# Integrating health and sustainability in life cycle assessment

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**ABSTRACT**
Until now health impact assessment and environmental impact assessment were two different issues, often not addressed together. Both issues have to be dealt with for sustainable building. The aim of this paper is to link healthy and sustainable housing in life cycle assessment (LCA). Two strategies are studied: clean air as a functional unity and health as a quality indicator. The strategies are illustrated with an example on the basis of Eco-Quantum, which is a Dutch whole-building assessment tool. It turns out that both strategies do not conflict with the LCA methodology. The LCA methodology has to be refined for this purpose.

**INDEX TERMS**
Housing; Indoor air; Human health; Life cycle assessment; Sustainability

**INTRODUCTION**
The report 'Our Common Future of the World Commission on Environment and Development' (Brundtland, 1987) has led to a worldwide notion of the concept of sustainable development, which is a 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'. This very general definition demands for a more operational one when narrowing the scope from sustainable development towards sustainable building. The Dutch Ministry of Housing, Spatial Planning and the Environment (1990) defines sustainable construction as reduction of the environmental and health impacts of construction, buildings and the built environment. This definition places health impact next to environmental impact. In the discourse on the position of health in sustainable building, both a narrow and broad definition of sustainable building is being used. The WRR (scientific advisory council in the Netherlands) advises to limit the definition of sustainable building to ecological aspects (WRR, 2002). Others focus on the wellbeing of humans and use health impact as a quality indicator of sustainable building.

This paper considers health issues equal to environmental issues in sustainable building. It is important to study the links between health and sustainable building to find out what conflicts arise and how it can improve the quality of buildings. Design strategies that can be evaluated deal in different ways with human health, for instance in life cycle assessment (LCA), or health performance as quality criteria in the design process of sustainable building, or even fresh indoor air as a substitute for health. The aim of the paper is to link healthy and sustainable housing in life cycle assessment. The paper answers the following questions:

1. What is the relationship between LCA and health indicators (section 2)?
2. How can we include health issues in LCA (section 3)?
3. What kind of outcomes can we expect (section 4)?
4. Which recommendations for LCA development result in better input of health aspects (section 5)?

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## METHOD

The essay continues the discussion of the authors on sustainable building and indoor air quality (OHI, 2003), which started at the Indoor Air 2002 Conference at Monterey.

## RESULTS

### Relationship between LCA and Health Indicators

LCA is a method for the analysis of the environmental burden of products (goods and services), starting form the process of extraction of raw materials, through the production of materials, product parts and products and finally the discarding process, either by recycling, reuse or disposal (Guinée *et al.*, 2002). LCA is defined as the 'compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle' (ISO, 1997). The product system is the total system of processes needed for the product, which in this case is a building. Inputs and outputs are materials, water and energy, which enter and then leave the product system. The framework for LCA, which has been internationally agreed upon, distinguishes four phases, as is shown in Figure 1.

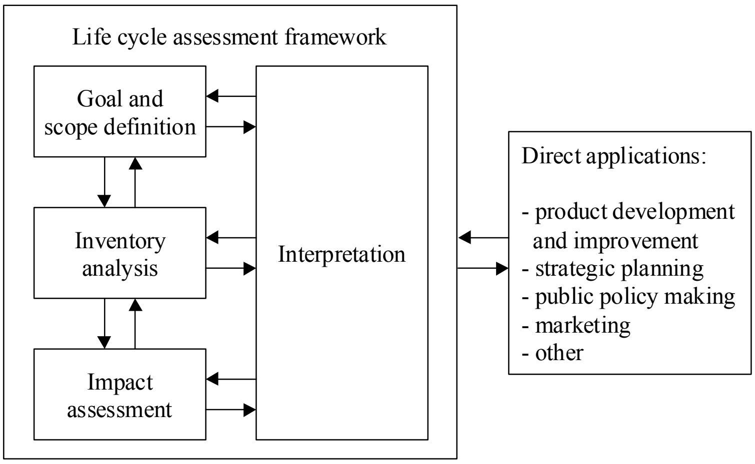


**Figure 1** Phases of LCA (Source: ISO, 1997).

1. Goal and scope of an LCA have to be clearly defined and geared to the intended use. An important part of the goal and scope definition is determination of the functional unity, which is the quantified function of the product system under study, to serve as reference unity in an LCA.
2. Inventory analysis is the second phase of an LCA, in which the inputs and outputs of the product system are compiled and quantified, including natural resources and emissions to air, water and soil.
3. Understanding and evaluation of the magnitude and significance of the potential environmental impacts of the product system. Impact assessment encompasses assignment of inventory data to impact categories (classification), modeling of inventory data within impact categories (characterization) and, only if useful, aggregation of the results (weighting). Examples of impact categories are depletion of raw materials, ozone depletion, acidification and eutrophication.
4. Finally, the interpretation of the results of the inventory analysis and impact assessment in the light of the goal and scope definition, in order to draw conclusions.

With LCA many impact categories can be evaluated. The so-called baseline impact categories should be taken into account in every LCA. Inclusion of study-specific impact categories depends on the goal and scope definition. Table 1 lists all impact categories (Guinée *et al.*, 2002).

**Table 1** Impact categories in LCA

| Baseline impact categories | Study-specific impact categories | Other impact categories |
|---|---|---|
| Depletion of abiotic resources | Impacts of land use: | Odour: |
| | Loss of life support function | Malodourous water |
| | Loss of biodiversity | |
| Impacts of land use | Ecotoxicity: | Depletion of biotic |
| Land competition | Freshwater sediment ecotoxicity | resources |
| | Marine sediment ecotoxicity | |
| Climate change | Impacts of ionizing radiation | Desiccation |
| Stratospheric ozone depletion | Odour: | |
| | Malodourous air | |
| Human toxicity | Noise | |
| Ecotoxicity | Waste heat | |
| Freshwater aquatic ecotoxicity | | |
| Marine aquatic ecotoxicity | | |
| Terrestrial ecotoxicity | | |
| Photo-oxidant formation | Casualties | |
| Acidification | | |
| Euthophication | | |

Regarding the baseline impact categories of climate change, stratospheric ozone depletion and human toxicity are relating to human health, although this is not accounted for. Human health is seen as one of the areas of protection foreseen with LCA. Here human health is seen from a global point of view. Health indicators such as air quality, radiation, noise, nuisance and personal accidents belong to the study-specific impact categories. These are often not addressed in LCA. This kind of health aspects relate more to here and now than there and later (see Figure 1) (Duijvestein, 2002), so with liveability of a small area instead of sustainability as development worldwide. This implies a short-term focus instead of long-term. Although spatial differentiation in LCA is being studied, LCA does not deal with impact assessment of the indoor environment. Moreover, health indicators typically address the occupancy phase of housing, while LCA is concerned with the whole life cycle.

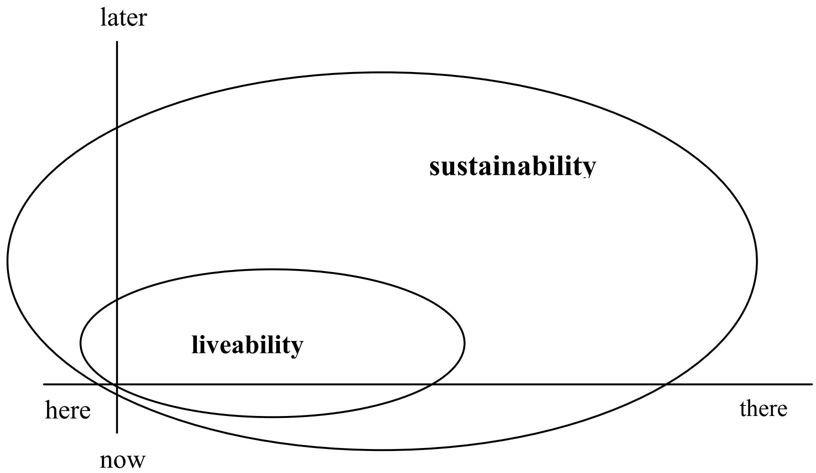


**Figure 2** Liveability as part of sustainability (Source: Duijvestein, 2002).

**Including Health Indicators in LCA**
Indoor air is a major research and design field in healthy building, but plays a minor role in sustainable building. Köhler (2002) and Hasselaar and Morawska (2003) argued that clean indoor air can be treated as a service, for which life cycle assessment or LCA can be performed. However, finally other health risk indicators also have to be involved: radiation, contamination of drinking water, noise. Therefore, an approach equal to the Eco-indicator (Goedkoop and Spriensma, 2000) can be chosen. The Eco-indicator goes one step further than LCA. The scores on the environmental impact categories are evaluated with respect to damages to human health on the basis of DALY (disability adjusted life years). These two strategies are subsequently addressed in the following sections.

**Clean Air as a Service**
Indoor air can be treated as a service or consumption good, which is 'produced' by building services (Köhler, 2002). Clean indoor air is produced in a process that starts with intake of outdoor air, which needs to be filtered, heated and transported before it can be consumed. So clean air is a flow and both input and output can be defined. On the building level, the required quality can be defined as a functional unity: 1 $m^3$ of clean air, with specific properties, for instance temperature = 22$^oC$, 50 < RV > 65%, $CO_2$<1000 ppm and harmful gaseous of aerosol contents below certain limits. Clean air is a functional unity, comparable to 'a floor with a span of 6000 mm'. During the consumption process the air will get polluted with smell, dust particles, gaseous substances and humidity. Part of the polluted air is exhausted as waste material and a part will be re-used after a new cycle of treatment. The energy consumption, materials use and emissions for air conditioning can be calculated with LCA tools. Calculations of environmental impacts indicate how the functional unity (1 $m^3$ of clean air) can be produced in the most sustainable way. Used in this way, LCA supports the design of sustainable air-conditioning.

The health aspects of indoor air are related to the effectiveness of the ventilation (quality and amount of outdoor air) but also to the emissions indoors, the occupancy rates and the type of activity. In order to relate indoor air to health, there must be information on the effect of the construction and performance of ventilation systems on agents. This relation can be put in models and databases, which allow for easy evaluation in LCA design tools. To start with, the actual situation has to be reduced to standardised situations, but eventually it will be possible to design the optimum ‘production system’ for clean air on the basis of LCA, which includes ‘air’ as a flow, integrating both environmental and health quality.

**Health as Indicator**

The question still remains how health aspects will be part of life cycle analysis. We have to define health impacting factors (indicators) and measure the health impact of simple and complex phenomena, so the value of different input and output variables can be calculated. Health impacting factors of indoor air are the different agents in air: aerosols, gases and the comfort level defined by temperature and humidity. One of the measures for the effects on health is DALY. The DALY (Murray *et al*., 1996) quantifies the damage or suffering due to a disease as the number of years lived with disability multiplied by a disability weight. This weight varies form 0 (healthy) to 1 (dead). For mortal diseases the years that may be lost due to premature death are multiplied by the disability weight 1 and added.

DALY = YLD + YLL
DALY = disability adjusted life years;
YLD= years lived with disability = duration of disability × disability weight;
YLL = years of life lost = reduced life years due to the disease.

With DALY the severity of all health problems can be measured and compared. Multiplied by the probability of occurrence they can be compared on a risk scale. Optimal health can be defined as ‘no increased health risk’ or ‘no effect on disability adjusted life years’ (zero DALY). DALYs can be calculated on the basis of a building design, using forecasts about material emissions, dust build-up, moisture levels, air change rates and physical properties of the building on agents such as bio-chemical pollution, noise and radiation. By quantifying the health effects of the building in terms of DALYs, one comprehensive DALY could be calculated, which would be a measure for indoor health aspects of the building. The DALY would be a label, subject to regulations or quality control. It can be achieved in different ways, like the different ways in which the required energy quality (EPC) can be achieved. A method that links health effects and properties of the building design still has to be developed.

**Difference between the Strategies**

To illustrate the differences between the strategies mentioned in the previous section, we use the Dutch tool Eco-Quantum. In the Netherlands, the development of environmental assessment tools has proceeded very well. The Dutch tools are Eco-Quantum and GreenCalc. GreenCalc is for non-residential buildings. Eco-Quantum is a tool for environmental impact assessment of houses and can be used by architects and municipal councils for optimizing designs, for benchmarking and for policy making. LCA is conducted for the flows of materials, energy and water in houses. The flow of materials concerns the use of materials of all building components, including material-embodied energy. The flows of energy and water comprise energy consumption and water consumption in the occupancy phase of the house.

Eco-Quantum expresses the results of the calculations in four ways: volumes; environmental impact; environmental measures and environmental indicator. The volumes represent the amount of materials (in kilograms) per component, the amount of energy (in megaJoules, or MJs) per energy function and the amount of water (in $m^3$) per water function. The environmental impact refers to the twelve perspectives (see Figure 3) and Eco-Quantum aggregates these perspectives into measures for four environmental categories: Natural Resources, Emissions, Energy and Waste. Finally, an experimental environmental indicator aggregates the score for Natural Resources and Emissions. Figure 3 shows how the environmental measures converge into the environmental indicator. The reference is set at 100 and decreases as the building has a better environmental quality (Mak *et al.*, 1999, modification of Figure 3 by Klunder).

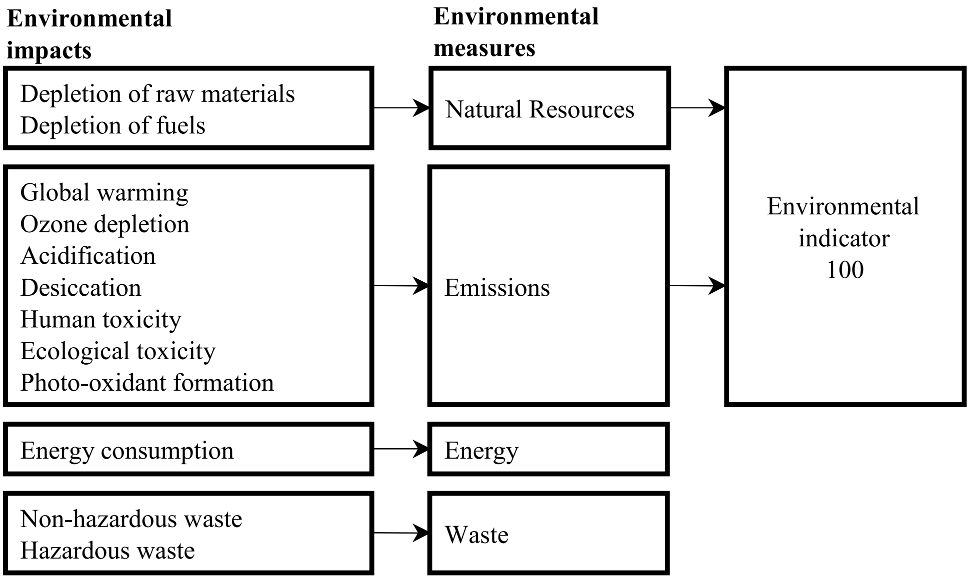


**Figure 3** Environmental impacts, environmental measures and eco-indicator in Eco-Quantum.

By treating clean air as a flow, the environmental impacts, the environmental measures and the environmental indicator will be accounted for as usual. The installations to guarantee a good indoor air quality, are reflected in the input data and the outcomes of the calculations include the environmental consequences of the indoor air quality to be achieved. Minimization of the environmental consequences comes into sight. Treating health as a quality indicator next to the environmental indicator is possible in Eco-Quantum. This procedure needs some additional data about the design of the house, but in this way indoor and outdoor environment are combined. As with the environmental indicator the reference should be set at 100. Changes in the input of data are reflected both in the environmental and health indicator. Conflicts and synergies between health and sustainability are easily discovered with these two indicators.

## CONCLUSIONS AND RECOMMENDATIONS

Although there are some major differences between health impact assessment and environmental impact assessment, there are no insuperable barriers to combine or integrate them. However, we want to find out if integrating them can solve conflicts and identify synergy between sustainable and healthy housing. We have to combine indoor and outdoor environments, short- and long-term approaches and occupancy phase and whole life cycle.

Refining of the LCA methodology is desirable. Further development along the presented strategies should answer these questions:

- What is the impact of the flow of air through a building on the health of the building occupants, considering it is polluted by emissions from building materials and services, by emissions from the occupants and by the different processes in the building?
- What is the health performance of a building (100% is 0 DALY)?
- What is the optimum in building design, when the health performance (in DALY) can be achieved by different design alternatives?

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