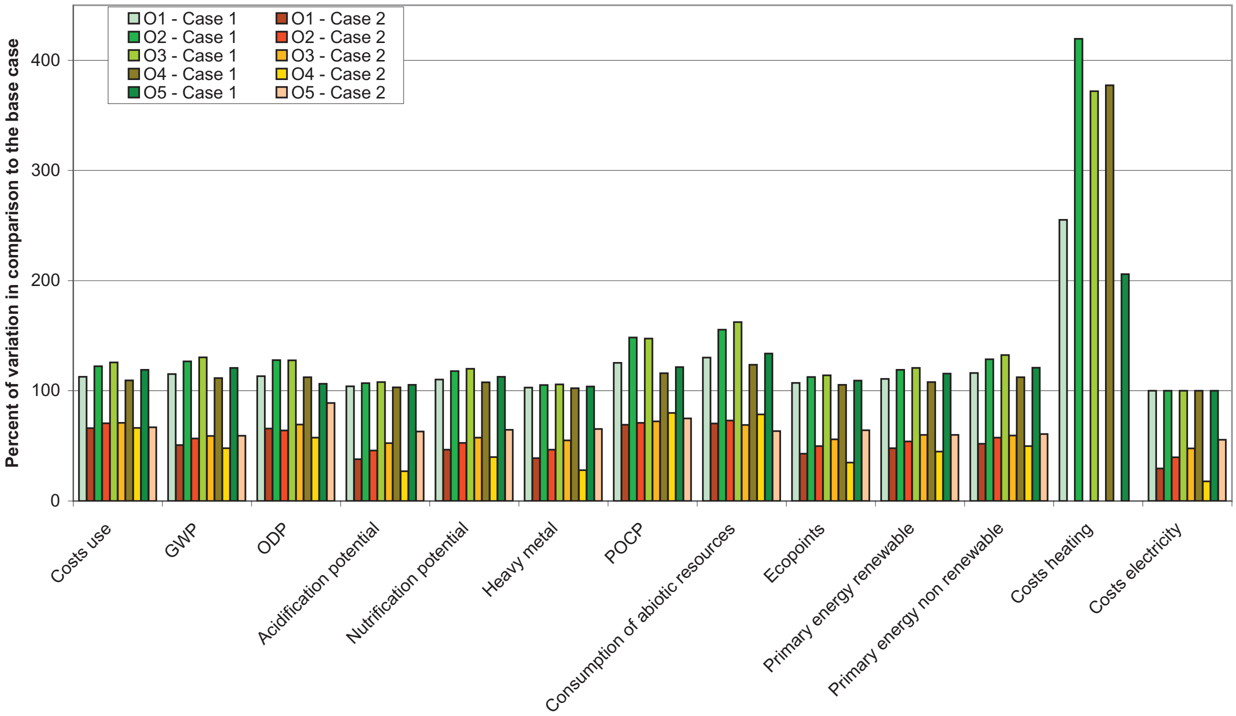
Variation of LCA results due to change in the renovation cycles of construction elements



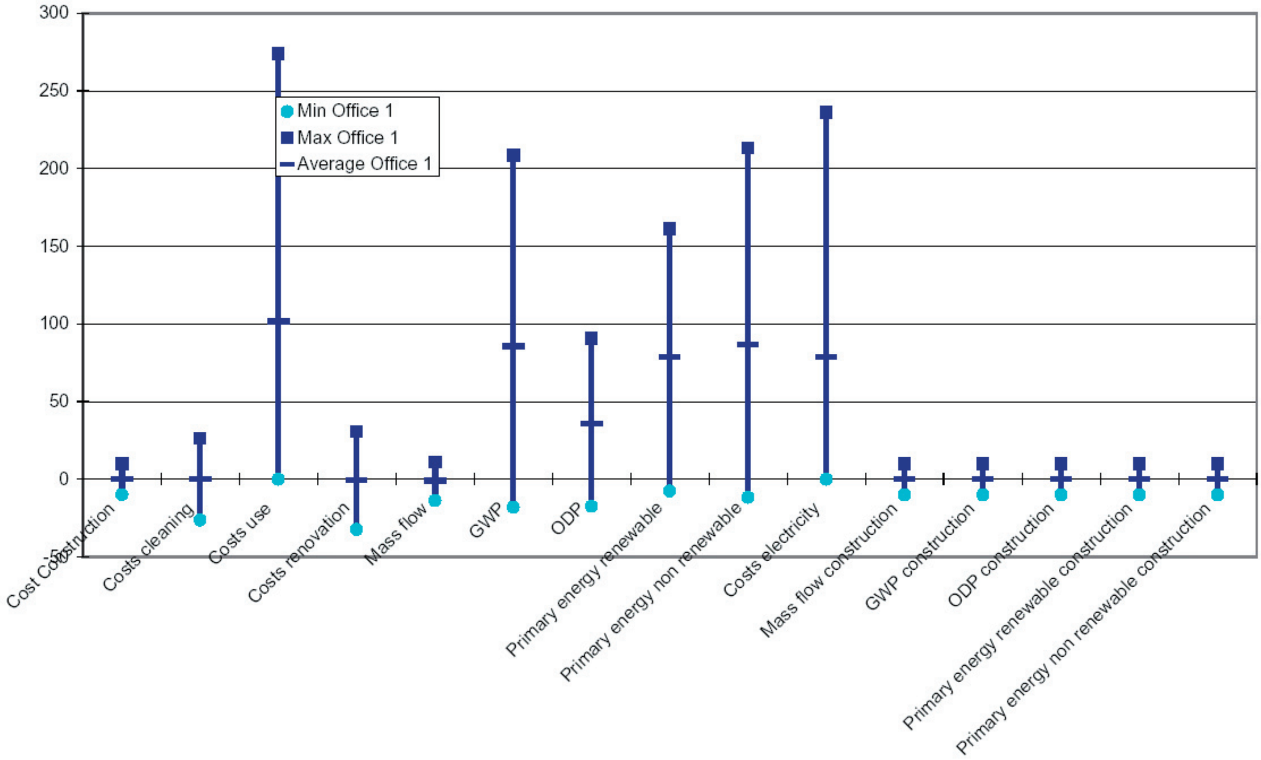

Variation of LCA results due to change in the quantity of construction elements
Percent of variation in comparison to the base case
120
100
80
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Mass flow construction
GWP construction
ODP construction
Acidification potential construction
Nutrification potential construction
Heavy metal construction
POCP Construction
Consumption of abiotic resources construction
Ecopoints construction
Primary energy renewable construction
Primary energy non-renewable construction

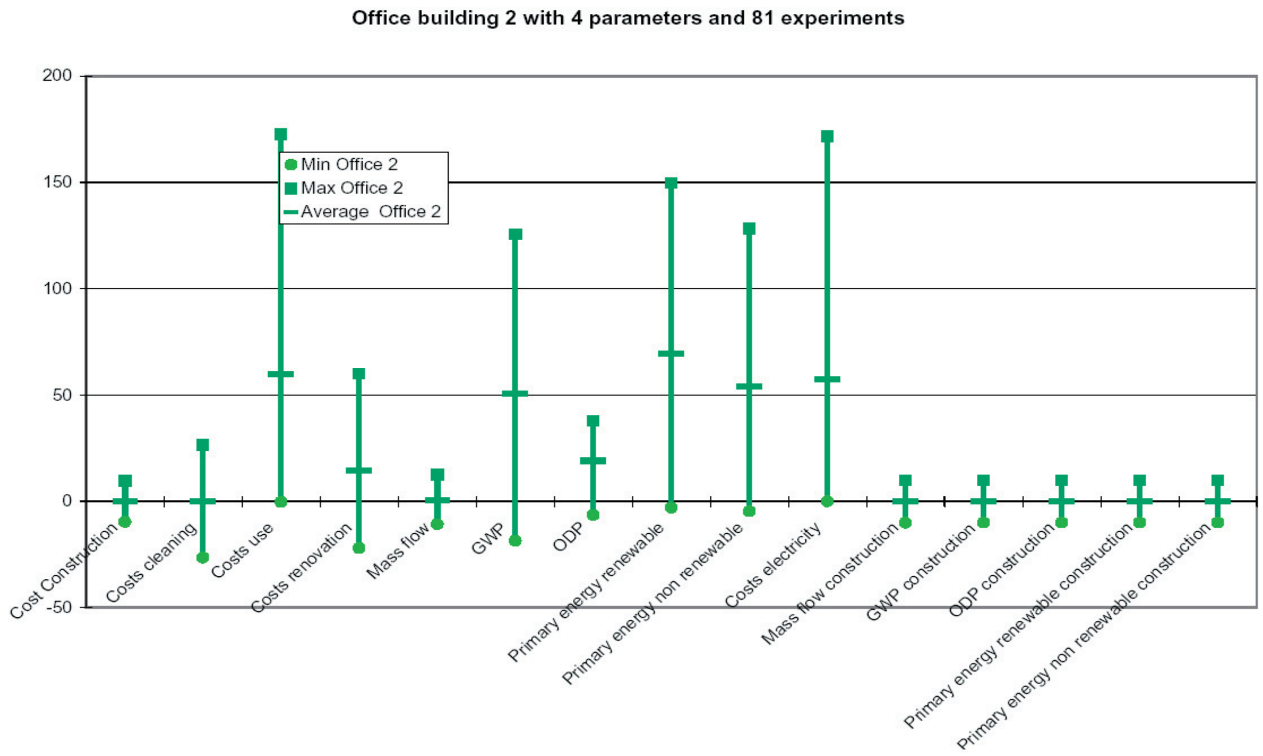

Variation of LCA results due to change in the quantity of construction elements
Percent of variation in comparison to the base case
100
80
O1 - Case 1
O2 - Case 1
O3 - Case 1
O4 - Case 1
O5 - Case 1
O1 - Case 2
O2 - Case 2
O3 - Case 2
O4 - Case 2
O5 - Case 2
Costs construction
Costs cleaning
Costs maintenance
Costs renovation
Costs demolition
Mass flow
GWP
ODP
Acidification potential
Nutrification potential
Heavy metal
POCP
Consumption of abiotic resources
Ecopoints
Primary energy renewable
Primary energy non renewable

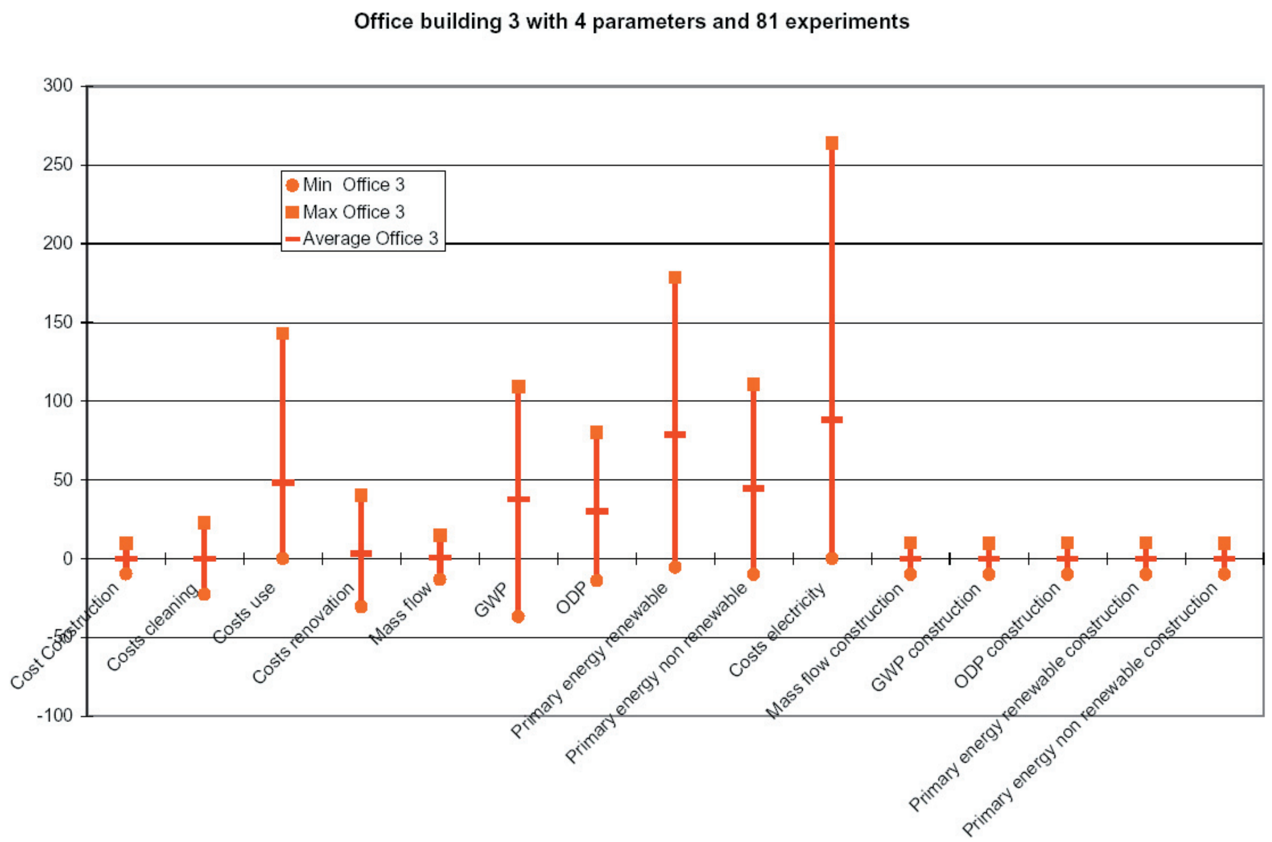
Variation of LCA results due to change in the energy consumption standard of the building



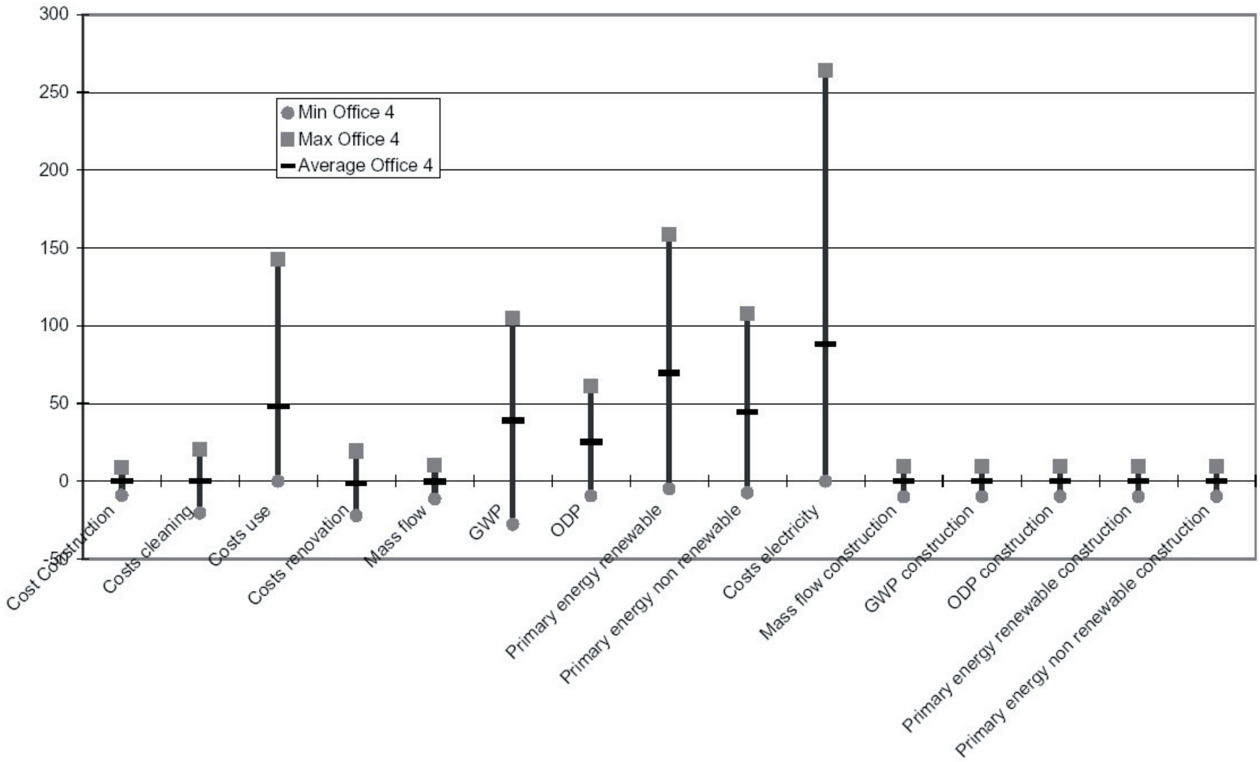
Office building 1 with 4 parameters and 81 experiments




Office building 2 with 4 parameters and 81 experiments
Min Office 2
Max Office 2
Average Office 2
200
150
100
50
0
-50
Cost Construction
Costs cleaning
Costs use
Costs renovation
Mass flow
GWP
ODP
Primary energy renewable
Primary energy non renewable
Costs electricity
Mass flow construction
GWP construction
ODP construction
Primary energy renewable construction
Primary energy non renewable construction


Office building 3 with 4 parameters and 81 experiments
Min Office 3
Max Office 3
Average Office 3
300
250
200
150
100
50
0
-100
Cost Construction
Costs cleaning
Costs use
Costs renovation
Mass flow
GWP
ODP
Primary energy renewable
Primary energy non renewable
Costs electricity
Mass flow construction
GWP construction
ODP construction
Primary energy renewable construction
Primary energy non renewable construction

Office building 4 with 4 parameters and 81 experiments



Office building 5 with 4 parameters and 81 experiments