Life Cycle Impact of Floor Coverings: A Model for the Contribution of the Usage Phase

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Abstract
Compared to other industrial products, building products have a significantly longer service life. When applying LCA methodology to building products, one obvious problem is how to take into account the environmental impacts from the usage phase. In this paper, the usage phase is analysed and a proposal for a model is given based on a division of the usage phase into three parts representing frequent, periodical and upgrading maintenance. The model is applied to floor coverings and some preliminary characteristics and results are presented and discussed.
Keywords
LCA, Service life, Environmental impacts, Floor coverings, Usage phase.

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1. Introduction

Life cycle assessment (LCA) methodologies have developed rapidly during the recent years. The technique is to a large extent used and developed for environmental assessments of short life products from industrial sectors such as packaging and vehicles. LCAs are frequently used for assessment of materials and components either for the purpose of comparing different alternatives or for proposing improvements. The methodologies have to a large extent been adopted into the building sector and have given much valuable input. But, one obvious distinguishing property of building materials and components is their significantly longer service life compared to other industrial products. Therefore, the usage phase might be of major importance in the building sector from an environmental point of view.

Unfortunately, it can be problematic to take the usage phase into account in a product or component LCA. The problems are connected to the lack of information on this phase (Paulsen & Lundblad 1996). To give an overview of the problem, the life cycle is here divided into three main steps:

1) Raw material extraction and production of a product or a component.
2) Maintenance of a product or a component during the usage phase.
3) Waste treatment or recycling of the product or component.

According to LCA methodology, the analysed object has to be assigned a functional unit and the environmental impacts expected from this unit. This means information and data are needed for the whole life cycle of the object (cradle to grave). Normally, for building products, the information and data range is available to the first part of the life cycle, step 1, extraction of raw materials and production of the object, also called cradle to gate inventory. This stage is therefore normally quite simple to handle.

To collect data on the usage phase (here called step 2), information is needed on for example the application of the object in the building, its expected lifetime, maintenance 'methods and intervals, auxiliary products and local conditions. Without this type of data/information, it is almost impossible to include the usage phase in an LCA for building products.

To analyse stage 3, waste treatment or recycling, information is needed concerning contents of hazardous materials in the product together with knowledge about techniques and market for recycling and development of techniques for waste treatment. Here scenarios normally are based on the assumption that today's techniques are used in the future. It does not give the same reliability as in step 1, but possibly a reasonable estimation of the possible environmental impacts.

In summary, the first and the last stage of the life cycle can be regarded as less complicated to analyse while the stage in the middle, the usage phase, is more complicated to analyse since the environmental impacts from this stage are difficult to predict. However, one reason for being concerned about the usage phase for building products is the long-term perspective. It could possibly turn out to be the step with the largest environmental impact.

A number of LCAs have already been carried out on long-life products from the building sector, despite the problems with lack of information concerning the usage phase (Erlandsson et al 1994, Jönsson 1995, Erlandsson 1994). In general, two different methods have been used to circumvent the problems. It has either been assumed that the environmental impact from the usage phase is zero, or a comparative analysis has been carried out with the assumption that the environmental impacts from the usage phase are the same for the analysed products. In this case, they cancel out each other.

A method to take this step into account might enable the choice of more favourable products, auxiliary materials or maintenance methods, and at the same time give feedback to manufacturers. Only considering impacts from the first and third step could lead to sub-optimisations, and thereby failure to reduce the total environmental impacts.

One possible solution to this problem is to divide the LCA into the three different steps (1,2 and 3) mentioned above. For steps one and three, an LCA can be carried out with the most commonly used LCA methods. On the other hand, step two has to be analysed in a less traditional way, due to lack of information. The assumed condition is that the product type is known, but not the exact conditions for the usage phase. However, for some product groups it might be possible to predict the most important parameters causing environmental impacts in the usage phase, even though the extent of these impacts can be hard to estimate for each parameter. The needed information is normally unknown until the application of the product is known. However, if the most probable application and circumstances can be reduced to a limited number of possibilities, maybe different scenarios can then be carried out and the expected quantities and extents estimated for each scenario.

In this paper, an inventory of the usage phase for floor coverings is carried out to illustrate this approach and to examine the extent to which environmental impacts can be predicted in the usage phase.

2 LCA-model for floor coverings in the usage phase

The suggested model refers to a scenario in Sweden where the floor coverings are placed in large buildings and maintained by a contracted cleaner, assuming that an industrial cleaning machine is used. No specific floor covering type is selected.

The emphasis is on the external environment. Human health and indoor environment will not be included.

2.1.Determination of environmental impacts from the usage phase

For this kind of flooring, it can be assumed that the maintenance consists of three maintenance stages (Lidström 1997, Franzén 1997), which are frequent, periodical and upgrading maintenance respectively. The aim of the frequent maintenance is to remove dirt and maintain a healthy and aesthetic indoor environment. The aim of the periodical maintenance is to satisfy the technical function of the floor e.g. an easily cleaned surface. For some types of floor coverings, this can be achieved by periodical polishing. Other types of floors do not need any periodical maintenance at all. The aim of the upgrading is to improve an older floor covering to a level where both the aesthetic and technical functions are satisfactory. The upgrading is similar to the action performed for periodical maintenance, but is likely to be more extensive, e.g. non-periodical polishing or grinding of linoleum, wood or stone flooring. This is done only a few times during the whole usage phase, in some cases never. The suggested model in this paper is an overview model where the type of floor covering is not yet decided. With specified type of floor covering, the importance of environmental impacts from periodical and upgrading maintenance should be easier to estimate.

It is suggested that the environmental impacts for floor coverings during the usage phase are a combination of impacts from maintenance products and the maintenance methods in all three maintenance stages mentioned above. This gives six parameters to determine (see table 1).

Table 1	Maintenance stages		
Source of impacts	Frequent	Periodical	Upgrading
Impacts from products	I_{pf}	I_{pp}	I_{pu}
Maintenance methods	I_{mf}	I_{mp}	I_{mu}
Totally from the stage	I_f	I_p	I_u

The total environmental impact I_{tot} in the usage phase can then be calculated as shown in equation 1a or 1b:

$$I_{tot} = I_{pf} + I_{pp} + I_{pu} + I_{mf} + I_{mp} + I_{mu} \tag{1a}$$

$$I_{tot} = I_f + I_p + I_u \tag{1b}$$

For all the environmental impacts one square metre can be used as the functional unit.

2.2 Determination of environmental impacts from the frequent cleaning

The environmental impacts from the frequent maintenance I_f can be expressed as shown in equation 2:

$$I_f = \int_0^T \left[i_{pf}(t) + i_{mf}(t) \right] dt \tag{2}$$

where $i_{pf}(t)$ and $i_{mf}(t)$ are the time-depending momentary environmental impacts per time unit from frequently used maintenance products and methods.

However, this study concerns floor coverings placed in larger buildings and maintained by a contract cleaner. Therefore, the variation over time for daily cleaning can be considered minimal, at least during one year (Lidström 1997). Assuming that the same products and methods are used during the whole usage phase, the yearly environmental impacts will be constant. This is not quite accurate but one possible way to give an estimate of the total environmental impacts. With this assumption, equation 2 can be simplified to equation 3:

$$I_f = N^* (I_{pfy} + I_{mfy}) \qquad (3)$$

where N is number of years for the maintenance period, I,, and I,, are the yearly environmental impacts from maintenance products and maintenance methods respectively, in the case of frequent cleaning. Assuming that only one cleaning product is used, and that the environmental impacts from the maintenance method are caused by energy use, I, can be calculated from equation 4 and I,, from equation 5:

$$I_{pfy} = E_{pf} * A_{pf1} * n_f \qquad (4)$$

$$I_{mfy} = E_{el} * n_f * A_{fel1} * \eta_1 + E_{ew} * n_f * A_{fw1} * AT * c_w * \eta_2 \qquad (5)$$

where

E_{pf} Environmental impacts from one litre or kg of the used cleaning agent.
E_{el} Environmental impacts from one MJ electricity, primary energy.
E_{ew} Environmental impacts from one MJ energy produced to heat water.
A_{pf1} Amount of cleaning agent for one cleaning.
A_{fel1} Amount of electrical energy required for one time of cleaning (MJ).
A_{fw1} Amount of water required for one cleaning (litre).
n_f Number of times the floor is cleaned during a year.
η_1 Efficiency for electricity production and machinery.
η_2 Efficiency for energy production to heat water.
AT Increase in temperature when heating water for cleaning.
c_w Heat capacity for water (0,0042 MJ/kg*°C).

2.3 Determination of environmental impacts from the periodical cleaning

The environmental impacts from the periodical maintenance I, can be expressed as shown in equation 6 also assuming that the same products and methods are used during the whole usage phase, for each periodical maintenance occasion:

$$I_p = N * (I_{ppy} + I_{mpy}) \qquad (6)$$

where I, and I_{mpy} are the yearly environmental impacts from maintenance products and maintenance methods respectively, in the case of periodical cleaning. Here it has to be assumed that several maintenance products are used. At least one product is needed to prepare the floor surface and another to treat and protect the surface for the future. Furthermore, it is assumed that the environmental impacts from the maintenance method are caused by energy use. Thus, the I,, can be calculated from equation 7 and the I_{mpy} from equation 8:

$$I_{PPY} = n_p * \sum_{k=1}^{k=K} E_{pp,k} * A_{pp1,k} \qquad (7)$$

$$I_{mpy} = E_{el} * n_p * A_{pel1} * \eta_1 + E_{ew} * n_p * A_{pw1} * AT * c_w * \eta_2 \quad (8)$$

where

$E_{pp,k}$ Environmental impacts from one litre or kg from maintenance product No. k.

K Number of maintenance products used for periodical maintenance.

$A_{pp1,k}$ Amount of maintenance product k for one periodical maintenance.

A_{pell} Amount of electrical energy required for one periodical maintenance .

A_{pw1} Amount of water required for one time of periodical maintenance (litre).

n_p Number of times the floor is periodically maintained during a year, (can be less than 1).

2.4 Determination of environmental impacts from the upgrading

The upgrading maintenance can be expressed in almost the same way as the periodical maintenance assuming that the impacts are the same for each occasion, but here there is a difference in the time perspective. The upgrading can be expected to be done only a few times during the whole usage phase. Therefore, it is not appropriate to express the environmental impacts on a yearly basis. Equation 9 shows the environmental impacts from the upgrading maintenance.

$$I_u = m * (I_{pu1} + I_{mu1}) \quad (9)$$

I_{pu1} and I_{mu1} are the environmental impacts from maintenance products and maintenance methods respectively, related to one upgrading maintenance. The factor m is the number of times this can be expected to be done during the whole usage phase.
Products like abrasive paper and other grinding materials can be taken into consideration, but are excluded in this study, assuming they cause a negligible environmental impact. Therefore, the I_{pu1} and I_{mu1} can be calculated similarly to equation 7 and 8. This is done in equations 10 and 11:

$$I_{pu1} = \sum_{h=1}^{h=H} E_{pu,h} * A_{pu1,h} \quad (10)$$

$$I_{mu1} = E_{el} * A_{uel1} * \eta_1 + E_{ew} * A_{uw1} * AT * c_w * \eta_2 \quad (11)$$

where

$E_{pu,h}$ Environmental impacts from one litre or kg from maintenance product No. h.

H Number of maintenance products used for upgrading maintenance.

$A_{pu1,h}$ Amount of maintenance product No. h for one upgrading maintenance.

A_{uel1} Amount of electrical energy required for one upgrading maintenance.

A_{uw1} Amount of water required for one upgrading maintenance (litre).

3. Predictability of input data

In table 2, the parameters from the suggested model are listed together with a suggestion as to where the information should be collected.

Table 2

Type of parameter	Parameter	Where to collect information
Length of usage phase	**N**	Recommendations and feedback from practice
Amounts of products	$A_{pf1}, A_{pp1k}, A_{pu1h}$	Contracted cleaner
Amounts of electricity	$A_{fel1}, A_{pel1}, A_{uel1}$	Contracted cleaner
Amounts of water	$A_{fw1}, A_{pw1}, A_{uw1}$	Contracedt cleaner
Maintenance intervals	n_f	Recommendations
	n_p	Recommendations
	m	Recommendations
Environmental impacts from maintenance products	E_{pf}	Cleaning-agent producers
	$E_{pp,k}$	Manufacturer
	$E_{pu,h}$	Manufacturer
Environmental impacts from energy production	E_{el}	Swedish average
	E_{ew}	Swedish average
Other factors	η_1, η_2	Swedish average
	AT	Estimation of Swedish average

For some parameters, Swedish averages can be used allowing quite acceptable estimates. This concerns environmental impacts from energy production, efficiency factors for water heating and temperature increase needed for water in the different maintenance steps.

With regards to environmental impacts from the products, it is important to know firstly which products are used, and secondly what environmental impacts they have. Therefore, it is important to have LCAs or LCIs (life cycle inventories) carried out on the most commonly used products. Products with the largest market share could be selected and also some environmental labelled products which could serve as benchmarks.

Other key factors are the amounts of products, electricity and water involved. Here it is possible that larger cleaning companies have standard machinery where it is possible to estimate the electricity use and efficiency, and the amount of water for one square metre of floor (Franzén 1997). The dosage of cleaning agents for the frequent maintenance will probably depend strongly on the type of products used. Amounts of products for the periodical and upgrading maintenance are likely to be more predictable when the type of floor is specified.

Regarding maintenance intervals, the specification of type of floor and premises can be used to facilitate the determination. Here, experience from real-estate owners could be useful together with statistics from the Swedish building stock. Predicting the life time of a floor covering can be very difficult (GBR 1996, Langowski 1997). Actually, it is impossible to give an exact answer about the expected life time, because it depends on a number of independent factors, which together determine the total life time of the floor covering.

4. Discussion

It could prove to be possible to give a reasonable estimate of the environmental impacts in the usage phase for floor coverings in Sweden for special types of premises. However, it strongly depends on the predictability of the maintenance method and intervals. Furthermore, an extensive data base on maintenance products has to be created. As mentioned above, the lifetime of floor coverings is difficult to predict and needs further research. Still, a recommendation can be used in a scenario.

The suggested model introduced in this paper has to be tested in a number of case studies to reveal which parameters are most important. To carry out an LCA normally causes problems in deciding on limitations. The question is what to include and what to exclude in an analysis, as it is impossible to take everything into account. This suggested model may have to be extended or reduced depending on which parameters prove most important.

As a final point, it is important to remember that a product LCA is normally performed in the production stage with good knowledge of this step. In contrast, an inventory on the usage phase and waste/recycling stage contains many uncertainties about long lived products. Therefore it seems reasonable to divide the presentation of the LCA into three parts, production, usage phase and waste treatment/recycling, in a transparent way.

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