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ENERGY EFFICIENCY OF STEEL BUILDINGS

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ABSTRACT: The aim of this paper is to investigate the environmental credentials of steel buildings and to present the environmental impact categories and values in a steel housing activity through a case study of steel office building. In this framework, a life cycle assessment (LCA) methodology was applied, which provides an understanding of the overall environmental performance of a housing construction. The relative influence of the service lives of different building components compared to the energy use of the buildings with a different energy efficiency is presented. As the analysis showed, recycling of construction waste becomes a critical issue, which can ensure a number of environmental benefits. The aim of this research activity was also to point out the need for an integrated approach in the design process, combining environmental performance assessment with structural calculations. Environmental impact assessment of the construction activity was carried out, following the inventory listing, in order to reach to useful conclusions on the environmental study of the project. Although steel and concrete proved to be responsible for the negative environmental impacts the ability of reuse and recyclability of steel has decreased the negative impacts of steel construction on environmental burdens.

KEY WORDS: steel buildings, life cycle assessment, energy efficiency

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Introduction

Buildings are responsible for 40% of energy consumption and 36% of EU CO_2 emissions. Energy performance of buildings is a key to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the greenhouse gases emissions by 2020 and a 20% energy savings by 2020.

On 18 May 2010 a recast of the Energy Performance of Building Directive (EPBD) 2002/91/EC was adopted. This Directive, 2010/31/EU strengths the energy requirements for new and existing buildings. So, when a refurbishment is planning is important to plan also the improvement of the energy efficiency of the building. Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance.

A building is a complicated system with many sub-systems and built up out of many different materials. Alternative designs may have different material configurations and each of them may have different service lives. For reasons of comparison it would be good to calculate an impact per year of use. However, it is most likely to be very inaccurate to simply assume a service life of, let's say, 50 years, or perhaps 75 or 100 years. Also, it becomes difficult to compare building designs with relatively short service lives, with designs that may have longer service lives. It becomes even more complicated when we take into account that the building will be a combination of many different service lives. Because we cannot predict the future we can perhaps assume average expected service lives of subsystems with a certain distribution. What the influence will be of these assumed service lives and their distribution, combined with their specific environmental impact on the environmental impact of building as a whole, is the subject to be investigated in this case study "virtual office". For this reason, the virtual building will be divided in its elementary sub-systems ("building layers") for which basic alternatives, perhaps with different service lives can be used. The main focus is to study the influence of the materials impact due to the construction and demolition of the building and the intermediate replacements of building elements.

Environmental impact of the building

An impact of a building over its entire service life is assumed as the sum of one or more building elements, each with different service lives. The Annual environmental impact depending on the service life of a building might look like in figure 1.

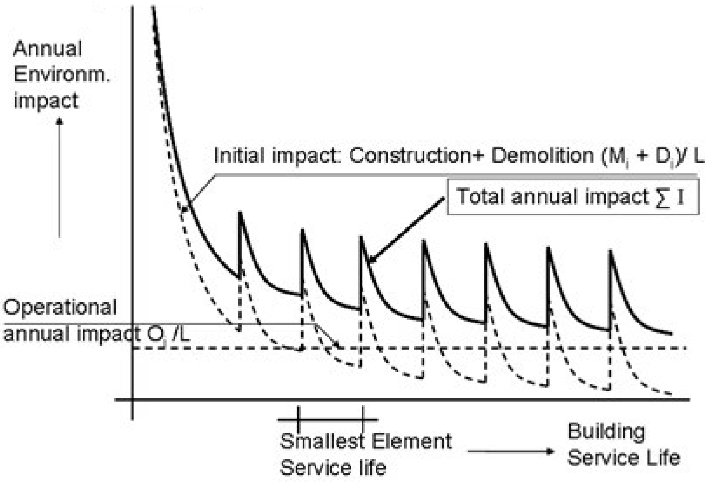

Figure 1. Annual environmental impact versus service life of a building with the influence of a recurring building element with a shorter service life

Source: (Blok, Herwijnen, 2006).

The total impact ∑I is the sum of the impacts related to all the needed materials and processes involved with the construction of the building (M_i) the materials and processes related to the demolishing of the building (D_i) and the materials, energy and processes related to the operation of the building (O_i).

The environmental impact of the building can be presented as:

$$\frac{(M_i+D_i)+O_i}{L} < R, \tag{1}$$

where:

M_i – initial impact of the building related to the materials and energy used in the construction of the building,
D_i – the impact of the building related to demolition,
O_i – operational impact over the whole service life of the building including energy and maintenance,
L – the service life of the building according to a Life scenario,
R – allowable maximum of the annual environmental impact.

In case when the building has not only a negative impact but also a positive effect for example by generating more energy than it uses (for example by photovoltaic cells) the annual total impact of a building with positive C2C (cradle to cradle) effects is presented in figure 2.

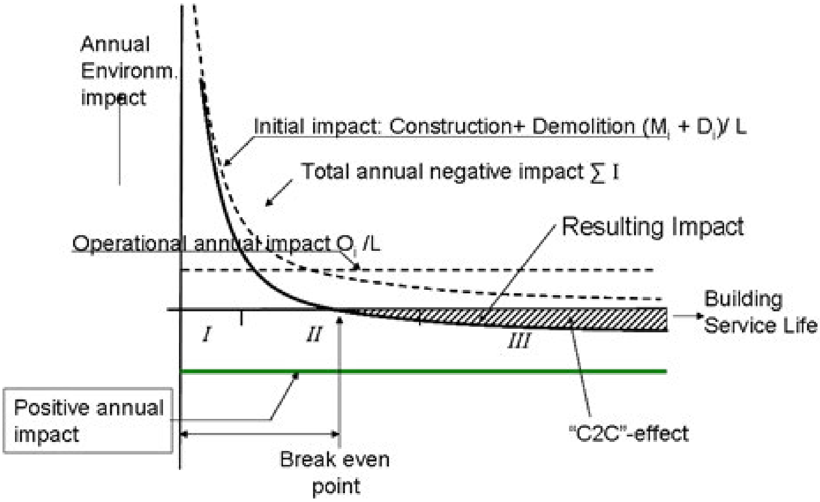

Figure 2. Total annual environmental building impact with positive "C2C" effect
Source: (Braungart, Mcdonough, 2002).

Because more and more the aim will be to realize zero energy buildings, the initial materials will become more and more important. Their relative contribution to the whole of the impact is likely to become bigger. The influence of the service life over which we depreciate these impacts, therefore will also increase.

Virtual model of the building

A very simple model of a virtual office building was used as the object of this study (figure 3).

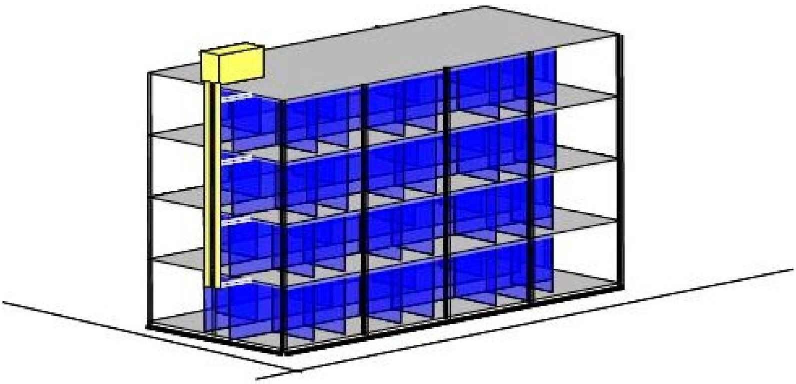

Figure 3. Virtual Office Building
Source: (Blok, WG1, Action C25, 2007).

It will be assumed that the different service lives of the building layers can actually be achieved. Whether or when flexibility is actual influential on the materials impact of a building could be an outcome of this case study.

The subdivision of the building layers and elements are presented in table 1.

Table 1. Subdivision of the building layers and elements

Building system	Building elements	Materials/ Alternatives
Structure	Columns Beams Floors (including Roof) Lateral Bracing systems	Steel structure Concrete structure (Timber structure)
Facade system	Glazing Window frames Closed window area's Thermal Insulation material	Aluminium curtain wall-systems (Brick in external wall) Thickness 50-150 mm, alternative materials
Roofing	Waterproofing Thermal Insulation Moisture barrier	
(Foundation)	Not into account yet	(Pile versus/ strip)
Infill /partitioning	Light weight partition systems Ceiling system Floor screeds	Light weight steel + plasterboard Lightweight clay fired bricks
Services	Material impact were assumed at a fixed amount	
Access	Material impact to be disregarded at this stage	

Source: (Action C25, 2007).

The overall dimensions of the building and relative figures which are used in the calculations are: length – 40 m, width – 15 m, floor to floor height – 3,5 m, the number of floors – 4, the number of persons working – 80, window openings – 25% of floor area, service life of a building – 80-year, ground floor area – 600 m^2, roof area – 600 m^2, foundation area – 600 m^2.

If, for example, a building layer skin, or façade, has a functional service life of 30 years and cannot be replaced because it is also part of the main bearing structure, it means that this layer is limiting the whole service life of the building to 30 years, despite the fact that other parts of the structure perhaps have a technical service life of 75 years.

The structure of the office building is a steel structure with pre-stressed concrete hollow core floor slabs and integrated steel beams. The dimensions of beams and columns of the steel structure is given in table 2.

Table 2. Steel structure materials

Steel column axis B	HE240A	60,3 kg/m
Steel columns axis A and C	HE220A	50,5 kg/m
Steel beams B	THQ 180×5-290×30-500×20	164 kg/m
Steel beams axis A and C	THQ 180×5-190×25-400×12	90,8 kg/m
Connecting members	HRS 120×5 on average	20 kg/m
Lateral bracing members	HRS 150×8	35 kg/m
Hollow core floor slabs	HVP 200 mm	270 kg/m^2
Concrete structural layer	50 mm concrete	100 kg/m^2

Source: (Action C25, 2007).

Total calculated amounts of steel for the virtual office: 105 Tons. Total amounts of concrete in the steel structure (floors): 810 Ton = 345 m^3 concrete. Building weight per gross floor area: 915.00/ 2400 = 381 kg/m^2.

Used Material and Energy data information

The material data, the CO_2-eq, was obtained from different sources. Too limit the complexity of the work and to simplify the case study, data was obtained from existing databases and/or the data obtained from material producers. For different locations and perhaps future studies these data can be adapted to local circumstances.

For structural steel, produced in Europe, the following figures can be found in table 3. The figures are based on Dutch product information on steel (MRPI, 2003).

No detailed LCA calculations have been carried out for the subsystems. For example, the construction methods and the way the components are assembled and installed to form building elements was ignored. This means that the data quality is rather rough, for example not high enough to compare different material solutions in great detail, or to exactly calculate the CO_2 burden for a given solution with great accuracy. Because here the main study focuses on the relevancy of the different service lives on the total CO_2 impact, this poses no direct problem. Also, the assumed service lives themselves are estimates. So even more exact material data cannot provide a much higher accuracy. The goal of the investigations is to see what the trends are in the relative influences of different building layers, compared to energy use (for different energy efficiencies) this approach gives a sufficiently clear insight.

Table 3. Impacts of Construction Steel in Building Construction (MRPI)

Index		Measurement unit (columns, beams etc.)	Heavy steel	Light weight steel
			(partition walls)	
Humane toxicity		kg 1.4 DB	2,9E+01	8,5E+01
Abiotic depletion		kg SB	2,8E+00	6,9E+00
Ecotoxicity	water	kg 1.4 DB	5,7E+00	1,6E+01
	sediment	kg 1.4 DB	9,2E+00	2,7E+01
	terrestrial	kg 1.4 DB	1,7E-01	1,7E-01
Acidification		kg SO_2	3,0E+00	3,0E+00
Eutrophication		kg PO_4	4,2E-01	4,2E-01
Global warming pot.		kg CO_2	4,8E+02	4,8E+02
Ozone depletion		kg CFK11	1,1E-04	1,1E-04
Energy		MJ	7,30E+03	1,70E+04

Source: (Action C25, 2007).

Other various data for building materials which were incorporated in the developed spreadsheet used for this case study was obtained from (Malmqvist, Glaumann, 2007).

The amounts of CO_2-eq for the materials used were calculated and aggregated to totals per building component, subsystem, or building layer. The results of kg CO_2-eq are given in table 4.

For this virtual office building case study, no specific location was chosen. Although for real buildings the location is very much influential on the energy consumption, for the virtual office building the location is unknown and the energy consumption therefore is also very much fictitious.

For this reason, it was decided not to calculate possible energy consumptions based on local climate, thermal resistance, thermal comfort and indoor climate in great detail. Instead of this, a comparison was made based on different assumed energy concepts. For these different building configurations, the energy consumption per square meter was estimated, and these estimates were used in the different life scenarios of the Virtual Office Building. Here the three most extreme energy concepts are given:

- Virtual Office Building with low thermal insulation and high energy consumption. (For example, old or not upgraded existing building stock). The energy consumption was based on 300 kWh/m^2/A.

Table 4. The amounts of CO_2-eq for the construction materials

Building element	Materials	Amounts	Burden	Totals
		[kg]	[kg eq CO_2]	[kg eq CO_2]
Structure A (steel)	steel	104.988	113.597	
	concrete reinforced	810.000	106.920	
	in situ layer	345.000	45.540	266.057
Structure B (concrete)	concrete reinforced	1.500.170	198.022	198.022
Internal partitions A	Light weight steel	1.368	1.481	
	gypsum board	15.484	4.645	
	rockwool	722	1.055	7.180
Internal partitions B	Clay fired bricks	33.540	4.773	6.573
	plasterboard	16.512	1.800	
Floor finish screed	sand cement	192.000	25.344	25.344
Ceiling system	particle boards	12.000	1.344	1.344
Facade system A	glass (double)	7.267	4.397	
	aluminium	1.836	20.449	
	brick	231.000	40.177	
	plasterboard	4.158	1.247	
	Light weight steel	378	409	
	insulation Rockwool 50 mm (Also alternative thicknesses were used)	1.617	2.361	69.040
Facade system B	insulation Rockwool 200 mm	6.468	9.443	
(3 double glazing)	Glass (other materials as A)	10.901	6.595	78.321
Roof insul. finish	expanded polystyreen (80mm) (Also alternative thicknesses were used)	792	1.428	1.428
Groundfloor insulation	expanded polystyreen (80 mm)	720	1.298	1.298

Source: (Action C25, 2007).

- Virtual Office Building with energy consumption in accordance with current energy standards. (For example, new office buildings). The energy consumption was assumed to be 90 kWh/m^2/A.
- Virtual Office Building with very low energy consumption. (For example, buildings using “passive house” concepts). The energy consumption was assumed to be 15 kWh/m^2/A.

Results of the research

As could be expected for (old) buildings with a high annual energy use, the annual CO_2 impact is almost entirely depending on the (high) annual energy use for the operation (mainly heating and/or cooling) of the building.

Overall, it can be said that the influence of service lives of the infill partition walls (taken as 20 year), and the services and building envelope (40 years) is relatively small. It is not new, but building codes and building energy standards can strongly reduce the CO_2 production and that upgrading and increasing the energy efficiency of existing building stock can be very effective in terms of CO_2 reduction.

The expected annual CO_2 impact of this old virtual office building configuration, with its assumed energy use lies approximately between 300 and about 240 Tons eq CO_2. From this, based on the assumed average use of 80 persons staff, this would amount to 3,8 Ton P/A to 3,0 Ton P/A (eq CO_2 per person per year). Again, it should be noted that these figures are just estimates with a relative value, rather than an absolute value, due to the assumptions that were made.

One step further, of course, is to decrease the annual energy use and increase the energy efficiency. It was assumed that with passive concepts, and further improvements on insulation (thickness of 200 mm was assumed) as well as using triple glazing solutions, use of highly energy efficient services, the energy consumption could be reduced to a level of 15 kWh/m^2/A. It can be clear that by drastically reducing the energy impact, the resulting overall CO_2 burden almost entirely depends on the materials and the service lives of the building and its elements.

Because the impact of the materials is relatively high in buildings with high energy efficiency the effect of different service lives was studied for this Virtual office configuration with this assumed very low energy use. In the above scenarios, the assumed service lives of envelope (facade and roof) of 40 years and infill partition walls of 20 years are relatively long. To see what the influence of changes in the service lives would be, a scenario with, just the opposite: relatively short service lives was studied. As the results show the CO_2 impact rises depending on the service life of the building from 30-15 Tons eq CO_2/A for service lives of 25 years to approximately 50-25 Tons eq CO_2/A for service lives of 40 years.

Conclusions

In general, it can be said that for “Virtual office Buildings” built according to current energy standards, the overall CO_2-impact mostly depends on the annual energy use. The initial material influence remains comparatively small for “Virtual Office Buildings” that can achieve a service life of approximately 15 to 20 years or more. For buildings with shorter service lives, the shorter the service life will be, the more governing the material impact will become.

For future buildings with much lower energy consumptions the material impact becomes much more important and cannot be ignored when minimizing the CO_2 impact. Especially the building layers with shorter service lives can have a big influence on the overall CO_2 impact. Though not studied in this case study it can be expected that this trend will also be seen in other impact categories.

The influence of the building structure (causing the highest amount of initial CO_2 impact) still remains rather small if service lives of 20 years or more can be achieved. The difference between a steel structure and concrete structure configuration in the case study also was rather small.

For building elements with short service lives it becomes very much worthwhile to minimize CO_2 impacts by using materials and solutions with a low CO_2 impact.

In achieving CO_2 neutral building, the material impact cannot be ignored. To compensate for the initial materials, this annual positive C2C effect, the compensation or storage of CO_2, needs to be much higher than the annual energy use of the building. With current possibilities to generate energy or compensate CO_2, it will be, though it is possible, very difficult to achieve a CO_2 neutral building.

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