TREES **Training for Renovated Energy Efficient Social housing**

Intelligent Energy Europe

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Section 2 Tools

2.3 Life cycle assessment

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1. Introduction

The building sector is a major source of environmental impacts :according to the United Nations Environment Programme[1] it represents 40% of the total energy consumption in the world, 30% of raw materials use, 20% of water consumption and effluents, and materials consumption, as well as 40% CO2 emissions, and 30% waste generation. In Europe, its contribution to the total energy consumption is around 45%.

There is a large potential to reduce these impacts thanks to a proper design of new buildings and renovation projects (e.g. bioclimatic architecture, passive buildings), the implementation of low impact techniques (e.g. thermal insulation, solar energy systems, low flow rate sanitary equipment) and behavioural measures (e.g. choice of thermostat set points, use of low consumption lights and appliances, domestic waste sorting etc.).

Eco-design means Integrating environmental aspects during the design of a product. It can be applied to new constructions and renovation projects. These environmental aspects include :

- Preservation of resources (energy, water, materials, land),
- Protection of ecosystems at different scales : planetary (climate, ozone layer), regional (forests, rivers…), local (waste, air quality…),
- Links between environment and health (toxicity).

Various methods are proposed to evaluate the environmental quality of buildings. In general, these methods integrate issues of concern like the protection of the human health and eco-system (e.g. protection of the climate, fauna and flora), and the efficient use of resources (energy, water, materials). Life cycle assessment (LCA) allows a quantification of indicators related to these issues and is widely used among industrials as well as academics.

Life cycle assessment also allows various alternatives to be compared, therefore helping in decision making. This method has first been elaborated in the industry sector, but it can be applied in the building sector for various purposes :

- manufacturers can study the eco-design of building materials and equipment,
- architects and building consultants can compare various alternatives during the design phase in order to reduce the environmental impacts of a project,
- facility managers can study the influence of the users behaviour and advise appropriate measures during the operation phase of a building,
- building owners and local communities can require and check the environmental performance level of projects.

LCA studies are snapshots in a dynamic environment – so their significance relies on appropriate estimations of future trends. This applies especially for the building sector with the long life span of its products.

Economic optimisations are insufficient or even lead to wrong conclusions because they don't integrate external costs. Economy generated many environmental problems – we can't solve them with the same mechanisms, therefore environmental studies like LCA are needed.

Several tools have been developed. This paper presents the method and tools, illustrating their application by case studies.

[1] Sustainable building and construction initiative, 2006 information note, www.unep.fr

2. Presentation of the Method : Life cycle assessment applied to buildings

Evaluating the environmental quality of buildings has been discussed in various seminars (e.g. [1]). The ISO standards for environmental management[2] include various tools : a management system (how to organise an environmental quality approach in an organisation), audit (how to identify the strong and weak aspects e.g. in a factory, and to propose improvement measures), labels (how to inform consumers about the environmental quality of products), environmental performance assessment (how to evaluate the environmental impacts of an organisation), and life cycle assessment (how to evaluate the environmental impacts of a product).
The life cycle assessment (LCA) method [2.3] allows the whole life of a complex system to be studied. The ISO 14 040 series includes several parts :

- 14040 : principles and framework (2006)
- 14041 : goal and scope definition and inventory analysis (1998)
- 14042 : life cycle impact assessment (2000)
- 14043 : interpretation (2000)
- 14044 : requirements and guidelines (2006)
- 14047 : examples of application of ISO 14042 (2003)
- 14048 : data documentation format (2002)
- 14049 : examples of application of ISO 14041 (2000)

More information can be obtained from the web site of the technical committee 207 in charge of environmental management within ISO : www.tc207.org

Regarding LCA applications in the construction sector, occupants behaviour and interactions with the surrounding site should be taken into account, so that a specific approach must be developed for buildings [4]. Specific standards have been elaborated by the French standardisation organisation, AFNOR :

- P 01-010 : information about environmental characteristics of construction products
- P 01-020 : environmental and sanitary characteristics of buildings
- P 01-030 : environmental management of building projects

LCA methods represent a rational approach, which can evolve with the progress of knowledge, and this may help various actors to agree on common strategies. The interest and potential of new technologies can be assessed by this precise approach. Another advantage is the standardisation of LCA [3], allowing a link between evaluations concerning materials and buildings.

A general framework for applying LCA in buildings has been elaborated in the European project REGENER [4], accounting for previous experience in The Netherlands [5] and Germany [6]. Such a model has been developed within the French EQUER project (Evaluation of environmental quality of buildings) [7] and is presented hereunder, as well as an intercode comparison performed in the frame of the European thematic network PRESCO [8].

The different phases considered in a building life cycle are: the fabrication of components, the construction, the use of the building, the renovation and the renewal of components, the final dismantling and the treatment after use of components. The possible reuse and recycling of components is also taken into account.

[2] ISO 14 000 series, see http://www.tc207.org/

LCA regards environmental impacts : aspects related to indoor comfort are supposed to be addressed by other existing tools. Therefore the evaluation of indoor air quality, illumination and noise level as well as the thermal comfort analysis are not dealt with in this presentation. They are however implicitly taken into account in the definition of the "functional unit", see next § 2.1.

The ISO 14040 standard [3] defines the following steps of an LCA :

- Goal and scope definition, including :
  - Functional unit (see § 2.1)
  - Systems boundaries (see § 2.2)
- Inventory analysis

The overall input and output - material and energy fluxes - related to a building during its life cycle are calculated by the tool and constitutes the inventory of the building (see § 2.3). The models considered for energy, transport and recycling processes should be presented (see § 2.4).

- Impact assessment, environmental profile

The used method for aggregating the data of the building inventory, in order to get an environmental profile, has also to be indicated (see § 2.5).

- Interpretation

The results of the previous steps have to be analysed, in order to answer questions like :

  - Are the results comparing several alternatives different enough (compared to the uncertainty of the assessment) to prove that one of the alternatives induces lower environmental impacts ?
  - Is the raking of alternatives the same if some hypothses are varied (e.g. considering a 50 years life span instead of 80 years) ?

Sensitivity analyses are performed in order to answer such questions.

As mentioned previously, LCA can be performed for various purposes, e.g. choosing a building site, advising the architect during design, proposing improvements in a renovation project, or regarding facility management (e.g. electricity and water use, domestic waste sorting), studying building materials etc. According to the goal of the study and the corresponding audience (e.g. architect, manufacturer, client, municipality etc.), some aspects of the methodology have to be adapted. For instance if the goal is to compare different building sites, transport related impacts have to be included in the analysis because an isolated site may increase the transport needs. It is assumed in this document that the purpose is to study a renovation project. LCA can be used e.g. to choose a window type, insulation material, to compare various heating equipment and energy types, etc. in order to minimize environmental impacts.

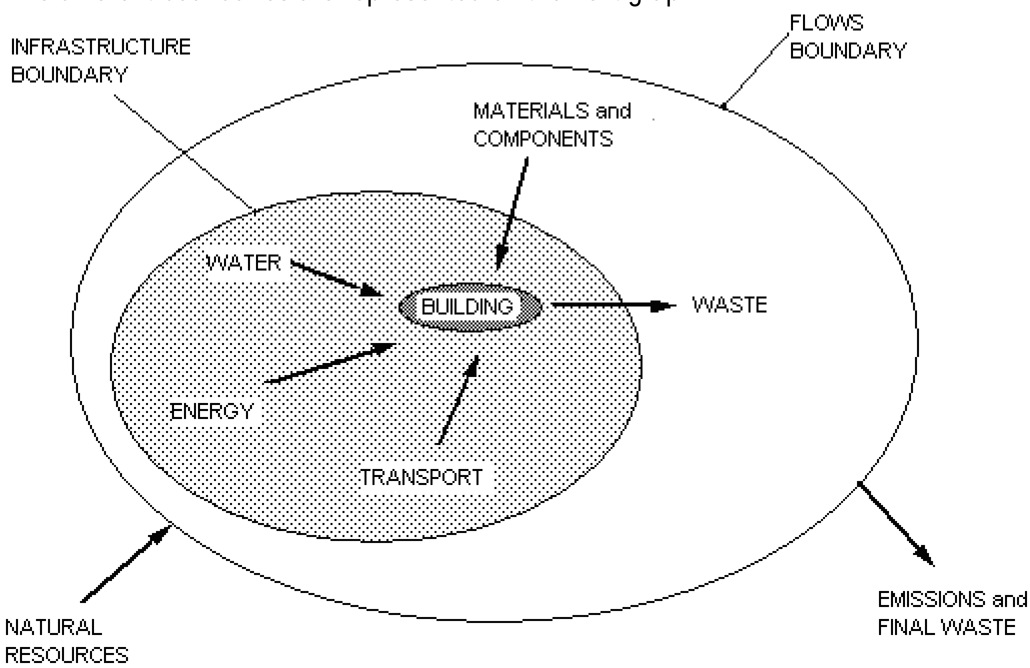
2.1 Definition of the functional unit

Comparing different products using LCA is meaningful only if these products fulfil the same function. A building has many functions : allowing activities, providing comfort, etc. Therefore the functional unit has to be defined so that the different alternatives compared provide the same services, over a similar duration.

The functional unit can be a whole building, built in a given site and planned for a specified use (dwelling, office,...), or one m^2, during a certain period, e.g. 80 years, or 1 year. A unit of one m^2 allows different projects to be compared and reference ratios to be defined (e.g. CO_2 emissions per m^2 and per year). A building is of course generally occupied and is assumed comfortable and healthy. Its comfort is defined by a given set point temperature (possibly varying in the time), for heating and if needed for air conditioning, and by sufficient illumination, ventilation and noise protection. A satisfactory indoor air and water quality is necessary for sanitary reasons. Other quality of life issues can be précised according to the context.

2.2 System boundaries

The system boundaries define which fluxes (e.g. materials and energy used, emissions) are taken into consideration and if the impacts due to infrastructure (construction, maintenance,...) are assigned to the studied system in a certain proportion.
Processes take place inside or outside a building. External processes are for example the fabrication of building components, their transport and recycling processes and waste treatment. Daily transport of occupants and urban waste processing may be included according to the purpose of the study.
For instance if different building sites are compared, the availability and type of a public transport system may be different and therefore transport related impacts must be accounted for. In a renovation project, the building site cannot be varied, so that the transport of persons does not have to be included in the study : it is the same for all compared alternatives. If the possibility of sorting domestic waste is studied, urban waste processing has to be included in the system.
For processes which could also be located in a building (e.g. water treatment) making their infrastructure available is taken into account. This allows a comparison between an external system and a system integrated in the building, for which the construction impact is accounted for. This approach is applied to energy production and water processing, so that local electricity production by a photovoltaic system, solar space heating, passive cooling, reuse of grey water, rain water collection, etc. can be studied.
An example of this approach is the production of domestic hot water which can be done either by using a solar collector or fossil fuel. All the fabrication processes of the solar collector are attributed to the building, as well as its maintenance and dismantling. This represents the infrastructure for the used solar energy. Therefore, to be homogeneous when comparing both systems, the infrastructure of the used energy for hot water production by fossil fuel (for fuel oil extraction, transport and refinery) has also to be taken into account. The corresponding data is available in data bases, see next §.
The different boundaries are represented on the next graph.



The first boundary corresponds to the building envelope. The second boundary includes water, energy and transport processes for which the infrastructure has to be accounted for. The third boundary includes materials and components fabrication processes, and waste treatment, for which the infrastructure related impacts can be neglected : for instance the impacts.related to the construction of a brick factory can be neglected compared to the flux of energy and material corresponding to the production of the bricks.

2.3 Energy, transport and recycling processes

The energy load for heating and if needed for air conditioning during the operation phase has to be calculated (see sections 2.1, Monthly heating load calculation and 2.2 Thermal simulation). For instance the EQUER building LCA software is linked to the thermal simulation tool COMFIE [11]. Compared to simplified correlations, simulation allows solar heating and passive cooling to be evaluated on a dynamic basis, accounting for energy collection, storage and distribution, and provides an assessment of thermal comfort.

Building components can be transported successively by different means (ship, railway, truck…). They differ much in density (from very light weight insulation materials to heavy masonry and metals). Therefore an approach based on the load of a transport mean is generally adopted. According to the density of a transported good the load is either expressed by the weight or by the volume which can be transported. The inventories for a transport over 1km correspond to a full load. The part attributed to a building component is evaluated by the weight or volume ratio based on the full load. Common assumptions are to consider that vehicles return empty, or to use an average load for each transport mean.

Recycling products reduces in general environmental impacts, particularly the use of resources and waste creation. For example, the fabrication of steel from old iron needs about half the energy used to produce steel from iron ore, according to Haberstatter [12]. The recycling process of concrete produces granules which can be used in road construction, avoiding the use of other resources like gravel.
These two examples allow to distinguish two different recycling types for building materials. Steel is an example for a material, which after recycling can be reused for the same application. This is called closed loop recycling. On the other hand, recycled concrete can less easily be reused for the same application. The corresponding recycling process is called down-cycling or open loop recycling. It concerns materials which were degraded during their use or recycling process, or compositions where the materials can not be separated. Reuse corresponds to a process during which a material is not transformed between two cycles, whereas it is transformed temporarily into another state during the recycling process (e.g. melted). Reusing a building material is handled like closed loop recycling.

Several ways are possible to account for recycling processes : examples are shown and discussed in the inter-comparison study presented in §3 hereunder.

2.4 Inventory analysis

The environmental impact of building components or processes (e.g. energy use, transport) can be evaluated on the basis of inventories. An inventory is a table of impact factors, indicating the quantity of each emitted or used substance with regard to the unit of the component or process. The used inventories contain impact factors on the following categories:
- the used resources (e.g. rare materials, energy),

- the emissions into air, water, ground (e.g. CO_2 into air, ammonia into water, oil into ground),
- the created waste (e.g. inert, toxic, radioactive).

Several data bases include inventories corresponding to the different processes considered (energy, transportation, manufacturing of building materials etc.), for instance :
- the Oekoinventare data base [9] ,
- the new version EcoInvent [10], **www.ecoinvent.ch** (Switzerland, hundreds of materials and processes)
- **www.ivam.uva.nl/uk/** (The Netherlands, data base compatible with the SIMA PRO LCA tool),
- **www.inies.fr** (France, no process and fewer materials : concrete blocks, timber, gypsum, PVC tiles, aluminium, polystyrene, reflecting insulation…).

Inventories for material fabrication, drinking water preparation, delivery of useful heat and electricity etc. include upstream processes, e.g. extraction and transport of raw materials and gas, production of electricity etc.
Inventories can be derived for the different phases of a building life cycle (construction, operation, renovation and end of life), and for the whole cycle.

2.5 Impact assessment and environmental profile

An inventory corresponds to a large amount of data: up to a few hundreds of substances. Therefore, comparisons between products are hardly possible by using such inventories.

Hence, data is usually aggregated into indicators corresponding to environmental themes, in order to present the final output in the form of an environmental profile. As an example, the profile considered in EQUER (see table 1) is partly based on a classification method published by Heijungs et al. [13]. For some of the themes (e.g. energy or water consumption) an absolute value is calculated. On the other hand, themes like global warming or acidification can only be assessed by a potential, expressed as an equivalent quantity of a reference substance (e.g. kg CO_2 equivalent for global warming). The list of environmental themes and aggregation methods is still in evolution [14].

environmental theme	expressed by	Profile name in graphs	unit
energy consumption	absolute value	ENERGY	MJ
water consumption	absolute value	WATER	m^3
depletion of abiotic resources	absolute value	RESOURCES	10^{-9} (1/1 billion), dimensionless, calculated by dividing used resources by known resources
waste creation	absolute value	WASTE	tons
radioactive waste creation	absolute value	RAD-WASTE	dm^3
global warming	potential	GWP_{100}	ton CO_2 equivalent
depletion of the ozone layer	potential	ODP	kg CFC-11 equivalent
acidification	potential	ACIDIFICATION	kg SO_2 equivalent

eutrophication	potential	EUTROPHICATION	kg PO_4^{3-} equivalent
aquatic ecotoxicity	potential	ECOTOX-W	m^3 of polluted water
human toxicity	potential	HUMAN-TOX	kg, human weight
photochemical oxidant formation	potential	O3-SMOG	kg C_2H_4 equivalent
malodorous air	potential	ODOUR	m^3 of contaminated air (ammonia is used as a reference)

TABLE 1: Environmental themes considered in EQUER

Each indicator is the sum of the contributions of all substances playing a role in the corresponding environmental issue. For instance the indicator corresponding to global warming integrates all quantities of greenhouse gases emissions, weighted by the global warming potential (GWP) of each gas (e.g. around 25 for CH_4 –methane-) [15], [16] :

$$GWP_{100} = \text{kg } CO_2 + 25 \times \text{kg } CH_4 + 320 \times \text{kg } N_2O + \Sigma\, GWP_i \times \text{kg CFC, HCFC, HFC etc.}$$

The GWP of a gas depends on its optical properties (absorbing of the infra-red radiation from the earth like glazing in a greenhouse) and its duration in the atmosphere (a gas rapidly decomposing in the atmosphere has a limited greenhouse effect). The acronym GWP_{100} means that a 100 years duration period is considered to calculate the GWP of the gases, relatively to CO_2 which is the reference greenhouse gas. The GWP is expressed as CO_2 equivalent quantities (Carbon is also sometimes used as a unit). This indicator corresponds to a potential effect and not to a real impact because it is today impossible to predict real impacts like storms and floods. Objectives like reducing the GWP indicator result from the application of the precaution principle : even if we cannot predict all consequences of a pollution, it is preferable to limit this pollution if the associated risk is high.

Other potential indicators are :

- the acidification potential, expressed as SO_2 or H+ equivalent

It is a potential because the real impact only takes place if the acid concentration reaches a certain threshold in the region.

- the eutrophication potential, expressed in eq. PO_4^{3-}

The impact is higher if the pollution is released in a small river or lake than if it is diluted in a large river or in the sea.

- the summer smog, or photochemical oxydant formation indicator, expressed in eq. C_2H_4

Smog is an acronym from smoke and fog, and corresponds to health problems regarding the respiratory system. Winter smog is linked to the emission of dust and SO_2. Summer smog is due to the decomposition of various volatile organic coumpounds (like C_2H_4 – ethene) and nitrogen oxides (Nox), emitted for instance by vehicles and aircrafts, into ozone (tropospheric level, i.e. at ground level). This decomposition is higher during sunny days, and the resulting ozone concentration is higher if there is no wind to dilute the pollution.

- The ozone depletion potential, expressed in eq. CFC-11

Another problem involving ozone (but here ozone plays a positive role) is the depletion of the ozone layer, situated in the atmosphere at around 30 km altitude (stratospheric level). This layer filters some dangerous solar radiation (UV, X-rays) and protects us from cancer risks and eye problems. Attention must therefore be paid on the 2 different indicators, corresponding to 2 different altitudes of ozone in the atmosphere and 2 different environmental problems.

Toxicity indicators can be based upon the critical volumes method. Regarding water eco-toxicity, the principle is the following :

- a concentration thershold C is defined for each pollutant, for instance the concentration above which more than 5% organisms are dying in a river,
- for each pollutant, a "critical volume" is calculated by dividing the quantity of this emitted pollutant by C : the more toxic is a pollutant, the lowest C is (a low concentration is enough to kill 5% of the fishes) and the greatest the critical volume is,
- the indicator is the sum of the critical volumes of all substances.

A similar indicator is defined for human toxicity, but the concentration is replaced by a dose.: a dose is a quantity of pollutant absorbed by a person (through air, water, food) divided by the weight of this person. For instance the same concentration of a toxic pollutant in a room is more dangerous for a small child, who moves and breathes a lot, than for a quiet adult who weights more. Similarly as in the previous method, a dose threshold is defined for all pollutants (e.g. corresponding to a risk of 1 cancer for 10,000 inhabitants). Average values are considered for the weight, inhaled air and ingested water volumes per person and per day. The total world population and air volume of the atmosphere are considered to estimate the indicator, which corresponds to a planetary average effect on human health and not to a local indicator. Other types of methods would be necessary to evaluate the toxicity effect on a local level, e.g. for the residents of a particular building.
Another human health indicator is the DALY (Disability adjusted life Years [17]), which integrates premature mortality and illness.
More sophisticated models exist, accounting for the transport of pollutants among different ecological compartments (air, river water, sea water, sediments etc.), the (bio)-degradation of pollutants, their transfer into the food chain. But such models require more data on the substances, which are presently available only for a few tens of pollutants. Around 100,000 chemicals are on the market, which shows the remaining knowledge gap. There is also little information about possible interaction between pollutants.
Another indicator based upon the critical volumes method is the malorodous air indicator. The thershold concentration corresponds to the detection of the substance by 50% of a representative sample of persons. Like for eco-toxicity, the critical volume is obtained by dividing the emissions by the thershold concentration, and the indicator is the addition of the critical volumes for all concerned substances.

Some indicators are related to the exhaust of resources :

- primary energy consumption

Because more energy is needed to produce 1 kWh electricity than 1 kWh heat (due tio the efficiency of electrict plants and losses in the grid), it would not be relevant to add different final energy consumptions. This why primary energy is used to assess impact on energy resource. Primary energy corresponds to energy that has not been subjected to any conversion or transformation process. This concept allows different types of energy to be integrated in a common indicator on a homogeneous basis.
Upstream processes like the extraction and transport should be included, otherwise possible displacement of pollution would not be accounted (e.g. replacing a boiler by electric heating reduces emissions inside a building but increases them upstream in electricity plants).
The "gross calorific value" or "upper heating value" is generally preferred because it includes the maximum energy quantity that can be produced by a fuel (e.g. 1 kg of coal, oil, uranium etc.). In the case of hydro-power, the primary energy may be derived from the produced energy using the efficiency of the system.

It is not always meaningful to include renewable energies in the balance. For instance the resource corresponding to biomass and geothermal heat is limited : if this type of energy is used in a low performance building, less resource will be available for other buildings. In this case, it is relevant to include the corresponding energy consumption in the balance, even if it is renewable. On the other hand, using the energy of a solar collector on the roof of a building does not reduce the resource available for other buildings, therefore this energy can be disregarded in the balance.

Another indicator, related to the exhaust of abiotic resources, can be used to distinguished the use of fossile fuels and renewables.

- water use

The quantity of consuled water can be assessed, and different water types can be defined in inventories (e.g. rivers, underground water etc.).

- exhaust of abiotic resources

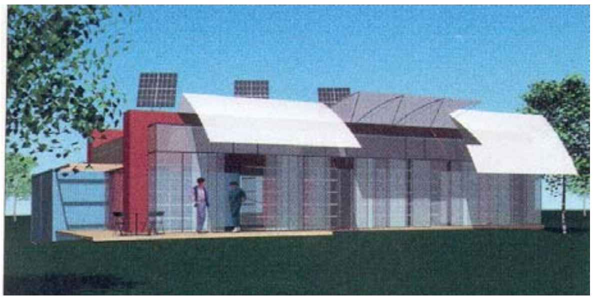
This indicator can be defined as the ratio of the used quantity of each rare substance divided by the corresponding available reserve (technically exploitable). Other definitions account for the velocity of resource depletion.

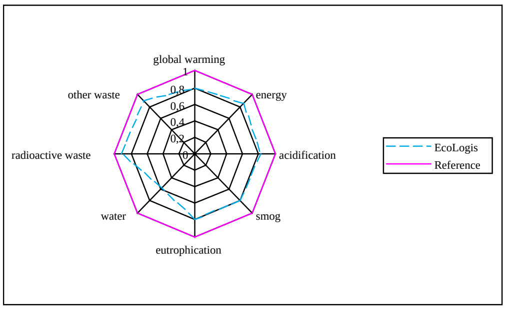
- use of land

Several types of land transformation may be defined in inventories, e.g. from forest to urban, from green space to building, etc. A land use indicator can be derived from these informations.

Finally, some indicators are related to waste generation, distinguishing several types of waste (e.g. inert, toxic, radioactive etc.).

Indicators are expressed in different units and their orders of mangitude differ a lot, e.g. from 10^{-9} for the exhaust of abiotic resources to 10^{+6} for energy consumption. This is why relative values are often used. For instance the indicators for a project can be compared to a reference. In the example shown below, the indicators corresponding to the EcoLogis exhibition in Paris are related to a reference house in the same location. This reference has been defined using statistics about the most common building materials, and considering the same climate and users behaviour. The results are presented in a web diagram : each axis correspond to an indicator ; the reference value is 1 and relative values are given for the project, e.g. the contribution to global warming is reduced by 20% compared to the reference.





The Ecologis exhibition house in Paris, and corresponding LCA results

In such a graph, all indicators are represented using the same scale. But the absolute values and the related contribution of buildings, may be much higher for some indicators than others. This is why normalised indicators are used. For instance, if a building emits 1,300 tons of CO_2 over its life cycle and if one average person emits 13 tons per year, the corresponding normalised indicator for the building would be 100 equivalent persons.Normalisation can be applied to all indicators, provided that average values per person and per year are available.

This method allows a single unit (equivalent person) to be used for all indicators. One main advantage is to compare the contribution of a building to different impacts, and to derive some priorities : it is in general more important to reduce the contributions corresponding to the higher number of equivalent persons. For instance if the greenhouse gases indicator is 100 equivalent persons and the eutrophication indicator is only 1 for the same building, the priority could be given to climate protection measures (unless the project is situated for instance near a small lake and a high priority is given to protecting this lake).

Some indicator values that can be used for normalisation at a European level have been collected, e.g. from EUROSTAT, DG TREN or NOVEM [18].

Impact indicator	Unit	Source
Global warming potential (GWP)	12 978 kg CO_2 eq./pers/year	average calculated for European Union (25) in 2004 [Eurostat, 2005]
Acidification (AP)	113 kg SO_2 eq./pers/year	average calculated for Europe by NOVEM,
Photochemical ozone production (POCP)	19.7 kg. C_2H_2 eq./pers/year	average calculated for France in 1997
Eutrophication (EP)	38 kg PO^{3-}_4 eq/pers/year	average calculated for Europe by NOVEM,
Primary energy	43 052 kWh/pers/year	average calculated for European Union (25) in 2002, from [EC-DGTREN, 2004]
Water used	339 m^3/pers/year	average calculated for France in 1997
Non-radioactive waste	10 400 kg/pers/year	average calculated for France in 1997
Radioactive waste	0.12 dm^3/pers/year	average calculated for European Union (25) in 2002, from [EC-DGTREN, 2004]

Equivalent persons indicator values for Europe

National or local average values can be used for normalisation, but this requires to collect appropriate data.

2.6 Limits of the approach

There are still many uncertainties and limits to the present state of the art of LCA. The uncertainties concern both the data (inventories) and indicators : for instance, the global warming potential (GWP) of other gases than CO_2 is known with 35% uncertainty [14]. Fortunately, CO_2 represents 80% of the impact, so that the overall uncertainty is only 7%. Indicators related to human or eco-toxicity are less precise because the location of the emissions is not considered. Air pollution inside buildings might have a much larger effect than diluted external emissions.

Some processes are likely to vary along time, e.g. the European electricity production mix may vary, with an increased share of renewable production. A solution can be to perform the analysis on a whole life cycle, e.g. 80 years, then to divide indicator values by 80 so that one year is considered in the functional unit, assuming this year is not too far from the present time. Processes occurring at the end of the building life cycle are difficult to foresee, particularly because buildings are generally long lasting (though it may be assumed that mixing materials - concrete with polystyrene or wood for instance- will make the future waste management more difficult). A solution is either to compare different scenarios (landfill, incineration, recycling), or to affect probabilities to each scenario.

Several indicators are assessed and if one alternative performs better for one indicator but worse for others, a multi-criteria decision making process is needed. Priorities can be defined in agreement with the concerned actors (building owner, possibly municipality etc.). Priorities may be chosen according to the geographic extension of impacts (planetary, regional or local impact), their duration, their importance, reversibility etc. They may depend on a specific regional context, e.g. water shortage may be very important in some regions.

3. Presentation and inter-comparison of some building LCA tools

The LCA method presented above has been applied in the building sector and several tools have been developed. The precision of these tools and their relevance as a design aid is often questioned. Eight European Building LCA tools have been compared in the frame of the PRESCO European thematic network [19], [8].

This § presents these tools, the case study buildings, and the results of the comparison exercises which lead to draw some overall conclusions on best practices for applying LCA in the building sector. Based upon this, a number of recommendations are formulated for the future improvement of existing tools. These recommendations also aim at harmonising European environmental assessment tools.

3.1 Presentation of the participating tools

The following table provides the list of participants and tools involved in the exercise.

Partner	Country	Tool
ASCONA	Germany	LEGEP
W/E	The Netherlands	ECO-QUANTUM
ARMINES	France	EQUER
BRE	United Kingdom	ENVEST
EMPA	Switzerland	OGIP
IBO	Austria	ECOSoft
VTT	Finland	BECOST
CSTB	France	ESCALE

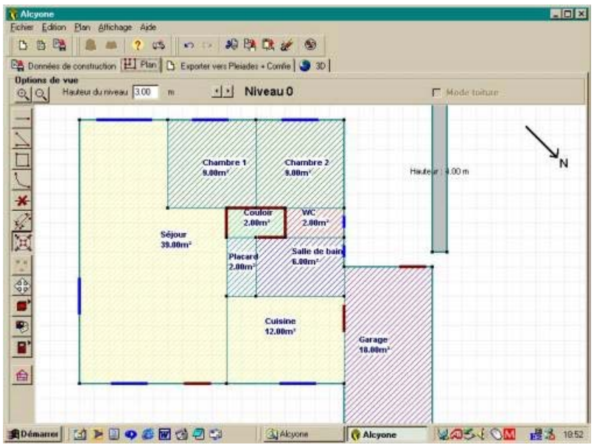
3.1.1 EQUER

EQUER performs simulations of a building’s life cycle, in order to provide professionals with environmental indicators, allowing a project to be assessed from an environmental perspective (e.g. global warming, acidification and eutrophication potentials, exhaust of natural resources,…). The Swiss Ekoinventare 1996 database and other data collected in the frame of the European REGENER project are used for material fabrication and other processes (energy, water, waste, transport). EQUER is linked to the energy simulation tool COMFIE.

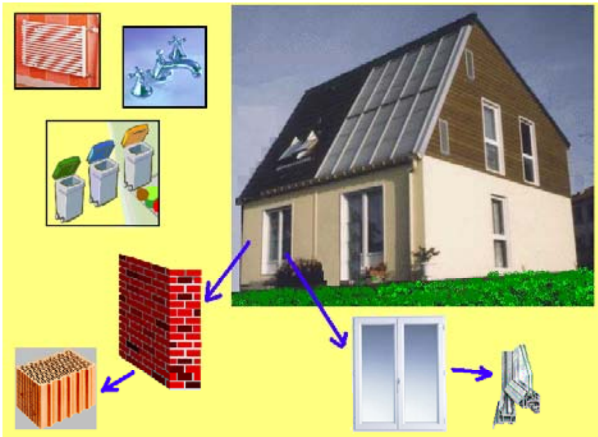
The tool is aimed at a wide range of professionals, such as mechanical, energy, and architectural engineers working for architect/engineer firms, architects, consulting firms, utilities, federal agencies, urban designers, universities, and research laboratories.

It requires input from the user about the building geometry, material characteristics, internal loads and schedules, climate, heating and cooling equipment characteristics. Water consumption, waste generation and transport issues may be taken into account, depending on the goal of the study. Readable, structured input file is generated by the PLEIADES (thermal simulation) and ALCYONE (2-3D modeller) user interface (see next figure).

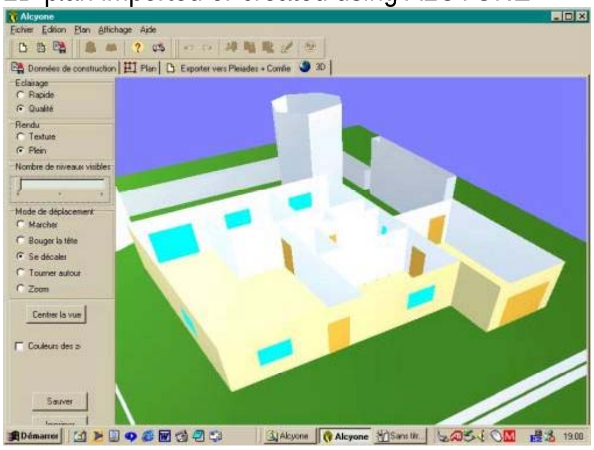
Input of EQUER



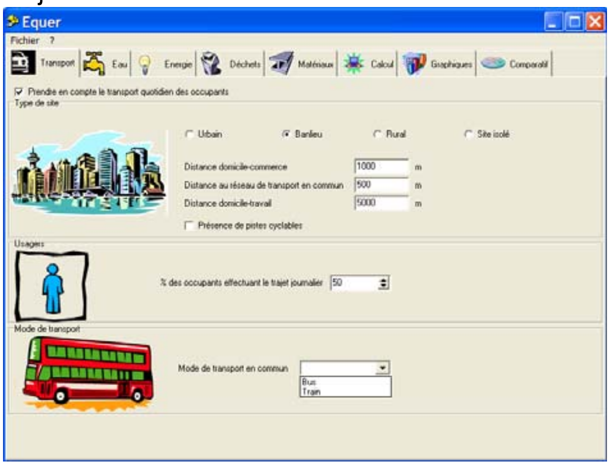
2D plan imported or created using ALCYONE



Object oriented model in PLEIADES-COMFIE



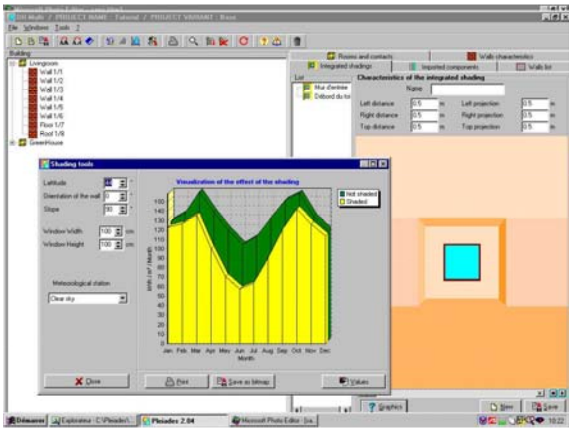
3D view, ALCYONE



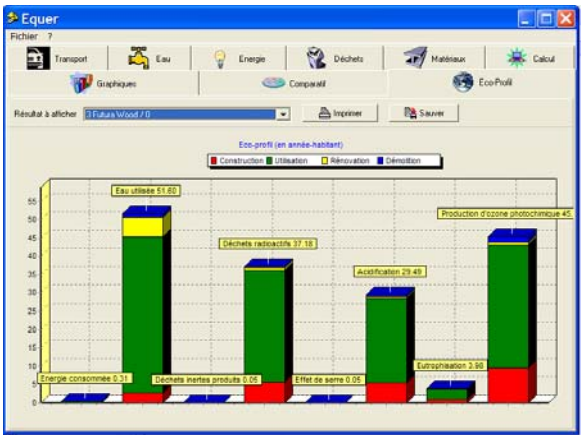
Supplementary input (transport, water, waste…) in EQUER

The assessment results are represented by means of environmental indicators such as contribution to global warming, acidification, eutrophication, exhaust of abiotic resources, human toxicity, ecotoxicity, smog and odours, primary energy and water consumption, radioactive and other waste production.

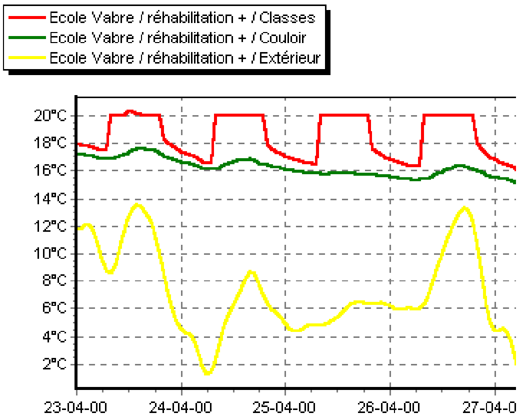
Output of EQUER



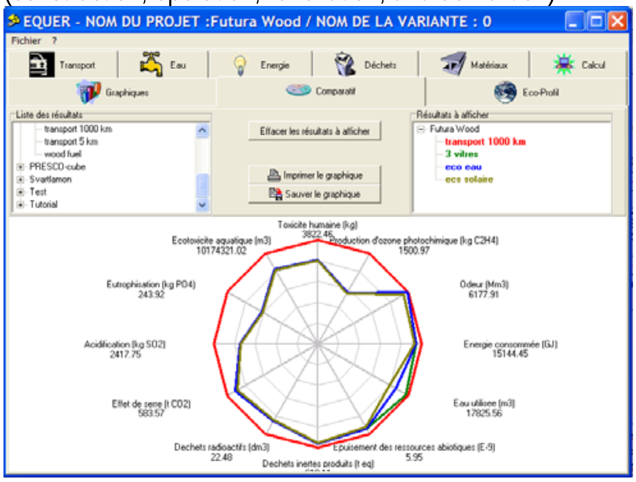
Calculation of solar gains, shading, energy load



EQUER output : environmental indicators for 4 phases (construction, operation, renovation, and demolition)



Evaluation of temperature profiles using PLEIADES-COMFIE



Comparison of alternatives using EQUER

The main strengths of EQUER are the link with an energy simulation tool and a user friendly interface (PLEIADES, ALCYONE). Life cycle simulation reduces the risk of errors when taking renovation into account because the materials quantities are automatically calculated; focussing on the envelope allows for use by architects. Future improvements can be implemented with regard to building equipment. Currently, equipment is very simply modelled (maximum power, set point, position of the thermostat in the building), impacts from heating equipment fabrication is included in the inventory of 1 kWh heating.

The EQUER model is used by some architects and consultants. It is being improved by updating the CML indicators from the 1992 version [13] to 2001 [14], integrating other environmental indicators like the Disability Adjusted Life Years [17], and by updating the inventories according to the evolution of the Ecoinvent data base [10].

An extension to settlements, including various buildings, open spaces (streets, green spaces…) and networks has been developed in the frame of the E-co-housing European project [20].

3.1.2 ENVEST

Envest was the first UK software programme to explore ways of reducing a building's environmental impact at the design stage. Four years on, the programme has been upgraded

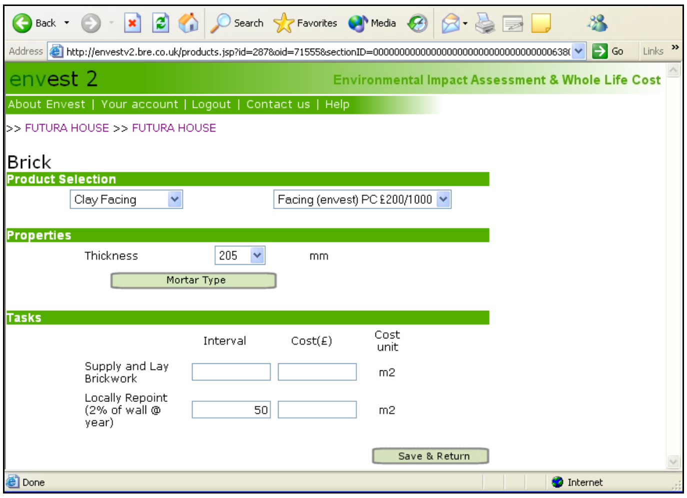
to include a whole life costing tool that will help designers minimise not just the environmental impact, but the long term cost of maintaining and operating a building as well.
Now a web-based tool, Envest 2 also enables the user to share information with colleagues and so promote improved understanding of environmental design and in-house benchmarking.

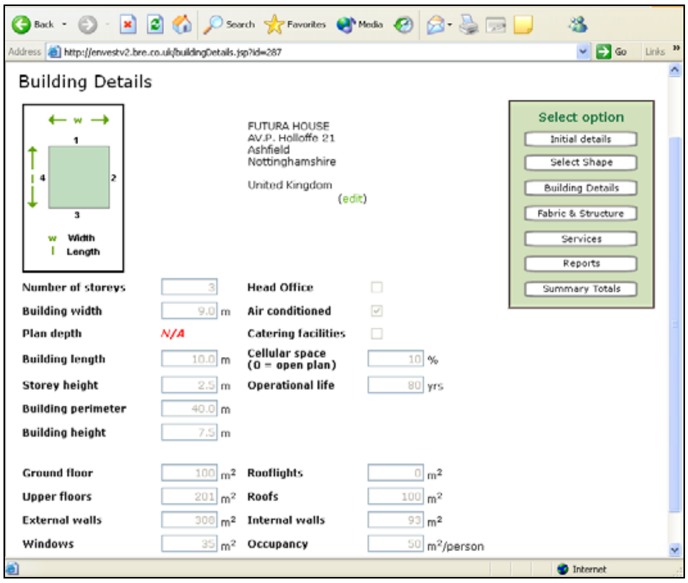
Entering simple data about building form, materials, components and operating systems, designers can identify those elements that most influence environmental impact and cost. Alternative options can then be weighed up until the optimum balance is reached.

Graphs and reports help the user to compare different specifications and decide which is the most appropriate. The graphs can also be used to benchmark one building against others.
The data is easy to understand. Environmental impacts are calculated under twelve headings ranging from climate change to toxicity, but are also given as a single Ecopoint score. Costs are measured using net present value and discounted with a rate set by the user.

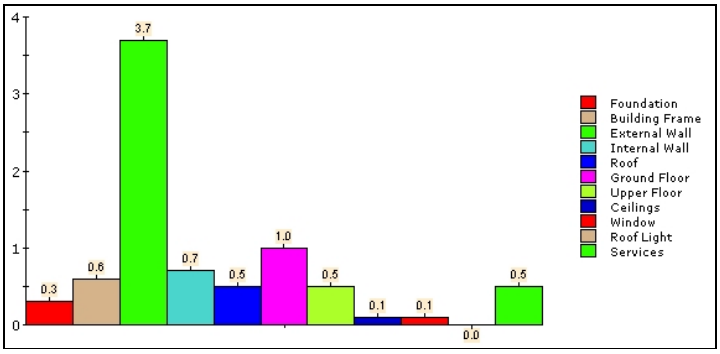
The tool is available in two versions

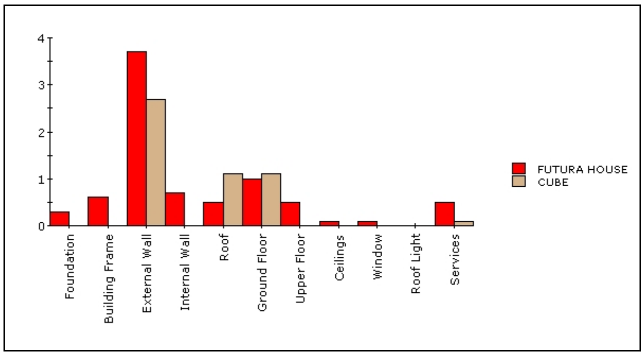
- *Envest 2 estimator* in which cost and replacement intervals are set and cannot be seen or changed by the user
- *Envest 2 calculator* for those who want the choice of either entering their own costs/replacement intervals or using the defaults.





Input of building data in ENVEST 2





Presentation of results in ENVEST 2

3.1.3 LTE OGIP

LTE OGIP is a design tool for the integral planning of buildings. It permits the evaluation of construction and operating costs, the cumulated energy demand (CED) of the structure and the operating energy and it provides a standardised method for calculating the environmental impact of the building's construction and operation phase. LTE OGIP can be linked to standard tools developed by the CRB[3], building associations and the SIA[4].

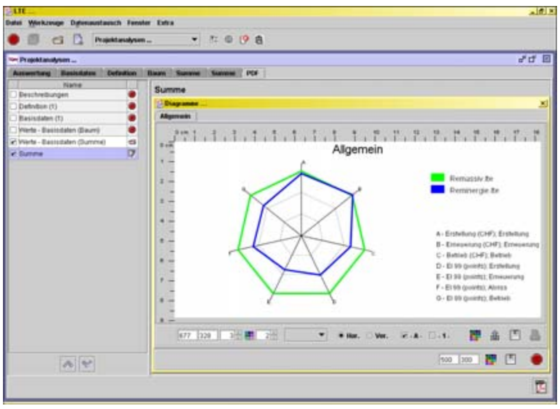
LTE OGIP gives architects and designers a practical tool that outlines the complex relationships between costs, energy and environmental impact over the building's life cycle and assists those in charge of the project in the decision-making process. Consumption of resources is optimised interdependently and represented graphically.

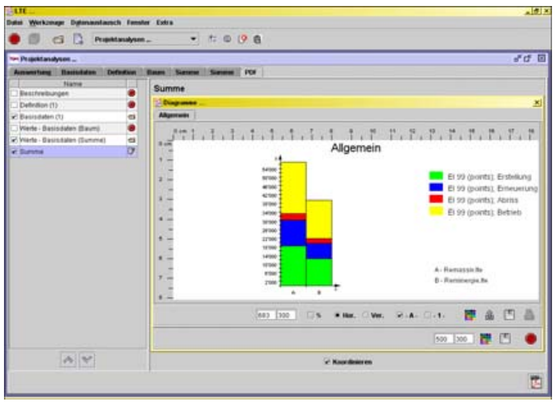
The program is based on the construction element method developed by the CRB. Construction elements are structures which are assembled from various materials and components into functional units – e.g. a window, rendered external thermal insulation or a thermally insulated flat roof. A function can be assigned to each element which, for example, enables the definition of the expected life cycle to be defined or the calculation of the annual heat losses. If the materials from which these elements are made are linked to material data, periods of use, life cycle inventory data and appropriate analytical models, judgements can be made with regard to consumption of the resources costs, energy and environment. These analyses can be carried out for individual construction elements, systems or whole buildings.

LTE OGIP's database currently contains some 2,500 construction elements ranging from peripheral works and the foundations right up to the service equipment. The life cycle inventory data is based on the ecoinvent database version 1.1[5] developed by the Swiss Centre for Life Cycle Inventories under the leadership of EMPA,. It includes information on building materials, fuels and processes.

LTE OGIP presents the results of an assessment in seven categories: costs, non renewable (fossil and nuclea), renewable (from water, wind, solar and geothermal) cumulated energy demand (CED), the biomass CED, the total eco-indicator 99, (H,A), the total ecological scarcity 1997 and the Global Warming Potential (100a). The calculated indicators are displayed either absolutely (tabular) or in comparison with similar structures (graphically). Up to 5 different buildings or variants can be compared.

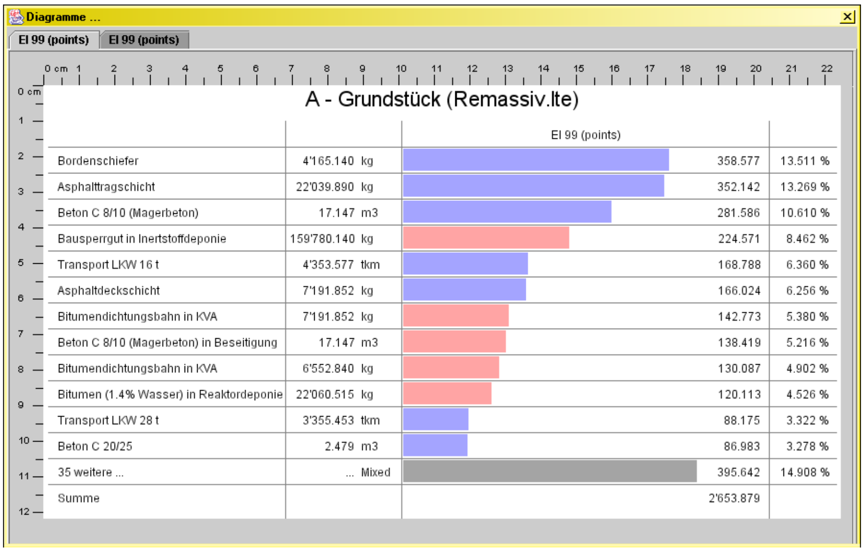
Presentation of results in LTE OGIP





[3] Swiss research centre for rationalisation in building and civil engineering
[4] Engineers and architects society
[5] www.ecoinvent.com

presentation of results with a spider diagram presentation of results with a bar chart



analysis of the used basisdata assessed with a certain indicator (e.g. EI 99)

3.1.4BeCost

BeCost is a web-based tool for life cycle assessment of building structures and for the whole building[6].

The program includes:

- Environmental profiles, costs and maintenance costs of building materials produced in Finland,
- The structures for designing outdoor walls, indoor walls, roofs, floors, etc.
- Material quantity calculations
- Environmental profile calculation for designed structure
- Result as plot of environmental profile (emissions), energy- and raw-material use, and cost impact for the structure and whole building.

BeCost is an easy to use program. The user should first define the building by making relevant choices, by choosing the structure and materials, by giving the volumes in m2 and by choosing the service life of the building.

This can be used for different purposes:

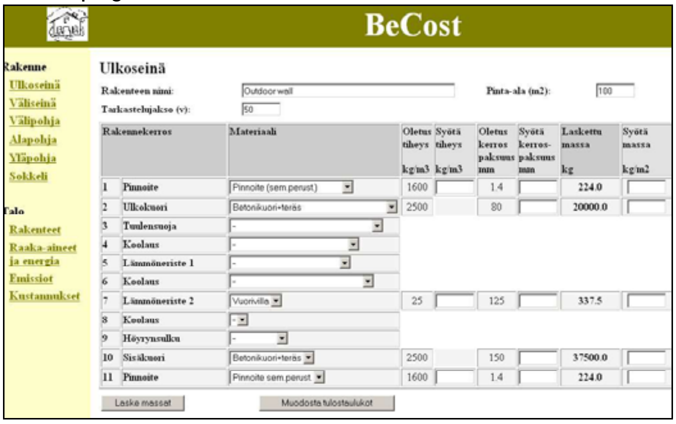
- to examine the ecological effect of building choices related to materials used and service life of the whole building (designer and constructors use);
- verifying environmental characteristics' fulfillment, if such has been demanded (designer use);
- for owners to examine their building's environmental profiles (owner use);
- checking the affect of care, maintenance and repairing actions on the environment;
- comparing environmental profiles of structures having the same functional units; and
- comparing environmental impacts of produced- and competing materials in certain structure or building (use of building material producer).

Input and outputs in BeCost

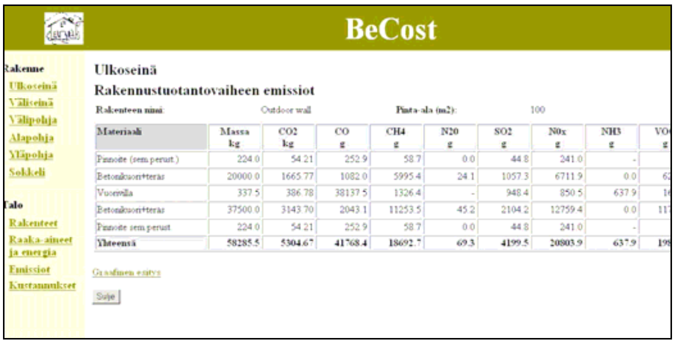
[6] see http://www.vtt.fi/environ

Cover page of the BeCost tool

Page for structure design



Calculation page



Environmental profile for the designed structure (emissions)

3.1.5Eco-Quantum

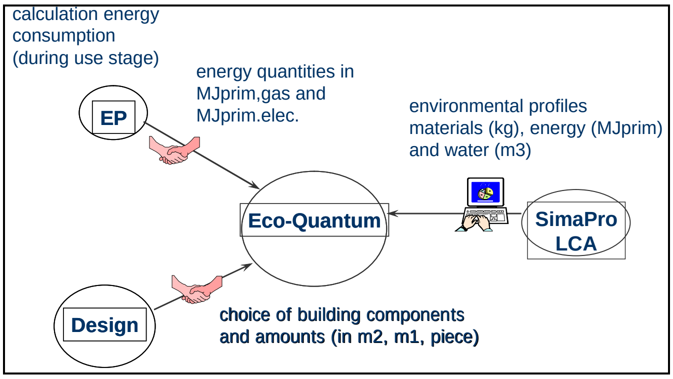
One of the main motives for the development of Eco-Quantum was the need of the Dutch building market for environmental information. As the multitude of different qualitative methods and checklists for building materials were felt to be confusing, there was a need for a generic, quantitative assessment method.

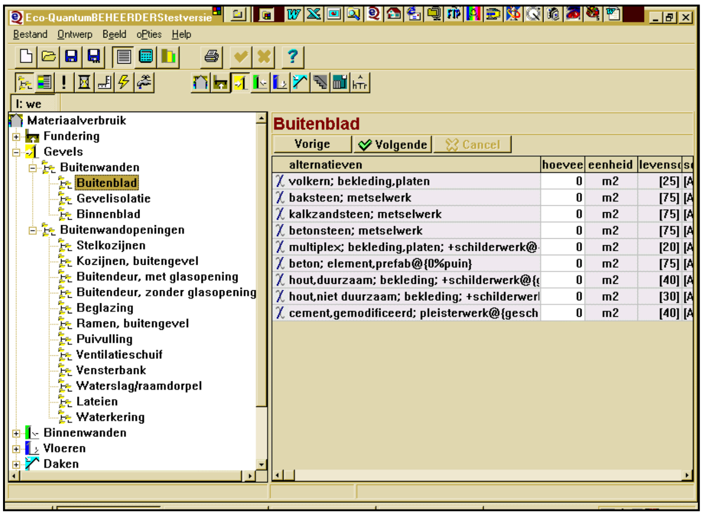
The main aim of Eco-Quantum was to develop a tool for the determination of the environmental performance of a building over its total life span, with a calculation method based on LCA, which would offer architects quick analysis of their building design, a communication tool between actors and which could be used to optimise building components and the entire building design. Furthermore, local governments can use Ecp-Quantum to set environmental requirements and for communication between the different actors of the building sector.

An Eco-Quantum assessment consists of 5 steps:

1. from design to material & energy flows and input in Eco-Quantum
2. calculation of environmental in- and outputs
3. calculation of environmental effects (12)
4. calculation of environmental scores (4)
5. calculation of Eco-Quantum indicator (1)

Input data in Eco-Quantum

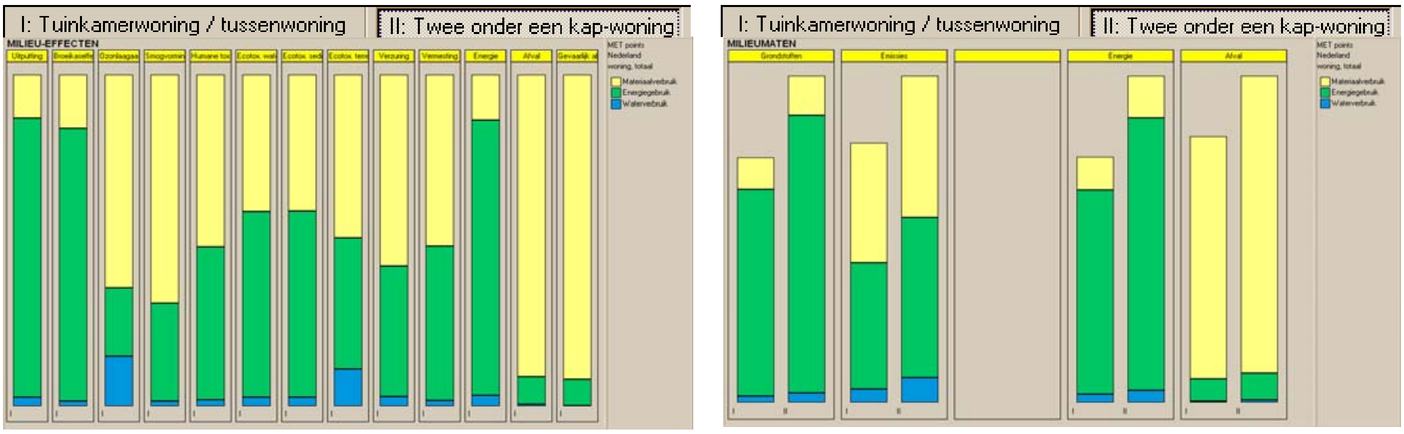




After the calculation of the environmental in- and outputs, Eco-Quantum gives the environmental performance of the building, using a set of environmental effects:

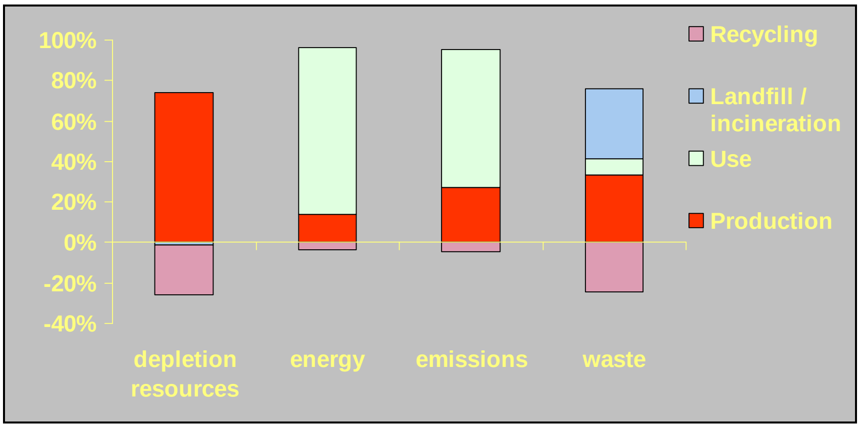
1. depletion of resources
2. greenhouse effect
3. depletion of the ozone layer
4. photochemical oxidant formation
5. human toxicity
6. ecotoxicity (water, sedimental, terristic)
7. acidification
8. nutrification
9. energy consumption
10. waste
11. dangerous waste

These environmental effects are then aggregated into 4 environmental scores: resources, emissions, energy and waste. Each of the effects and scores are subdivided in the material related (yellow), energy related (green) and water related (blue) impact – see figure 15.



Environmental effects and environmental scores in Eco-Quantum

For the four environmental scores, it is also possible to split the environmental performance over the different stages of the building's life cycle (see next figure).



Environmental performance scores over the total life span of the building

The final step in the Eco-Quantum assessment is the calculation of the single environmental indicator. The results of the 4 environmental score are again aggregated and weighted to calculate an overall environmental performance for the building. This last step however is still experimental.

The main advantages of Eco-Quantum are that it is easy to use ("language" of the designer), it offers a wide variety of assessment methods, it is useful for target setting (policy makers) and is a useful decision support tool for designers and clients. Drawbacks however are that the tool is only applicable in the later design stages as a lot of data needs to be available and that the user can't extend the materials database. The tool can only be used for residential buildings and the advanced aggregation leads to a subjective weighting in the assessment.

3.1.6 Eco-Soft

ECOSOFT is a LCA tool developed by IBO. It provides environmental indicators for the construction and the energy use of a building.

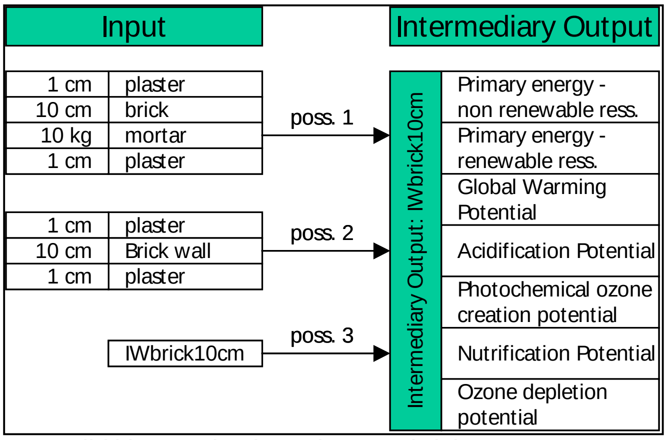
ECOSOFT is mainly used as a research and education tool.
It's database and method is also :

- part of building certification systems as "Total Quality" or "Ökopass"
- part of calculation tools for building physics (f.e. A0, Zehetmayer, ECOTECH)
- part of government aid for housing (f.e in Salzburg and Vorarlberg)

The constructions of the building are calculated by choosing the building materials from the database and put in the thickness of the layer and the percent in volume of material within this layer. The database contains a suggestion for the density and the life-span of the material. This parameters can easily be changed by the user.
For functional units as f.e upgraded insulation you have two possibilities in ECOSOFT: you can either choose the whole functional unit f.e. 'upgraded insulation from polystyrene 5-10 cm' or you give in all layers separately (glue, insulation, fiberglass cloth a.s.o).

Inputs in ECOSOFT are:

- construction: amount (m, m^2 or m^3) + materials resp layers resp whole construction
- energy: amount (MJ) + type of energy
- transport: amount (tkm) + means of transport



3 possibilities to give in an internal brick wall

AW_brick_ExternalWall.xls

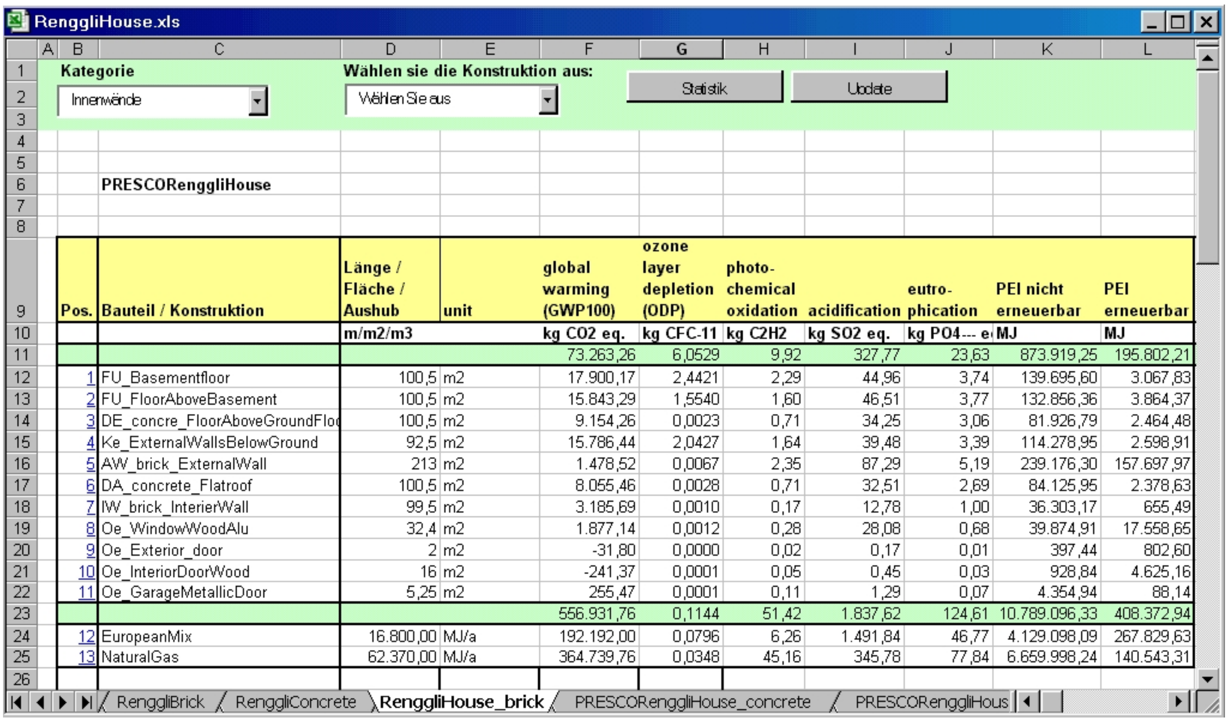
Baustofftabelle: Baustoffe.xls
Kategorie: Wählen Sie aus
Baustoff: Wählen Sie aus
Eintrag löschen | Update | Speichern

Schicht Nr.	Benennung der Schicht	Katalog	Dicke	Anteil	Dichte	Masse	Nutzungsdauer	global warming (GWP100)	ozone layer depletion (ODP)	photochemical oxidation	acidification	eutrophication	PEI nicht erneuerbar	PEI erneuerbar
			m	%	kg/m³	kg	Jahre	kg CO2 eq.	kg CFC-11 eq	kg C2H2	kg SO2 eq.	kg PO4 eq	MJ	MJ
1	Gipsputz	Baustoffe.xls	0,005	100%	1100	5,5	80	0,583	1,3915E-07	0,00005104	0,00159	0,000173	11,02	0,15
2	Hochlochziegel hochporosi	Baustoffe.xls	0,25	100%	750	135	80	33,750	0,000010449	0,0016065	0,1404	0,010679	370,74	6,52
3	Mörtel	Baustoffe.xls		100%		10	80	2,080	0,000000753	0,000159	0,00676	0,000673	15,78	0,72
4	Mineralischer Kleber	Baustoffe.xls		100%		5	80	1,040	3,765E-07	0,0000795	0,00338	0,000337	7,89	0,36
5	Holzweichfaserplatte	Baustoffe.xls	0,17	100%	210	35,7	80	-34,568	1,81237E-05	0,0088298	0,243593	0,011127	682,55	731,05
6	Glasfaserarmierung	Baustoffe.xls		100%		0,2	80	0,312	0,000000117	0,0000228	0,001904	0,000149	6,50	0,26
7	Silikatputz	Baustoffe.xls	0,01	100%	1800	18	80	3,744	1,3554E-06	0,0002862	0,012168	0,001211	28,41	1,30
	Betrachtungszeit	80						6,941	3,13138E-05	0,01103484	0,409795	0,024348	1122,89	740,37
	Materialkosten													
	Arbeitskosten													
	Gesamtkosten	0												

AW_brick_ExternalWall / Statistik

Input of the brick wall of Futura-house

Outputs of ECOSOFT are a set of environmental indicators: GWP100 (Green house potential 100 years), Acidification potential, Photochemical ozone creation potential, Ozone depletion potential, Eutrophication potential, primary energy consumption - renewable and primary energy consumption - non-renewable.


RenggliHouse.xls

Kategorie: Innenwände — Wählen sie die Konstruktion aus: Wählen Sie aus — Statistik — Update

PRESCORenggliHouse

Pos.	Bauteil / Konstruktion	Länge / Fläche / Aushub	unit	global warming (GWP100)	ozone layer depletion (ODP)	photo-chemical oxidation	acidification	eutro-phication	PEI nicht erneuerbar	PEI erneuerbar
		m/m2/m3		kg CO2 eq.	kg CFC-11	kg C2H2	kg SO2 eq.	kg PO4--- e	MJ	MJ
				73.263,26	6,0529	9,92	327,77	23,63	873.919,25	195.802,21
1	FU_Basementfloor	100,5	m2	17.900,17	2,4421	2,29	44,96	3,74	139.695,60	3.067,83
2	FU_FloorAboveBasement	100,5	m2	15.843,29	1,5540	1,60	46,51	3,77	132.856,36	3.864,37
3	DE_concre_FloorAboveGroundFlo	100,5	m2	9.154,26	0,0023	0,71	34,25	3,06	81.926,79	2.464,48
4	Ke_ExternalWallsBelowGround	92,5	m2	15.786,44	2,0427	1,64	39,48	3,39	114.278,95	2.598,91
5	AW_brick_ExternalWall	213	m2	1.478,52	0,0067	2,35	87,29	5,19	239.176,30	157.697,97
6	DA_concrete_Flatroof	100,5	m2	8.055,46	0,0028	0,71	32,51	2,69	84.125,95	2.378,63
7	IW_brick_InterierWall	99,5	m2	3.185,69	0,0010	0,17	12,78	1,00	36.303,17	655,49
8	Oe_WindowWoodAlu	32,4	m2	1.877,14	0,0012	0,28	28,08	0,68	39.874,91	17.558,65
9	Oe_Exterior_door	2	m2	-31,80	0,0000	0,02	0,17	0,01	397,44	802,60
10	Oe_InteriorDoorWood	16	m2	-241,37	0,0001	0,05	0,45	0,03	928,84	4.625,16
11	Oe_GarageMetallicDoor	5,25	m2	255,47	0,0001	0,11	1,29	0,07	4.354,94	88,14
				556.931,76	0,1144	51,42	1.837,62	124,61	10.789.096,33	408.372,94
12	EuropeanMix	16.800,00	MJ/a	192.192,00	0,0796	6,26	1.491,84	46,77	4.129.098,09	267.829,63
13	NaturalGas	62.370,00	MJ/a	364.739,76	0,0348	45,16	345,78	77,84	6.659.998,24	140.543,31

RenggliBrick / RenggliConcrete / RenggliHouse_brick / PRESCORenggliHouse_concrete / PRESCORenggliHous

Example Screen Shot: ECOSOFT-Results

ECOSOFT includes data for building materials, energy sources and transportation means. It uses data from the following sources:
- Oekoinventare 96 LCI database
- Baustoffe – Oekoiventare (Kohler,N. et al., Karlsruhe/Weimar/Zürich 1995)
- IBO-database (status april 2002)

The building materials are calculated by SimaPro using the CML 2 Baseline 2000.
Data for electric installation, sanitary installation or furniture are not included.

ECOSOFT is used both for calculating the ecological performance of the construction of a building and for calculating the ecological performance of the construction and operation of the building during life-time. It does not include the calculation of end of life (deposition and recycling) because of the incertitude of the deposition/recycling-scenarios.

3.1.7 ESCALE

ESCALE has been designed to be adapted to the iterative design process, to speak the decision-makers language and to provide understandable and interpretable results. It is structured by 11 main criteria, declined in sub-criteria. An assessment module corresponds to each sub-criterion.

Environmental criteria

1. **Energy resources** *
2. **Other resources**
   - water resource *
   - materials resources °
3. **Waste** °
   - construction waste
   - operation waste
   - demolition waste
4. **Large scale pollution**
   - greenhouse effect *
   - acid rains *
   - ozone depletion *
   - radioactive waste *
5. **Local pollution**
   - air pollution +
   - water pollution °
   - soil pollution °
6. **Contextual fit** +
   - landscape and architectural integration
   - respect of neighbours
   - users' local outdoor comfort
   - respect of the site ecology
   - adaptation to networks
7. **Comfort**
   - thermal comfort *
   - visual comfort *
   - acoustic comfort *
   - olfactive comfort °
8. **Health**
   - indoor air quality +
   - water quality °
9. **Environmental Management** *

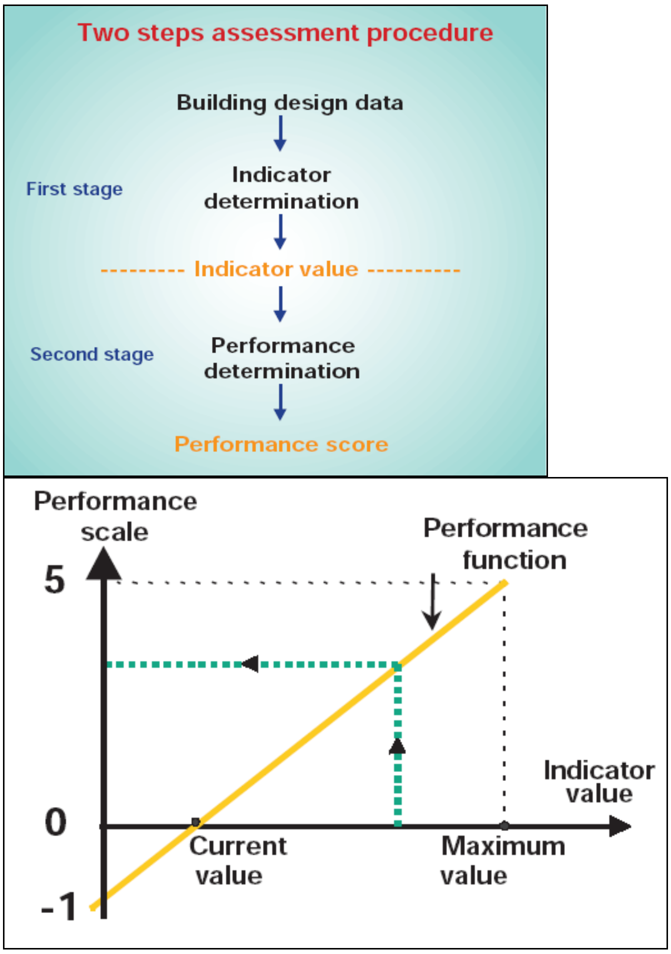
Indirect environmental criteria

10. **Maintenance** *
11. **Adaptability** *

** : operational model   + : partly developed model   ° : undeveloped model*

Hierarchical criteria structure

Escale has two levels of assessment modules: simplified and detailed. The elementary assessment is made in 2 steps, an indicator value and a score on a performance scale. The results are partially aggregated and finally result in an environmental multi-criteria profile with 24 components

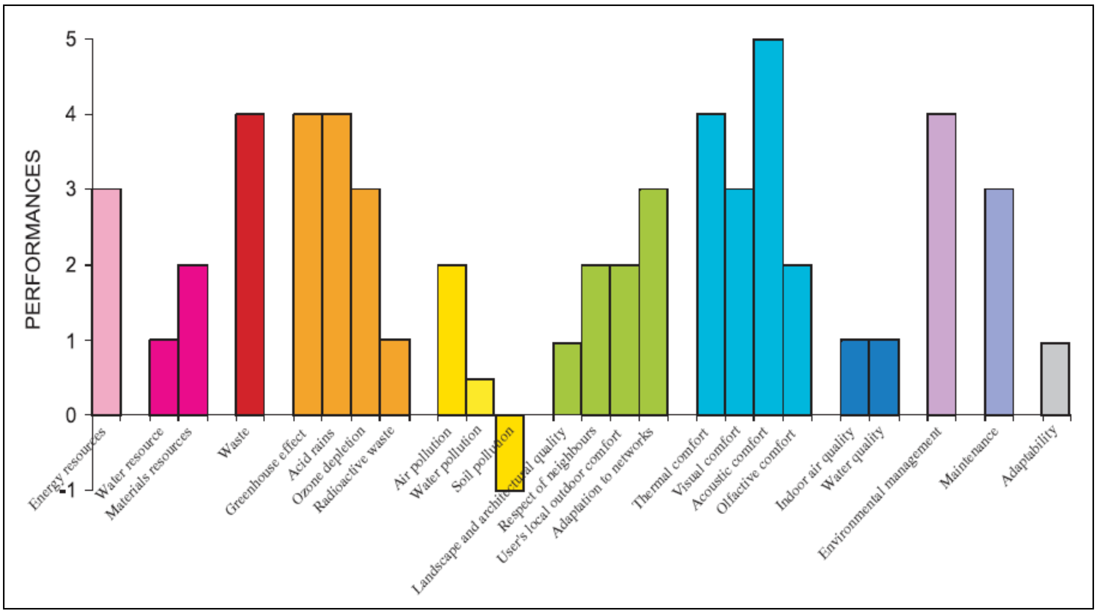


Two step approach – indicator value and score on a performance scale

The performance scale is defined by a reference value (0, equal to a statutory value or one frequently met in practice); a upper limit also called target value (5, equal to a best possible value); a lower value (-1, equal to a non-statutory value or below normal practice); and by a performance function that makes the link between the value of the indicator and a numerical value from -1 to +5 (not necessary linear).

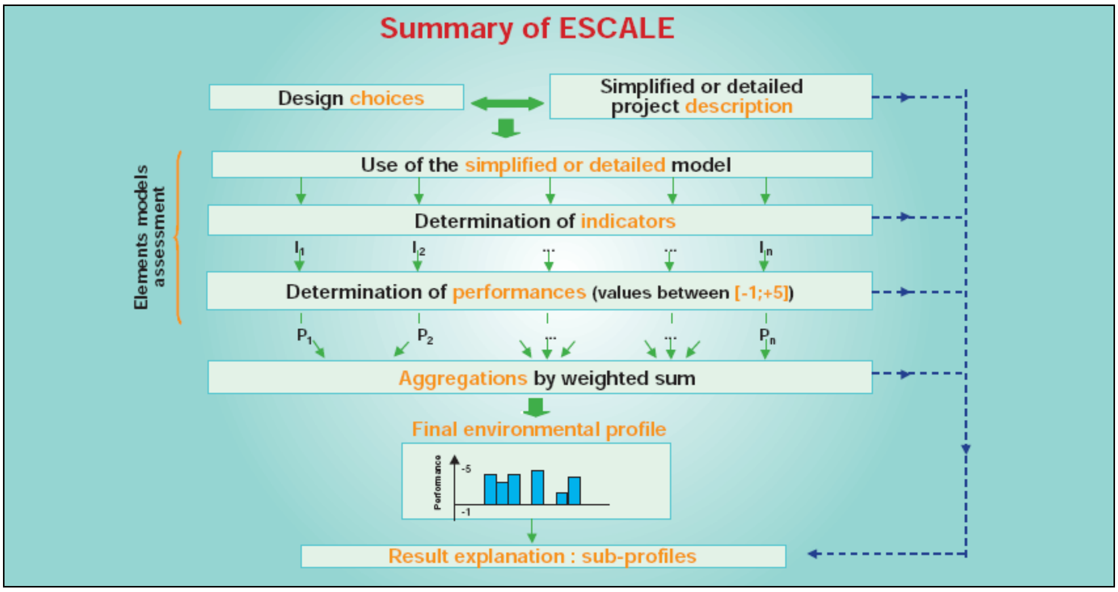
In the ESCALE method, the assessment based on each criterion (or sub-criterion) is the aggregated result, generally by weighted sum, of the assessments of the previous levels of the tree structure. However, complex and incomparable criteria are not aggregated.

The final environmental profile is a 24-component multi-criteria profile, expressed in terms of performance.



Final environmental profile

ESCALE, based on a wide range of criteria which are directly or indirectly environmental, is a first stage in a decision-making tool. The environmental information produced may form a common basis for discussion and negotiation with involved parties (building owner, architect, engineers, etc.).

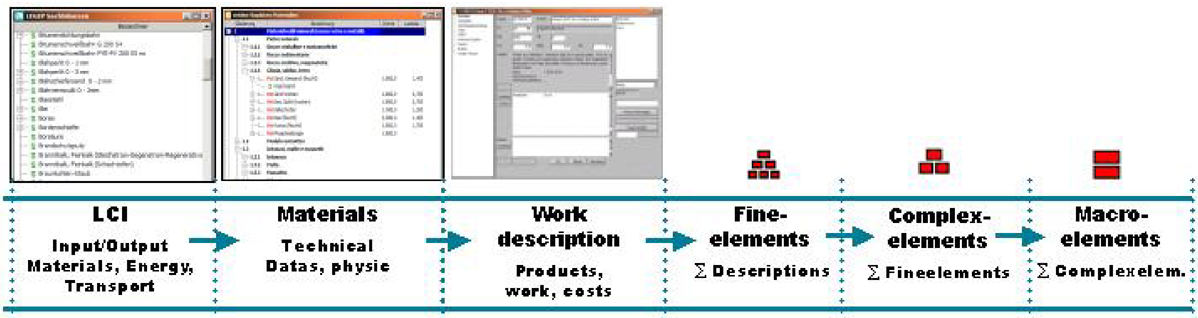


Summary of ESCALE

3.1.8 LEGEP

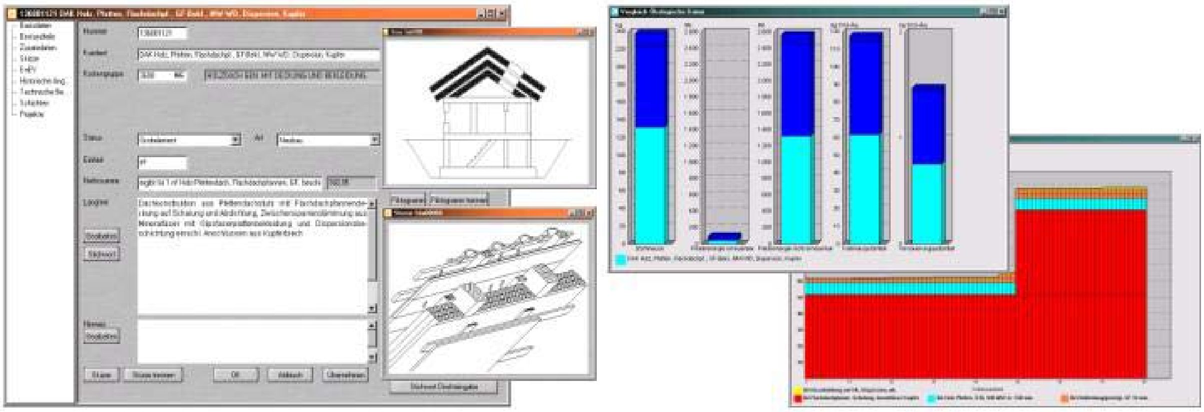
LEGEP is a tool for integrated life-cycle analysis. It supports the planning teams in the design, construction, quantity surveying and evaluation of new or existing buildings or building products. The LEGEP database contains the description of all elements of a building (based on DIN 276); their life cycle costs (LCC/WLC) based on DIN 18960 and the final report EU-TG4 LCC in Construction. All information is structured along life cycle phases (construction, maintenance, operation (cleaning), refurbishment and demolition. LEGEP establishes the energy needs for heating, warm-water, electricity and their cost (following EnEV 2002 and EN 832). The environmental assessment comprises the material flows (input and waste) as well as an effect oriented evaluation based on ISO 14040 – 43.

LEGEP is organised along four software tools, each with it's own database. 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 the complete roof. The data are fully scaleable and can be used either "bottom-up" or "top-down".



Hierarchical organization of data " Staircase" in LEGEP

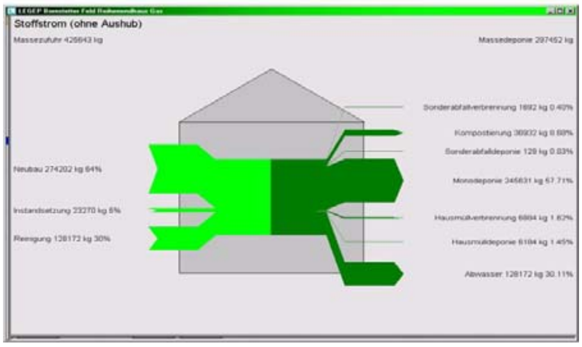
Elements at each level contain all necessary data for cost, energy, and mass-flow and impact evaluation. A building can be described using either preassembled elements or defining elements from scratch. The user can also define a specific composition by exchanging layers or descriptions of the element. The advantage of the top down approach is its completeness: if an element is not explicitly changed or eliminated it will remain in the calculation. The costs of the elements are established by the SIRADOS database, which is published each year. There are about 6.000 elements "ready for use" for the building fabric, technical equipment and landscape work. The LC Inventories are based on the ECOINVENT data and specific values from the Baustoff Ökoinventare (Kohler, N., Lützlendorf, Th. et al., Karlsruhe/Weimar/Zürich 1995).



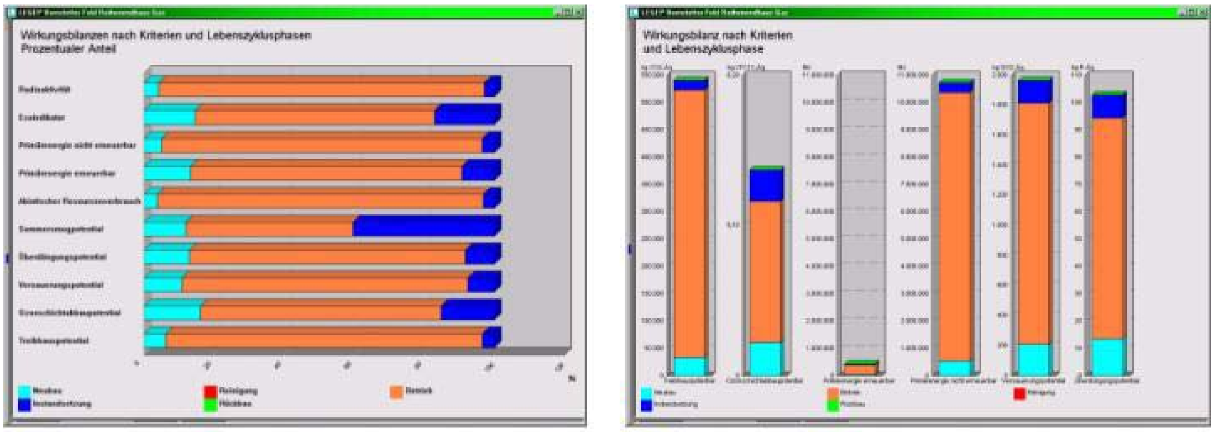
Element with environmental profile. Roof construction with five indicators and the impact of CO2 equiv. over eighty years.

Input in LEGEP: A building can be described alternatively with 15 macro-elements, 40 complex elements, or approx. 150 simple elements. This corresponds to the increase in knowledge during the design and planning process allowing describing the building more and more in detail without loosing the overall framework. At each level a complete evaluation can be made and documented automatically.

Output of LEGEP at each phase a complete, interrelated set of cost, energy, mass-flow and environmental indicators. The number of indicators, which are displayed, can be chosen from the CML indicators (Green house potential 100 years, Acidification potential, Photochemical Ozone creation potential, Ozone depletion potential, Eutrophication potential, primary energy consumption renewable and non-renewable, Ecoindicator etc.). Additional indicators are under implementation (DALY etc.). It is possible to show separately specific indicators or all indicators, for each life cycle phase (new construction, operation, cleaning, maintenance, refurbishment, demolition) of the building. The different evaluations are represented in the form of tables and appropriated graphs.
Through the use of LEGEP the main effort of the designers and other specialists is shifted from the extremely cumbersome description of a building and extensive input of data into a specific software to the interpretation of large number of synthetic results at each moment. The combined effects of changes can be immediately visualized; new methods of design can be founded on experience gained from LCA knowledge.

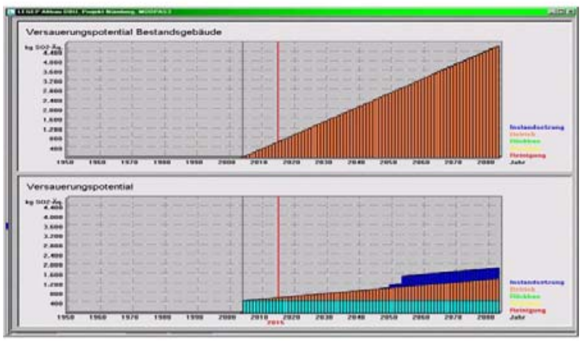


Material flows as realistic input and output in different EWC



Environmental impact of different indicators in percentage and absolute figures. The phases of the lifecycle are shown with different colours.

LEGEP is used at present mainly for the design of new built buildings, taking into account the future life cycle. The information is highly appreciated by clients and facility managers. For existing buildings LEGEP assists in the decisions on refurbishment operations and long term, sustainable management of buildings and building stocks.



Impact of CO2 equiv. for an existing building before (above) and after (under) the renovation with insulation, new windows and heating system over 80 years.

The software is available in German and Italian language; French and English versions are in preparation.

3.2 Description of the case studies

Because of the complexity of an environmental assessment of a building, the PRESCO inter-comparison started with the ‘easy’ exercise of assessing a simple geometric volume. After this, the tool developers compared the assessment of a real building.

3.2.1 The ”CUBE”

In order to compare the assessment tools and identify more easily the reasons for possible discrepancy (assumptions, data, methods...), it was decided to start with the evaluation of a simple parallelepiped, built up of 1 material. It was called the “CUBE” for practical reasons. All basic parameters of the CUBE were agreed on, so that every partner could use exactly the same data as input in their tool. The following details have been agreed:

<u>Geometry</u>

- The dimensions of the parallelepiped: 7m x 8m x 2,5m (interior dimensions)
- Thickness of all walls (including floor and ceiling): 20cm

<u>Other data</u>

- Material of the parallelepiped: reinforced concrete, on site fabrication
- Percentage of steel in the concrete: 3% in volume
- Life span: 50 years
- Neglect maintenance and replacements of components
- Electricity for space heating - ‘European mix’: 36.9% nuclear, 17.5% coal, 10.5% lignite (brown coal), 15.2% hydro, 9.7% oil, 7.9% natural gas, 1.9% other gas and 0.4% other
- no other energy consumption
- End of life and possible recycling: according to the assumptions in the tools / in the national practice

<u>Specific data for the evaluation of the heating load</u>

- Location: Switzerland (considering climatic data for Mâcon for the heating load calculation, altitude = 217 m)
- Thermostat set point : 20°C (constant)
- Ventilation : 0.6 ach (air change per hour)
- No internal gains
- Properties of the materials:

material	Density (kg/m3)	Conductivity (W/m/K)	Specific heat (J/kg/K)
concrete	2,100	1.28	820
steel	7,850	46	490

- Optical properties of the surfaces : absorption factor = 0.6, emission factor = 0.9
- The larger facades (8 m length) face north and south
- There is a ventilated crawl space under the floor (considered at the ambient external temperature)

- Resulting heating load : 38 900 kWh, i.e. 700 kWh/m2/a (the building is not insulated and all the walls are external, resulting in a very high heating load).

The reason for starting with this rather simple assessment was to identify the differences in input possibilities (e.g. being able to enter own data or modifying available data), to have a view on the different indicators used by each of the tools, to identify different assumptions of the tools (e.g. on transport, end of life, …) and finally to see if the obtained results were comparable.

3.2.2 The FUTURA house

The FUTURA house is a Swiss demonstration project for low-energy housing. The dwelling area is 280 m^2 and an 80 years period is considered in the LCA. The pictures below show the FUTURA project as built in Switzerland.


The FUTURA House as built

Three different structural versions of the FUTURA house were investigated, i.e. a wooden structure (comparable to 'as built' house), a concrete structure and a brick masonry structure. The design of the building was adapted: the insulation thickness in the brick and concrete alternatives were fixed so that the thermal losses were the same as in the wooden structure base case.

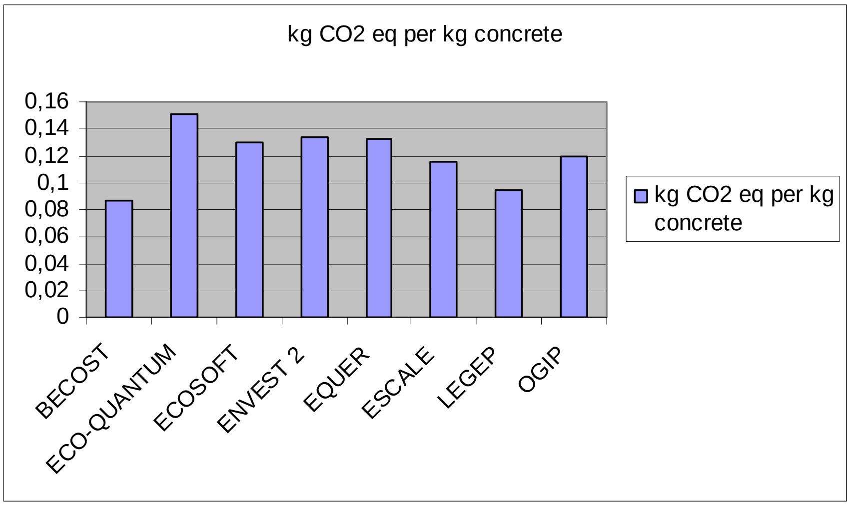
3.3 Presentation of the results

In a first step, the results of the tools were compared in the case of the "cube" and the main hypotheses were listed and analysed. The contribution to global warming, expressed as CO_2 equivalent emissions, is the most widely spread indicator among the tools, and corresponds to an important issue of concern. This indicator has therefore been used to compare the tools, even if each tool evaluates also other indicators.

3.3.1 CUBE

The analysis addressed the main assumptions of the tools (fabrication of the steel reinforced concrete, transport of the material to the building site, building process and waste, demolition process and possible recycling,…), the data (LCI of the concrete and electricity production, waste treatment, transport) and the results (impact indicators).

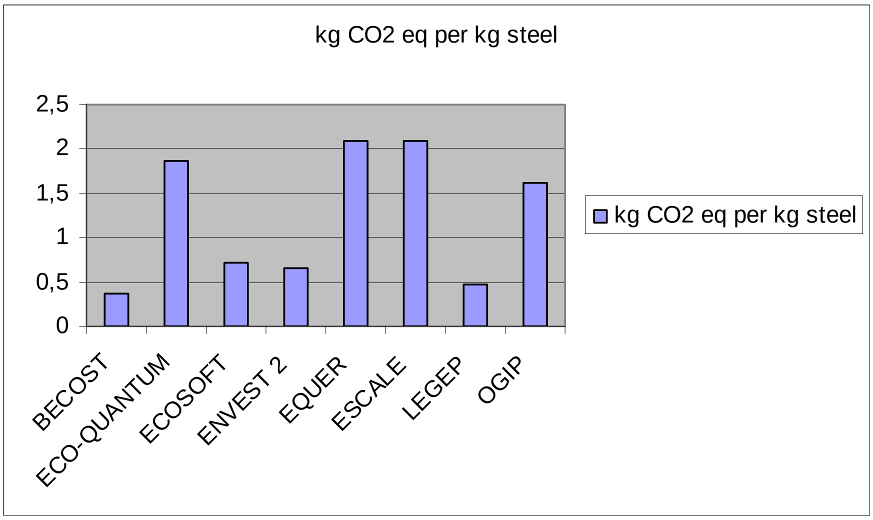
We present first a few examples of the greenhouse gases emissions obtained by the tools using life cycle inventory data concerning materials or processes.



Example 1 : Material data, contribution to global warming by the production of 1 kg concrete

The difference between tools may be related to :

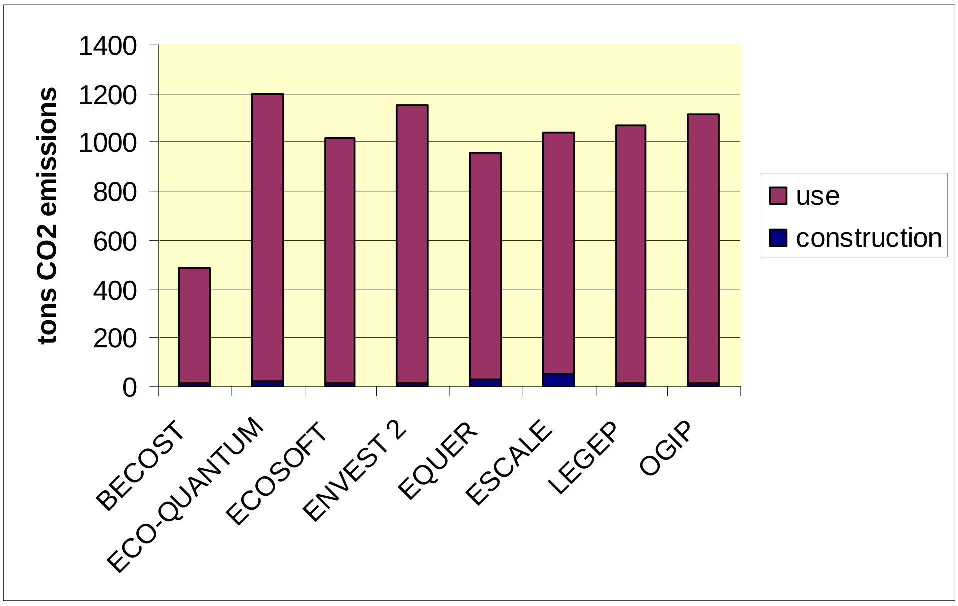
- different cement contents in the concrete,
- different density of the concrete,
- different production processes (national or European data bases),
- different global warming potential indicators (IPCC [15], [16], CML [13], [14]…).



Example 2 : Material data, contribution to global warming by the production of 1 kg steel

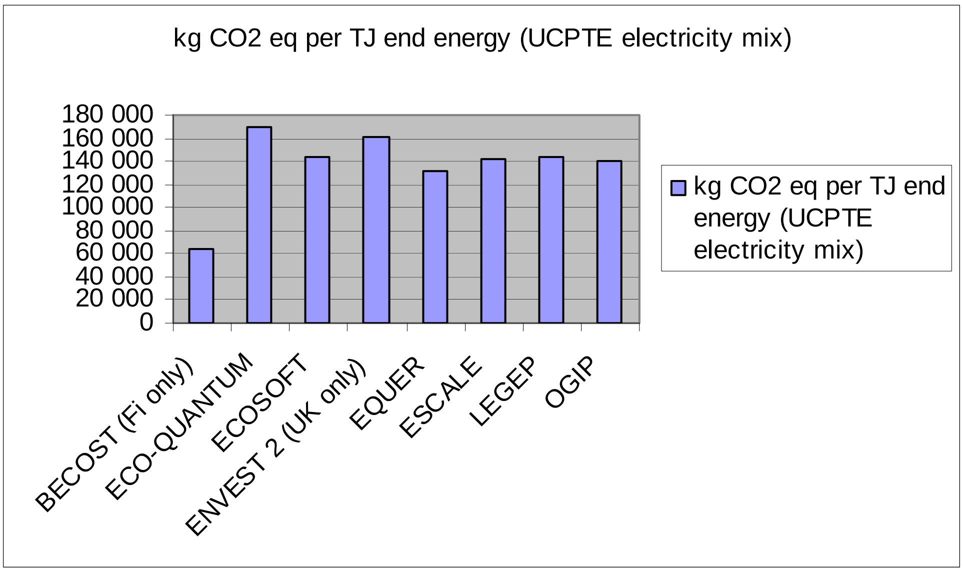
Different percentages of recycled steel and different fabrication processes (e.g. blast furnace or electric arc furnace) may explain the large discrepancy between the tools. Even tools using the same LCI database may provide different values, because the database proposes different types of steel with different assumptions concerning the use of recycled steel.

The following graph shows the greenhouse gases emissions corresponding to the construction and operation phases of the "cube". In two of the tools (BeCost and Envest), only a national electricity mix can be considered which partly explains the differing results. If we except BeCost (the Finnish electricity mix being very far from the European mix which was to consider), the overall discrepancy is +/- 10%.



Example 3 : building life cycle, contribution of the cube to global warming over 50 years

The graph hereunder shows which data has been used in the different tools regarding the impacts of electricity production and distribution.



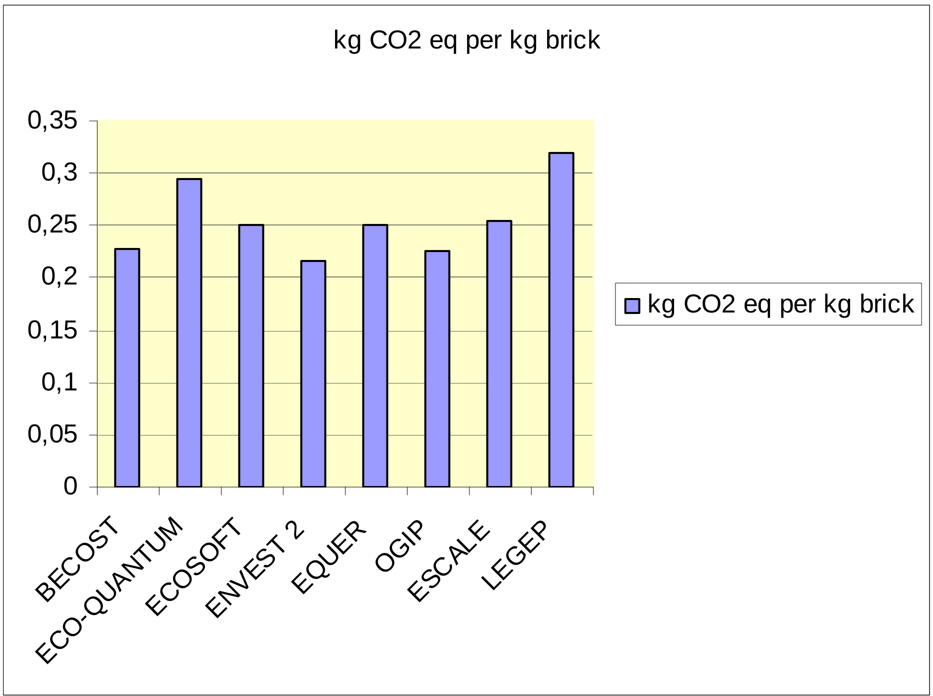
Example 4 : Process data, contribution to global warming of providing 1 TJ electricity

This graph confirms that the difference in the electricity production is a major cause for discrepancy. Some assumptions regarding the losses in the electricity grid also influence the results. Among the other causes of discrepancy for the global life cycle results of the cube are assumptions concerning :

- the material quantities (exact calculation or value derived from simplified geometric input),
- the material surplus or waste during construction (from 0 to 10%),
- the steel content in the reinforced concrete (from 0.83 to 3%),
- the use of recycled steel,
- the transport of materials (construction : from 0 to 50 km and end of life : from 0 to 20 km),
- the life span of building components,
- end of life processes,
- the global warming potential of greenhouse gases (IPCC [15], [16], CML [13], [14]…).

3.3.2 FUTURA

In a first step, the greenhouse gases emissions related to materials production and gas heating have been compared. This indicator has been chosen because it is the only common indicator between all tools (except OGIP). It is expressed as a weight of equivalent CO_2 emission (kg). The results are summarised in the table below, and illustrated by the following graphs.

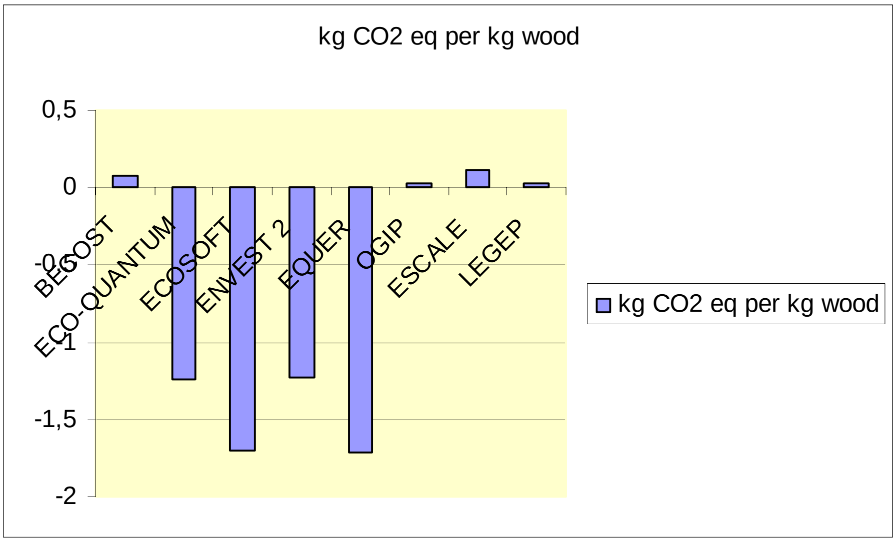


Example 5 : Material data, contribution to global warming of producing 1 kg brick

In the case of wood, some tools consider a CO_2 capture in the growth phase (because CO_2 is absorbed in the forest by photosynthesis) and a CO_2 and methane release at the end of the life cycle. Other methods take the neutrality as one's starting point and therefore do not account for biogenic CO_2. The total CO_2 balance for the whole life cycle should be the same, but :

- the carbon stored in the wooden structure during the building life span is not in the atmosphere, and this contributes to protect the climate ;
- several processes may occur at the end of life : the wooden elements may be land filled, incinerated with or without heat recovery, re-used etc. The choice between these options has consequences on the CO_2 balance (e.g. recovering energy from incineration avoids the use of fossil fuels) ;

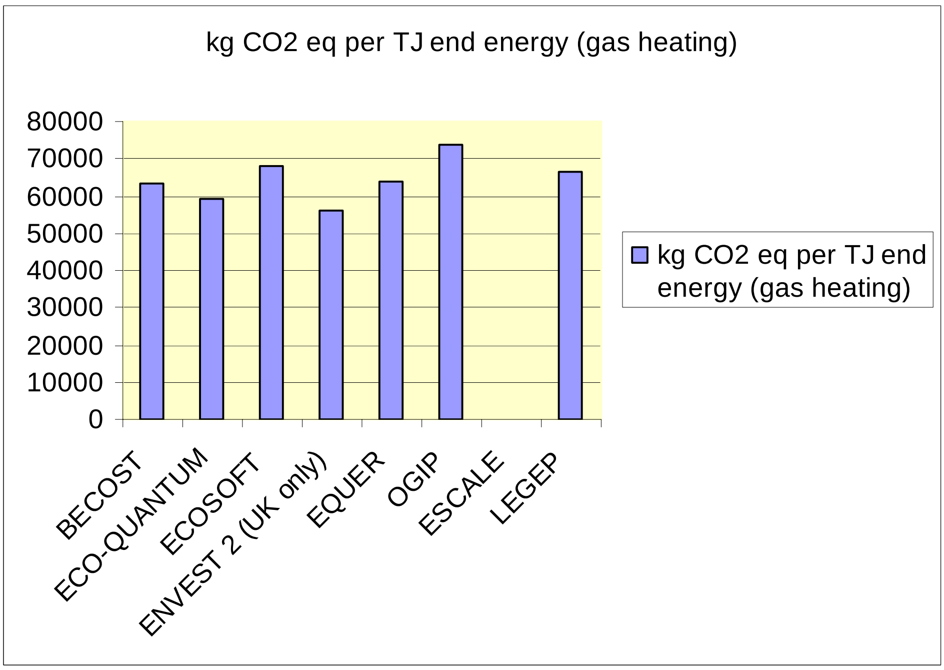
- problems can arise when an assessment is made without taking into account the disposal phase, which would not correspond to a complete LCA.



Example 6 : Material data, contribution to global warming of producing 1 kg timber wood
Even among tools using the same LCI database, the methodology considered to account for biogenic CO_2 can differ (e.g. ECOSOFT and EQUER account for CO_2 capture, OGIP and LEGEP do not).

Another discrepancy between the tools concerns the feedstock energy of wood as a material, which is included in some tools and not in others. Some tool developers consider that wood can be regarded as an energy source and include its heating value in the energy mobilized to provide this material in a building. For others, the wood used for timber would not be used as a fuel so that its heating value is not included.

The graph hereunder corresponds to the gas energy used for space heating, and complements the data on electricity production presented in the previous section.

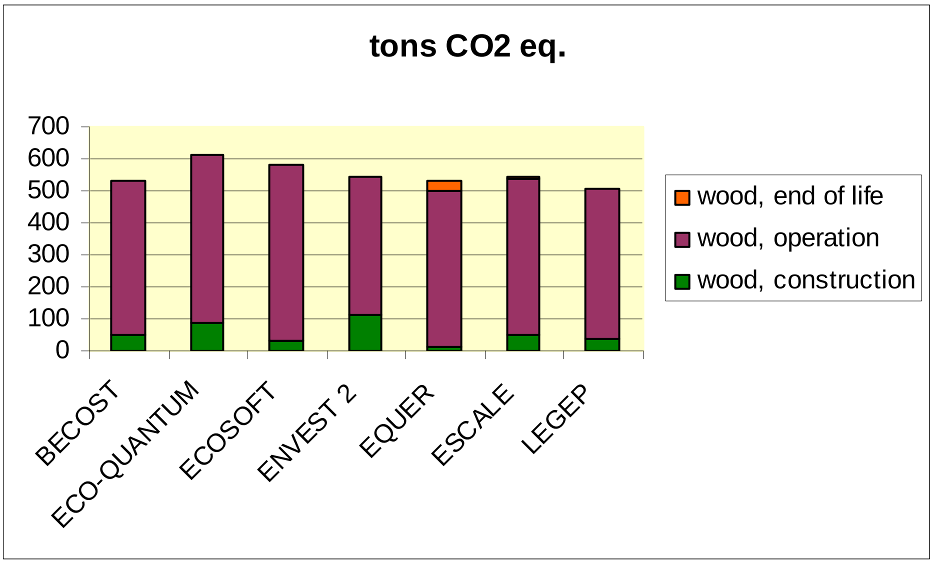


Example 7 : Process data, contribution to global warming of providing 1 TJ gas heating

Several causes may explain the differences :
- considering different boiler types (condensing/standard, low NOx, < or > 100 kW…),
- using different boiler efficiencies (space heating and domestic hot water),
- assuming different upstream processes (gas extraction , transport, distribution…),
- using different functional units - useful or end energy (i.e. related to heating load or heating consumption).

For the whole life cycle of the house, the results are similar to those obtained in the first case (cube) : there is a +/- 10% discrepancy between the tools, cf. the table below.

Functional unit	Mean eq. CO_2 emissions	Relative difference for the lowest value (%)	Relative difference for the highest value (%)
1 kg brick	0.255 kg	-15%	+25%
1 TJ gas (end energy)	64 400 kg	-15%	+15%
Whole house, wood structure, 80 years	550 tons	-10%	+10%

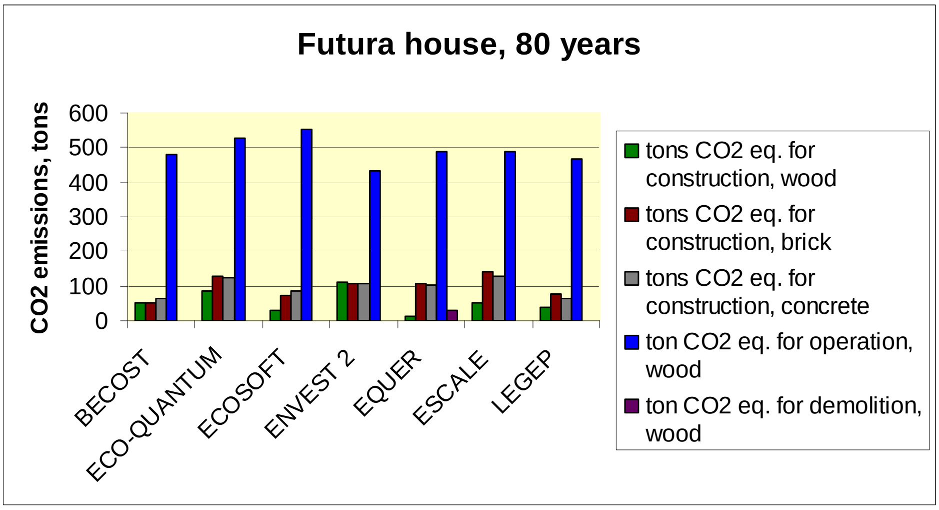


Example 8 : building life cycle, contribution to global warming of the wooden Futura house over 80 years

Concerning the comparison between wood, brick and concrete structures, the global warming indicator is lower for wood in all tools except ENVEST. But the results differ when comparing brick and concrete, as shown in the figure below : brick leads to higher emissions according to 4 tools, whereas the 3 others provide an opposite result, the difference between brick and concrete being small in all tools.

An overall view of the CO_2-Eq. emissions shows for all tools a domination of the operation phase. The emissions during this phase are very similar for the three alternatives, so only the case of wood is included in the figure. In most tools the same heating load has been considered for the three alternatives. EQUER being linked to a thermal simulation tool, the effect of thermal mass is accounted for, so that the heating load is slightly lower in the case of masonry structures (because the storage of solar gains is more efficient).

In the case biogenic CO_2 emissions (related to the wooden components) are included, some tools account for the release of greenhouse gases at the end of life. Therefore the demolition phase is also presented in the graph for the wooden alternative.



Example 9 : building life cycle, comparison of wood, brick and concrete alternatives

The indicator used for the discussion of the assessment results for the CUBE and the FUTURA house is related to global warming and expressed in kg CO_2-equivalent. Other indicators used in the tools are differing. The tools may address acidification, smog, waste (possibly indicating also radioactive waste), primary energy consumption, water consumption, exhaust of resources, eutrophication, ozone depletion, toxicity, eco-toxicity, cost, and some use also global indicators like eco-points or eco-scarcity. Therefore it is difficult to compare the multi-criteria ranking of the three alternatives considered (wood, brick and concrete).

3.4 Discussions about the harmonisation of LCA tools

During the analysis of the results presented in the previous §, the assumptions and methods implemented in the different tools have been compared. This comparison has also addressed the input and output of the tools. Possibilities for harmonisation have been studied. The group has agreed on some proposals whereas there was no consensus on others. The § hereunder presents the state of this discussion.

3.4.1 Scope and system boundaries

The main objective for performing a life cycle assessment of a building is to help the designers to reduce the environmental impacts related to this building over its life cycle. Therefore the building LCA-based tools have been developed mainly as design tools. Such tools can be used to design a new building, or a renovation project. But they can also be used for other purposes, e.g. to choose a building site by comparing several possibilities, or to advise the users (inhabitants in a residential building, persons working in an office building etc.) on the management of a building.

The functional unit considered by the tools is the entire building over a certain time period (e.g. 80 years). The function of the building is indicated (e.g. residential, office) as well as the quality of this function (e.g. office building heated at 20°C during working hours and 16°C the rest of the time, with also possible cooling set points). Other comfort issues (lighting, noise protection, ventilation…) can be specified in the functional unit.

The system boundaries can be defined according to the objective : if the objective is to choose a building site, the transport of persons should be included because it has often a large influence on the environmental impacts. Some other aspects may also be important (e.g. the solar access may be different in the compared sites, as well as the waste treatment processes). On the other hand if the objective of the LCA study is to help to design a building on a specific site, these aspects may have less importance.

Except in very particular cases, energy issues should be included in the studies : energy is needed for heating, domestic hot water, lighting and appliances, ventilation, possibly cooling. Upstream processes (production and distribution of gas, electricity, fuel…) should be accounted for. The design of a building has a large influence on its heating and lighting load. Linking energy and LCA makes the comparison of alternative designs more convenient. Different energy calculation methods are used. Dynamic simulation is more precise to evaluate space heating loads in low energy buildings, and cooling loads.

Water related impacts (impacts of drinking water production and sewage) are less influenced by the building design. Nevertheless features like low consumption sanitary equipment and composting toilets are integrated in some constructions. This is why this aspect is also addressed in some of the tools.

A larger kitchen and some space to store collected waste in a building may influence the sorting efficiency and the resulting impacts of waste treatment, but this is difficult to assess. Integrating a waste sorting scenario in a tool may be useful to evaluate the importance of such issues, but in general the municipal policy has more influence on these aspects than building design. Therefore operational waste is not included in most tools.

The question whether or not to include transport issues is rather similar : the existence of a bicycle garage may lead to reduce the use of cars. Again it is difficult to assess and depends on the behaviour scenarios of the inhabitants which are assumed in the design phase. On the other hand this question can be more easily studied in an existing building if the purpose of the LCA is to study a renovation project.

Extending the system boundaries allows more possibilities of using the tools. On the other hand including more aspects in a LCA reduces the sensitivity of the results to design choices. For instance replacing one material by another may lead to 4% difference in the result if only materials and energy are accounted for, but only 2% if water, waste and transport are also included. In the second case the choice of this material could be considered as having a negligible effect. This question is related to the interpretation of the results, which will be addressed in a further paragraph.

Regarding cut off rules, some participants have proposed that :

- all input and output materials which constitute more than 2% mass of the end product must be included independently of their environmental effects,
- if some effects can be proved also materials with less than 2% mass must be taken into account.

Other tool developers account only for materials having a significant influence.

3.4.2 Data input

A building is a complex object, including many different components (rooms, walls, materials, windows etc.). Beside an exact description of the geometry all the different materials used in these components must be linked to corresponding LCI (Life Cycle Inventory) data. This § describes some recommendations concerning the data describing the building and its connection to the LCI data.

The detailed description of all components of a building can be very time consuming if no user friendly interface is proposed. A graphic geometry input is in general more convenient, but may be less precise (e.g. wall may be defined by their internal or external area, and the derived quantity of materials can therefore be under or over-estimated).

Users have less difficulties if they use a software more frequently, otherwise they often forget how to use a tool. Therefore it is advised either to use one tool developed for all types of buildings (residential, offices, etc.) or including modules with a consistent interface (e.g. same way to input wall compositions etc.).

A user interface is in general the result of a compromise between precision and simplicity : more precision often requires more data, making the input more time consuming. The use of default values is in most cases a relevant solution. For instance in the early phase of a project, the designers do not know where building materials will be produced. Default values can therefore be considered, e.g. 50 km transport distance by truck. In a later phase of the design, it could be interesting a distinguish between e.g. locally produced concrete and other components like windows being produced far away from the building site. Also, it could be interesting to compare a locally produced material and an imported one. In such cases, the default values will have to be replaced by specific ones. The data is similar concerning transport of materials at the end of life.

Default values may also be used for the life span of materials, and for the amount of construction waste : for instance at the end of the day some concrete is remaining and constitutes waste, some components can be broken (e.g. bricks) or a surplus can remain (e.g. insulation, tiles etc.). This means that a supplementary quantity of materials has to be produced, transported and disposed (e.g. land-filled, incinerated…). Default values may also be used for low impact building processes (e.g. construction, maintenance, dismantling).

Default values may be proposed for the electricity mix, but it may be useful to allow changes so that different electricity types from different producers may be compared (e.g. green electricity is proposed in some countries). If the user can choose between various energy sources for space heating and hot water, this will allow alternative energy sources to be compared (e.g. gas, fuel, electricity, wood, district heating including energy recovery from waste incineration or geothermal source, etc.). This possibility is particularly useful for low impact buildings. The possibility to provide part of this energy by a solar system (e.g. solar water heater, photovoltaic system) is also useful, but accounting for these alternative techniques requires appropriate data (which exist in some databases).

Walls, floors and ceilings can be described using pre-defined “building elements” (e.g. a set of materials with pre-defined quantities), which are linked to certain life cycle inventory data. Alternatively, the user can define a specific building element “manually”, e.g. defining a wall composition by giving a list of materials and thickness. The impacts related to the construction and disposal of such elements are then estimated by adding the impacts related to the included materials, neglecting assembling related impacts. It may be less precise but gives more possibilities to the user for customizing these elements.

LCA-based building assessment tools are usually connected to life cycle inventory databases, which relate either to regional, national, European or world contexts. Therefore it is essential to benefit from as transparent data as possible. In general, it is advised to use the most recent and specific data, with the following remarks :

- the methodology for collecting this data should be consistent, it would not be relevant to compare two materials using different system boundaries, assumptions etc.,
- some generic data can be used for an assessment at the beginning of the design phase (e.g. European brick, corresponding to a representative sample of European producers) and replaced by specific data (when available) in a later phase (e.g. data for a specific local brick producer).

End of life processes must be included in an LCA. Therefore certain disposal LCI-data must be collected and included (e.g. incineration or disposal of materials) even though there is a big uncertainty about future recycling and disposal techniques. (see §. 3.4.4.3).

Harmonisation of LCI data is a pre-requisite for the harmonisation of LCA-based tools.

3.4.3 Output and interpretation of the results

The output interface also corresponds to a compromise between precision and simplicity. Most tools provide a set of indicators corresponding to the main environmental issues of concern : e.g. climate change, acid rains, depletion of resources, waste production etc. The following table presents some examples of these indicators, sometimes complemented with several possible definitions : for instance the primary energy consumption may be expressed using a lower or upper heating value, including or not renewable energies and feedstock energy.

Resources	
primary energy consumption	Lower or upper heating value Renewable energies included ? feedstock energy included ?
land use	Considering different types of land
water consumption	Quantity in m^3
exhaust of abiotic resources	CML 1992 [13] or 2001 [14]
Eco-systems	
global warming, CO_2 eq	CML, 1992 or 2001, IPCC, 1994 [15] or 2001 [16]
acidification potential	CML, 1992 or 2001
eutrophication potential	CML, 1992 or 2001
ozone depletion potential	CML, 1992 or 2001
Photochemical oxydant (smog)	CML, 1992 or 2001
human toxicity	CML, 1992 or 2001, DALY [17]
ecotoxicity	CML, 1992 or 2001
inert waste production	tonnes or CML 2001
radioactive waste production	Used only in very few tools, quantity in m^3
dangerous waste production	Used only in very few tools, or included in waste with a higher weighting factor
Economic	
external cost	Used only in very few tools

Life cycle cost	Included in half of the tools
Global	
ecoscarcity points	Used only in very few tools
environmental footprint	Used only in very few tools

Weighting factors allow several indicators to be aggregated in a single note (e.g. ecoscarcity points, ecopoints) but the meaning of this note is less clear than single indicator values. Design aid is more difficult, because the impact sources are more difficult to identify. According to ISO 14040, "there is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their life cycle".

Most tools provide the contribution of each life cycle phase –construction, operation, renovation and demolition- in the overall impacts.

Some tools provide the contribution of different building elements (e.g. walls, floors etc.) to the impacts. But this can only be evaluated for the construction, renovation and demolition phases. During the operation phase, the energy related impacts depend on interactions between several building elements (e.g. the solar radiation through windows can be stored in a slab and contribute to heat the building, depending on the control system). Due to these interactions it is not possible to allocate the global impact to each building element over the whole life cycle (in the previous example, would the energy saving be allocated to the windows or the slab ?). Therefore the interpretation of these results must be performed carefully : for instance the construction related impacts of a heavy slab might be large but this slab may contribute to save energy by storing solar gains, resulting to an overall benefit compared to a lighter floor.

Using LCA in the design of a building consists in comparing the impact indicators corresponding to several alternatives. Sensitivity analysis may be needed to draw a conclusion from such studies : is the ranking of these alternatives modified if a different assumption is made e.g. concerning the life span of the building ? If the ranking remains the same, the selection of the alternative with the lowest impact is more reliable.

In general, further work is needed concerning some indicators, for instance :

- land use (accounting for qualitative aspects by defining different types of land),
- waste (integrating all downstream processes until final waste).

3.4.4 Methodology

The ISO 14040 standards provide a framework for life cycle assessment. However the tools may differ in some specific aspects, and it is useful to review these differences and to propose some recommendations when it is relevant.

3.4.4.1 Recycling

The evaluation should account for recycling at both "ends" of the building life cycle : when recycled material is used for the construction, and when material is recycled at the end of life. But the possible benefit of recycling should not be accounted twice. Several methods are possible to model recycling, for instance the following approaches are implemented in some tools.

a) the “bonus” method

If the impact of recycling I_r is lower than the impact corresponding to the fabrication of the equivalent new material I_n (for the same functional unit, e.g. 1 kg), the “bonus” is defined by :

$I_n – I_r$

If $I_r > I_n$, the “bonus” would be negative because recycling would increase the impact. If the recycling rate is not 1 (100%) but r, the bonus is reduced accordingly : $r . (I_n – I_r)$

If recycled material is used at the construction phase, half the bonus is accounted : the impact of using 1 kg of this recycled material is I_n – ½ bonus =1/2 $(I_n + I_r)$.

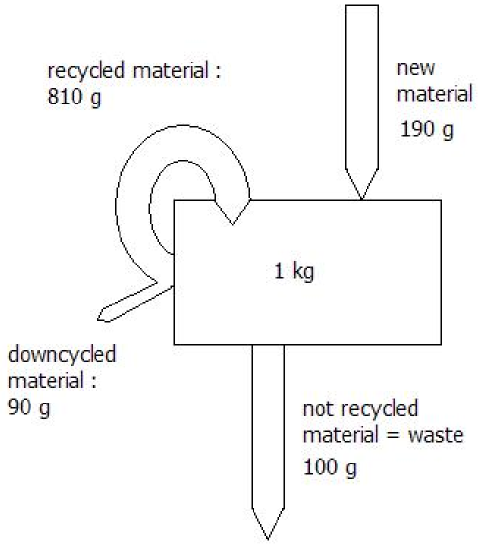
If the material is recycled at the end of life, half the bonus is also accounted for. The impact when recycling the same functional unit is evaluated by : – ½ bonus. In total, if 100% recycled material is used during the construction and if the material is also 100% recycled at the end of life, the impact is I_r.

If the recycling rate at the end of life is not 100% but r, and if the impact corresponding to the waste treatment (landfill, incineration…) is noted I_t, the impact related to the non recycled fraction is (1-r) x I_t. In this case the impact over the whole life cycle is $(1-r) (I_n + I_t) + r I_r$. The approach is similar for reuse and down-cycling (considering different impacts for the initial and replaced materials).

The advantage of this method is to reward both the use and the production of recycled materials : for instance if recycled concrete is used but mixed with polystyrene to produce light concrete, the recycling at the end of life will surely be very problematic. In this case, only half the bonus is accounted for.

b) the “value corrected substitution method”

This approach makes no distinction between recycling at the beginning and at the end of the life cycle. A recycling rate of the material at the end of life is assumed, e.g. 90% for aluminium. The impact of the rest is calculated like in the previous approach using I_t (impact of waste treatment). The method also assumes that a certain proportion of the recycled material is down-cycled, so that 1 kg recycled material corresponds only to p kg of new material (e.g. p = 0.9) which can be substituted. The impact related to the down-cycled fraction is neglected. The balance is shown in the next figure.



Over the whole life cycle, the impact of the same functional unit as in the “case a” method (1 kg material, including fabrication and disposal) is :

$r \times I_r + (1\text{-}r \times p)\ I_n + (1 – r)\ I_t$

This equation is equivalent to the previous method considering a recycling rate r x p and a down-cycling rate r x (1-p), and assuming the same impact for recycling and down-cycling.

The second method assumes that the recycling rate is the same at the beginning and at the end of the life cycle.

c) IISI-method for metallic products

Introduction

Environmental pressures can be allocated for scrap from the industry that produces the original products only in such cases where the scrap has economical value and it is recycled. In addition, the ISO 14041 standard states “allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration”. A closed-loop allocation procedure applies to closed-loop product systems according to the standard. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. According to the ISO 14041 standard “an open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties”. Allocation should be based on physical properties, economic value (e.g. scrap value in relation to primary value) or the number of subsequent uses of the recycled material.

Scrap metal

This recycling model was originally developed by the International Iron and Steel Institute (IISI). The model is based on the concept that the original product and all products generated by the material in the original product should share the total environmental impact. Therefore the recycling model promotes the use of products with high recyclability and reusability. The recycling model should not be applied in such cases where the aim is for instance to describe real impacts for a certain area and time.

The recycling model is based on the closed-loop allocation. Recycling can be treated according to ISO 14041 as a closed-loop system when no changes occur in the inherent properties of the recycled material. Recycled steel, aluminum, zinc, copper and some other metals have practically identical physical properties to those produced from virgin materials.

The equation for all environmental parameters in the whole product system is (Brimacombe et al. 2001[7]):

$$X = X_{primary} + [(X_{recycled} - X_{primary}) \times R \times Y]$$

where:

X	=	LCI values for the whole system
$X_{primary}$	=	LCI values for the virgin material route
$X_{recycled}$	=	LCI values for the recycling route
R	=	recycling ratio (the percentage of material which is recovered as scrap)
Y	=	metallic yield ratio at the recycling process

This method is similar to a), but the whole “bonus” is accounted at the production phase and the end of life is not addressed.

3.4.4.2 CO_2 storage

During the growth of plants, CO_2 is absorbed from the atmosphere in the photosynthesis process (around 1.85 kg CO_2 is absorbed to produce 1 kg cellulose for instance). At the end of life of the material, greenhouse gases are released (e.g. during incineration or landfill). Some of the tools assume a global CO_2 neutral process, assuming that a corresponding amount of CO_2 is released after the end of life cycle as the original amount stored in the products. Other tools account for a CO_2 capture during the production phase, evaluated as a “negative” emission, and a CO_2 release at the end of life according to the process (e.g. heat may be recovered from the incineration and substitute the use of fossil fuel, methane can be collected on a landfill etc.). The second approach makes visible the CO_2 storage during the life span of the material in a building.

In any case, the method should be consistent : if CO_2 capture has been accounted for, the end of life processes should also be modelled, and a CO_2 release should be accounted for.

One participant has proposed to distinguish the use of wood from certified forests, e.g. according to the forest stewardship council (FSC). If the forest is certified, the cleared trees will be replanted so that more CO_2 can be stored compared to a non certified forest. But this principle has been judged too difficult and complicated by another participant.

3.4.4.3 Renovation and demolition scenarios

In general, a life span is associated to each building element (default values can be used, see the paragraph on data input). This life span results from technical and economical aspects,

[7] Brimacombe, L., Schonfield, P. and Buriard, M. 2001. Sustainability and Steel Recycling. SAE Technical Paper Series 2001-01-3766. Society of Automotive Engineers. 4 pp.

possibly also changes in fashion, and interrelation with other components. If the default life span can be changed by the user, the benefit from long lasting components and good maintenance can be evaluated using the tool.

A theoretical renovation process is modelled in most tools, assuming that a component is replaced by an identical component and accounting for the related impacts. But we know that this rarely happens in practice. We may consider that this accounting method gives an estimate of the yearly impacts during the first years of the building life cycle, and the evaluation is less and less precise in a longer term.

The models should include the assumption that in practice, no replacement occurs in the final years of the building life span.

Studying a renovation project would require a specific interface. Using the tools as they are presently requires several calculations : one for the building before and one after renovation, and specific calculations if some elements have to be replaced (e.g. windows) so that the replacement related impacts are known. To avoid this multiple calculation, a specific interface would be more convenient in the case of refurbishment.

Concerning end of life processes after demolition, scenarios can be defined for different product categories (metals, masonry, wood…) assuming possible waste treatment processes (landfill, incineration, recycling…) according to the present state of the art.

3.5 Conclusions of the tool comparison and recommendations

This inter-comparison work allowed a deeper analysis to be performed, regarding particularly :

- the assumptions,
- the methodologies,
- the resulting indicators.

This exercise allowed the software to be improved and aims at increasing the confidence in the tools : the discrepancy in the results between the studied tools remained in a reasonable range (+/- 10%) concerning the global warming indicator. The analysis has resulted in various recommendations. The following sample shows some important ones:

- Try to have consistent LCI data with high transparency (same system boundary, clear allocation methods, no mixing of data from different sources, etc.).
- If possible use up to date specific product LCI data with a clear user area.
- Include all transports (also in upstream processes). If no exact data are available some country specific default values should be proposed for transport distances, to the building site in the construction phase and from the site at the end of life, for the different waste treatment processes (incineration, landfill, recycling, ...).
- Account for all materials having a significant influence.
- Account for both the use of recycled material in construction and for recycling at the end of life in a consistent and transparent way.
- If possible include the land-use in the whole process from cradle to gate.
- Include water consumption in the analysis.
- The choice of the impact assessment indicators is arbitrary but needs explanation. Be careful using cumulated indicators as different environmental impacts are calculated into one value.

- Substitutions of certain materials/constructions must be taken into account after their service life. Be aware that a certain time before demolition no substitution will be made.
- Upstream processes (production and distribution of gas, electricity, fuel…) must be accounted for.

Transparency is very important : the system boundary, the database, the assumptions and the calculation of different impact indicators (particularly if several indicators are combined using weighting factors) should be clearly described.

For the interpretation of the results the practitioners (architects, civil engineers, etc.) must be trained : building designers are no environmental experts and therefore some minimal knowledge should be provided so that they can interpret the results of an LCA.

LCA based tools should also evolve according to the progress of knowledge (e.g. evolution of environmental indicators, progress in LCI data bases).

Further work is needed to harmonise the methods and to facilitate the interpretation of the results by the building practitioners. Some tools are already used in practice, and educational material is available for the training of professionals. Therefore, impact reduction objectives could be integrated in the design briefs for low impact buildings. If a general target is to reduce the greenhouse gases emissions by 75% in the year 2050, it is necessary to integrate this objective in new and renovated buildings because they are likely to remain part of the building stock for a long time.

4. Example applications

The EQUER model presented above has been implemented in a software linked to a user friendly interface[8]. This allows a building project to be described using a graphical input, and facilitates the interpretation of results by graphs. Two example applications are presented hereunder.

4.1 Renovation of a social housing building

A large part of the building stock in Greater Paris area has been built in the 60's and early 70's before any thermal regulation exist. These buildings were not insulated and their facades include a high percentage of windows with single glazing. The corresponding environmental impacts are high, and also the potential for improvement by renovation. The municipality of Montreuil, a city located east of Paris, has launched a green neighbourhood pilot project. The municipal social housing office has planned a renovation project concerning 500 apartments. In one of the buildings including 52 dwelling units, a more energy efficient renovation has been performed within the European REGEN LINK demonstration project [21].

This renovation project aims to improve the general image of the neighbourhood, and to reduce the greenhouse gases emissions by 25% compared to a standard renovation. The building is heated by a district heating system which uses fuel oil and coal as energy sources.

[8] See www.izuba.fr

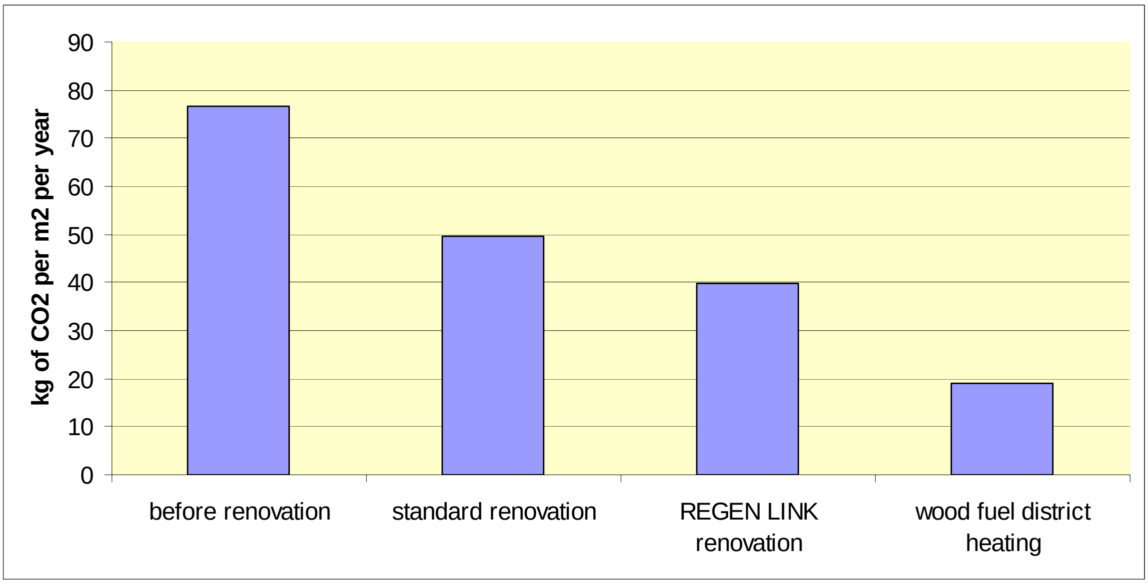
The REGEN LINK social housing building in Greater Paris Area, before and after renovation

The building before and after renovation has been modelled considering the different orientations of the rooms and separating the apartments situated under the roof, where the thermal losses are higher. The walls are constituted by 20 cm concrete. The facades include a high proportion of windows (nearly 50%). The standard renovation initially planned consisted in replacing the single glazing by double glazed windows, and insulating the walls with 6 cm glass wool. Several measures have been implemented in order to improve the thermal performance of the building :

- increased insulation thickness (10 cm),
- use of advanced glazing (low emissivity, argon filled),
- preheating of ventilation air in glazed balconies,
- moisture controlled ventilation,
- low flow rate sanitary equipment.

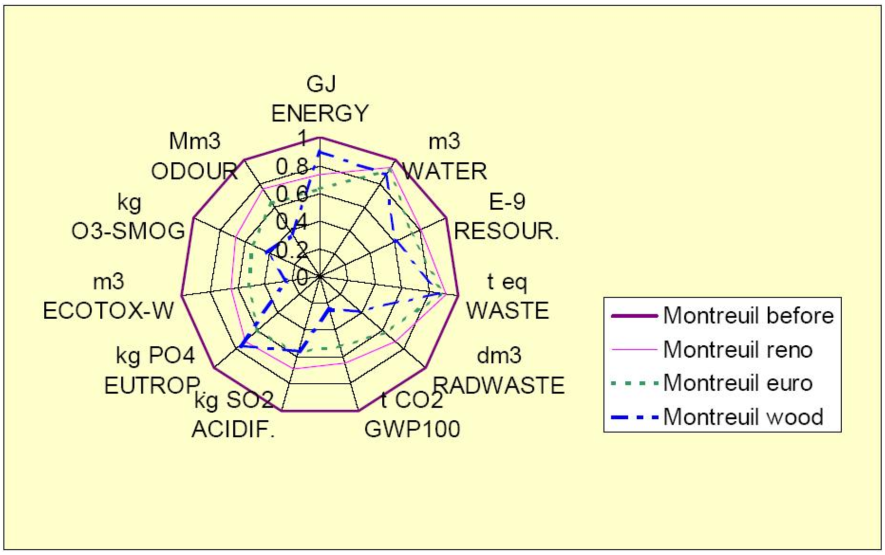
Thermal calculations, performed using the simulation tool COMFIE, have been complemented by LCA using the EQUER software. The following graphs compare environmental indicators for the project before renovation ("Montreuil before"), after the standard renovation initially planned ("Montreuil reno"), after the renovation re-designed within the European REGEN LINK project ("Montreuil euro"), and the fourth case corresponds to the use of wood fuel in the district heating system.

The first graph regards only greenhouse gases emissions, expressed in kg CO_2 equivalent per m^2 of dwelling and per year.



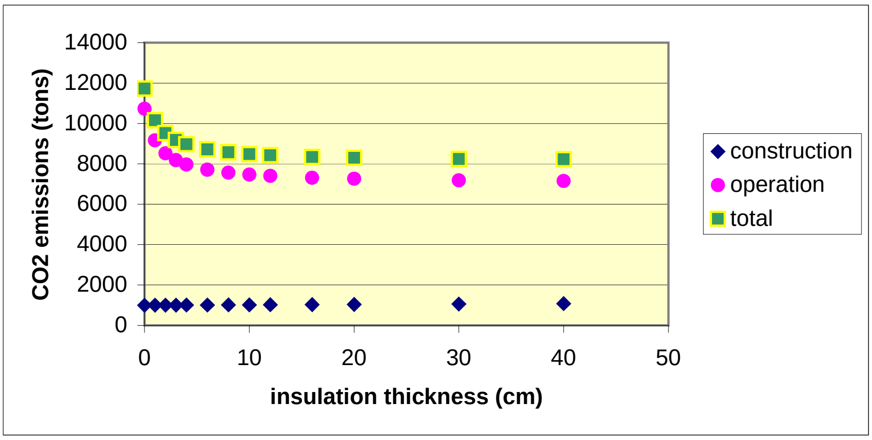
The energy mix for the district heating is 70% coal, 12% fuel, 5% gas and electricity in summer (78% nuclear, 14% hrydro-electricity and 8% coal and gas thermal plants). This mix leads to a GHG emission factor of 343 g CO_2 per kWh. This high emission ratio could be reduced if e.g. wood fuel could replace some coal or oil in the heat production mix of the district heating system.

The second graph shows the comparative environmental profile. Each axis corresponds to one indicator. The case before renovation is considered as a reference and the indicators for the other cases are given in relative values (e.g. the CO_2 emissions are around 50% lower after renovation, 70% lower if wood fuel is used).



Reduction of environmental impacts by various renovation alternatives

An example sensitivity result is given below regarding the insulation thickness (see also section 1.1 Insulation and thermal bridges).



Example LCA result, CO_2 emissions in terms of the insulation thickness

This graph shows that the first centimetres of insulation produce a large reduction of CO_2 emissions (related to the reduced heating load), but this effect is much smaller if the insulation thickness is further increased. The variation of the heating load induces a variation of CO_2 emissions corresponding to the operation of the building, accounting for the district heating system. The energy mix for the district heating system leads to a GHG emission factor of 340 g CO_2 per kWh.

The CO_2 emissions for the construction phase vary in a linear way in terms of the insulation thickness. In this case study, the total emissions curve shows a flat optimum with very small variation from 10 to 40 cm. A value of 10 cm has been chosen for economic reasons : the cost of 1 kWh saved is around the cost of 1 kWh provided by district heating (see the following table).

This study shows that increasing the insulation thickness is not the most appropriate measure in our climate (around 2,700 degree days). Improving the quality of the glazing, preheating ventilation air, reducing the domestic hot water use by low flow rate showers seem more promising.

Economic data

Technique	Overcost (incl. VAT)	Estimated energy saving	Cost of 1 saved kWh	Cost of 1 ton CO_2 avoided
+4 cm insulation	13,500 euros	21,000 kWh/a	3.2 euro cents	84.6 euros
Low emissivity glazing	6,500 euros	82,000 kWh/a	0.3 euro cent	7 euros

These results can vary with the constructional (proportion of windows, design layout of the thermal envelope,…) and economical conditions (progression of energy costs over the lifetime of the refurbishment measures). The economic optimum is increasing permanently – with it the “allowed cost” of 1 saved kWh. See also the section Techniques \ Insulation and thermal bridges.

4.2 Links between design and occupants behaviour

Design choices have a great influence on the entire life cycle of a building, but the behaviour of occupants is also of great importance. We analysed the relationship between design and operation, performing a sensitivity study combining both aspects. Two types of dwellings are compared: a reference corresponding to a current standard house in France with a north orientation of the most glazed façade, and a higher environmental quality dwelling, see next table.

Building characteristics

Component	Reference (REF.)	"Higher environmental quality" (HEQ)
insulation	8 cm internal	12 cm external
glazing area	10 m2, north oriented	25 m2, south oriented
controlled ventilation	without exchanger	heat recovery, efficiency 0.5
sanitary installations	standard	reduced water flow rate (of 50%)
waste sorting equipment	only for glass	for paper and glass

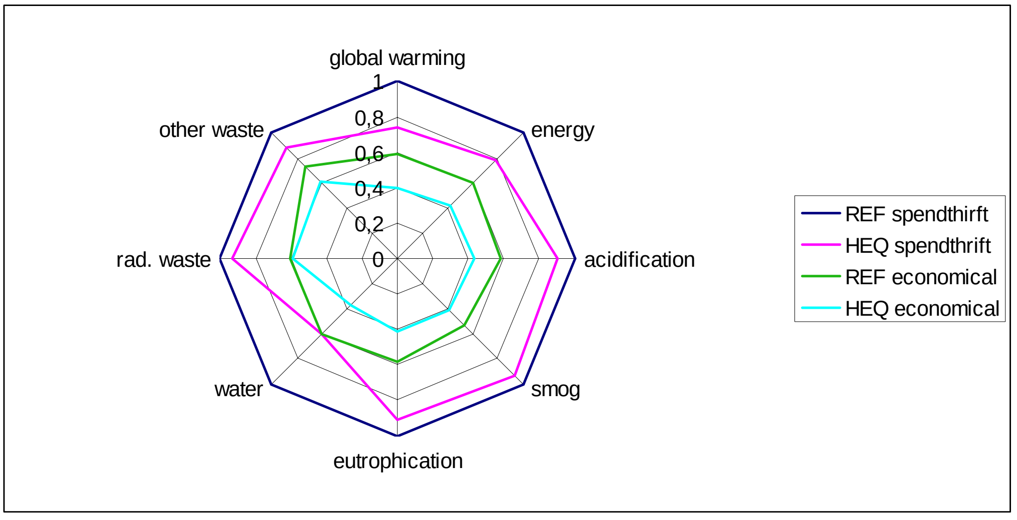
Also two extreme behaviours are modelled: an “economical” occupant and a “spendthrift” one. The occupants behaviour is characterised by parameters concerning energy, water and waste, see next table.

Occupancy scenarios

Parameters	"Economical"	"Spendthrift"
Set point temperature	varying between 14°C and 19°C	21°C constant
Ventilation	0.5 ACH	1 ACH
Electricity consumption	150 W	300 W
Domestic hot water	40 l/person/day [A]	60 l/person/day [A]
cold water	80 l/person/day [A]	150 l/person/day [A]
urban waste	0.8 kg/person/day	1.5 kg/person/day
paper sorting	60% [B]	0%
glass sorting	80%	0%

[A] divided by two for the "Higher environmental quality" case, due to the reduced flow rate.
[B] 0% for the reference case as there is no paper sorting possibility.

In this study the transportation of people is not taken into account. The results of this double comparison are given in the next figure.



Environmental performance in terms of building design and occupants’ behaviour

Occupants behaviour has a large influence over major fluxes (energy, water, waste) and hence environmental impacts. Even if this effect does not annihilate the efforts made by designers to propose environmentally friendly buildings, it is essential to inform the occupants about the function of equipment, put at their disposal, so that they can use it in an optimal manner: e.g. proper control of heating and ventilation systems, water use, waste collection.

5. Conclusions

Building LCA Tools have been developed in several countries and their use is progressing, particularly in building design. These tools can be used for the design of a renovation project. They allow several alternatives to be compared, and help designers to identify the lowest environmental impact solution.

Energy issues contribute to a large extent to the environmental performance of a building. LCA shows the environmental benefit of energy saving and renewable energy use. But the fabrication of materials becomes important in the environmental balance of a low energy building : beyond a threshold that varies according to the climate and indoor temperature level, increasing the insulation thickness may increase the environmental impact of a building.

LCA also shows the important role of the residents regarding the control of equipment (heating, ventilation), energy consumption (choice and use of lighting and domestic appliances), water consumption (cold and hot), waste management (sorting) etc. Information and participation of the residents is therefore essential for a proper management of a building in its operation phase.

At the moment, LCA is only emerging and used by specialised architects and consultants. But its use could expand in relation with increasing concern about environmental issues. Beyond a design aid, LCA could also allow renovation and re-construction (demolition + construction) to be compared. Environmental performance targets could be set in the programme of a renovation project, for instance greenhouse gases emissions lower than 30 kg CO_2 per m^2 dwelling and per year : in such a case, LCA could be used to determine appropriate target values according to a specific context, and to check the compliance of a project with these targets.

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