Introduction to LCA of Buildings

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Introduction
to LCA of Buildings

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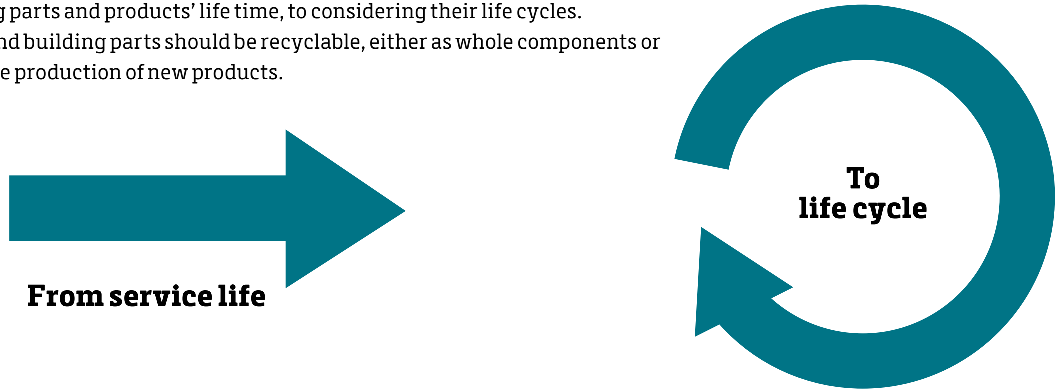
Introduction

Life cycle assessment (LCA) is a method which is being increasingly used to evaluate the potential environmental impacts of products and services and their resource consumption. LCA is also being used in the building sector, where it is a crucial part of the assessment of buildings environmental sustainability. The life cycle approach moves focus from factors related to the completed building, to involving the entire life cycle of the building. LCA is included in European standards for sustainable construction, Construction Products Regulation (CPR) and in the certification schemes for sustainable building. LCA is also named as an important part of the focus area sustainable building in the Danish government's building policy strategy from 2014.

For the different players working in the assessment of the environmentally related part of sustainable building, LCA provides a basic knowledge of the parameters that contribute to resource use and the potential environmental impacts during a building's life cycle. Incorporating LCA as a tool in the building design stage, makes it possible to evaluate the environmental significance of building elements or of the different life cycle stages of the building. LCA can thus be used as part of the environmentally friendly design of buildings and in documenting the results.

Figure 1

More sustainable solutions will be achieved by shifting the focus from optimising the building parts and products' life time, to considering their life cycles. Materials and building parts should be recyclable, either as whole components or as part of the production of new products.



This introduction to LCA of buildings is published in relation to the launch of the tool for LCA of Buildings – LCAbyg. The publication is also related to a number of other publications on sustainable building: "Vejledning for bæredygtigt byggeri" (Guidelines on Sustainable Building), "Introduktion til LCC på bygninger" (Introduction to LCC of Buildings) and "Bygningens livscyklus" (A building's life cycle).

This publication provides an introduction to:

- **How LCA can be used in the building design process**
- **How a building's life cycle can be characterised**
- **How to implement LCA of buildings in practice**

This publication is intended for architects, consultants, developers, contractors and others who wish to gain an insight into how LCA can be used as a part of the development of sustainable building.

A building's life cycle

A life cycle assessment of a building normally involves evaluating its whole life cycle. This means including all of the stages in the assessment – raw material supply, manufacture of construction products, the construction process stage, use stage, demolition and when the materials are disposed of or recycled.

The building's life cycle is therefore divided into five stages which need to be dealt with: The product stage, construction process stage, use stage, the end-of -life stage and benefits and loads beyond the system boundary.

Most often, the first two stages are the best known, even though in practice acquiring sufficient data for the calculations can be problematic. The next three stages are scenario-based, which means that assumptions have to made about how the building will be used, maintained, and finally demolished. According to European standard EN 15978:2011, the final stage, which concerns the recycling of building waste, must be reported as a separate part of the calculations.

1. Product stage

The product stage concerns the processes which involve the production of construction products used in the building: Raw material supply, transport to the production site as well as the final production of the construction products.

2. Construction process stage

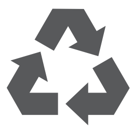
The construction process stage involves the construction products' journey from production line to the point where they are installed as a part of the finished building: Transport from the manufacturer to the construction site as well as installation in the building.

3. Use stage

The use stage involves the processes related to the construction products' continued performance as part of the building, e.g. maintenance, replacement, repair. Processes related to the building's ongoing operational energy and water use are also included. Most often, the processes will be based upon scenarios, i.e. perceptions about how the processes will take place.

4. End-of-life stage

The processes in this stage are also scenario-based. They concern what happens when the building reaches the end of its life, i.e. the building's demolition and the subsequent processes involved in reprocessing or handling the construction products/materials before further use of in other product systems.



5. Benefits and loads beyond the system boundary

This scenario-based stage contains the calculated gains and drawbacks from reusing and recycling construction products/materials. In accordance with the European standards, contributions from this stage must be considered outside the system boundary and be reported separately.

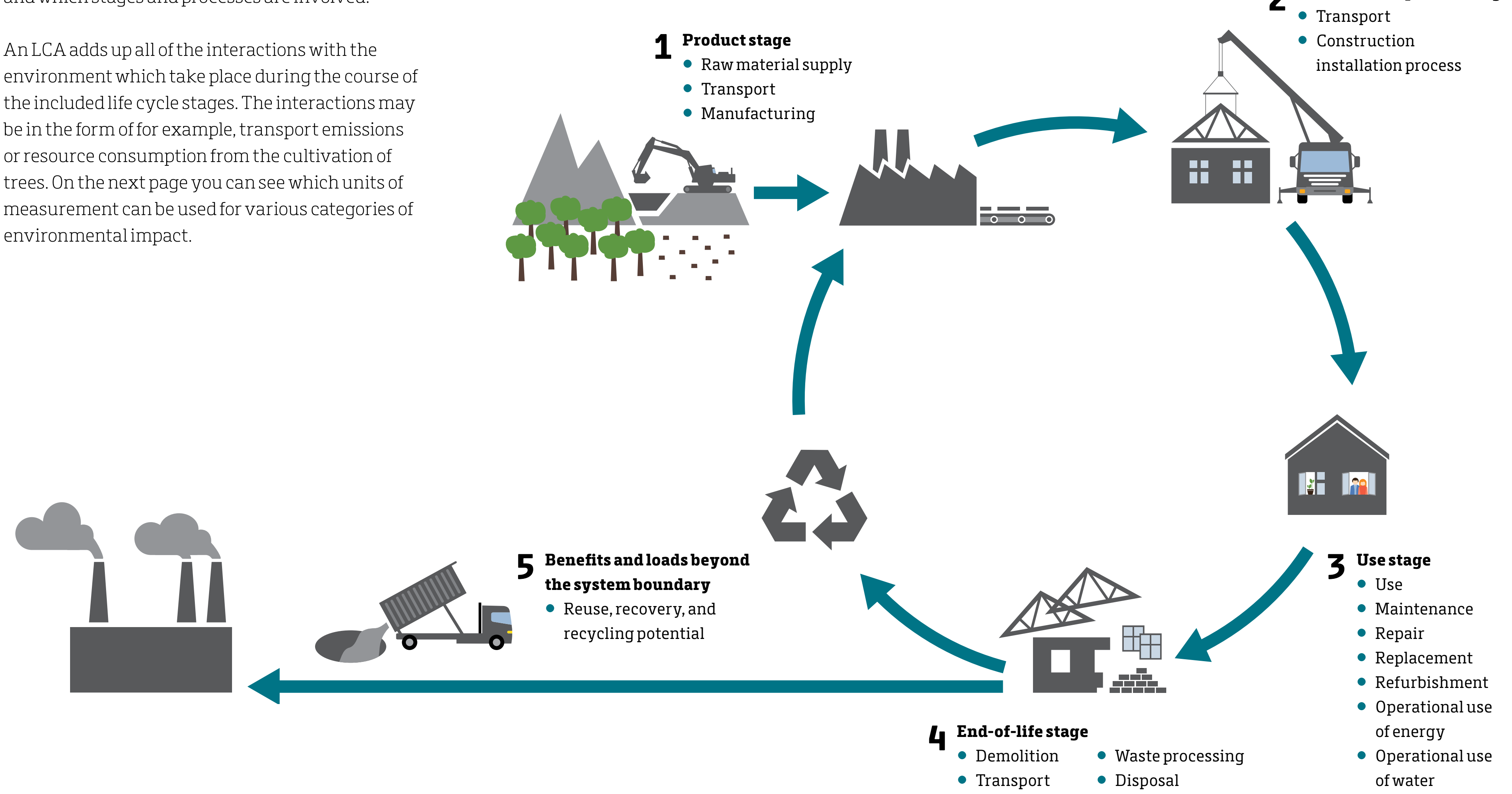
What does a building's life cycle look like?

Figure 2 illustrates the typical life cycle for a building and which stages and processes are involved.

An LCA adds up all of the interactions with the environment which take place during the course of the included life cycle stages. The interactions may be in the form of for example, transport emissions or resource consumption from the cultivation of trees. On the next page you can see which units of measurement can be used for various categories of environmental impact.

Figure 2

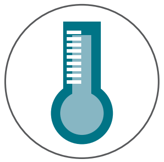
Typical stages of a building's life cycle: The product stage, construction process stage, use stage, the end-of -life stage and benefits and loads beyond the system boundary.



Typical environmental impacts which are included in a life cycle assessment

LCA involves surveying all of the inputs and outputs linked to the examined system's life cycle. The potential environmental impacts are calculated on the basis of all of the inputs and outputs, i.e. consumption of resources and emissions which can be associated with the different processes.

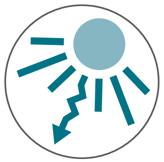
The results of a life cycle assessment can be calculated using a selected range of measurable indicators. The most used indicators for assessing environmental impact and resource use are shown below.



- **Category**
  Global Warming Potential (GWP)
- **Unit**
  CO_2 equivalents
- **Problem**
  When the quantity of greenhouse gasses in the atmosphere increases, the atmospheric layers near the earth are heated up, resulting in climate change.

- **Category**
  Acidification Potential (AP)
- **Unit**
  SO_2 equivalents
- **Problem**
  When acidifying substances react with water and falls as 'acid rain', this leads to, among other things, decomposition of root systems and leaching of nutrients from plants.

- **Category**
  Abiotic Depletion Potential for Fossil Resources (ADPf)
- **Unit**
  MJ
- **Problem**
  Heavy consumption of abiotic resources can contribute to the depletion of available fossil energy sources such as oil or coal.



- **Category**
  Depletion Potential of the Stratospheric Ozone Layer (ODP)
- **Unit**
  R11 equivalents
- **Problem**
  Depletion of the stratospheric ozone layer which protects flora and fauna against the sun's harmful UV-A and UV-B radiation.

- **Category**
  Eutrophication Potential (EP)
- **Unit**
  PO_4 equivalents
- **Problem**
  An excessive supply of nutrients generates unwanted plant growth in delicate ecosystems, for example the growth of algae which results in the death of fish.

- **Category**
  Total Use of Primary Energy (PEtot)
- **Unit**
  MJ or kWh
- **Problem**
  A high use of resources in the primary energy form from fossil and renewable sources can contribute to depletion of natural resources.

- **Category**
  Formation Potential of Tropospheric Ozone Photochemical Oxidants (POCP)
- **Unit**
  Ethylene equivalents
- **Problem**
  Contributes in connection with UV radiation to the formation of ozone in the lower atmosphere (summer smog) which is damaging to the respiratory system, etc.

- **Category**
  Abiotic Depletion Potential for Non-fossil Resources (ADPe)
- **Unit**
  Sb equivalents
- **Problem**
  A high use of abiotic resources can contribute to the depletion of available elements, e.g. depletion of metals and minerals.

- **Category**
  Use of Renewable Secondary Fuels (Sec)
- **Unit**
  MJ or kWh
- **Problem**
  Secondary fuels (e.g. waste) are in principle limited resources, and therefore a high use of secondary fuels can indirectly lead to scarcity of resources.

What can an LCA show?

Life cycle stages' significance

LCA can provide you with an overview of the environmental impacts in the different stages of a building's life cycle.

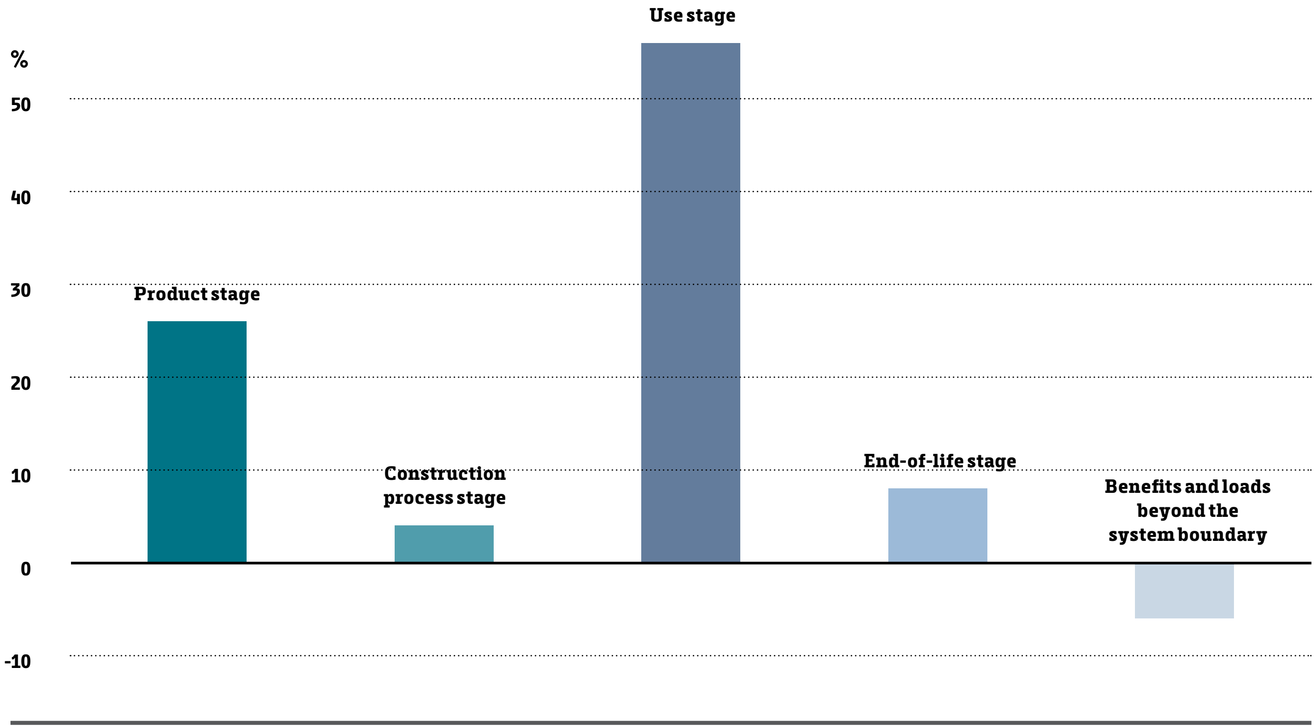
The figure on the right illustrates how a building's LCA results for an impact category, in this case the global warming potential, can be divided among the different life cycle stages that are included. From there, it is possible to bring focus to bear on the most prominent life cycle stages and try to minimise the adverse contributions.

An LCA helps you to prioritise your optimisation efforts on an informed basis and assess the individual processes against the larger perspective of the building's total life cycle. For example:

- **How are impacts from materials versus impacts from operational energy distributed?**
- **How much do the different building parts contribute to the total impacts?**
- **How can the selection of materials be optimised in order to reduce the environmental impacts?**

Figur 3

An example of the contribution distribution of environmental impact from different life cycle stages. In this case, the distribution of global warming potential (GWP) as a percentage.



1. Materials versus energy

As shown in the figure below, LCA allows you to divide the processes into those that are related to energy use during the building's use stage and those that are related to materials. The latter are often described as "embodied" impacts.

Environmental impacts from energy use have traditionally been the greatest contributor to a building's LCA results. Since it is expected in the future buildings will use less operational energy and this energy will come from renewable energy sources, it means embodied impacts from construction products will become proportionally more significant in the total LCA for a building.

2. The significance of building parts

LCA gives you an overview of how the different building parts contribute to the overall environmental impacts. In this way, you can get help when deciding which building parts you will need to be aware of if you want to limit the potential environmental impacts from your building.

Or, as shown in the figure below, you can test different building forms and see how the overall results change as well as the distribution between each building part.

3. Significance of materials

With LCA, you can compare materials or construction products with the same properties on their environmental profile. In this way, you can get help in assessing the environmental profile of different solutions, for example, with the choice of materials for building parts.

Note that the results of the many categories of environmental impacts cannot be combined to make a single score result. This means it is necessary to evaluate the results for the different categories separately.

Figure 4

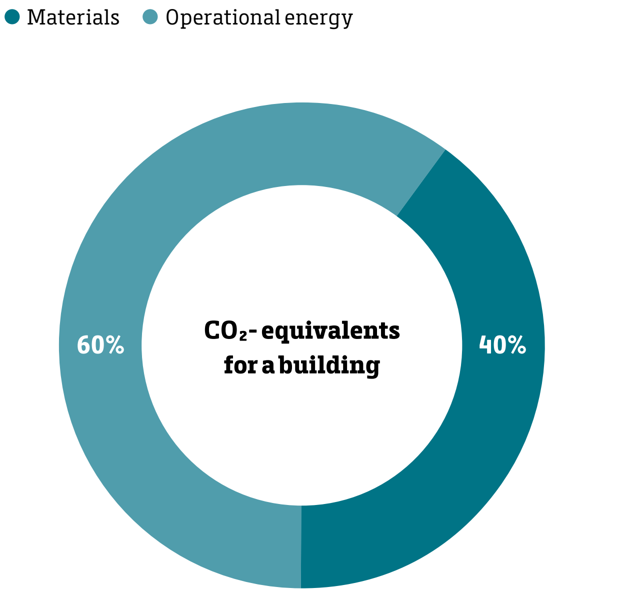


Figure 5

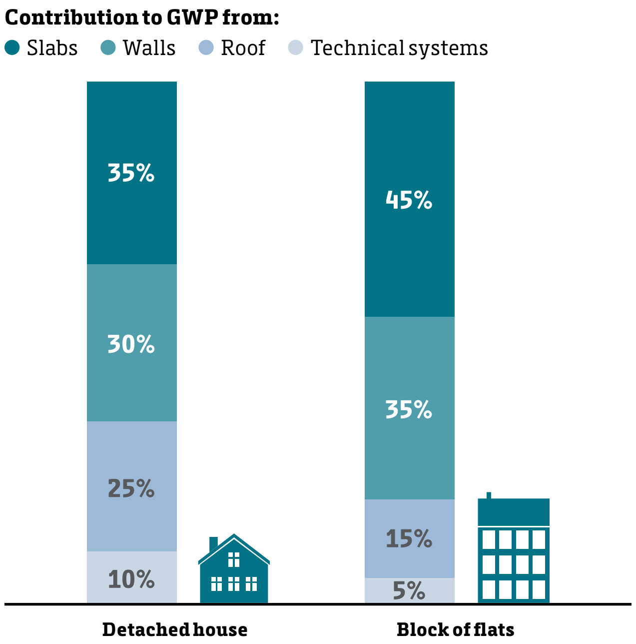
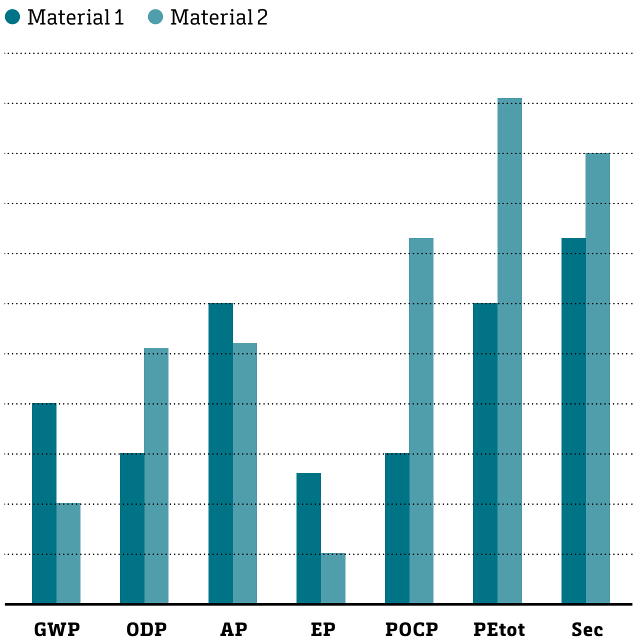


Figure 6



What is needed
to perform LCA on a building?

In order to carry out an LCA of your building, you must have knowledge about and access to the following, which is described in detail on the next pages:

INFORMATION ABOUT THE BUILDING

- Materials and quantities
- Service life of the building and construction products
- The building area
- Energy in the operation stage

Page 10

TOOLS

- Underlying data
- Calculation tools

Page 13

LCA SPECIFIC CONSIDERATIONS

- Life cycle stages
- Categories and indicators

Page 15

Materials and quantities

Information on quantities of all of the used materials shall be used to calculate the building's potential environmental impact in an LCA calculation.

Depending on the aim of the LCA, the specification may be more or less detailed. For the purpose of early screening, it may be sufficient to make calculations on the main components in the primary building parts. A more detailed assessment contains more information, e.g. a more detailed material specification. In principle, the LCA can be calculated down to the last screw and seal in your building, but it can be a time-consuming process to survey amounts in such great detail.

Collecting the data on material consumption is certainly the most time-consuming part of carrying out an LCA. This is because under normal circumstances there is never a final calculation for the total consumption of all of the individual materials. This is why it is often necessary to piece together this information on the basis of, for example:

- **Tender documents**
- **BIM models**
- **Drawings**
- **Product information for the used construction products**

Subsequently, all of the materials are associated with one or more datasets for the processes that are to be included in the life cycle. Datasets can originate from databases or from specific environmental product declarations (see page 13).

In most Danish buildings, cement-based materials and/or brick constitutes a great part of the building's overall mass, as illustrated in figure 8. However, this does not necessarily mean that these materials represent the greatest contribution to the LCA results. Kilogram for kilogram, there can be great differences in the environmental data between the materials.

Figure 7

Examples of material in an external wall.

- 13 kg fibre cement per m² external wall
- 10 kg mineral wool per m² external wall
- 47 kg aerated concrete per m² external wall

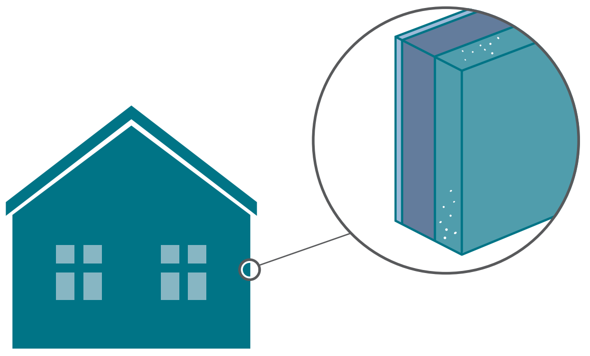
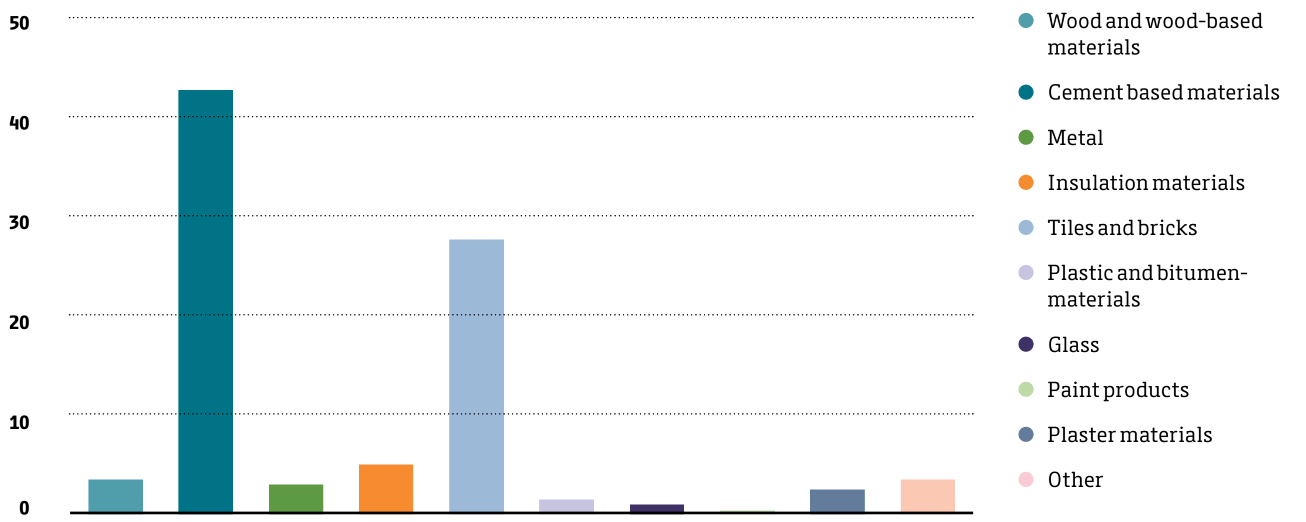


Figure 8

1,000 kg material used in the construction of a typical Danish single family, single-storey house.



Service life of buildings and construction products

The reference study period denotes the total number of years the life cycle assessment is calculated for. The selected period therefore has significance for how many replacements of construction products are included in the calculations, and what the total operational use of energy for the use stage is. As a starting point, it is recommended that the building's required service life is used as the reference study period.

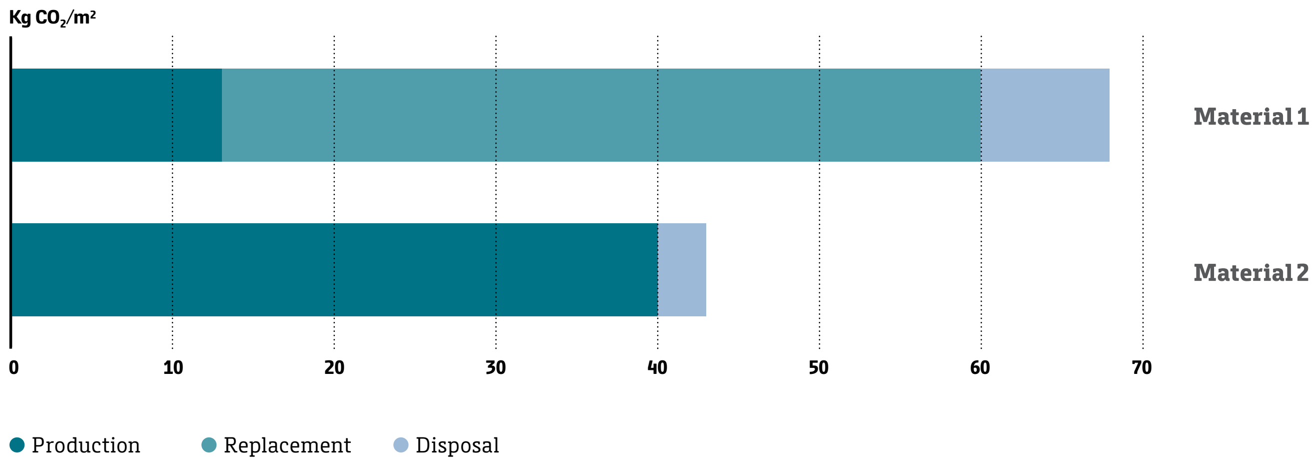
The reference study period is often used in the analysis of results. A building's LCA results are distributed over the number of years in order to make them comparable with other buildings' LCA results, even though the service life for the compared buildings may not be identical. If a short period of time is used for this annual distribution of impacts, for example 30 years, long-lasting materials will appear worse than if a period of 70 years is selected.

Naturally, the service life of construction products included in the building, are also significant for the building's overall LCA results. In the sense that, the more frequently a construction product needs to be replaced, the greater the number of construction products need to be produced. The increased production leads to further environmental impact, so there may be benefits associated with envisaging long-lasting materials for use in the building's design.

There are various sources on the average service life for materials and construction products, including the Danish Building Research Institute report 2013:30, "Levetider af bygningsdele ved vurdering af bæredygtighed og totaløkonomi" (Service life of building parts when assessing sustainability and overall economy).

Figure 9

Example of distribution of two alternatives for the section of material with very different service lives. Material 1 must be replaced frequently and therefore overall, it contributes more to the building's LCA results than Material 2, which is long lasting.



Recommended service life of buildings

Building	Examples	Service life
Home, office, institution, teaching and culture.	For example, home, office, hotel, restaurant, cultural centre, school and institutions.	100 years
Production and leisure buildings	Factories, warehouses, transport centres, etc.	60 years
Smaller buildings for storage	Garages, carports, outhouses, etc.	40 years

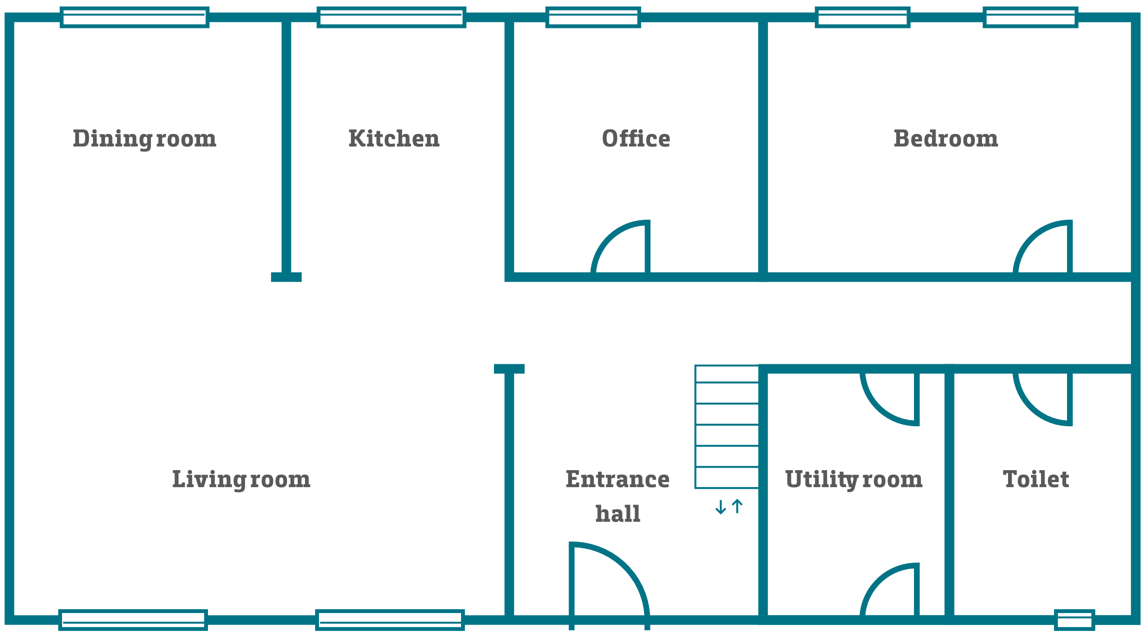
The building area

In order to compare different buildings' LCA results, the results need to be calculated using the same units. In most cases, the results for each indicator are calculated per m^2 per year, e.g. 10 kg CO_2 equivalent/m^2/year. In this case, we divide the building's total emissions of greenhouse gasses throughout the whole life cycle across building floor area and the number of years that have been selected as the reference study period.

The building floor area is the Building and Dwelling Register (BBR) area, which is a sum of the gross area of all the floors. The gross area is measured to the outside of the exterior walls.

Figure 10

Example of floor plan for measuring floor space.



Energy during the operation stage

A building's expected energy requirements during the use stage is an important contributor to the results of an overall LCA for a building. This means that it is important to know:

- **Energy requirement per m^2/year in kWh or MJ**
  Needed for building operation.
- **Energy supply composition**
  Environmental impacts may vary considerably, all according to the technology that lies behind the production of electricity and heat. For example, the environmental impacts from a gas fired and a wood fired boiler differ.

The European standards for the LCA of buildings, prescribe the use of energy EPDs for calculating environmental impact from electricity and heat.

Because electricity and district heating supply combinations change over time, there are however different approaches in how it is included in the building's life cycle, which is expected to last for up to 100 years in the future. Basically, there are two different approaches:

1. The present day scenario for energy supply is used for the whole of the reference study period. In other words, the present combination of energy technology is used for every year in the calculation of the reference study period.
2. Projected scenarios for energy supply. This approach covers a projection of the energy technologies that lie behind the energy supply.

Data

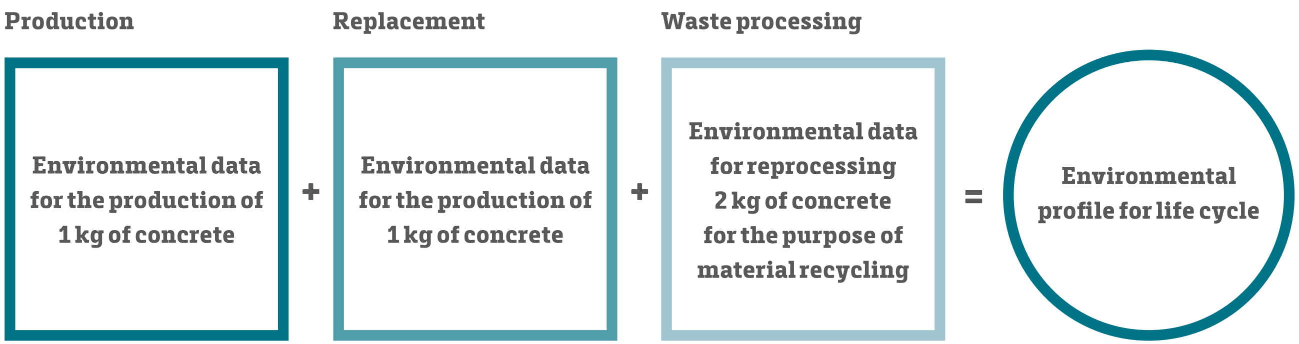
Data for materials and processes which are included in the life cycle of a building are linked with relevant LCA data. Data may be generic data, i.e. average data for a product group, or it can be product-specific data from a given manufacturer. This data is obtained through LCA databases or through Environmental Product Declarations (EPDs) for specific products.

There is no original Danish LCA database listing construction products. This means that it is important to be aware that data which may be obtained from databases from other countries may not necessarily reflect Danish conditions. The imbalance this gives to the results must be kept in mind, and ffor example, the interpretation of results should focus on the relationships between building parts and not the precise figures for each building part.

LCA data for individual construction products' selected life cycle stages is linked to the used quantities of construction products in the building, as illustrated in the example in figure 11. The same linkage is implemented for all construction products included in the building, and on that basis, the total LCA results are calculated.

Figure 11

Example of linkage between quantities and environmental data.



Environmental Product Declarations

An Environmental Product Declaration (EPD) documents a construction product's environmental qualities, and it is developed in accordance with recognised European and international standards. In other words, it is a standardised method for supplying information about the consumption of energy and resources as well as environmental impacts from production, use and disposal of construction products.

- **Visit the EPD Danmark website for Environmental Product Declarations of construction products from the Danish EPD program.** (www.epd.dk)
- **Visit the EPD Norway website for Environmental Product Declarations of construction products from the Norwegian EPD program.** (www.epd-norge.no)
- **Visit the Institut Bauen und Umwelt website for Environmental Product Declarations of construction products from the German EPD program.** (www.bau-umwelt.de)
- **Visit the ECO Platform website for Environmental Product Declarations of construction products from the European EPD program.** (www.eco-platform.org)

Calculation tools

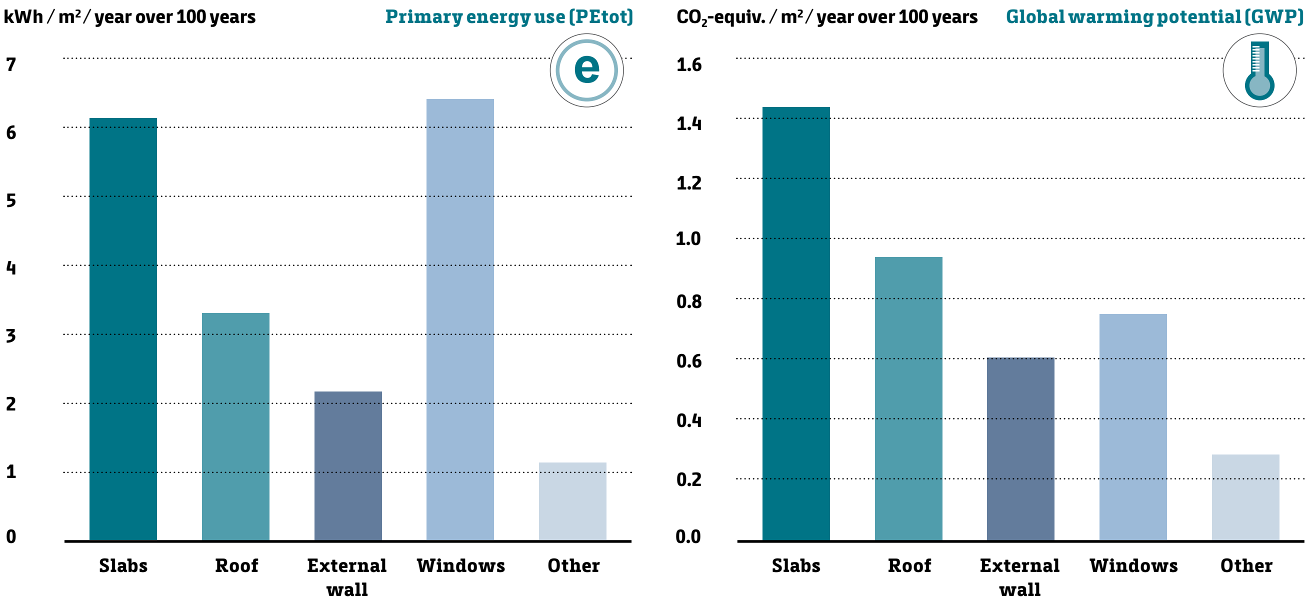
The actual calculation of the LCA results should be carried out when all of the material quantities have been identified and the data for all of the materials and processes are available.

Software tools intended for this purpose make the calculations much easier. They will often also provide options for different ways of displaying and analysing the results, which can make it easier when using the final LCA results.

There are a number of different tools on the market. Most of these tools require some form of licence, however there are also some tools that are freely available.

Figur 12

Examples of selected results for an office block construction, calculated using LCAbyg software tool.



LCAbyg

LCAbyg is an LCA tool developed by the Danish Building Research Institute. It was launched in spring 2015. LCAbyg allows you to calculate a building's environmental profile and its consumption of resources. Enter the information about the building parts and if required, the building's operational energy use. The tool automatically performs the LCA calculations and compiles the results in a report.

LCAbyg is based on a German database for construction products, Ökobau. This programme can calculate a number of the building's life cycle stages on a sample of the indicators that are found in the European standards for assessing the building's environmental quality.

The program is flexible and it can be used for new buildings and for refurbishment projects. LCAbyg contains a few building examples that can be used for inspiration. These show the type of information that an LCA for a building contains, and the LCA results of a couple of typical Danish buildings.

LCAbyg is freely available and it can be downloaded from The Danish Transport and Construction Agency's homepage (www.trafikstyrelsen.dk/DA/Byggeri/Baredygtigt-byggeri/Livscyklusvurdering.aspx)

System boundaries

Definition of the LCA system boundaries are an important parameter when an LCA is to be carried out. The system boundary tells you which phases and which processes during each stage are included in the LCA.

An understanding of the LCA system boundaries is also important when LCA results from construction products need to be used in an assessment of a building in order to make decisions based on it.

The system boundaries must be clearly defined and easy to make out for the LCA results to be transparent.

The European standard EN 15978:2011 defines the building's life cycle stages as shown in the figure below.

Note that LCAs of buildings rarely include all of the stages and processes that must be included in accordance with the standard. This may be due to insufficient underlying data or it may be because the aim of the LCA justifies simplification.

Irrespective of the grounds for simplification, it ought to be shown clearly which processes are included in an LCA.

Figure 13

Life cycle stages as defined in the European standard EN 15978:2011.

Module	A1-A3			A4-A5		B1-B7							C1-C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - installation proces	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/ demolition	Transport	Waste processing	Disposal	Reuse, recovery, and recycling potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Categories and indicators

The potential environmental impacts and resource consumption from a building's life cycle is calculated in categories, for example global warming. Within each category the extent of the impact is measured in an indicator unit. For example, the indicator unit is kg CO_2 equivalents for the category global warming.

The categories which are selected for an LCA should reflect as broadly as possible potential consequences for the three main protection areas:

1. **Human health**
2. **The natural environment**
3. **Natural resources**

In LCAbyg, a decision has been made to use the nine categories introduced on page 6. These nine categories have primarily been selected because they are used in the database which is included in LCAbyg, Ökobau.dat. At the same time the categories are a sample of the categories that are used in connection with the European standards for sustainable building (see page 17). In addition to the categories that are used in LCAbyg, there are many other categories and indicators which contribute to a more detailed picture of the consequences for environment and resource stocks, e.g. the categories shown in figure 14.

It is important to remember that the results which are obtained within the selected categories cannot immediately be added up across the categories. Only with a preceding process that includes principles on normalising and weighting, can the results be added up across the categories. It is however a process that requires specialised knowledge since it implies balancing the various environmental consequences.

Figure 14

Examples of different categories for further illustration of potential impacts and use of resources.

Background
– standards for LCA

The life cycle assessment method is standardised, both generally and for all products with ISO standards, and specifically for buildings and construction products with the European EN standards. It is important that you are familiar with these standards since they establish an important framework for how LCA should be implemented, both generally and specifically for buildings and construction products.

General procedure for LCA

- **DS/EN ISO 14040:2008 Environmental management – Life cycle assessment – Principles and framework**
  The standard outlines the principles for compiling an LCA, e.g. requirements for data transparency, etc.

- **DS/EN ISO 14044:2008 Environmental management– Life cycle assessment – Requirements and Guidelines**
  The standard describes requirements for implementation of LCA. It is an aid for implementing an LCA and it is normally referred to.

Specifically for buildings

- **EN 15643-2:2011 Sustainability of construction works. Assessment of buildings. Part 2 Framework for the assessment of environmental performance**
  This standard outlines requirements and assessment of environmental impacts from building.

- **EN 15978:2011 Sustainability of construction works. Assessment of the environmental performance of buildings. Calculation method**
  This standard outlines the calculation method for implementing LCA of buildings.

- **EN 15804:2012 Sustainability for construction works. Environmental product declarations. Core rules for the product category of construction products**
  This standard outlines structure, content and principles of an Environmental Product Declaration (EPD) for construction products in order to ensure that they are made according to the same procedure and are presented in a uniform format.

Find out more

Further information about sustainable building (Danish reports):

- **The government building strategy.** Published by the Danish Ministry of Climate, Energy and Building, 2014.

- **"Bæredygtigt byggeri" (Sustainable building).** Published by the Danish Energy Agency, 2015

- **"Kortlægning af bæredygtigt byggeri." (Surveying sustainable building).** Published by the Danish Building Research Institute, 2013.

About LCA of buildings:

- **"Bygningens livscyklus – Identifikation af væsentlige bygningsdele, materialegrupper og faser i en miljømæssig vurdering" (A building's life cycle – Identification of significant building parts and stages in an environmental assessment).** Published by the Danish Building Research Institute, 2015.

- **"LCA-profiler for bygninger og bygningsdele" (LCA profiles for buildings and building parts).** Published by the Danish Building Research Institute, 2014.

- **"Arkitektur og miljø – form, konstruktion, materialer og miljøpåvirkning" (Architecture and environment – form, construction, materials and environmental impact).** Published by Arkitektskolens Forlag, 2000.

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Danish Building Research Institute

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