Environmental impact assessment of building construction systems

Reto Camponovo, Catherine Merz and Laurent Vorlet

LEEA, Laboratory Energy Environment Architecture
EIG, Ecole d'ingénieurs de Genève Hes-so, Geneva, Switzerland

ABSTRACT: The concept of durability for buildings was until recently mainly limited to the reduction of energy consumption during the use phase, in particular for heating requirements. Because of the constant improvement of the thermal performances of the envelopes, the share of the environmental impacts due to building materials takes an increasingly significant share.
In this study the environmental impact assessment of three construction systems (wood frame, thermal insulating brick and concrete block with a peripheral insulation) has been established and analysed.
The results of the assessment show that energy requirements for the use phase of the building are more significant than for the manufacturing of building materials. On the contrary the environmental impacts of building materials are bigger than those of the energy resources for heating and production of hot water.
It comes out from this study that there are no very significant differences for the environmental impact assessment between the three considered construction systems. Each system shows advantages and disadvantages. The share of steel as well as the nature and the quantity of insulation material are the main causes of variations between the construction systems.
A significant reduction in the environmental impact of buildings can be reached easily by a reduction of the non renewable energy requirements for the manufacturing of building materials.

Keywords: building system, life cycle assessment, tools

1. INTRODUCTION

Buildings are large-scale consumers of resources and important producers of waste. In Switzerland, more than 60% of the energy requirements and 75% for the waste production are related to the building stock.

The concept of durability for buildings was until recently mainly limited to the reduction of the energy consumption during the use phase, in particular for heating requirements. This step, by which a considerable reduction of the environmental impacts of buildings could be reached, relates however to only one single stage of their life cycle.

In order to establish the real environmental impacts of buildings, it is necessary on the one hand to look at the whole of the building's life cycle (construction, exploitation, maintenance, demolition), and, on the other hand, to consider additional indicators others than energy consumption such as the effects on health and on ecosysem quality.

The study of building materials takes consequently a very particular importance. Because of the constant improvement of the thermal performances of the envelopes, building materials take an increasingly significant part in the environmental impacts of buildings. Moreover building materials have an impact of all the phases of the building's life cycle.

The choice of the constructive systems proves to be determining because it influences in a significant way:

- the construction and demolition phase through quantities and the nature of building materials used;
- the use phase through the requirements in heat and the maintenance of the building.

2. AIMS OF THIS STUDY

The principal aim of this study is to establish, analyze and interpret the environmental impacts of three different building construction systems.

The environmental impacts of building materials have to be in particular analysed between each system. To this end the energy requirements during the use phase have to be identical for each system.

This study must also highlight the share of the environmental impacts induced by building materials with the impacts caused by energy requirements during the use phase.

3. METHODOLOGY

3.1 Overview of Life Cycle Analysis

Life Cycle Analysis is a tool developed in order to describe the environmental impact caused by a product in all the stages of its life, from the extraction of resources until the disposal of waste. This method allows comparative studies between products and processes having the same function.

3.2 The four steps of LCA

In the "goals and scope definition" the questions that need to be answered are clarified, the product or service under study is described, the system boundaries are defined, a functional basis for comparison is chosen and the required level of details precision and reliability is described.

This step is followed by the "inventory of extractions and emissions". In this phase, data concerning energy and raw materials consumption are collected and calculations are made regarding emissions to atmosphere, water and land. The inventory is calculated by multiplying the production inventory (building materials and energy requirement during use phase) with specific extractions and emissions factors.

In the "impact assessment" phase, the product is examined from an environmental perspective using category indicators. The impacts of the extractions and emissions inventoried in the preceding stage are balanced according to their potential to cause an environmental disturbance.

The "improvement assessment" is the phase where results are analysed and where conclusions are reached.

3.3 System boundaries, functional unit and method of impact assessment

The system boundaries take into account in this study all stages of the building life cycle, except for the erection of the building (former studies showed that this stage of life has a small environmental impact [1]) (Fig.1).

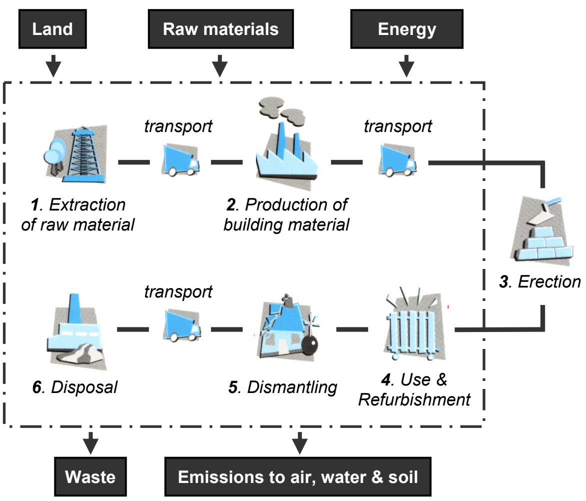


Figure 1: System boundaries for the comparison of the construction systems.

The functional unit is chosen in order to allow a comparison between the different construction systems. For this reason, a building with the same built-up area and number of floors was chosen as functional unit. The building's lifespan is set at 60 years.

The impact assessment method chosen for this study is Eco-indicator 99 (H,A), developed by the Dutch office Pré Consultants [2]. This method allows an analysis of environmental impact according to eleven categories of effect (acidification, respiratory effects, greenhouse effect, etc). These effects can be aggregated into three damage categories (human health, ecosystem quality, resources depletion) and finally into a single environmental score (expressed in a number of points).

3.4 Data collection

3.4.1 Production inventory

The quantities of building materials are calculated from the plans of the reference construction project [3] and its two alternatives [4]. These quantities include losses during transport to and on building site and refurbishment needs (lifespan of building materials). Data of material looses have been collected by LEEA. The lifespan of building material corresponds to average values resulting from various sources of literature.

Transport distances of building material from the production site to the building site are based on average values collected by LEEA.

The waste management of building demolition (disposal, incineration or sorting for recycling/reuse) is done according to the elimination channels and legal standards currently into force in Geneva (state 2006).

Final energy requirements during the use phase are estimated for heating by using the EnerCAD software [5] and correspond for hot water production to Swiss standard values [6].

3.4.2 Extractions and emissions factors

Extractions and emissions factors come from the database Ecoinvent [7]. Ecoinvent contains more than 2'000 datasets for which more than 400 substances and resources are indexed. Data from Ecoinvent are in major part valid for Western Europe.

4. CONSTRUCTION SYSTEMS STUDIED

4.1 Choice of the building type

We chose to study a collective residential building. It is in this sector indeed that there are the greatest needs in Geneva.

As reference project, we chose a building in course of erection, situated in Grand-Lancy, and designed by the office ATBA in Geneva.

4.2 Choice of the construction systems

The first studied construction system is a **wood frame construction** (V0). This is the reference project which is carried out in Grand-Lancy.

The second construction system taken into account is a building envelope made up of a **thermal insulating hollow bricks** (V1).

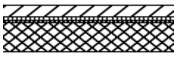
It appears certain that this type of material will be more and more used in the future. That is the reason for the choice of this system.

The last construction system is a building envelope made up of **concrete block with a peripheral insulation** (V2). It corresponds to the most current standard execution.

The reference building shows a great area of balcony walkways and balconies. Two alternatives have also been designed.

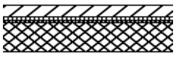
A description of the principal structural components is illustrated for each construction system in figure 2.

Ground floor (V0)



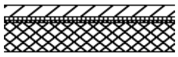
anhydrite screed (70 mm)
soft fibreboard insulation (50 mm)
reinforced concrete slab (200 mm)

Ground floor (V1)



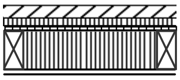
anhydrite screed (80 mm)
extruded polystyrene insulation (2x20 mm)
reinforced concrete slab (200 mm)

Ground floor (V2)



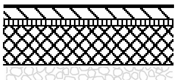
anhydrite screed (80 mm)
extruded polystyrene insulation (2x20 mm)
reinforced concrete slab (200 mm)

Under-floor slab (V0)



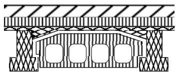
anhydrite screed (70 mm)
soft fibreboard insulation (20 mm)
rock wool insulation (30 mm)
three layered laminated board (27 mm)
glued laminated timber floor joist (120/240 mm)
cellulose fibres insulation between joists
gypsum fibre board (15 mm)

slab-on-grade (V1)



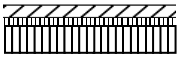
cement screed (80 mm)
extruded polystyrene insulation (40 mm)
reinforced concrete slab (200 mm)
foam glass insulation (100 mm)

Under-floor slab (V2)



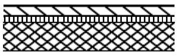
anhydrite screed (80 mm)
extruded polystyrene insulation (60 mm)
Hollow block with extruded polystyrene (220 mm)

Intermediate floor (V0)



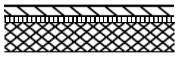
anhydrite screed (70 mm)
soft fibreboard insulation (50 mm)
glued laminated timber slab (160 mm)

Intermediate floor (V1)



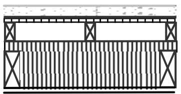
cement screed (60 mm)
glass wool insulation (20 mm)
reinforced concrete slab (200 mm)

Intermediate floor (V2)



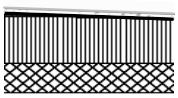
cement screed (60 mm)
glass wool insulation (20 mm)
reinforced concrete slab (200 mm)

Roof (V0)



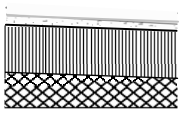
ballast of gravel (70 mm)
damp-proof barrier (2mm)
three layered laminated board (27 mm)
wooden stud (60/100 mm)
polyolefin roofing membrane (1mm)
fibreboard soft insulation (60 mm)
glued laminated timber roof joist (80/200 mm)
cellulose fibres insulation between joists
three layered laminated board (16 mm)

Roof (V1)



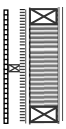
ballast of gravel (60 mm)
polyethylene fleece (2 mm)
bitumen damp-proof barrier (2mm)
sloping glass wool insulation (300-350 mm)
vapour barrier (0.5 mm)
reinforced concrete slab (200 mm)

Roof (V2)



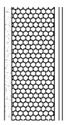
ballast of gravel (80 mm)
polyethylene fleece (2 mm)
extruded polystyrene insulation (350 mm)
bitumen damp-proof barrier (2 mm)
vapour barrier (0.5 mm)
sloping reinforced concrete slab (200-250 mm)

Façade (V0)



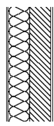
three layered laminated board (27 mm)
wooden stud (27/40 mm)
soft fibreboard insulation (60 mm)
gypsum fibre board (12.5 mm)
glued laminated timber load bearing structure (60/160 mm)
cellulose fibres insulation between structure
gypsum fibre board (12.5 mm)

Façade (V1)



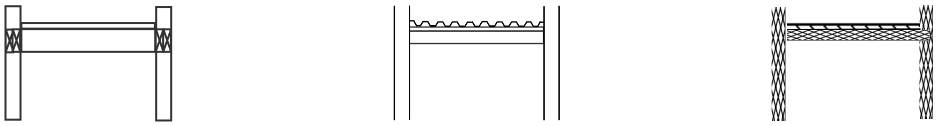
thermal plaster (15 mm)
thermal insulating brick (365 mm)
wooden stud (40 mm)
gypsum plaster board (2x12.5 mm)

Façade (V2)



mineral cover coat (15 mm)
peripheral glass wool insulation (200 mm)
concrete block (180 mm)
plaster (10 mm)

Balcony walkways and balconies (V0)	Balcony walkways and balconies (V1)	Balcony walkways and balcony (V2)



wooden flooring (40 mm)	smoothed cement coat (40 mm)	cement skim (20 mm)
glued laminated timber sectional deck joist (60/180 mm)	sectional steel sheet (51 mm)	reinforced concrete slab (180 mm)
glued laminated timber longitudinal deck joist (60/180 mm)	longitudinal steel beam (UNP 200 mm)	reinforced concrete post (200/200 mm)
glued laminated timber post (120/120 mm)	steel cross-girder (HEA 200 mm)	
	steel post (HEA 200 mm)	

Figure 2: Details of principal structural components for the three construction systems.

4.2 Building plans

The built up area (280 m2) as well as the balcony walkways and balconies area (89 m2) are identical for each construction system.

The height of the building differs slightly between the three projects because the roof size is not the same in each construction system. Variations also appear by the floor area cause of different thickness in the walls and the partitions.

The plans of the three construction projects are very similar. The plans of the reference project are illustrated for outline (fig. 3 to 7).

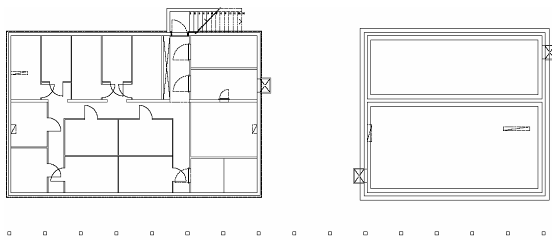


Figure 3: Basement level plan (V0)

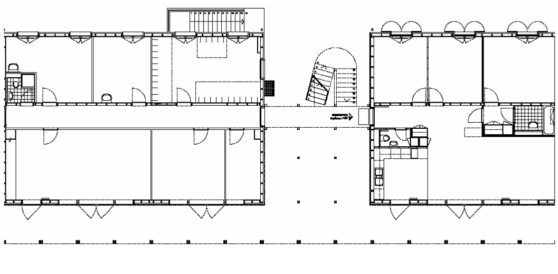


Figure 4: Ground level plan (V0)

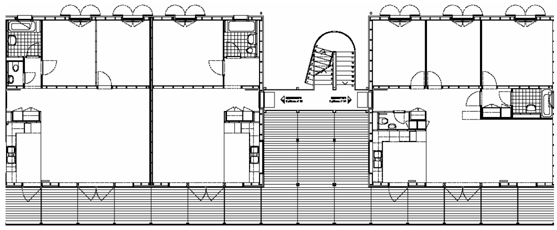


Figure 5: Floor level plan (V0)

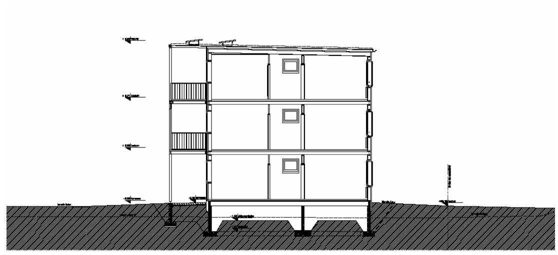


Figure 6: Cross section (V0)

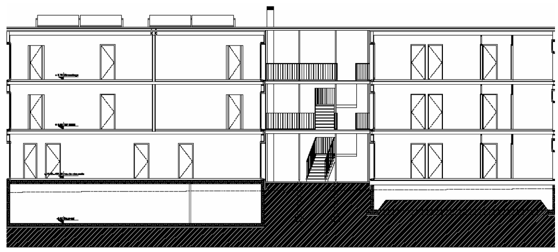


Figure 7: Longitudinal section (V0)

4.4 Technical supplies

Technical supplies are identical for the three construction systems. The annual final heating energy demand is for each construction system amount to 150 MJ/m2 and the demand for hot water production is 75 MJ/m2 for a collective habitat.

Preparation of hot water is covered to 80% by a solar thermal installation. A boiler with pellets covers the balance (especially in winter) and provides the heating energy. The surface of thermal solar panels rises to 22.5 m2. The power of the boiler is 60 kW.

5. INVENTORY RESULTS

5.1 Mass balance

The reference project has a mass of 524 t and is the lightest building (fig. 8). The construction system out of insulating bricks is the heaviest building (871 t). The third project "concrete block" is located between these two values (817 t).

Whatever is the considered construction system, balcony walkways and balconies represent only one small share of the total mass (between 7 and 15%).

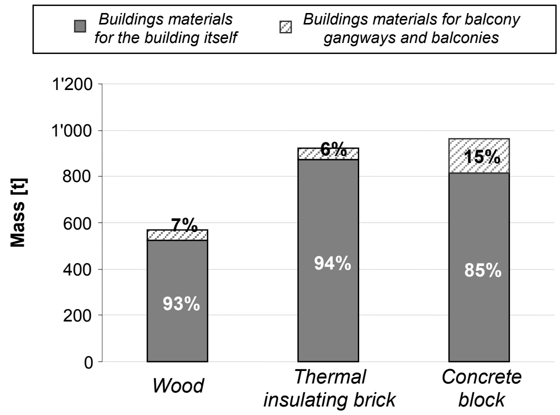


Figure 8: Weight of the buildings. (*Hatched surface represents the balcony walkways and balconies, full surface represents the building itself*).

5.2 Energy balance

The primary energy demand related to building materials is in all projects less significant than that related to the building use (heating and hot water preparation) (fig. 9).

Heating represents in each project more than 50% of the total energy consumption. The results presented here are however only valid for a use phase of 60 years. If the use phase would be lower, the share of the energy consumption related to building materials would be obviously higher.

The reference project shows a high primary energy demand. This can be explained by the very significant presence of wooden elements (structural elements and insulation) which has a high biomass energy.

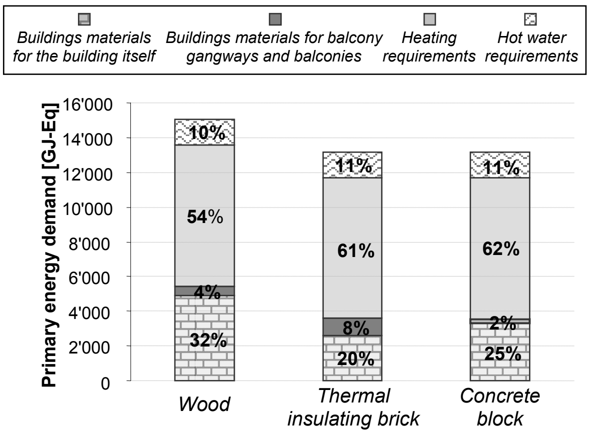


Figure 9: Distribution of the primary energy demand.

In this study we could also find out that transport represents only one small share of the energy (less than 6%) spent on the whole life cycle of building materials (production, transport and waste management).

6. IMPACT ASSESSMENT RESULTS

Contrary to the analysis of the primary energy demand, building materials make the major part of the environmental impact of the building (fig. 10). The nature of the energy resources for the manufacturing of materials, the heating of building and the preparation of hot water is mainly responsible for this established fact. In this study the requirements for heating and hot water are covered with renewable energy resources (wood and sun). For the manufacturing of building materials the used energy is of non renewable origin. The first resources have a small environmental impact, the second a big impact.

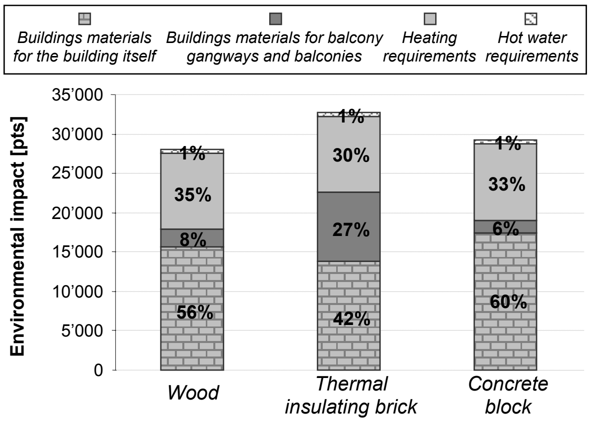


Figure 10: Distribution of the environmental impact.

The reference project has the smallest environmental impact of the three construction systems. The floor areas are also the largest because this construction system shows the thickest facades.

By disregarding balcony gangways and blaconies, it is however the construction system out of thermal insulating bricks which has the smallest environmental impact (although showing the heaviest building mass). The material used for the structure of the balcony walkways and balconies in this alternative penalize in a signifcant way the environmental balance of this project.

Apart from the balcony walkways and balconies, the floors are the structural components which have the highest impact in each construction system, followed by the frontages. The impact of foundations and basement of the building takes part to a small extent in the total environnemtal score.

The use of thermal insulating bricks proves to be very interesting. This type of building material avoids the installation of an additional thick insulating layer on the facade with materials (like mineral wool, or expanded polystyrene) whose manufacturing has a high environmental impact. In practice we can note that this type of system is often set with an interior doubling (wood fibre board, gypsum plaster board and gypsum fibre board), wich has a big environmental impact, mainly with the aim of hiding the cables of the electrical installations. But we should say that the doubling is in fact not necessary because the cables can be hidden directly in the thermal insulating bricks or in the floor.

The use of a hollow block slab system also appeared interesting (project "concrete block") because this type of slab contains less reinforced concrete (and consequently less steel) than a traditional slab. Although the quantity of insulating material (in our case extruded polystyrene) is bigger in a hollow block slab system and shows per unit weight an higher environment impact than steel, the reduction realized on reinforced concrete (1'350 kg) is definitely more worthwhile than the surplus of extruded polystyrene (295 kg) to be set up.

Concret blocks have a small environmental impact. But in this construction system the peripheral glass wool insulation influence the environmental balance very negatively. It is the main reason for which this alternative is the worst of the three construction projects.

The high score of the reference project could be astonishing. Wood is presented as an ecological material and it could be expected that this type of construction system is by far having the smallest environmental impact, which is definitly not the case.

It should be kept in mind that wooden materials require for manufacturing a lot of energy (cuting, drying, sawing, joining, etc.) as well as an important land-use (occupation and transormation) which can affect the number of species in the ecosystem. These two parameters are strongly penalized in the impact asssessment method used in this study.

For technical supplies the use of thermal solar panels is very profitable. Although the annual requirements for domestic hot water are 50% smaller than the requirements for heating (150 MJ-Eq), the environmental impact of the production of hot water is indeed 15 times less than that of the heating.

7. CONCLUSIONS

It comes out from this study that there are no very significant differences for the environmental impact assessment between the three considered construction systems. Each system shows advantages and disadvantages. It does not mean that environmental impacts of buildings cannot be reduced. But in order to realize a real environmental benefit, the construction system has to be optimized, which was not the object of this study.

The analysis of the balcony gangways and balconies shows that buildings with a steel frame construction would have the highest environmental impact. The mass of the building is consequently not a correct indicator for the environmental impact assessment of buildings. It means also that the use of reinforced concrete has to be minimized for the building structure and that interior walls of steel frame should be avoided.

It seems also obvious that the nature and the quantity of the insulation influence in a considerable way the environmental balance of a building. This type of material (as steel) needs a lot of non renewable energy for its manufacturing in comparison of wooden materials, thermal insulating bricks and concrete block.

The reduction of non renewable energy requirements for the manufacturing of building materials should be consequently a priority to decrease the environmental impact of building, which was made successfully in the last years for the heating requirements and preparation of hot water.

ACKNOWLEDGEMENT

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