Life Cycle Assessment and Indoor Environment Assessment

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Abstract
Life Cycle Assessment (LCA) is frequently used as a tool for environmental assessment of buildings and building materials. Generally, the main focus of LCA is impact on the regional and global external environment. However, a considerable part of the environmental problems related to the building sector arise locally in connection with the indoor environment, like effects on human health. The study deals with what environmental issues arise for the external and indoor environment, respectively, in the building sector, how these issues relate to each other and whether some issues connected with the indoor environment may be included in an LCA. The study is mainly based on data from an LCA of three flooring materials (linoleum, vinyl flooring and solid wood flooring) and on measurements of indoor air emissions from these flooring materials. Methodological issues are pursued.
Keywords
building materials, buildings, floorings, LCA, life cycle assessment, indoor climate, SBS, VOC

1 Introduction

Life Cycle Assessment (LCA) is frequently used as a tool for environmental assessment of buildings and building materials. Generally, the main focus of LCA is impact on the regional and global external environment. However, a considerable part of the environmental problems related to the building sector arise locally in connection with the indoor environment, like effects on human health.

Research about the environmental impact from buildings and building materials has been performed separately for external and indoor issues respectively, and today this research is continued within two separate disciplines. In the last years, an increasing number of tools for environmental assessment have been developed. When constructing a new building today and when environmental concern is focused, there is generally a desire to minimise the total environmental impact on the external environment and the indoor climate at the same time, but there is a lack of knowledge on how improvements in one area affect the other. Hence, there is a need to map the correspondence between indoor and external environmental issues.

Final results of the study are not yet available. A report containing background data, final results and complete references will be published in spring 1998 [1].

1.1 Aims and objectives

The study deals with what environmental issues arise for the external and indoor environment, respectively, in the building sector, how these issues relate to each other, how they are dealt with in environmental assessment methods used today and whether some issues connected with effects of the indoor climate on human health may be included in an LCA.

1.2 Scope

Some main system boundaries and delimitations of the study are:

- flooring materials were chosen as object of the study
- the study mainly focuses on Volatile Organic Compounds (VOCs) as this is the environmental load most frequently considered when trying to assess the environmental impact on the indoor climate from flooring materials. Also, VOC is a parameter that occurs in several steps of the life cycle of flooring materials, both in connection with industrial processes, transports and the user phase
- non-industrial indoor environment was studied
- only LCA was included of existing methods dealing with impact on the external environment. However, some of the conclusions may also be valid for other methods.

The conclusions are partly based on data from an LCA case study of three flooring materials (linoleum, vinyl flooring and solid wood flooring) and on measurements of indoor air emissions from these flooring materials. Also, existing research in the fields of LCA, environmental assessment of building materials and buildings, VOC, indoor climate and human health was used to answer the questions above.

2 LCA , indoor environment assessment and VOCs

This section gives a brief theoretical background for what characterises LCA, indoor environment assessment and VOC measurements.

LCA is a method for analysing and assessing the environmental impact of a material, product or service throughout its entire life cycle, usually from the acquisition of raw materials to waste disposal. The environmental parameter groups most commonly accounted for in LCA are use of materials, use of energy, emissions to air and water and waste generation. International standardisation work on LCA takes place under the auspices of the IS0 [2]. The methodology of LCA is a systems analysis and generally consists of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results. Generally, LCA input data and results have the following characteristics:

- the results are product oriented
- regional/global effects on the external environment are mainly focused
- input data consist of environmental loads (total dose), and mainly quantitative information is used
- in the improvement assessment, inventory data alone (environmental loads) may be sufficient for an evaluation, and when this is not the case the environmental impact of these loads may be assessed.

Indoor climate is a term used for describing physical factors in *the indoor environment,* like temperature, ventilation, humidity, air content of particles and gases, lighting and noise. The *indoor air quality* is one of the factors that affect the indoor environment, and it may be assessed by measuring what substances are present in the air (see for example [3]). Building materials is one of several emission sources that affect the indoor air quality. When, in a specific building, a larger quantity of users than may be expected have certain health symptoms (headache, itching, dry skin, eye irritation etc.) the term *Sick Building Syndrome (SBS)* is used. The indoor air quality is generally considered to be closely related to SBS, and emissions from building materials are often mentioned as one of the reasons for “sick” buildings. However, there is today no consensus on what health effects are linked to building material emissions, and how important these health effects are. Only in exceptional cases has a connection been found between SBS symptoms and the presence of specific building materials or building constructions. Factors that have been shown to influence the rate of SBS symptoms are cleaning conditions, occurrence of copying machines, insufficient ventilation, damage caused by damp and mould and occurrence of putty with a casein content etc.. Primary data and results used in indoor environment assessment may be characterised in the following way:

- the results are building related and site specific
- human health effects are focused
- the aim is often to improve a deficient indoor climate in an existing building

- input data for discovering the problem are generally qualitative and effect oriented, while in the improvement assessment both qualitative and quantitative information is used.

When studying the environmental impact from building materials during the user phase, *Volatile Organic Compounds (VOCs)* are frequently used as a measure, generally defined as those organic compounds that have a boiling point in the interval from 50-100 to 240-260°C. VOCs are regarded to affect the external regional and global environment as well as human health directly. For indoor air the VOC mixture is often expressed as Total Volatile Organic Compounds (TVOCs). As there is today a large variety of ways to calculate a TVOC value and there is no standardised procedure for how to do this, published TVOC data are often not comparable. Odour, sensory irritation and perception of discomfort are the main potiential health effects of VOCs indoors (see for example [4]). According to some sources, no clear difference in VOC concentrations has been found between "sick" and "healthy" buildings. It is today not possible to conclude that health effects like sensory irritation are associated with the concentration of TVOCs at normal exposure levels in non-industrial indoor environments. VOC emissons also have an important impact on the external environment as they contribute to an increased formation of ozone which will affect human health, cause damage on eco-systems like forests and agriculture and also inflict on global effects like the greenhouse effect. Some significant features for assessment of building related VOCs are:

- VOC measurements may be related both to a product (for example one m^2 flooring during a specific time period) and the indoor climate (as concentration in indoor air)
- the parameter is used both in a life cycle perspective and during the user phase
- human health effects in indoor climate and work environment are generally focused.

3 Including external and indoor environment in one method - State of the art

In last years, methods have been developed for assessing and comparing the environmental impact of building materials and buildings. It was studied if and how human health aspects were considered by some of these methods.

According to IS0 among others, the three general categories of environmental impacts that need consideration in an *LCA* include resource use, human health and ecological consequences. It may be concluded that, principally, LCA should include impacts on human health, both regarding occupational and work environments. Several actors working with LCA methodology have tried to include work environment issues in **LCA,** and various approaches are available for doing this [5]. However, not much has yet been done to include indoor climate in LCA. When it comes to the impact assessment step, several weighting methods have indices for VOC emissions, generally with the aim to decrease the impact on the global/regional external environment. Methodologically, it would be possible to include VOC indices based on local human health effects in LCA. Thorough knowledge would then be needed about what is the connection between VOC emissions and specific health effects.

Eco-labelling is one of the methods used today for minimising the environmental impact of building materials. The Svanen criteria document for flooring materials [6] is one such example. The document does not clearly account for what environmental issues are primarily considered. However, the intention is to consider factors that are of *major importance during the life cycle* of the flooring, that are *easy to measure* and that are *relatively easy for flooring manufacturers to influence.* VOC emissions are restricted in one aspect; a limit value is set for VOC emissions per m^2. This refers to the manufacturing process only, and nothing is stated about VOC emissions during use of the floorings.

As an example on the building level, *BREEAM* [7] was developed to set criteria for good environmental performance in buildings. This method seeks to minimise the adverse effects on the *global* and *local* environment while promoting a *healthy indoor environment.* Items are included for which there is *good evidence of the environmental problems they cause,* for which *performance criteria can be defined,* and which *can readily be assessed at the design stage.* The environmental issues covered are grouped under three main headings: global issues and use of resources, local issues and indoor issues. All indoor issues relate to human health, and mostly raise absolute demands on the whole building. No issues take VOC emissions into account, except for one criterium regulating formaldehyde emissions. The functional unit used for the final assessment is the whole building. However, for each criterium a specific functional unit is used (i.e. the environmental impact is assessed per m^2, per kWh, as volume percentage etc.). Also, some credit requirements are defined for the whole building, especially regarding local issues.

It may be concluded that several methods for building related environmental assessment include issues regarding both the external and the indoor environment. It is not always made clear what environmental issues are the main objective of the method and how external and indoor environment issues are weighted for the final results.

4 Empirical analysis

An *LCA **of** flooring materials* was performed at Chalmers University of Technology (CTH), in which the environmental impact of linoleum, vinyl flooring and solid wood flooring during their life cycles was assessed and compared [8]. Only impacts on the external environment were studied, and local indoor effects on human health were omitted. The parameter categories included to present the environmental load were use of resources, use of energy, emissions to air and water and waste generation. Values for VOC emissions obtained in the inventory were sometimes available as specific VOCs and sometimes as TVOC values. According to the inventory, linoleum caused the highest TVOC emissions and solid wood flooring the lowest. However, the difference between the floorings was not large, considering the data uncertainty. The quantitative results of the inventory analysis were then evaluated by using three weighting methods. According to the results from the impact assessment, the impact of VOCs was moderate compared with the total environmental impact, except for solid wood where terpene was the main contributing VOC parameter.

Another *case* study was performed at the Swedish National Testing and Research Institute (SP) [9]. The flooring materials vinyl, linoleum and wood were studied with respect to their *VOC emissions during the user phase*. Measurements were carried on for up to two years, depending on the material. The measurements were performed with a small model test chamber, FLEC (Field and Laboratory Emission Cell). The study was limited to measuring VOC, both as TVOC and as specific main components. Total VOC emissions during the user phase were then assessed, based on some assumed conditions regarding user time, room size etc.. There was a great difference between the floorings regarding what specific VOCs dominated the TVOC measure.

Based on the two case studies, the VOC emissions during the user phase were compared both over the life cycle for each flooring type and related to the total environmental impact of the life cycle of the floorings. It was found that TVOC material emissions during the user phase were of the same magnitude as for the rest of the life cycle. For the solid wood flooring, VOC emissions during the user phase far exceeded VOC emissions during the rest of the life cycle. Three weighting methods were then used to assess the importance of the VOC emissions from the user phase in a life cycle perspective. It could be seen that the user phase had a relatively small contribution to the total environmental impact of the floorings. Only for solid wood did the material emissions of the user phase play a significant role.

Some calculations were made, based on the case studies, literature data and some assumed conditions:

- the relative importance of VOC emissions from floorings for the VOC content in indoor air was assessed
- the contribution of VOCs from indoor air to the external environment was estimated, especially the contribution related to floorings and other building materials
- total VOCs from indoor air were compared with total statistical VOC emissions to the external environment.

5 Discussion and conclusions

Different approaches for building related environmental assessment were compared, and differences and similarities were discussed. Table 1 summarises some main characteristics for LCA, material emissions and indoor environment assessment.

	Life cycle assessment	Material emissions (VOC)	Indoor environmental assessment
Primary data	Dose Quantitative Measurements, calculations Independent of site	Concentrations Quantitative Measurements Site specific	Concentrations, health effects Quantitative, qualitative Measurements, experience Site specific
Environmental problems/effects	Regional, global External environment Contribution Exposure independent	Local Human health Contribution Exposure dependent	Local Human health Whole effect Exposure dependent
Functional unit	Building material, building	Building material	Building, individual
Life cycle steps	Whole life cycle	User phase	User phase
Influencing actors	Whole life cycle	Whole life cycle	Whole life cycle
Influenced actors	All	Users of the building	Users of the building
Results	Loads, effects	Loads	Effects

Table 1. Metodological comparison of LCA, material emissions and indoor climate related effects. Most significant characteristics are presented.

The final results of this study are yet to be published. However, some preliminary conclusions were drawn.

For the studied floorings, the VOC material emissions during the user phase were of the same magnitude as those related to the remaining life cycle. However, the impact of these emissions was marginal in a life cycle perspective when comparing it with the total environmental impact of the floorings.

Some methods for environmental assessment of buildings and building materials include criteria dealing with both external and indoor environment issues. Then for the final results external and indoor environment issues are evaluated either integrated or separated. It is not always made clear what environmental issues are the main objective of the method and how external and indoor environment issues have been weighted in the final results.

Methodologically, it would be possible to include indoor climate issues in the impact assessment step of building related LCA. However, no scientifically verified methods are today available for weighting effects on the external and indoor environment against one another. For building materials there is today no consensus on what health effects are linked to material emissions and how important these health effects are. The indoor environment is affected by the qualities of the building rather than by choice of specific building materials. Hence, issues concerning indoor environment effects on human health may be included in LCA of the whole building rather than in LCA of building materials.

In product related environmental assessment like LCA, environmental loads from processes and transports that may be related to the product are primarily taken into account. Likewise, in human health related environmental assessment like indoor environment assessment, data are primarily used that may easily be related to human health and the indoor climate of a specific building. It is hard to include these two approaches in the same method without making one of the approaches less effective. The method of LCA is not well suited to minimise either local health effects or regional/global total emissions, like national environmental goals.

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