GREENHOUSE GAS EMISSIONS REDUCTION AND MATERIAL FLOWS

Housing system analysis

Part I – Detailed description of the system and evaluation of the potential of emissions reduction

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For

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Institut Wallon de développement économique et social et d'aménagement du territoire asbl

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1. Introduction

The aim of this report is to describe the detailed analysis made by Institut Wallon of the housing system in the framework of the project “Reduction of greenhouse gas emissions and material flows” conducted with Vito and IDD and co-ordinated by IW. The specific tasks performed by IW within that project was to analyse the life cycle emissions resulting from the housing demand in Belgium as well as the potential of reduction of these emissions both through changes in consumer choices and in technology improvements within the production system involved by the housing system.

This report explains the methodology and results from this detailed analysis. Supplementary results are also described in a separate report (see IW, 2001)[1].

Other methodological developments are also presented in the final report of the project prepared by all three partners (IW, Vito, IDD, 2001)[2].

2. Backgrounds

The choice of residential housing in the scope of this study is justified on both end-use and materials production standpoints.

Buildings, especially residential buildings, play a major role in satisfying human needs : the primary function, i.e. sheltering people is primordial for the satisfaction of other needs (heating, private life, leisure, aesthetic, space, health…).

On the other side, building construction implies the use of different materials like cement, steel, glass, bricks, plastic, … involving high levels of energy consumption per ton produced and the existence of potential options to reduce these emissions. The potential role of wood in building poses also the carbon sink problem, which is a great issue in the Kyoto Protocol.

Waste is also a significant issue regarding building materials.

2.1. Legislation

The Directive 89/106/CEE on building products aims at the harmonisation of the building material market at the EU level. In practice the ECN (European Centre for Normalisation) receives a mandate from the Commission for each building material category. This mandate entrusts the ECN to prepare standards for testing methods aiming to ensure that buildings satisfy 6 conditions :

- Mechanical resistance and stability
- Fire security
- Healthiness and environment
- Acoustical insulation
- Thermal insulation and energy saving

One product that satisfies the ECN standards can get a EC label and can be freely marketed in the EU. In the other case the product is not allowed to be marketed.

However even the Directive was adopted in 1989 no product EC label was given.

In the land planning legislation in Belgium construction and renovation requires a prior authorization from the Regions and Municipalities. Some specifications also are required for some defined construction. This is especially the case for wood house construction : in most municipalities, brick facing is an obligation. Some more flexibility is given is some municipalities however.

3. System definition and boundaries

3.1. Functional group

The system refers to the functional group "Sheltering people". This group comprises different functions according to the kind of activities :

- domestic activities (residential housing),
- tertiary activities (non residential housing),
- activities in public spaces (public works).

3.2. Functions/functional units

Residential housing is the function studied in this project. As said before this primary function involves other secondary functions. One of these secondary functions relates to transportation as, in many cases, one part of the product (the dwelling) that fulfils the human sheltering function actually also shelters the household's car(s). It is not possible to dissociate this secondary function from the main function studied. However it is important to take it into account when discussing the products studied and their indirect impacts in term of material used and energy contents.

3.3. Products

3.3.1. Introduction

There is a large class of products available for the fulfilment of the function studied. Categorisation of the products can be made according different criteria.

Two large product categories can be distinguished: "single family houses" (SFH) and "multi-family houses" (MFH). In both categories, distinction can be made between new buildings and renovated buildings. Two sub-categories of renovated buildings can be defined : "lightly" renovated and "in-depth" renovated buildings, including transformation to increase the size (see Figure 1). In practice, light renovation can be attributed to all the existing houses. In-depth renovation is more generally observed for recently bought building.

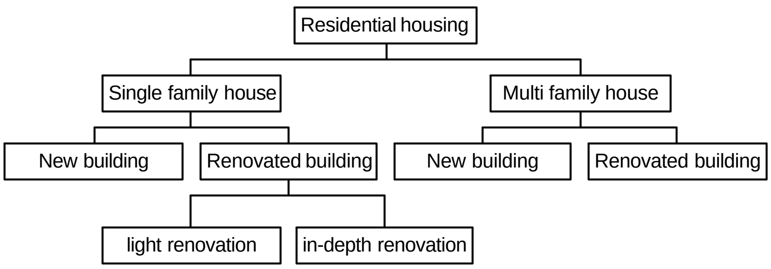

Figure 1 : Products categories for the residential housing function

Within these categories, the size of the building is an additional criteria. It can be expressed as the living surface and volume for SFH and the flat number for MFH.

The large diversity of building materials used for new constructions and for renovations results in a huge number of combinations of the different materials used for a building construction. Definition of representative categories corresponding to this criteria will be discussed later (4.1).

Finally, for the product category "SFH" a distinction can be made between 2-, 3- or 4-walls, as well as between bad or well insulated.

All criteria have obviously to be discussed as demand issues. This is one of the aims of paragraph 3.3.2.

The analysis of the weight of the different categories mentioned above can be done following a logical pattern. This pattern is illustrated in Figure 2. Grey cells indicate the elements for which demand trends will be ievaluated.

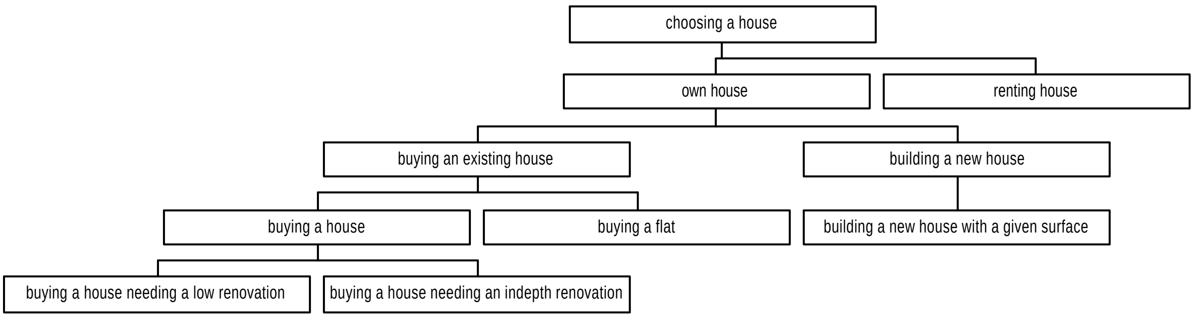

Figure 2 : Schematic consumption patterns for residential housing

The building sector market evolution is driven by the sum of all the decision patterns followed by the individual households, influenced by their own socio-economic situation. In theory this consumer behaviour could be simulated. However, this implies to identify all the socio-economic factors that are significant at each node of the decision tree, but also to quantify these parameters.

Table 1 identifies several socio-economic factors that may influence the different decision elements (first column). The second column indicates the availability of related statistics. The next paragraph will present the main data available describing the building market sector. It will appear that the data availability will limit the modelling of demand evolution for the future.

Decision node	Socio-economic factor	Comment on availability of data
Owning/renting :	Household income	Existing yearly data
	Mean age of population	Existing data but with a 10 years frequency (census)
	Ownership rate	Idem
	Interest rates	?
Existing house/new house	Household Income	See supra
	Land price	Existing yearly data
	VAT	Existing yearly data
House/flat	Household composition Population age	Existing data but with a 10 years frequency (census)
Low renovation/in-depth renovation	Household Income	See supra
	Age of existing buildings	Existing data but with a 10 years frequency (census)
surface	Household composition Household income VAT Land price	See supra

Table 1 : Availability of data on socio-economic factors of the housing market

3.3.2. Description of the housing in Belgium

The National Statistic Institute (INS) in Belgium issues a large set of data on the building sector and on the residential building especially. The description of the sector given in this paragraph is mainly based of these data.

It is out of the scope of this study to analyse the residential building market in detail. However it is to be noted that geographical dispersions characterise this sector : obvious differences exist between the three regions in Belgium, between the city and the country side, and even between cities (for instance, market is different between Namur and Liège).

3.3.2.1. General description

Table 2 gives an overview of the existing buildings in Belgium. It shows that residential buildings represent about 84% of the total buildings.

No recent data exist on total houses. According to the last census carried out by INS there were 3748160 housings.

New buildings represent 0.8% of the existing buildings, of which 94% are single family houses. Less than 4% of the existing houses have been renovated in 1997 and 0.04% have been demolished. This means that the net creation of new buildings is 0.76% per year.

	1 996		1 997		
	existing	%	New	demolished	renovated
residential buildings in Belgium	3 477 190	84	28 241 of which 26524 SFH	1 506	12 971
non residential buildings	655 086	16	4 068	1 369	2 990
total	4 132 276	100	32 309	2 875	15 961

Table 2 : Overview of buildings in Belgium
Source : INS

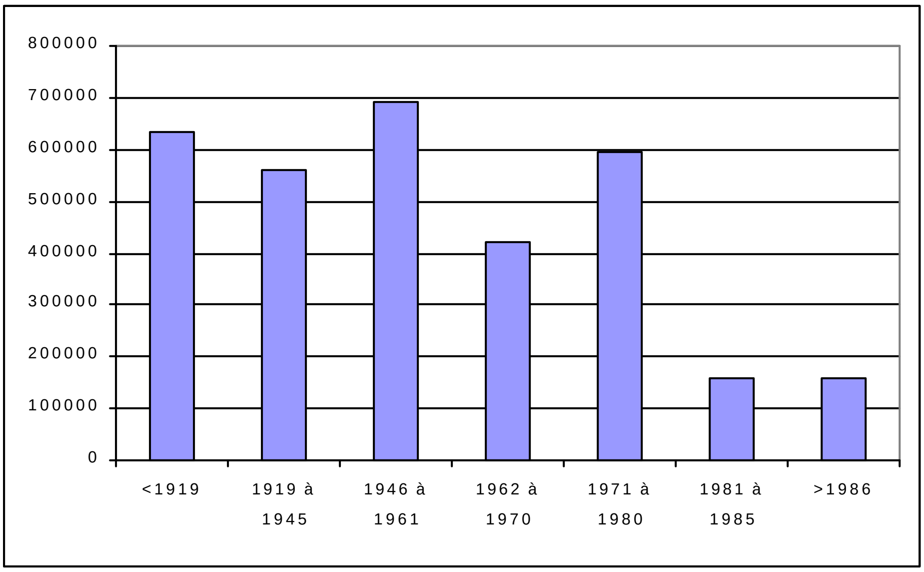

Figure 3 : Distribution of existing residential building according period of construction
Source : INS

Figure 3 presents the age-class distribution of the existing residential buildings in 1991. It shows that buildings having less than 20 years represented less than 10% of the total. If we assume that the houses constructed prior 1919 are from 100 to 200 years old on the average, we estimate the average age of the existing houses between 50 and 70 years.

If we take into account new buildings and demolished buildings since 1991 we can estimate that the average age has increased by 5 years until 1997.

The ownership rate has increased between since 30 years : in 1970, 55% of dwelling were occupied by their owner. In 1991, this rate raised to 65%.

Figure 4 gives an overview of the residential building market. Dwellings sales are distributed between "modest" single family houses, "high standing" single family houses and flats. Total sales amount to

100000 in 1997. The bulk of these sales (75%) consists in single family houses. One unknown part but probably a important part of flats sales will be rented.

Within new dwellings, SFH represent 65% of the total in 1997.

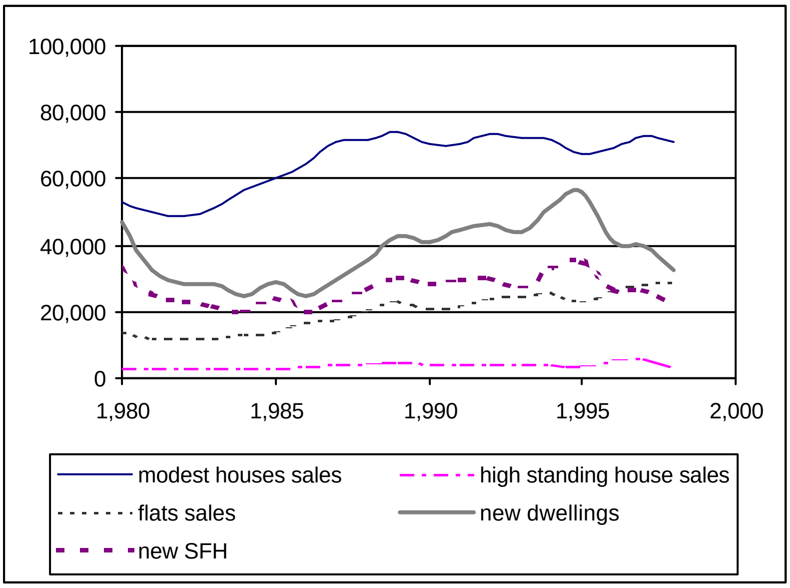

Figure 4 : Evolution of sales and new constructions in Belgium
Source : INS

3.3.2.2. New single family constructions

Regarding number of new constructions, it is to be noted that the situation is different between Flanders and Wallonia, especially between 1980 and 1995 (Figure 5). Evolution in Brussels has not been represented because it is quite atypical : number of new SFH constructions per year varies between 100 and 370 with the highest rate in the eighties. One important part of new constructions in Brussels are expected to be rebuild as the availability of lands is very low.

The discrepancy between Flanders and Wallonia is also observed for the living surface[1] of new single family houses constructed as shown in Figure 6. In 1980 the mean living surface was already higher in Flanders than in Wallonia. In both regions, the mean leaving surface has increased especially since 1985 (the current mean surface for the whole Belgium is 160 m^2), but more rapidly in Flanders. These differences are not easily explained : reasons could be searched in income differences, land availability, land management differences…

The size increase shows the change in households space needs in Belgium, while the mean household size was decreasing (from 2.7 in 1991 to 2.4 people in 1997 per household).

The average surface of new residential buildings in Belgium is much higher than the average in Western Europe. For instance, in 1992, the mean total surface per dwelling in Belgium was about 200 m^2 and the Western Europe mean was 125 m^2.

[1] Living surface includes all living space. So it excludes garage, caves and unoccupied lofts. It is to be noted however that for different reasons there can be a discrepancy between the actual living surface and the declared value.

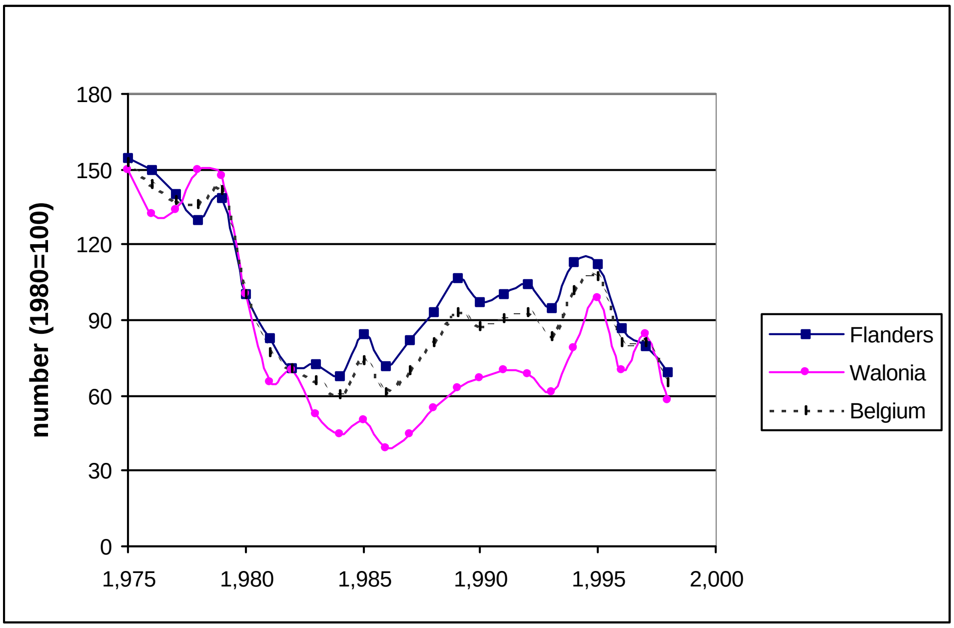

Figure 5 : Evolution of the number of new SFH
Source : INS

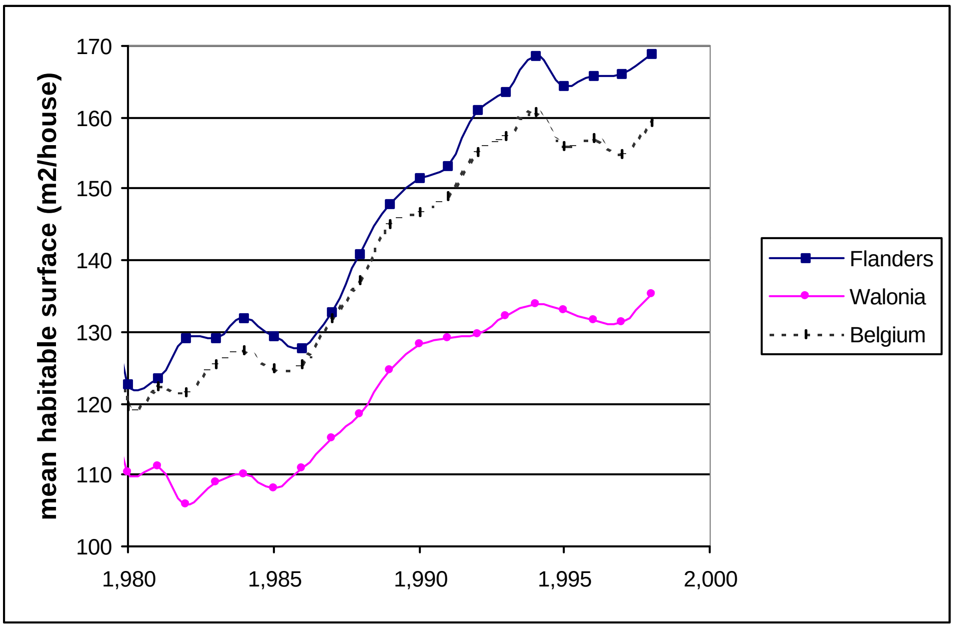

Figure 6 : Evolution of mean living surface of new SFH
Source : INS

With respect to material consumption, living surface is not the only relevant architectural parameter. Total surface and volumes have to be taken into account too. Figure 7 shows the evolution of the mean ratios "living surface / total surface" and "total surface / volume" for new SFH houses. It shows a steady increase for both ratios. One of the reasons is the increase of living surface per house. For the first ratio, it is also explained by the fact that, in most new houses, lofts are occupied which was not the case in the past. An other reason is the fact that a large part of new houses do not include any cellar. The second ratio also illustrates the fact that the height of rooms is decreasing.

The first ratio is also influenced by the number of garages per house. As an illustration Table 3 gives the distribution of new SFH houses according to the number of garages. Most of SFH have one garage and more than 20% of them have 2 garages. On the other side, one tenth only have no garage. The average value is 1.2.

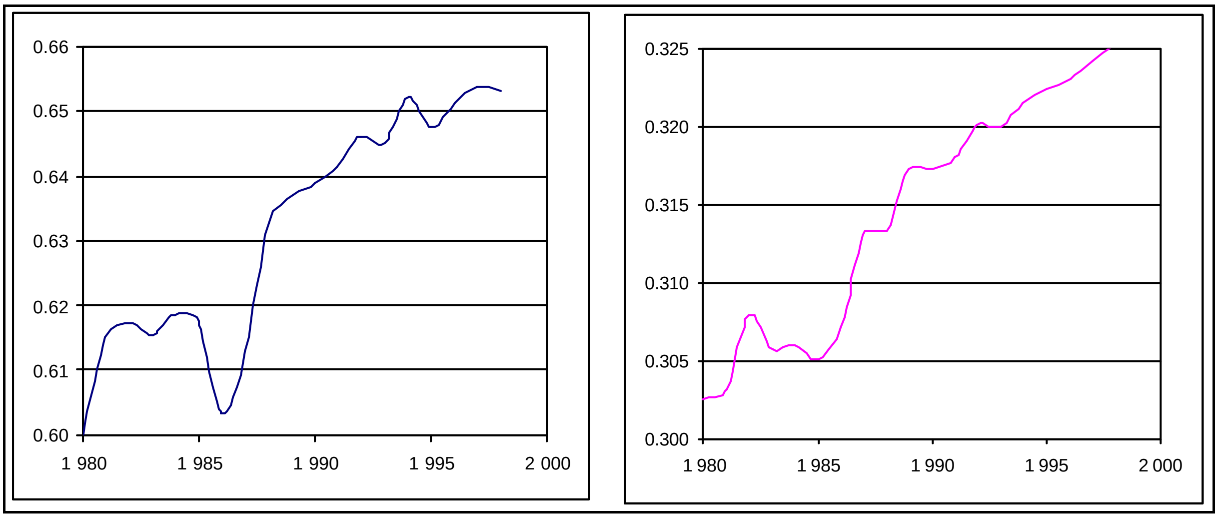

Figure 7 : Evolution of mean surface and volume ratios for the new SFH houses
- on the left : mean ratio living surface / total surface; on the right : mean ratio total surface / volume (m)
Source : INS

Number of garages	Number of SFH	%
0	2 365	11%
1	14 425	64%
2	5 460	24%
3	173	1%
4	21	0%
5	5	0%
6	2	0%
	22 451	100%

Table 3 : Number of garages in the new SFH houses (1997)
Source : INS

3.3.2.3. Renovation

As shown in Table 4, renovation of residential buildings has concerned about 13000 buildings in 1997. Renovation includes any transformation of an existing building that requires an authorisation. This authorisation is required when transformation results in a change in the appearance of the building (frame replacing, surface extension, roof renovation,…). Unfortunately, it is not possible to get further detail on renovation. The only distinction made among renovations in available statistics is between renovations implying no surface change and renovation resulting in increase or a decrease of the house volume.

The bulk of the renovation consists in extensions (85%). This ratio is about constant since 1990 but was a bit large before (until 90% in the 70's).

The mean additional volume is 155 m^3 per building in 1997. Since 1970, this average volume has increased (see Figure 8). If we make use of the more recent ratios as given in Figure 7 this corresponds to a 50 m^2 total surface.

With volume increase		With volume decrease		Without volume change	total
building number	volume (m3)	Building number	volume (m3)	building number	building number
11 003	1 705 275	1 011	151 924	957	12 971
85%		8%		7%	100%

Table 4 : Renovated residential building in 1997
Source : INS

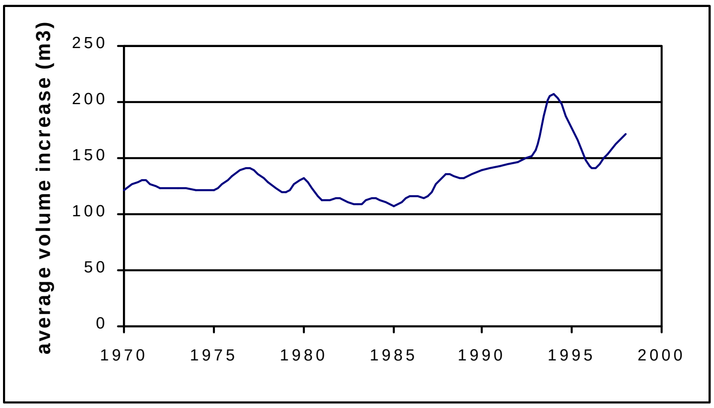

Figure 8 : Evolution of the average volume increase for transformation with volume increase
Source : INS

<u>3.3.2.4. Market price analysis</u>

Some statistical data allow analysing the evolution of the building construction market. However, these data are incomplete and do not allow a comparison of existing houses and new constructions.

Figure 9 depicts the evolution of the mean declared prices of houses sold since 1975, with a distinction between modest houses and high standing houses. This second category represents only 10% of the total sales. Total cost including registration and lawyer costs lays between 3900000 and 4100000 BEF. Is to be noted here again the very large geographical dispersion.

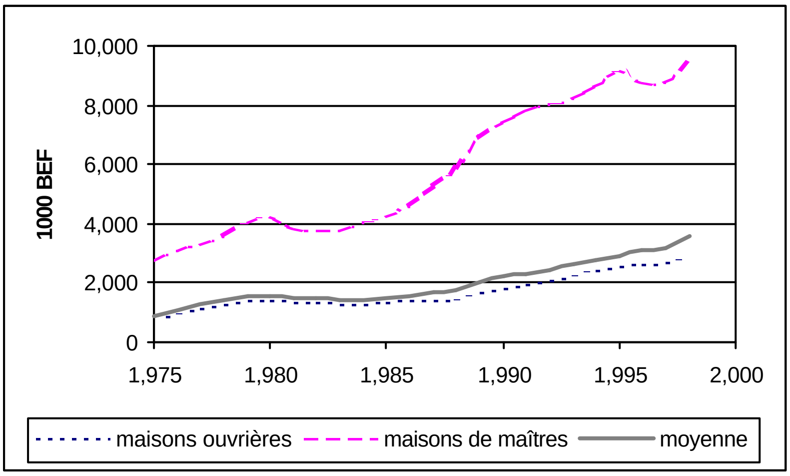

Figure 9 : Evolution of the mean prices of houses
Source : INS

No statistics exist for new constructions costs. SFH construction is dominated by "Clé sur porte" houses companies.

Current cost lays between 35 000 and 40 000 BEF/m2 living space (cost for houses "clé sur portes" prices vary from 20000 to 35000 BEF/m2 total surface[3]), which gives an average price around 6 millions BEF per SFH. An indication of the evolution of price is given by the ABEX index[2]. It indicates that the mean price has increased by 50% since 1980 (+128% for house sales).

Land price has also rapidly increased and is still increasing in some part of Belgium especially. INS gives the average prices shown in Figure 10. According to these statistics, land prices have increased by 145% since the last 15 years. These high costs are the result of high speculation in some regions and to accute scarcity of land in some areas (Brussels for instance).

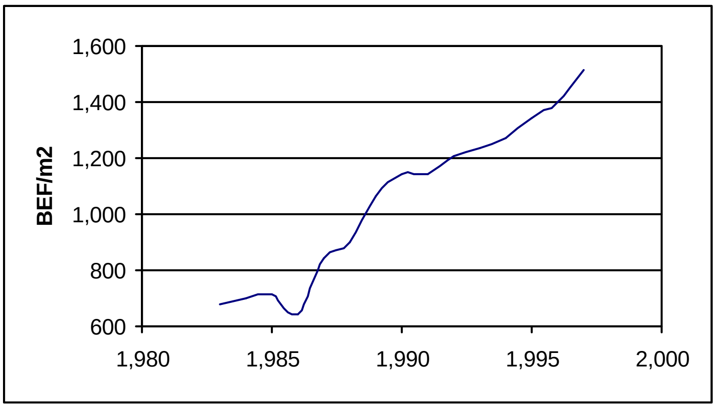

Figure 10 : Evolution of land prices in Belgium
Source : INS

[2] The definition is "Index expressing the evolution of the different elements constituting the total actual cost of a dwelling : study costs, working force, materials, company's benefits, taxes. Its aim is to establish a coefficient of evolution of the construction of residential buildings.(source : ABEX).

The comparison of data for houses sales with new construction (building plus land) must be done very carefully for the following reasons :

- No detaled information is available on the way the ABEX index is calculated.

- The great geographical dispersion is not exactly the same for both markets.

- Existing houses cost prices does not take into account the cost for renovation which occurs in the short term after the buying.

Data presented confirm the generally agreed perception that buying an existing house is generally cheaper in the short term as it allows to spread the expenses due to renovation over several years.

3.3.3. Building materials

In this study analysis will be restricted to the shell only.

The great diversity of available building materials for a given element of a building, results in a huge number of combinations. Table 5 gives a rough overview of the amount of possible combinations of materials for a house.

	baked clay +concrete	concrete	stone + concrete	cellular concrete	baked clay tile	natural slate	artificial slate	zinc	steel	plaster	lime	PVC	aluminium	PS	rock wool	glass wool	biomaterial	wood	number of possibilities
foundations																			1
external walls																			4
internal walls																			3
wall cladding																			1
insulation																			4
roofing																			7
roof structure																			1
beams																			3
floor																			3
window frames																			3
doors																			3
stairs																			2
total number of combinations																			163,296

Table 5 : Options for material use for the fabrication of the main elements of a house

In the framework of this project, it is obviously not possible to account for this large diversity but it is necessary to select a set of representative combinations regarding the Belgium market.

Unfortunately no statistics exist on the representativeness of the different building materials in the new constructions. The grey cells in Table 5 indicate the most common options encountered in current new constructions. Wood construction is also retained in the table as a major alternative considered in the bio-construction sector.

The selection of building materials studied in the project should be based on statistical data. Unfortunately no such data have been found. Discussion with architects and entrepreneurs and the observation of the building market, visits at building sector exhibitions have given indication of the more common options.

For this purpose we have contacted different architects and “Clé sur porte” building companies. We got descriptive information from some of them but quantitative data were more difficult to receive. Two architects kindly accepted to provide quantitative data on different buildings and they collaborated for the analysis of those data[3].

These data enabled us to make a first estimate of the indirect emissions resulting from the construction of a new conventional house.

In the next chapter we will discuss and describe the main material options for the different building elements.

[3] We would like here to thank Mister Tyberghyn, architect, who provided useful data and advice for the evaluation of the material intensity of the builsings.

4. Product system description

4.1. Product description

Here below, we make a systematic description of existing building practices and used material for each building element.

4.1.1. Foundations

The role of foundations is to transmit the building load to the soil. The choice of foundations depends on the load of the building (a conventional house represents a 15 to 20 t load), its distribution on the ground surface and the pressure the soil can support without sinking. A good soil structure is able to stand a 1 to 2 kg/cm^2 load. A wooden or cellular concrete building will require lighter foundations than heavy concrete block buildings.

Three main foundation types are encountered depending on those three parameters.

The most common type is the **sole foundation** which consists in concrete soles that support the loading walls. They width is generally about 60 cm and they height of 30 cm and they are placed at a deepness of at least 80 cm for frost protection. The width is to be increased for less stable soils. The concrete is made with granulates mixed with 250 to 300 kg cement per m^3.

This solution represents a price around 8000 BEF/m^3.

A second type is the **slab foundation** which is required for unsteady soils. In this case the soil is covered by a concrete slab with reinforcement steel (2 wire-meshes placed at the lower and the upper sides of the slab). The width of the slab varies from 20 to 30 cm.

This solution is from 12 000 to 15 000 BEF/m^3.

A third solution which is justified for less loading soils is the **pile foundations** system. The piles made of concrete have generally a diameter between 30 to 70 cm and a length from 5 to 10 meters. The techniques used for this system vary but represent a high cost (100 000 to 150 000 BEF).

A comparison of cost prices for the three solutions is given in Table 6 for a 70 m^2 ground surface house.

	Average cost (BEF)
Sole foundation	110000
Slab foundation	260000
Pile foundation	410000

Table 6 : Cost comparison of three foundation systems, including “hourdis”
Source : Tu bâtis, Je rénove

The same comparison can been made for material consumption (see Table 7) which shows that the sole system is clearly the less material intensive.:

	Concrete (m^3)	Steel	comment
Sole foundation	9	0	50 current meters soils (0.6 width, 30 cm height)
Slab foundation	17.5	2 wire-meshes	25 cm thickness
Pile foundation	110		20 piles, 7 m length, 50 cm diameter

Table 7 : Material intensity of three foundation systems

Both cost prices and general soil structure and composition explain that sole foundation system is the most common. Slab foundation is implemented in less favourable soils and pile foundation is an exceptional solutions.

4.1.2. Exterior walls

4.1.2.1. Conventional Construction

Most of building conventional constructions in Belgium are composed of "empty walls" that consist in a exterior wall with a loading layer (masonry) and a facing layer. Both are separated by insulating material (fixed against the masonry with metal hooks) and a empty layer that allows ventilation of humidity transmitted through the bricks. This practice constitutes a specificity of the belgian building construction compared to other European countries : in many other countries the "empty wall" practice is not implemented. It was introduced before the emergence of thermal insulation concerns as a response to humidity problems. In Germany or in France for instance this problem is solved with the application of roughcast on the sole masonry layer (concrete blocks or other material). The insulation is applied either at the external side of the wall (covered by the roughcast) in Germany, either at the internal side in France (this solution leads however to thermal bridges).

The choice between both practices do not influence significantly the insulation performance of the wall. The Belgian practice is the more labour and material intensive.

The general schema of a empty wall is depicted in Figure 11.

The wood construction most frequently developed in Belgium but also in other countries like Canada and France is a wood skeleton construction.

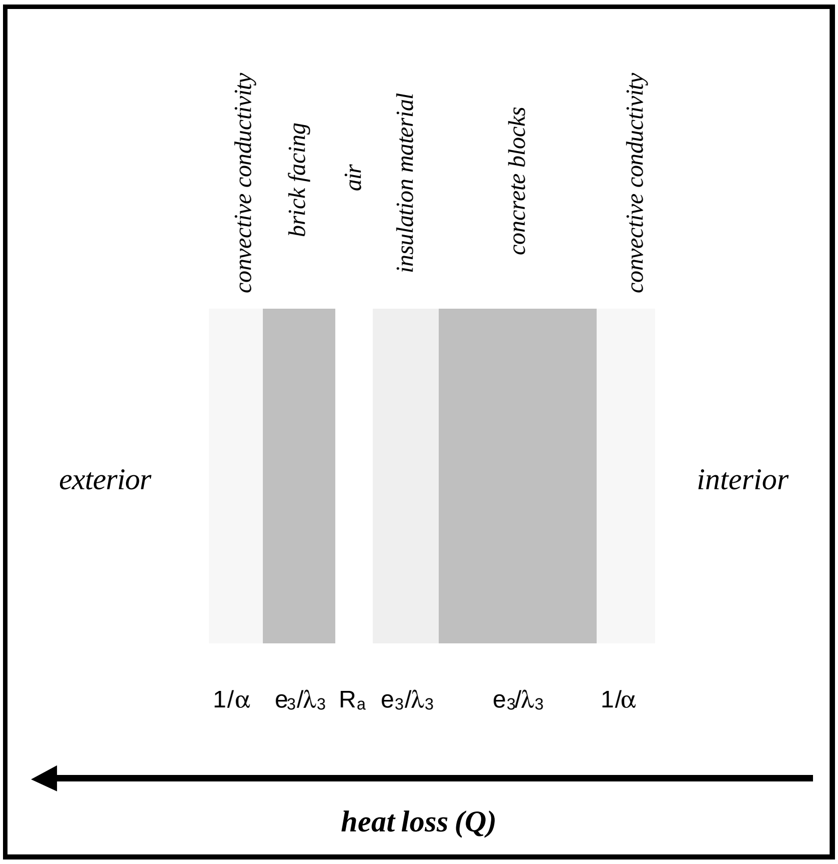

Figure 11 : General structure of a empty wall in Belgian constructions

Loading structure

In most cases the loading structure is composed of a **masonry**. In many cases it is made of concrete blocks. Since the last years however new materials like expanded clay blocks are used. Other materials like cellular concrete are also used. Among those possibilities there is no significant differences regarding cost. The differences more concern the insulating properties and the density. The different main materials are described here below :

Mortar : it is the binding material used for most of the masonry construction. On the average it is made of 24% cement. Other binding agents are used in specific masonry type : this is the case for cellular concrete blocks for which cement-glue is used instead of mortar.

Concrete : concrete is a mix of cement, granulates and sand. The proportion of each of them depends on the type of product and its use.

The average content of cement is as followed :

- Ready mix : 10-15%
- prefabricated elements : 20-25%
- blocks : 10%

Brick : masonry bricks can be used to build loading or non loading walls.

Poroton : this material, is produced by one main company (BREAK SA, Greece)[4] by mixing clay and polysterol grains (a product of BASF). During firing a cellular structure is created due to those grains. The process results in a material 30% lighter than bricks and its insulating properties are improved due to the air chambers and polysterol content. However no more precise data are available to characterise the material.

Expanded clay is a light granulate material produced by clay expansion and firing at 1100°C temperature. The capacity production in Europe is around 500000 m^3/an and is dominated by the ARGEX Company. Special building blocks produced by ARGEX (Topargex) are composed of 40% air, fired expanded clay incorporated in a concrete skeleton. The average density is 0.8 t/m^3 and 1.1 t/m^3 for empty and full blocks. Its thermal conductivity is of 0.35 W/m.K [5].

Cellular concrete is composed of Portland cement, high quality lime, sand, aluminium powder and air. The density is about 0.4 t/m^3 [(4)].

In the **wood skeleton construction**[5] system the loading structure is made (from the interior to the exterior) of (Parthoens, 1997)[6] :

- A finished surface either made of wood panels, either of plaster panels.
- A wood skeleton[6] composed of wooden uprights.
- An insulating layer inside the chambers.
- Fiber wood panels (thickness 22 mm) or OSB panels (15 mm thickness) .

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[4] Documentation Ytong

[5] About 18 wood skeleton systems have technical agreement in Belgium.

[6] The uprights are sawn wood sections (38 mm * 89 mm) spaced out by a distance of 40.6 cm. Thus a 1 m^2 wall surface represents 2.25 current meter uprights, i.e. 0.0076 m^3 / m^2 or 3.8 kg wood / m^2 wall.

Facing layer

Brick facing uses different types of bricks (width from 50 to 90 mm; length from 19 to 21.5 cm).

The brick number per unit of surface influences the labour intensity. But in any case this latter represents about two thirds of the total cost price of the facing wall (hourly cost around 1200 BEF):

	Cost (BEF/m^2)	Share
Brick	830	34%
Mortar	150	6%
Various materials	20	1%
Labour	1430	59%
Total	2430	100%

Table 8 : Cost price for brick facing
Source : Tu Bâtis, Je rénove

Roughcast is an other type of house facing. This is the most common solution when cellular concrete blocks are used for the loading layer. But is also valid for all the classic materials.

In the wood construction both **wooden facing** and brick facing are used. The latter case is the most common presently in Belgium resulting from a legal obligation in the town planning regulation. However some flexibility exists depending on the municipality : some municipality are firmly opposed to wood facing, other being much more tolerant. For the former system the facing material is composed of wooden planks[7].

4.1.3. Interior walls

Interior wall are generally made of concrete blocks. However like for external walls other materials are more and more used : expanded clay blocks, poroton, cellular concrete.

In most cases the wall is recovered with plaster. Wood is also used, especially in the wood construction.

4.1.4. Roofs

The large majority of houses have a roof with a wood skeleton. In many cases this skeleton is on-site build. But more and more elements of the skeleton are industry made. This is specially the case for

[7] Lattes et contre-lattes 35*7 mm distantes de 20 cm donc 1 m2 couvert représente 100/20 = 5 mc soit 0.001 m3 de bois. Si les lattes verticales sont espacées de la même façon, cela donne **0.002 m3 de bois par m2** couvert.

Bardage : planches de mélèze rabotées en pente de 22 à 9 mm d'épaisseur (soit une moyenne de 15.5 mm et une largeur de 14 cm et couvrant 12.5 cm. Recouvrement : 15 mm. Donc 1 m2 couvert représente environ 100/(12.5-1.5) soit 9.09 mc de planches et donc un volume de l'ordre de **0.136 m3 de bois par m2**. On peut utiliser du mélèze ou du cèdre. Le traitement n'est pas nécessaire pour ce type d'essences, sauf pour éviter l'effet des rayonnements UV.

large buildings with large ranges. In those cases engineered wood elements is an attractive solution notably in terms of available roof in the loft.

Slates are one of the more common roofing material especially in some areas in Belgium : Flanders region, Brussels but also in walloon cities and their suburbs.

Tiles are used in the other parts comprising artificial tiles or natural tiles. For the last few is produced in Belgium even resources still exist. But the extraction is costly[8]. Since more than two decades cheaper natural tiles come from Spain notably.

4.1.5. Window frames

According to data reported for Belgium by “Tu bâtis, je rénove” about 39% of window **frames** are wooden made, 28% use PVC and 33% use Aluminium. A small part is made of other material like steel. It is to be noted that the share of wooden window frames has decreased from 1988 to 1998 as it was around 60% in 1988. This figure relates to all buildings. However for residential buildings only wood and PVC have higher parts.

For **wooden frames**, meranti has been the most common wood used during the last years. However its success has encouraged an intensive exploitation of tropical forests and mature trees have been depleted. Moreover there is a new tax on export which explains the increase of price. Other species are more and more used like afzelia, merbau. Wood from temperate or boreal forests are also used like oregon.

Small quantities of steel or aluminium are used.

The advantage of wood is its low thermal conductivity and its stability. It needs however to be periodically treated (painting or protected).

Aluminium window frames are generally “thermic cut” frames. They are made of metal elements composed of at least two sections separated by insulating material like PVC, polyurethane or other synthetic resins. Aluminium is indeed a high conductive metal. Two processes are used to improve the resistance of the metal : on one side anodisation consists in creating a alumine layer with an electrolysis. On the other side, thermo- laquering consists in oven firing of a polyester powder at the surface of the metal.

PVC window frames are composed of heavy elements prepared by PVC extrusion. The resulting chambers are reinforced with steel.

As for windows double **glazin**g is the most common. Super insulated (with argon) windows are also favoured due to they benefit in terms of energy efficiency and comfort (see Table 9).

[8] Significant exploitation of the resources in the southern part of Belgium could resume in the next future

	Thermic coefficient
Single glazing	5.8
Double glazing	2.9
Double glazing with argon superinsulation	1.5
Triple glazing	1.2

Table 9 : Thermal conductivity of different windows (unit?)

The price of window frames depends on the surface. For surfaces between 1 and 2.5 m^2 market data show that the price per m^2 is quite constant : according to the magazine “Tu bâtis, je rénove”, average prices for wood, PVC and aluminium frames are respectively 8900, 8600 and 13800 BEF (see Figure 12).

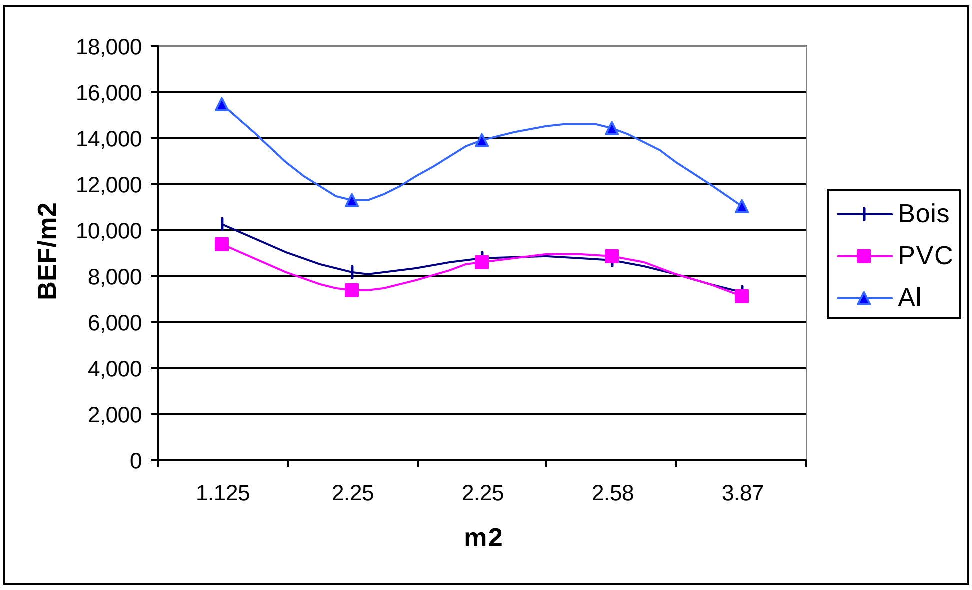


Figure 12 : Price of window frames per m2 as a function of surface
Source : Tu bâtis je rénove

5. Building material flows analysis

A description of the single family houses as the product system studied needs to evaluate the different flows of the different materials involved in the system. This type of analysis is useful for the detailed description of the system. Indeed it allows to :

- Quantify the part of the products studied in the project in the domestic consumption : this has been done through a combination of a top-down approach based on national statistics on production and consumption and a bottom-up approach based on the material intensity of the different most relevant buildings and their representativeness in the market.
- Quantify the part of imports for satisfying domestic demand for those materials.
- Roughly evaluate the life cycle GHG emissions associated with those flows.
- Quantify the exogenous residual demand to be introduced in MARKAL (see 8).

Material flow analysis (MFA) has gained interests in European and national research efforts. Let's here mention the EUROSTAT Project "Material Flow Accounts of Selected and Substances Harmful to the Environment" that ended in 1997 and the important contribution from the Wuppertal Institute notably through the study "Construction Materials, Packagings, Indicators" focused on the flows in Germany. Efforts in that country are already advanced : for instance the Federal Statistical Office of Germany has established the first physical input-output table (PIOT) for the West German in 1990 and the European Environmental Agency (EEA) is enforcing activities about the integration of material flows accounting into measurements of progress towards sustainability.

No such efforts have been undertaken in Belgium up to now. The effort made in this project is a first contribution in this sense. A quantification of the main flows of some materials that characterise the Belgium economic system has been done as well as an evaluation of the GHG emissions that are associated with these flows. The analysis has been limited to the materials that potentially enter the composition of the products studied here.

5.1. Cement

Cement is used as a binding agent for different applications. The most important is the fabrication of concrete. Other applications are mortar, stabilised sand and fiber-cement.

Cement industry in Belgium produces two types of cement : Portland and blast furnace cement (58% and 42% respectively in 1998). According Febelcem (Belgian Federation of Cement) total production is about 7000 kt per year. Detailed data are not published since 5 years. However data on total deliveries are available (see Table 10). We can consider these deliveries as production volumes. Imports are very low (border exports) and the bulk of this production is delivered in Belgium.

Per capita Belgian consumption is particularly high (550 kg/inhabitant) compared to the average consumption for the whole European Union (470 kg/inhabitant).

	Deliveries (kt)			Exports (kt)	Imports (kt)	domestic consumption (kt)	consumption per capita (t/inhab)
	portland cement	blast furnace cement	Total deliveries				
1980	4 353	2 444	6 797	1 423	248	5 622	0.56
1985	2 559	2 185	4 744	1 029	321	4 036	0.40
1990	3 559	2 645	6 204	1 203	555	5 556	0.56
1995	4 117	3 127	7 244	2 039	527	5 732	0.57
1996	3 961	2 884	6 845	1 781	751	5 815	0.58
1997	3 971	2 903	6 874	1 867	725	5 732	0.57
1998	3 933	2 870	6 803	1 982	679	5 500	0.55

Table 10 : Deliveries, exports, imports and consumption of cement in Belgium
Source : Febelcem

Table 11 gives the share of the deliveries in Belgium. Most of the deliveries are used for concrete fabrication (concrete products and ready mixed concrete). Table 12 shows that the residential building construction consumes 45% of the cement in Belgium. This figure is in accordance with data reported by Gielen[7] for the Western Market where new residential sector represents 30% of cement and repair and maintenance represents 15% of the end use market.

	1998	
	kt	%
Fibres-ciment	102	2.1%
Fabrication de produits en béton	1 229	25.5%
Béton prêt à l'emploi	2 176	45.1%
Livraisons sur chantier	309	6.4%
Livraisons au négoce	1 005	20.8%
Total	4 821	100%

Table 11 : Share of the belgian deliveries of cement
Source : Febelcem

Génie civil	13%
Bâtiments non résidentiel	42%
Bâtiment résidentiel	45%

Table 12 : Share of use of cement in Belgium
Source : Febelcem

As imports are small, transport distance of cement to the Belgian end uses is not important. However it is to be noted that road transport represents 98% of the cement transported.

A rapide estimation based on total surface of built single family houses and the average cement consumption (about 12.6 t/100 m^2 including cement for concrete production) leads to a 16% part from the SFH construction. If we take into account renovation this ratio can be estimated to 20%.

5.2. Concrete

Concrete production comprises pre-cast concrete and ready-mixed concrete represented by two separate federations.

5.2.1. Precast concrete

Precast concrete comprises a large set of products used for roads (pavements, borders, gutters,…) and for buildings.

Production capacity of precast concrete in Belgium is around 13000 kt per year. Production has increased from 6400 kt in 1980 to 9700 kt in 1997 (see Table 13). This production includes cellular concrete but this represents a small amount and is concentrated in one company. Most of this production is consumed in Belgium : the high weight of concrete prevents to import or export on long distances. External flows are estimated to about 5% of the production, limited to border regions[8]. Consumption per capita has also increased to raise 970 kg/inhabitant.

Table 16 gives an overview of the different uses of precast concrete. It is not possible to quantify precisely the relative shares. However, we can state that building construction represents about two thirds of the domestic consumption.

kt	Production
1980	6 421
1985	4 337
1990	8 333
1995	9 450
1996	9 550
1997	9 740

Table 13 : production of precast concrete in Belgium
Source : FeBe

	quantity	unit
Voiries		
Carreaux de béton	3 800	1000 m2
Pavés	13 000	1000 m2
Brodures	6 195	1000 m ct
Caniveaux et filets d'eau	822	1000 m ct
Tuyaux	1 214	1000 m ct
Construction		
Béton décoratif	540	1000 t
Gros él. de construction	495	1000 t
Blocs lourds	1 200	1000 m3
Blocs légers	703	1000 m3
Planchers	11 660	1000 m2
Citernes	23 730	nombre
Fosses sceptiques	14 675	nombre
Carreaux de mosaïque	830	m2

Table 14 : Overview of precast concrete uses in Belgium (1997)
Source : FeBe

5.2.2. Ready mixed concrete

About 300 companies produce ready-mixed concrete (2.4 t/m3 cement is required) and stabilised sands (1.7 t/m3 cement used) in Belgium. The total production is about 10 millions m3[9]. As indicated in Table 11, ready-mixed concrete production represents 45% of the cement market.

Per capita consumption is about 1 m3/inhabitant which is one of the highest values in Europe (between 0.3 and 1.4 m3).

5.3. Bricks

Belgium produces two types of bricks : ordinary bricks for masonry (full or perforated) and bricks for facing. This second category comprises drawn out bricks and manually mould, however the last subcategory is industrially made. Hand made production is not significant now in Belgium.

Refractory bricks are also produced in smaller quantities.

Table 15 and Figure 13 present the evolution of productions of the different types of bricks in Belgium. The most important productions are perforated bricks for masonry (58%) and by-hand mould bricks for facing (30%). Full bricks have been progressively replaced by perforated bricks.

Exports and imports are low compared to productions. Domestic consumption is high compared to the rest of Europe : the average consumption per capita is around 270 kg/capita (per capita consumption in Western Europe was about 160 kg in 1994[7]).

	masonry bricks production		facing bricks production		total production	Exports	Imports	domestic consumption	consumption per capita
	Full bricks	perforated bricks	Drawn out bricks	Manually mould					
	1000 m3								t/capita
1985	201	791	189	245	1225	102	46	1169	0.15
1990	188	1427	275	550	2252	154	121	2219	0.28
1991	195	1383	215	529	2127	152	101	2076	0.26
1992	136	1429	280	549	2258	198	105	2165	0.27
1993	119	1555	279	543	2377	233	79	2223	0.28
1994	39	1607	336	658	2601	388	78	2291	0.29
1995	81	1631	388	792	2811	439	75	2447	0.31
1996	68	1498	347	682	2527	402	64	2189	0.27
1997	61	1451	311	748	2510	462	85	2133	0.27

Table 15 : Production, import, export and consumption of bricks in Belgium
Source : Fédération belge de la brique

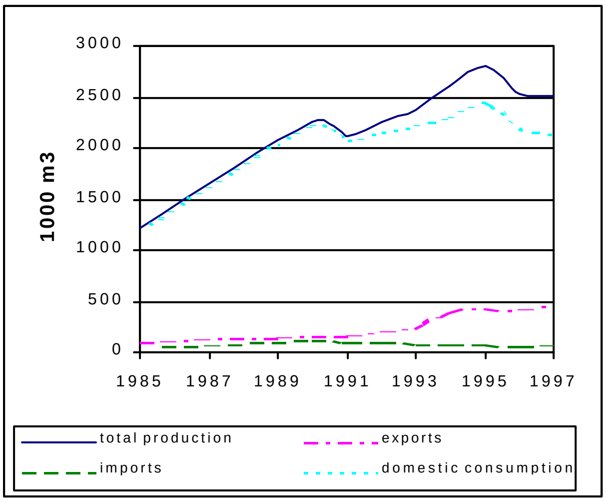


Figure 13 : Production, import, export and consumption of bricks in Belgium
Source : Fédération belge de la brique

Brick production and consumption in Belgium have increased since 1985. However consumption has become more or less constant since 1991. One increasing part of production has been exported.

5.4. Glass

Glass comprises flat glass, hollow glass and special glass. Flat glass is used for windows in building and cars, including security glass and mirrors. Within this category non transformed glass (produced in a limited number of industries) is to be distinguished from transformed glass (produced in a large set of companies).

Hollow glass is used for bottles, dishes and also for lighting. Special glass includes notably glass wool for thermal insulation and fibre glass used for different purposes.

Non transformed flat glass production volumes are published by the Belgian Federation of Glass (FIV). Unfortunately, productions of transformed flat glass is not available after 1993 from this federation. From 1990 to 1993, the mean annual production of transformed flat glass turned around 300 kt/year. Estimation from NIS for 1998 is about 327 kt.

Imports and exports flows are given for the Economic Union of Belgium and Luxembourg (EUBL). Belgian figures will be available in the course of this year. (see Table 16). In Luxembourg one company produces non transformed flat glass. Other types of glass are not produced in that country.

The last report from the FIVE indicates that in 1999, total glass imports arose to 1110 kt, production to 1474 kt, exports to 1885 kt and consumption to 699 kt. It is also estimated that about 65% of the belgian flat glass production is used by the building sector and 20% to the automotive sector. The other 15% are used in furniture, decoration and other uses.

Production is steady from 1980 to 1998. Exports from EUBL have globally increased, especially exports of non transformed flat glass even if it decreased between 1996 and 1998. Imports have also increased since 1980.

kt	production (BELGIUM)				export (UEBL)				import (EUBL)			
	Non transformed flat glass	Holl glass	Other glass	total	Non transformed flat glass	Holl glass	Other glass	total	Non transformed flat glass	Holl glass	Other glass	total
1980	856	429	-	-	576	268	139	983	111	211	59	381
1990	1 044	336	-	-	961	284	216	1 461	142	335	54	531
1994	967	339	219	1 306	-	-	-	-	-	-	-	-
1995	912	343	262	1 255	-	-	-	-	-	-	-	-
1996	926	344	244	1 270	1 066	271	293	1 630	177	321	86	584
1997	986	356	239	1 342	893	346	272	1 511	203	324	104	631
1998	1 057	300	192	1 357	919	336	281	1 536	334	381	134	849
1998	78%	22%	14%	100%	68%	22%	18%	100%	39%	45%	16%	100%

Table 16 : Data for production of glass in Belgium and import and export for the EUBL
Source : FIV

Table 17 gives an overview of the share of belgian production and UEBL imports and export flows between the different types of glass in 1998 based on data from the National Statistical Institute and

FIV as well as data collected by IW. Data from NSI are initially given in usual units for some of the products (m2 or pieces). The data have been converted to tons making use of assumptions on average thickness for flat glass or densities for hollow glass. This gives rise to uncertainty ranges for some of the products but they do not affect the most important categories.

Even export and import flows relate to the UEBL area, we can conclude that for Belgium flat glass imports are low compared to the production (about 30%). For the window glass this ratio is still smaller. Regarding hollow glass, net exchange is negligible and the bulk of exchanges is due to packaging.

Regarding wool and fiber glass production, wool production alone in 1998 was around 111 kt and fiber glass production alone was 60.8 kt.

kt	Productions (Belgium)	Imports (UEBL)	Exports (UEBL)
Glaces	859	323	840
Verre à vitres	0	4	6
Verre coulé	127	7	73
verre plat non transformé	986	*334*	*919*
Vitrages isolants	46	10	35
Verres de sécurité	70	66	256
Miroiterie	130	10	116
Autres verres plats transformés	0	3	25
verre plat transformé	247	*89*	*433*
Total verre plat	**1 233**	**422**	**1 353**
Bouteilles et flacons	336	338	299
Verre domestique	23	38	37
Verrerie d'éclairage		5	1
Total verre creux	**359**	**381**	**336**
Fibres et laine de verre	154	108	197
Ampoules, lampes et tubes	107	2	46
Autres verres plats transformés		24	37
Total verre technique	**261**	**134**	**281**
Total	**1 853**	**938**	**1 969**

Table 17 : Share of import and export between different types of glass
Source : import and export : FIV, production : NSI and IW

5.5. Steel

Despite the growth of scrap-based steel-making, iron ore remains the principal source of iron for steel production. In 1998, consumption of scrap in Belgium was 3,8 million tonnes compared to a apparent consumption of 13.8 million tonnes of iron ore imported (pellets included) to produce 8,6 million tonnes of pig iron.

About two third is imported from Latin America and 15% from Africa.

These 8,6 million tonnes of pig iron provided the principal basis for the 11,4 million tonnes of crude steel produced in Belgium.

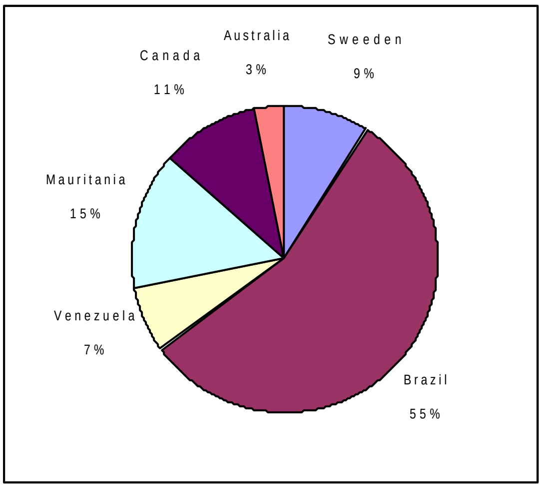


Figure 14 : Iron ore imports per origin
Source: Rapport Annuel du Groupement de la Siderurgie 1999

Year	**Scrap consumption** (million tons)		
	BOF	EAF	Total
1994	1,7	1,6	3,3
1995	1,8	1,6	3,4
1996	1,4	1,5	2,9
1997	1,3	2,2	3,5
1998	1,4	2,4	3,8

Table 18 : Scrap consumption in Belgium
Source: Rapport Annuel du Groupement de la Sidérurgie 1998

Recycled steel (scrap) is a required and essential component of new steel.. In basic oxygen steel-making (BOF), scrap represents up to 30 percent of the raw materials charged into the furnace. It represents between 90 and 100 percent of the charge in EAF (electric arc furnace) production, which is also the principal route for stainless steel production.

About 3,5 million tons of steel scrap are recycled each year in Belgium.

t scrap/t crude steel	1994	1995	1996	1997	1998
BOF	0,181	0,185	0,154	0,154	0,155
EAF	0,971	0,989	0,963	0,966	0,979

Table 19 : Use of Scrap in Basic oxygen steel making and in electric arc furnace
Source: Rapport Annuel du Groupement de la Sidérurgie 1998

Table 20 gives an evolution of the production of pig iron and crude steel along the BOF route and the EAF route. It shows the increase of the EAF crude steel production which however remains the smallest.

Year	**Pig iron**	**Crude Steel**		
		BOF route	EAF route	Total
1994	8,98	9,6	1,6	11,2
1995	9,2	9,8	1,7	11,5
1996	8,6	9,2	1,5	10,7
1997	8,1	8,4	2,3	10,7
1998	8,6	9	2,4	11,4

Table 20 : Pig iron and crude steel production (kton)
Source: Rapport Annuel du Groupement de la Siderurgie 1998

Regarding the flows of the different products in Belgium data are incompletely available as the published data concern the Belgian-Luxembourg area for imports. However, the Belgian Iron steel group has made estimations of the apparent consumption of the different steel products for the EUBL area. We made use of those figure to recalculate a Belgian apparent consumption on the basis of the population. The results are given in Table 21.

kt	production	appearent consumption
Fonte	**8430**	
Acier brut	**10910**	
O2	*8832*	
Électrique	*2078*	
Laminés à chaud	**12780**	**2068**
Larges bandes àchaud	*10981*	*1284*
Tôles laminés	*607*	*372*
Fil machine et ronds àbéton	*944*	*1212*
dont : fil machine	*930*	*1008*
ronds en béton	*14*	*204*
Profilés	*248*	*468*
Tôles à froid	**4951**	**636**
Tôles revêtues	**3370**	**1116**
Fer blanc & ECCS	*224*	*132*
Autres tôles revêtues (métal ou mat. Org.)	*3146*	*984*

Table 21 : Magnitude of the production and apparent consumption in Belgium or/and in the UEBL (1999)
Source : Groupement de la Sidérurgie and IW estimation

Steel slabs, billets and blooms are known as semi-finished products. Finished products include : hot- or cold-rolled flat products (such as plates, coils, strips or sheets) and hot-rolled long products (such as wire, bars, rails, profiles and structural or beams).

According to the GS final domestic consumption of steel is around 4300 kt in the UEBL area which leads to a Belgian consumption around 4200 kt in 1998 (420 kg per capita). Steel consumption of finished steel products ranges from approximately 340 kg per person per year in Europe to around 420 kg in the North America and 635 kg in Japan.

Steel is used in a vast array of products. Figure 15 illustrates the evolution of the consumption of finished products among the mains sectors. It shows that the largest consumers are the metallic construction sectors (24%), the mechanical construction (14%) the building construction (12%) and the automotive sector (8%).

Within the building sector we estimate that the construction and renovation of single family houses represent about one third of its consumption.

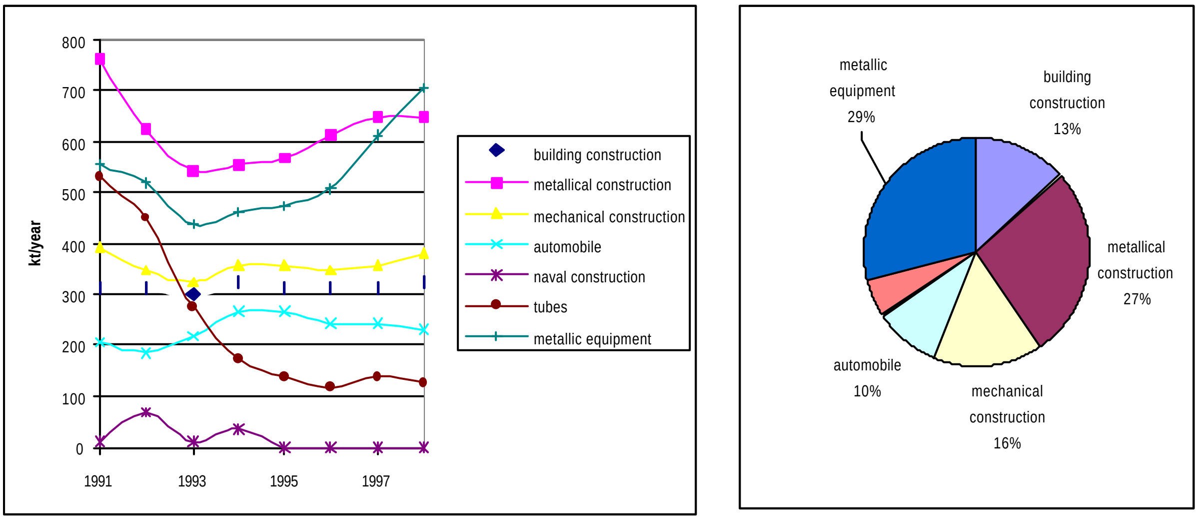


Figure 15 : Evolution of domestic consumption of steel in Belgium and distribution between the different sectors
Source : Groupement de la Sidérurgie and IW estimations

5.6. Non ferrous metals

The principal non ferrous metals include Copper, Aluminium, Zinc and Lead. All of them are at different degree concerned either with the residential buildings consumption either with packaging (mainly aluminium for the last). However if lead is used for the building construction the share of this sector among all the uses is negligible. For this reason we restrict the analysis to the three other metals.

Other metals are also included in non ferrous metals : precious metals and special metals. However they do not enter the fabrication of the products analysed in the present study.

Most of data useful for the characterization of flows for copper, zinc and aluminium come from Fabrimetal. Some data are also published at the European level[10], [11].

At the level of production, distinction has to be made between crude metal production and semi-finished production.

Crude metal is produced in foundries (1st transformation) which is implemented in Belgium (in Flanders) only for copper and zinc.

Second transformation is encountered for all four metals in Belgium. This second transformation includes recycling of used metals with a global rate around 80% according to Fabrimetal[12].

Evolution of productions of metals (crude and/or semi-finished) are represented in Figure 16. Comparaison of the orders of magnitudes for the different metals must be done with caution due the differences in densities.

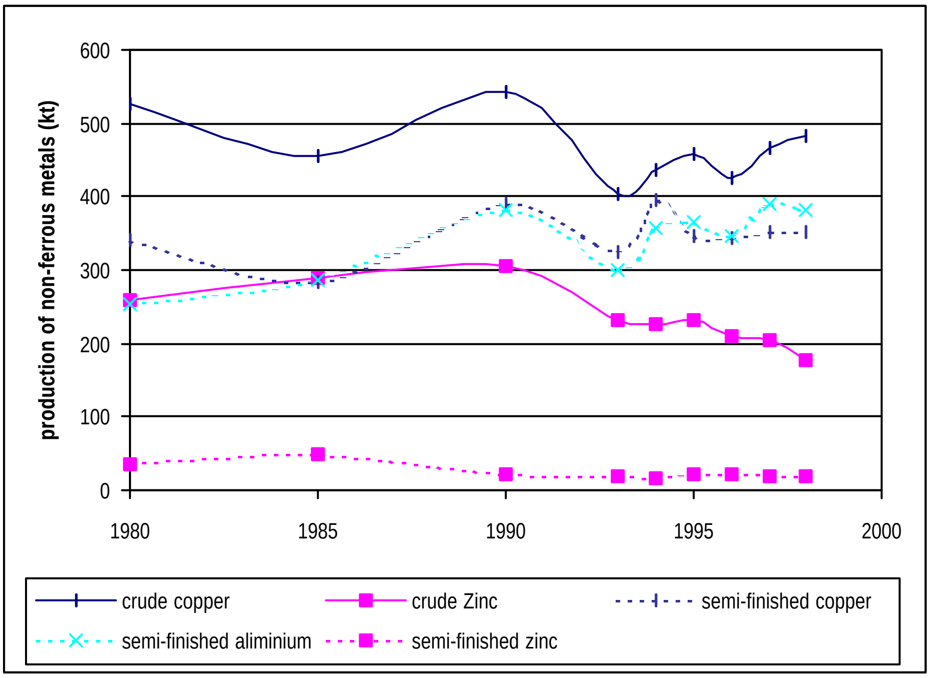


Figure 16 : Production of crude and/or semi-finished metals in Belgium
Source : Fabrimetal

Regarding crude productions of copper and zinc, the volumes have decreased since 1980. This not the case for semi-finished products. For zinc however we must note the low level of semi-finished product production compared to the crude metal production.

No evolutionary data were found about import of metals. Moreover data are either given as summation of all metals either as an aggregation of crude and semi-finished metals.

Data from 1992 enable however to give an overview of the different flows for the three metals and also of the different uses.

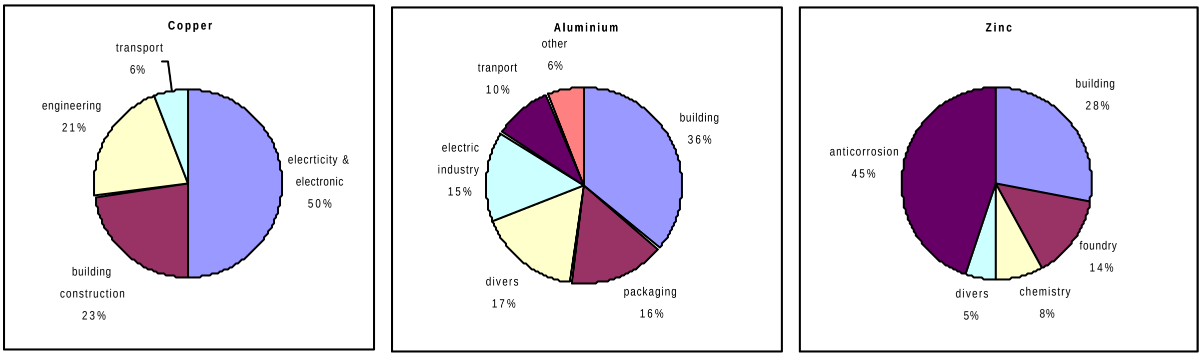


Figure 17 : Share of the different sectors in the consumption of Copper, Aluminium and Zinc in Belgium (1992)
Source : Fabrimetal

kt	import	domestic production	export	domestic consumption
Cu				
ore	0	0	0	
secundary material	251			
crude metal	375	472	196	651
semi-finished metal	62	373	328	107
Al				
ore	0	0	0	0
secundary material	169			
crude metal	347	0	75	272
semi-finished metal	181	333	341	173
Zinc				
ore	0	0	0	0
secundary material	150			
crude metal	151	237	207	181
semi-finished metal	23	63	41	45

Table 22 : Flows of Copper, Zinc and Aluminium in Belgium (1992)
Source : Fabrimetal

Table 22 gives an overview of the different flows of metals in Belgium. It is also to be noted that belgium imports large amounts of secundary materials consist in ash, residues and waste recycled in the production of semi-finished metal.

5.7. Wood

Wood comprises a large set of semi-finished products produced at different stages of the wood chain.

Roundwood from forest exploitation is converted to industrial roundwood as logs or wood in the rough (other than logs). Then this wood is submitted to a first transformation into sawn wood, panels (plywood, particle board and fibreboard), and wood pulp. A small part is used as fuelwood. The wood chain is represented in Figure 18.

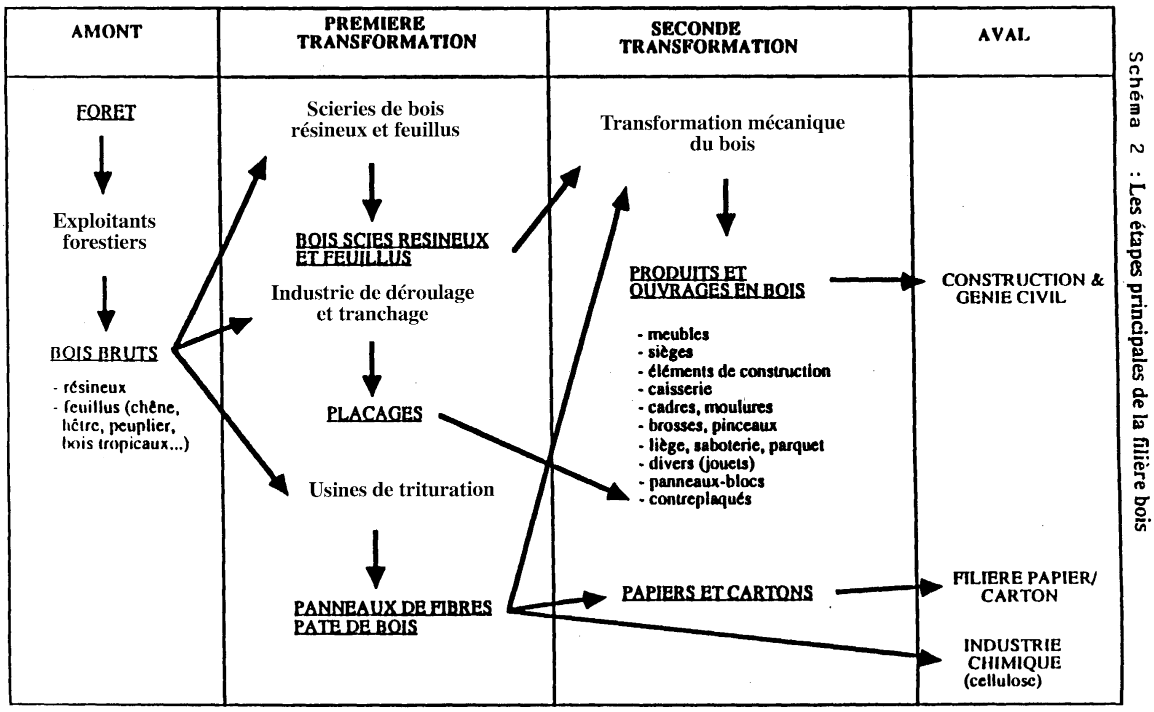


Figure 18 : Diagram of wood chain
Source : FEDEMAR/FNS[13]

Sawn wood and panels are mainly used in construction and infrastructures (sleepers) and in the furniture making.

National statistics have been produced by the National Federation of Sawneries (NFS) until 1992[14]. (INS statistics from 1994 to 1998 to be analysed).

The regional distribution of the sector varies from one level to the other : Forest is the most represented in Wallonia (more than 85% of the belgian forest). Sawneries are equally distributed betwen Wallonia and Flanders while second wood transformation is the more represented in Flanders (90% of turnover is flemish).

National statistics are published by the FAOas aggregated with data from Luxembourg[15]. Import, exports, production and consumption are provided for different categories of wood. Data are expressed in m3 or in tons. For pulp production data relate to Belgium as Luxembourg has not capacity production (see paragraph 5.7.1).

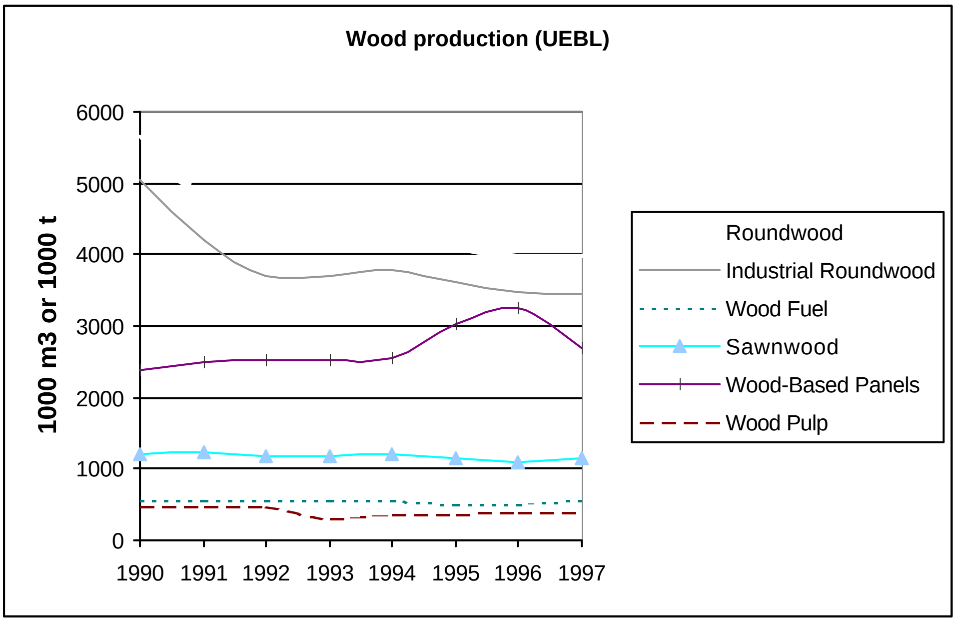


Figure 19 : Production of wood in the UEBL area for the different types of semi-finished products
Units : 1000 kt except for wood pulp (1000 m3)
Source : FAO

Figure 19 presents the levels of production and their evolution for the different wood products in the UEBL area. It shows that roundwood production has decreased since 1990. This decrease until 1992 is actually explained by storms in 1990 that generated excess of roundwood. Panels production is the most important compared to sawn wood and wood pulp, with a temporary increase between 1994 and 1996. Sawnwood, wood pulp and fuel wood production are not evolving since 1990.

A comparison of FAO's data with the NFS for the years 1990-1993, indicate that at that time Belgium production of wood panels represented 93% of the UEBL production. In 1992 the same comparison indicate that sawn wood and roundwood production in Belgium represented 60% of the UEBL productions. However this last ratio can't be extrapolated.

Table 23 presents production, export and import volumes for wood in the UEBL area. Data have been expressed in kt (average density of 0.52 t/m^3). This table shows that external wood flows are important for most of the products. Especially roundwood import represent near 50% of the apparent consumption and total transformed wood import represent 75% of the domestic apparent consumption and export flow are of the same magnitude. However the balance between both flows is not the same for all wood products : Belgium is a net importer of sawnwood while it is a net exported of wood panels.

According to this figure apparent consumption in the UEBL area is around 1400 kt of sawnwood and 500 kt of wood panels.

These estmations are to be compared with data reported by the National Statistical Institute about deliveries in Belgium by the belgian wood industry[16] (see Table 24). According to this source, the belgian sawneries delivered about 1360 kt wood in 1998, including 370 kt sawndust and 347 kt wood chips. The remainder (621 kt), which is in accordance with FAO database, is partly consumed as final products in the building sector or other purpose and partly as semi-finished products by the secundary industry for the fabrication of building elements (167 kt), packaging (about 252 kt), furnitures and other wood products.

Wood panel represents an important market in Belgium (more than 3000 kt). However this amount is discrepancy with FAO database.

Those data do not allow to evaluate the domestic wood consumption in the building sector. The only thing that can be stated is that building elements fabrication (window frames, doors and skeleton elements) represents about 26% of sawn wood production. Acccording to Table 23, we can also state that this consumption represents about 12% of the total sawnwood consumption in the EUBL area.

Due to the fact that sawnwood products (2010 prodcom code) include building elements products we than conclude that the building sector represents more than 12% of the domestic consumption for sanwood.

The actual level is probably much higher. Indeed on the basis of our bottom-up analysis we estimate that building and renovation of SFH represents a 210 kt sawnwood consumption, ie 15% of the UEBL apparent sawnwood consumption.

1,997	**Production**	**Imports**	**Exports**	**Consumption**
Roundwood	**2,082,600**	**1,496,768**	**496,132**	**3,083,236**
Wood Fuel	**286,000**	**28,964**	**26,416**	**288,548**
Industrial Roundwood	**1,796,600**	**1,467,804**	**469,716**	**2,794,688**
Sawlogs+Veneer Logs	1,284,400	0	0	1,284,400
Pulpwood+Particles	455,000	0	0	455,000
Other Indust Roundwd	57,200	0	0	57,200
Total sawn, panels & pulp	**2,200,120**	**1,723,436**	**1,644,708**	**2,278,848**
Sawnwood	**598,000**	**1,043,536**	**244,764**	**1,396,772**
Sawnwood (C)	457,600	660,400	165,776	952,224
Sawnwood (NC)	140,400	383,136	78,988	444,548
Wood-Based Panels	**1,403,480**	**401,492**	**1,302,964**	**502,008**
Veneer Sheets	23,920	28,132	16,432	35,620
Plywood	31,200	162,812	52,624	141,388
Particle Board	1,333,800	103,792	1,073,956	363,636
Fibreboard	14,560	106,756	159,952	-38,636
Wood Pulp	**198,640**	**278,408**	**96,980**	**380,068**
Mechanical Wood Pulp	89,960	1,508	884	90,584
Semi-Chemical Wood Pulp	0	3,900	520	3,380
Chemical Wood Pulp	108,680	269,100	94,692	283,088
Dissolving Wood Pulp	0	3,900	884	3,016
Paper+Paperboard	**744,640**	**1,379,976**	**908,908**	**1,215,708**
Newsprint	54,080	121,420	58,032	117,468
Printing+Writing Paper	515,320	670,124	656,812	528,632
Other Paper+Paperboard	175,240	588,432	194,064	569,608
Wood Residues	**0**	**463,684**	**148,252**	**315,432**
Other Fibre Pulp	**0**	**2,756**	**988**	**1,768**
Recovered Paper	**356,720**	**125,632**	**531,180**	**-48,828**

Table 23 : Statistics on wood production, import and export (ktonnes)
Note : C = coniforous, NC = non coniforous
Source : FAO

Code CPA/Prodcom	product	kt
2010	**produits du sciage**	**1,363**
201010	**bois sciés**	**590**
20101010	traverses en bois non imprégnées	10
20101033	bois de conifères sciés, …, rabotés ou poncés non collés par jointure digitale	188
20101035	bois d'épicéa ou de sapin pectiné	122
20101039	conifères : planchettes, bois épaisseur > 6 mm < 12.5 mm, bois sciés n.c.a.	179
20101053	chêne, hêtre, autres bois que conifères et tropicaux collés par jointure digitale	68
20101057	bois tropicaux rabotés ou poncés	9
20101059	chêne, hêtre, autres bois que conifères et tropicaux, rabotés ou poncés	13
20101077	lames et frises de chêne pour parquets	~2
201020	**bois profilés et sous-produits du bois**	**374**
20102110	bois profilés de conifères	18
20102153	bois profilés autres que conifères (excl lames&frises parquets)	9
20102155	lames et frises de parquet de bois non assemblés autres que conifères	~0
201023	plaquettes et particules de bois	347
201030	**bois traité**	**32**
201040	**sciures et déchets de bois**	**368**
20104005	sciures	160
20104009	déchets et débris de bois (même agglomérés sous forme de bûches	208
2020	**panneaux et placages à base de bois**	**~3,098**
202010	**contreplaqués et panneaux à base de bois**	**1,134**
202011	contreplaqués	1,059
202012	panneaux plaqués, revêtus, mélaninés ou stratifiés	75
202013	**panneaux de particules**	**1,686**
202014	**panneaux de fibres**	**~279**
2030	**charpentes et menuiseries de bâtiment en bois**	**~167**
20301110	fenêtres, portes fenêtres et leurs cadres et chambrales en bois	~13
20301150	portes et leurs cadres, chambrales et seuils en bois	~77
20301300	autres ouvrages de menuiseries et pièces de charpentes pour la construction en bois	~77
20401	**Emballages en bois**	**~252**
20401133	palettes simples en bois, rehausses de palettes	~174
20401135	palettes-caisses et autres plateaux de chargement en bois	~10
204012	palettes-caisses et autres plateaux de chargement en bois	~68
205114	**Autres ouvrages en bois**	**?**

Table 24 : Deliveries by the belgian wood industry in Belgium (1998)
Note : data preceded by «~ » symbol indicates that data is highly uncertain due to conversion from m^2 to kt
Source : NS

Eurostat also provides statistics on imports and exports for the UEBL (Table 25). They do not compeletly fit with FAO's data. However they give indication of the origing of imported product for the different categories (intra-Europe and extra-Europe origin).

It shows that 60% of imports are intra-european. However this part highly depends on the category. Most of industrial roundwood import originates from Europe (95%).

	Kt			%	
	Intra Europe	Extra Europe	total	Intra Europe	Extra Europe
Bois bruts, autres petits bois ronds ou en particules	2 851	141	2 992	95%	5%
Bois sciés	897	583	1 480	61%	39%
Panneaux et plaques	387	282	669	58%	42%
Ouvrages en bois	243	99	342	71%	29%
Pâte à papier / bois de pâte	715	3 678	4 393	16%	84%
Papier et carton	3 231	402	3 634	89%	11%
Liège et ouvrages en liège	2	0	2	100%	0%
Total	8 326	5 185	13 511	62%	38%

Table 25 : Import of wood for the UEBL (1997)
Source Eurostat

5.7.1. Paper pulp and paper

Belgium produces both mechanical and chemical wood pulp. The first is located in Gent (North of Belgium) and uses coniferous wood, the second in Harnoncourt (South of Belgium) and uses deciduous wood.

Data on productions, import and export are provided by COBELPA (Belgian Federation of Paper producers) (see Table 26).

	Pulp				paper and paperboard				recovered paper	
kt	production	exports	imports	consumption	Production	exports	imports	consumption	recuperation	consumption
1996					1328	885	2225	2668		
1997	406	150	428	666	1491	1051	2627	3067	1263	482
1998	381	132	421	660	1545	1.053	2.773	3265	1424	525

Table 26 : Paper pulp and paper productions, imports and exports for Belgium
source : COBELPA

Table 26 shows that pulp productions and imports are of the same order. Within pulp production, chemical production represents around 55% of the total. The rest is mainly mechanical pulp. This first production will increase in the next years as Burgo-Ardennes (Harnoncourt) will extend its production capacity by 30% with an investment of 5 billions BEF, including environmental investments : the current yearly production is 260 kt and will raise 360 kt. The company also produces 325 kt paper per year and the capacity will not change in the next years[17].

The wood consumed by BurgoArdennes originates from a 250 km diameter area and 73% of the wood used comes from France (the rest is coming from Belgium (18%), Luxembourg (8%) and Germany(1%)). It is considered that the storms that occurred in France in 1999 will not change this figure.

For paper, production represents 49% of the domestic consumption (61% for UEBL).

5.8. Lime

Lime intervenes in a large array of industrial processes : iron, glass, sugar,… It is also a used as a final product in different applications (agriculture, infrastructure,…).

Belgium is one of the greatest producers of lime. The belgian group Lhoist dominates the world market with a total production of 1700 kt over the world. An other group is also important, namely Carmeuse, with a total world production of 1500 kt.

The total production in Belgium is nearly constant since 1990 : about 2000 kt per year (see Figure 20).

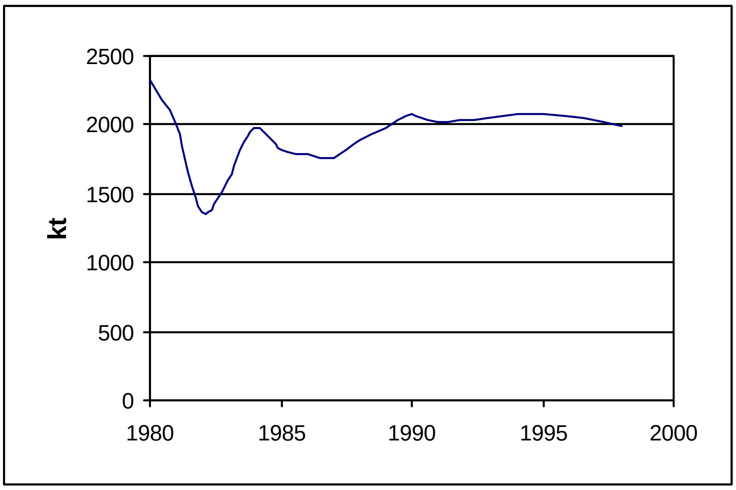


Figure 20 : Evolution of lime production in Belgium
Source : FEDIEX + IW survey

According the Federation of Extractive Industry (FEDIEX) imports are negligible and are limited to France, influenced by comparative prices sometimes more attractive than the Belgian market. Exports represent about 50% of the production (Luxembourg, The Netherlands, France and Germany).

Consumption is shared as followed :

- Steel industry : 50%
- Other industry (chemistry, Sugar rafineries, glass production) : 20% - 30%
- Environment (gaz desulfuration and water treatment) + agriculture (calcareous enrichment) : 20% - 30%

Moreover lime has been used last years for soils stabilisation for infrastructures works.

5.9. Material flows balance

Previous paragraphs have described with data available the flows related to different materials used in the building sector.

As those data can be used for different purposes :

- Quantify the part of imports for satisfying domestic demand for those materials
- Quantify the part of the residential housing (especially single family house construction) in the domestic consumption or in the domestic production
- Quantify the exogenous residual demand to be introduced in MATTER
- Roughly evaluate the life cycle GHG emissions associated with those flows and compare those life cycle emissions with national sectoral and total emissions.

The construction of a matrix representing the flows (import, export, production, consumption) versus the different materials is helpful for this purpose. A first matrix can be built with the physical material flows data (see Table 27). Consumption data are given for the total, the building sector and the SFH residiential building sector especially. For the two first figures results come from the statistical data discussed in previous paragraphs.

For the third one, data are deduced from own estimations made with a bottom-up approach. This approach has made used of the analysis made in this study. This analysis aimed at evaluating the material intensity for different types of houses. Based on this analysis and making assumptions on the representativness of those houses categories in the new construction market and making use of the total built surface in 1998 we then estimate the total material consumption for this sector. We then could calculate the percentage of this consumption in the total material consumption as given in Table 27.

This estimation even subject to uncertainties allows to provide orders of magnitude regarding the importance of the construction of new SFH in energy intensive materials. This importance is the greatest for cement (as used for concrete fabrication) and bricks.

Being the big CO_2 indirect emitters the importance observed for these materials gives an idea of the potential impact of policy measures in the field of house construction in order to reduce CO_2 emissions.

New SFH house represents on the opposite a small relative consumption of steel in the total.

	année	Production	import	export	consumption		
					total	building construction	*of which SFH residential building*
bricks	1997	2,510	85	462	2,133	95%	*65%*
cement	1998	6,803	679	1,982	5,500	87%	*52%*
flat transformed glass	1988	307	-	-	~307	65%	*3%*
wool glass	1998	111	-	-	-	95%	*ND*
sawn wood	1997	*577*	*1,006*	*236*	*1,347*	ND	*11%*
wood-based panels	1997	*1,548*	*504*	*1,523*	*529*	ND	*3%*
Steel	1998	12,780	ND	ND	4,176	13%	*6%*
Copper	1992	373	-	328	107	23%	ND
Aluminium	1992	333	181	341	173	36%	ND
Zinc	1992	63	23	41	45	28%	ND
Lime	1998	1,982	0	0	1,982	ND	*ND*

Table 27 Material flowS balance for the main materials and part of the products in the domestic consumption (physical volumes)

6. Process description

6.1. Introduction

The housing system involves a large set of materials characterised by their process, energy intensity, environmental impacts and costs. The detailed description of the system needs an in-depth description of those existing or emerging process in order to compare the environmental performance of different options both in terms of materials and in terms of processes choices.

This description is made in a separate report (IW, 1999)[18]. Many elements of this description are used in the analysis described below.

In the next paragraphs, we will rather focus on wood life cycle emissions, transport emissions and waste.

6.2. Wood life cycle emissions

In most studies, wood products are considered as neutral in terms of life cycle CO_2 emissions. The rationale behind this is that all carbon emitted when the product is burned or decomposed at the end of his life or when the product is decaying, was previously (during the tree life) removed from the atmosphere.

However a more in-depth consideration is necessary in order to assess the validity of this statement.

This consideration must be done in the light of the appropriate temporal and spatial boundaries to be considered in carrying out a proper life cycle analysis in the context of the **present** Kyoto context : even though the Kyoto Protocol is not at all following a life cycle perspective it is useful to have in mind the time scale issue that it refers to.

The product for which we would like to apply a life cycle approach is a wood product. It can be either paper, either furniture either building material. We can for instance consider 1 tonne of wood product as the functional unit. Then a life cycle approach implies to consider **all the processes** from **cradle to grave** :

- Cradle : tree seeding or planting
- Intermediary processes :
  - Tree growing
  - Harvesting
  - Roundwood transportation
  - Wood product manufacturing
  - Wood product transportation
  - Wood product use
  - Wood product reuse or recycling (optional)
- Grave : wood product elimination (burning without energy recovery, burning with recovery, landfill)

Except for energy plantations with short rotation cycles (poplar plantations for instance) where the time span can be smaller than 5 years, this chain implies a long time span : from seeding to harvest, 50 to 100 years may elapse while subsequent stages can last from 1 week to 100 years, depending on the type of product (paper, furniture, building material). For this reason the total time period covered by the wood chain can extend to 200 years or more.

6.2.1. Roundwood production life cycle emissions

Here below we will focus on three first stages of the chain below (tree seeding or planting, tree growing, harvesting).

For this purpose we consider one piece roundwood as the functional unit.

The choice of the system boundaries must be guided by the natural processes that occur during the trees growing that will supply the roundwood.

A tree is composed of two main parts : the **above ground** biomass, including stem, branches, leaves or needles and fruits and the **below ground** part (the roots). The soil is also to be considered in view of the permanent exchanges : nutriments, water from the soil to the tree, wood debris or litter (branches, fruits, leaves or needles) to the soil.

All three components are to be considered simultaneously. The net annual biomass increment (also called "Net ecosystem production"[9]) is the net result of carbon removal from the atmosphere by photosynthesis and the carbon emission due to respiration by the biomass (autotrophic respiration) and by the micro-organisms in the soil that decompose the organic matter (heterotrophic respiration).

The distribution of the carbon between all is determined by the relative carbon fluxes : translocation from crown to stem and to root, dead matter from roots and aboveground biomass to soil.

All those fluxes depend on a series of parameters, of which : tree species, age, solar irradiance, temperature, soil humidity. Furthermore one tree and the surrounding soil do not constitute an independent system : they are part of a forest ecosystem having significant impact on the tree itself. The system to be considered is therefore a forest land (1 ha forest for instance).

[9] Net carbon sequestration in wood products refers to different definitions (see IPCC special report on LULUCF, 2000):

- **Gross Primary Production** (GPP) : total amount of carbon fixed in the process of photosynthesis by plants in an ecosystem such as a stand of tree.
- **Net Primary Production** (NPP) : net production of organic matter by plants in an ecosystem, that is GPP reduced by losses resulting from the respiration of the plants (autotrophic respiration).
- **Net Ecosystem Production** (NEP) : net accumulation of organic matter or carbon by an ecosystem. It is the difference between the NPP and the decomposition rate of dead organic matter (heterotrophic respiration).
- **Net biome production** (NBP) : net production of organic matter in a region containing a range of ecosystems. It is the difference between NEP and carbon losses due to various disturbances (fires, harvest, forest clearance,…).

On the global level the magnitudes associated with those four parameters are the following :

GPP ~ 120 Gt C/yr	(440 Gt CO_2 /yr)
NPP ~ 60 Gt C/yr	(220 Gt CO_2 /yr)
NEP ~ 10 Gt C/yr	(37 Gt CO_2 /yr)
NBP ~ 0.7± 1 Gt C/yr	(2.6±3.7 Gt CO_2 /yr)

This shows a large decrease from the GPP to the NBP. Especially NBP only represents 7% of the NEP so illustrating the importance of both natural and human induced disturbances on natural ecosystems.

At maturity a forest has accumulated carbon and an equilibrium is observed such that carbon removals and emissions are balanced. This equilibrium is rapidly achieved in tropical forests. Unlike temperate forests (it is to be noted here that planted forests in Europe have not reached maturity stage when harvested : forests are generally harvested after less than 100 years, while maturity should be observed much later on – more than 200 years). When the above ground biomass is cut and partially removed (debris are generally left on the soil) on a forest plot, the equilibrium previously achieved is disturbed : carbon is no more removed from the atmosphere as photosynthesis can not occur, remaining biomass (roots and other wood debris) is either burnt on site either left to decay. After a short time, soil will emit more carbon that received and all carbon will eventually be restored to the atmosphere.

Basically it could be considered that all the initially sequestered carbon by the tree and its surrounding is compensated by the carbon content in the roundwood and by the carbon emitted by the soil due to debris decaying.

This last process can last from 10 years to more than 100 years depending on the forest type : tropical soils lose carbon very rapidly while temperate soils need much more time.

These differences raise the question of the differentiated consequences of forest carbon cycles in different latitudes on the climate : given two harvest forests, one in the tropics and one in the temperate latitudes, subsequent carbon emission will occur over very different time spans so that due to different time horizons the global warming potential of carbon emitted in both cases should be treated in different ways : both the real quantity of carbon removed and then reemitted and the “ton carbon-years” involved that are important.

On the other side, it is to be taken into account the fact that climate change concerns are recent. The Kyoto Protocol as a first step to limit climate change, includes possibilities for the Annex I Parties, to achieve their emission reduction targets through emissions reductions and removals by sinks. Sinks are dealt with in articles 3.3, 3.4 and 3.7. The last Conference in La Haye failed to lead to a decision for the implementation of the Protocol. One of the main reasons was to achieve an agreement on the sink issue (see F.Nemry, 2000)[19]. Important elements of the Kyoto Protocol are here to be noted : activities eligible under article 3.3 (afforestation, reforestation, deforestation) and under article 3.4 (additional activities in land use, land use change and forestry) for the first commitment period have to be human induced activities begun after 1990. Hence, as the Parties are not penalised by their historical emissions (national emissions targets were not decided into consideration of those past emission), Parties should not be credited for past carbon removals.

As ecosystems are directly concerned in all the issue, biodiversity is an obvious criterium that has to be taken into account too.

With regard to the present climate change mitigation context a proper life cycle requires to distinguish different cases :

Wood from **native forests** requires a double concern : in many cases, native forests are deforested and converted to crops, pastures or roads. This process leads to a serious decrease of biodiversity and huge short time carbon emissions that was sequestered in the ecosystem over extremely long periods through natural processes that were not influenced by human induced activities. For those two reasons, it makes sense to exclude the historical carbon removals from the life cycle approach and on the opposite to consider the total carbon emission subsequent to harvesting. This option avoids giving incentives to native forests destruction.

Wood from **a deforested or an unmanaged forest land** also merits special concerns. In those cases harvest completely disturbs the carbon balance that prevailed in the forest ecosystem. Depending on the subsequent land use the perturbation will lead to net carbon emissions. Over the complete life of the trees, the result is a zero emission. However it is to be considered that tree planting prior to the

90’s were not part of climate mitigating measures. For this reason it is not justified that wood harvest in such cases could benefit from historical carbon credits. Hence we take the option to exclude in those cases the carbon removals prior to harvesting too.

In **sustainable forest management**, where the logging is maintained at a level such that the total biomass in the forest is maintained (or even expands), harvest-regeneration cycles do not disturb significantly the carbon balance in the overall forest system. For this reason in this case we will assume that the soil carbon emissions (due to debris decay) will last a short time and be rapidly reverted due to new tree planting or seeding.

It is then necessary to make estimation of the net indirect emission that should be allocated to roundwood in the first two cases. For this purpose we have gathered a series of data from the literature, mainly from the revised 1996 IPCC guidelines for national greenhouse gas inventories, from the IPCC special report on “Land use, Land-use change, and forestry” and from national submissions to SBSTA (FCCC/SBSTA/2000/MISC.6 add1 et add2). It is however to be noted the high degree of uncertainty of all those data due to the incomplete knowledge and measures and to the high variability of all parameters concerned. For this reason the estimations that can be done here are purely indicative. Uncertainty level can be as high as 50%. Further scientific work that will be carried out in the next future, notably in relation to the Kyoto Protocol process will probably enable to improve this kind of figures.

		above ground biomass	below ground	stemp	soil organic matter	carbon soil loss after deforestation	time delay (highly indicative)	carbon soil loss after deforestation	debris decay (40%)	total net emission (excluding stem carbon)	total net emission (excluding stem carbon)
		t dm /ha	t dm /ha	t dm /ha	t dm/ha	%	yr	t dm /ha	t dm /ha	t C/ha	t C/t rw
	broadleaf	274	270	183	227	60%	10	136	144	140	0.8
moist tropical forest	broadleaf	128	126	85	154	60%	10	93	67	80	0.9
dry tropical forest	broadleaf or mixed	73	72	49	86	14%	10	12	39	25	0.5
temperate forest	coniferous	258	36	172	192	40%	50	77	49	63	0.4
	Broadleaf	213	51	142	192	40%	50	77	49	63	0.4
boreal forest	Coniferous	110	24	73	780	40%	100	312	24	168	2.3
	Broadleaf	110	24	73	780	40%	100	312	24	168	2.3
		IPCC guidelines	IPCC guidelines + IPCC SR	IPCC guidelines + SBSTA/FCCC/	IPCC guidelines	IPCC guidelines + IPCC SR		IPCC guidelines	IPCC guidelines + SBSTA/FCCC/	calculation	calculation

Table 28 : Estimation of indirect CO_2 emission from harvest wood from native or deforested forests.

Table 28 presents the different relevant data related to different forest systems, namely tropical (wet, moist and dry), temperate (coniferous or broadleaf), and boreal (coniferous and broadleaf) forests. Wood density is supposed to be around 0.65 and 0.45 t dm/m^3 (dm = dry matter)[10]. Carbon content is the same for all species, namely 0.5 t C/t dm. For each ecosystem, average data are given for aboveground biomass and below ground biomass and soil organic matter surface density. Stemp density is also given and represents a fraction of the aboveground biomass. As for soil carbon content the data illustrates the influence of the climate condition : high levels are observed for boreal forests. Climate conditions also influence the time delay for organic matter decomposition and also the fraction of carbon losses after deforestation.

According to the data used and to the calculation most of roundwood harvest is a net carbon emission in the case of native or existing forest deforestation. The net emission varies from 0.4 to 2.3 t C/ t roundwood depending on the type of forest (1.5 to 8.4 t CO_2 / t roundwood). The highest values are expected for boreal forests.

6.2.2. Wood processing

Different studies have also evaluated the energy consumption of wood processing. The results generally indicate that wood is an advantageous material for that. This is indeed the case of timber wood as logging and sawing require few energy. Drying requires somehow more energy. The GHG emission will however differ from one fuel to the other : this process can indeed use waste wood. If the initial energy wood is supplied by a sustainably managed forest the carbon then emitted can be neglected as carbon was previously removed from the atmosphere (see 6.2.1).

However for other wood types (glulam, particle board or fiberboard) the process requires additional energy consumption’s for heating, mechanical compression…

Richter et al (1992)[20] have reported detailed data on energy consumption at the different stages of the harvesting wood downstream chain : logging, transport, sawing, drying, processing, additives. Additives refer to glue fabrication and use.

Data are given in Table 29. They confirm that sawn wood is the less energy intensive (~1.8 GJ/m^3). For the other wood processes, the total energy consumption per m^3 processed is from 2.7 to 7.7 higher.

	density (kg/m3)	**logging**	**sawing**	**kiln drying**	**processing (incl. drying)**	**additives**	**total**
Sawn wood (kiln dried)	470	110	288	1332	0	0	1773
glulam	450	150	400	**	4810	540	6000
particleboard	650	140	*	**	4220	2550	7030
HD-fibreboard	900	270	*	**	12265	750	13580
LD-fibreboard	300	85	*	**	3730	935	4845

Table 29 : Energy consumption for the different stages of wood for different types of products (MJ/m^3)
Source : Richter et al

[10] See IPCC guidelines.

Especially HD-fibreboard is the most energy intensive (~13.6 GJ/m^3).

For each stage CO_2 emissions can be calculated under defined assumptions on the fuel used. This has been done in Table 30. Two assumptions were made for the fuel used for drying (see column “kiln drying” for sawn wood or “processing” for other woods) leading to different total CO_2 emissions. Results are here expressed in t CO_2/ tonne wood so that the results compare differently then in the previous table (see especially the low density of LD-fibreboard). Sawn wood remains the more energy environmentally material. On the opposite, LD-fibreboard is the less efficient.

	Logging	**sawning**	**kiln drying**		**Processing (incl drying)**		**additives**	**total**
Sawn wood (kiln dried)	0.02	0.05	0.00	0.16	0.00	0.00	0.00	0.06- 0.22
glulam	0.02	0.07	**	**	0.43	0.59	0.07	0.59- 0.70
particleboard	0.02	*	**	**	0.20	0.36	0.22	0.44- 0.59
HD-fiberboard	0.02	*	**	**	0.59	0.75	0.05	0.67- 0.82
LD-fiberboard	0.02	*	**	**	0.53	0.68	0.17	0.72- 0.88
Main fuel used	*Diesel*	*electricity*	*wood*	*natural gas*	*wood + natural gas*	*natural gas*	*natural gas*	
fe CO2 (kg/GJ)	*74.1*	*79*	*0*	*55*	*0 / 55*	*55*	*55*	

Table 30 : CO_2 emission for the different stages of wood process for different wood types. The last two rows give the main fuel used and the emissions factor applied

6.2.3. Wood waste treatment

According to conclusions from section 6.2.1, wood decay or incineration produces no carbon emissions. On the opposite such treatments results in carbon emissions from 0.5 t C/t or 1.8 t CO_2/t if wood originates from deforested lands.

6.2.3.1. Total CO_2 emission from wood

From previous sections, we can calculate the total CO2 life cycle emissions from wood depending on its origin. Results are given in next table.

wood supply	wood type	carbon cycle	process	total
wood from managed forest	sawn wood	0.0	0.1 - 0.2	0.1 - 0.2
	glulam	0.0	0.6 - 0.8	0.6 - 0.8
	particle board	0.0	0.5 - 0.6	0.5 - 0.6
	fiber board	0.0	0.7 - 0.9	0.7 - 0.9
wood from deforestation	sawn wood	3.1 - 10.2	0.1 - 0.2	3.2 - 10.5
	glulam	3.1 - 10.2	0.6 - 0.8	3.7 - 11.0
	particle board	3.1 - 10.2	0.5 - 0.6	3.6 - 10.8
	fiber board	3.1 - 10.2	0.7 - 0.9	3.8 - 11.1

Table 31 : Wood life cycle emission for different assumptions (t CO_2/t wood)

6.3. Transport : Emissions and costs

6.3.1. Emissions from transport

A complete life cycle analysis of GHG emissions per product needs to estimate the impact of transport of goods all along the product system. This has to be done here for each building materials considered. It is of cause impossible to trace all materials that intervene in this chain and consequently to estimate with precision all the emissions from transport : this impact will depend on the transport modes involved, the origin of the different materials and the distances to the destinations.

Here we intend to determine the relevant orders of magnitude and confidence intervals given different assumptions regarding these parameters.

At first we will make use of mean CO_2 emission factors for the three transport modes involved namely, truck, boat and train. Airline is not a potential transport mode for most of building materials.

For emissions from truck we will make use of data provided by VITO for different vehicles and traffic categories (see Table 32). The emissions factor correspond to a 40% load. However we assume here the assumption that the emission factor is not highly dependent on the load. Cold start are also reported in the table. In order to estimate a mean emission for representative journeys we then consider two typical distances and assume weighting factors for the different traffic categories (see Table 33).

This is done in Table 34. It shows that there is few difference between both types of journey. For this reason we will use the average value calculated.

	Vehicle category

			unit	3.5-7.5	7.5-16	16-32	32-40
Trafic category	UN	urban normal	g/km	596	684	1,079	1,594
	UP	urban peak		801	966	1,528	2,057
	HN	highway normal		486	624	837	1,160
	HP	highway peak		543	750	1,182	1,718
	RN	rural normal		387	562	882	1,303
	RP	rural peak		543	750	1,182	1,718
	US	cold start	g	200	300	500	750

Table 32 : Emission factor for different vehicles and traffic categories in g/km (except for cold star emission)
Source : VITO

	weighting factor	
	long distance	***short distance***
urban normal	*0.05*	*0.03*
urban peak	*0.05*	*0.07*
highway normal	*0.45*	*0.35*
highway peak	*0.35*	*0.25*
rural normal	*0.09*	*0.25*
rural peak	*0.01*	*0.05*

Table 33 : Weighting factors for each traffic category for two typical distances

	3.5-7.5 t	**7.5-16 t**	**16-32 t**	**32-40 t**
Long distance	519	622	928	918
Short distance	558	485	712	1,009
Short and long distance	538	553	820	964

Table 34 : Mean CO2 emission factors for a long distance and a short distance and mean over both distances

Then in order to make estimation of the emissions factor per tonne transported it is necessary to perform the analysis per type of material : due to different densities or conditioning the maximal load per vehicle will differ from one material to the other. In order to illustrate that we will use estimations made in the BRE environmental profile methodology (DETR, 2000)[21] giving such estimates (see **Table 35**).

trucks	rigid					Articulated		Emission factor (g CO_2/km*t)
	<7.5 t	7.5-14 t	14-17 t	17-25 t	25+ t	30-33 t	33+ t	
maximum net load weight (t)	*4*	*7.5*	*9*	*14*	*16*	*18*	*23*	
mean CO2 emission (g/km)	*538*	*553*	*553*	*820*	*964*	*964*	*964*	
Wood	1.80	2.70	5.30	4.80	9.90	10.40	19.30	95
Manufactures of metal	1.50	2.50	4.70	5.40	6.30	8.70	12.80	164
Non ferrous metals	1.60	3.90	4.40	5.80	4.30	7.80	19.50	136
Sans, gravel, clay, slag	2.50	3.70	8.80	14.80	18.80	16.10	23.70	121
Other stone earths & minerals	2.20	3.80	8.00	14.90	18.50	13.60	23.80	129
Cement&lime	4.90	4.10	5.90	12.10	15.00	18.20	23.60	102
Glass&ceramic	1.90	2.30	4.30	6.80	9.40	11.10	16.80	193
Plaster	1.40	1.55	1.70	10.90	9.40	11.10	22.20	286
Other manufactured building materials	1.40	2.40	5.20	9.40	15.30	10.80	19.40	202

Table 35 : typical loads of different materials by vehicle size and mean emission factors
source : BRE environmental profile methodology, beyond factory gate)

In this table, grey cells indicate, the most frequent vehicle category used. Given that we can estimate the CO_2 emission par km*t transported (see last column).

For boat (fluvial and marine) and train we will use a simple coefficient as estimated by the MET (see Ministère de la Région Wallonne, 1995)[22], namely 27 g/km*t and 40 g/km*t respectively.

The next step is then to evaluate the total CO_2 emission due to transport for all the life cycle of one tonne of material considered. For this purpose we have to make assumption about the mean covered distances both abroad and in the national territory. For that reason we will distinguish tree paths : import path, domestic/transformation to distribution path and distribution to consumption path. For each of them we make estimation of the mean distance covered based on information about the origin of raw or finished material (import or national production), about mean distances as estimated by industry sectors and knowledge about the industry fabric in Belgium (geographic distribution) and observation of the traffic. Especially we make a distinction between intra- and extra-European wood as the distance and transport modes involved are different.

The assumptions made are given in Table 36. Then making use of the emission coefficients as given in Table 35 we calculate the emissions for each path. The intervals given for the total is delimited by the sums of average values for each path. We also calculated a mean emission factor as the central value of this interval.

	import			domestic production to distribution			distribution to consumption
	boat	railway	truck	boat	truck	railway	truck
Wood from Europe	0 -1000	0 -1000	0 -1000	0 -0	50 -300	200 -300	0 -100
Wood from extra-European countries	4000 -6000	0 -0	0 -0	0 -0	50 -300	200 -300	0 -100
Metals	4000 -6000	1000 -1000	0 -0	0 -150	50 -300	200 -300	0 -100
Sand, clay, slag	300 -5000	0 -1000	0 -1000	0 -150	50 -300	200 -300	0 -100
Gravel	0 -0	0 -0	0 -0	0 -300	50 -300	200 -300	0 -100
Other stone earths & minerals	0 -5000	0 -1000	0 -1000	0 -150	50 -300	200 -300	0 -100
Cement&lime	0 -1000	0 -1000	0 -500	0 -150	0 -150	0 -0	0 -100
Glass&ceramic	0 -1000	0 -1000	0 -1000	0 -0	50 -300	0 -0	0 -100
Plasters	0 -1000	0 -1000	0 -300	0 -0	0 -300	0 -0	0 -100
Other manufactured building materials	0 -1000	0 -1000	0 -300	0 -0	0 -300	0 -0	0 -100

Table 36 : Representative transport distances for each material (km)

	import			domestic production to distribution			distribution to consumption	total	mean
	boat	railway	truck	boat	truck	railway	truck		
wood from Europe	0.00 -0.03	0.00 -0.04	0.00 -0.10	0.00 -0.00	0.00 -0.03	0.01 -0.01	0.00 -0.01	0.00 -0.08	0.04
wood from extra-European countries	0.11 -0.16	0.00 -0.00	0.00 -0.00	0.00 -0.00	0.01 -0.05	0.01 -0.01	0.00 -0.02	0.11 -0.20	0.16
manufactures of metal	0.11 -0.16	0.04 -0.04	0.00 -0.00	0.00 -0.00	0.01 -0.05	0.01 -0.01	0.00 -0.02	0.05 -0.11	0.08
non ferrous metals	0.11 -0.16	0.04 -0.04	0.00 -0.00	0.00 -0.00	0.01 -0.04	0.01 -0.01	0.00 -0.01	0.05 -0.10	0.08
sans, clay, slag	0.01 -0.14	0.00 -0.04	0.00 -0.12	0.00 -0.00	0.01 -0.04	0.01 -0.01	0.00 -0.01	0.01 -0.13	0.07
gravel	0.00 -0.00	0.00 -0.00	0.00 -0.00	0.00 -0.01	0.01 -0.04	0.01 -0.01	0.00 -0.01	0.00 -0.03	0.02
other stone earths & minerals	0.00 -0.14	0.00 -0.04	0.00 -0.13	0.00 -0.00	0.01 -0.04	0.01 -0.01	0.00 -0.01	0.00 -0.13	0.07
cement&lime	0.00 -0.03	0.00 -0.04	0.00 -0.05	0.00 -0.00	0.00 -0.02	0.00 -0.00	0.00 -0.01	0.00 -0.06	0.03
glass&ceramic	0.00 -0.03	0.00 -0.04	0.00 -0.19	0.00 -0.00	0.01 -0.06	0.00 -0.00	0.00 -0.02	0.00 -0.13	0.06
platers	0.00 -0.03	0.00 -0.04	0.00 -0.09	0.00 -0.00	0.00 -0.09	0.00 -0.00	0.00 -0.03	0.00 -0.11	0.05
other manufactured building materials	0.00 -0.03	0.00 -0.04	0.00 -0.06	0.00 -0.00	0.00 -0.06	0.00 -0.00	0.00 -0.02	0.00 -0.08	0.04

Table 37 : CO_2 emissions for one tonne transported (t CO_2/t material)

6.3.2. Transport costs

Cost of goods transport has been estimated by De Borger and Proost for truck, train and boat to 2.49 BEF/t*km, 1.60 BEF/t*km and 1.24 BEF/t*km respectively.

Based on these estimates we calculated the mean transport cost of 1 ton of material along the typical distances as given in Table 36. This leads to average prices as given in next table

Euro/t material	import	domestic production to distribution	distribution to consumption	Production to consumption	
				Total	mean
Wood from Europe	22	3 -9	0 -6	3 -15	9
Wood from extra-European countries	198	3 -9	0 -6	3 -15	9
Manufactures of metal	114	3 -11	0 -6	3 -17	10
Non ferrous metals	114	3 -11	0 -6	3 -17	10
Sans, clay, slag	50	3 -11	0 -6	3 -17	10
Gravel	0	3 -13	0 -6	3 -19	11
Other stone earths & minerals	48	3 -11	0 -6	3 -17	10
Cement&lime	17	0 -5	0 -6	0 -11	6
Glass&ceramic	22	1 -6	0 -6	1 -12	7
Plaster	15	0 -6	0 -6	0 -12	6
Other manufactured building materials	15	0 -6	0 -6	0 -12	6

Table 38 : Average costs for material transportation along typical material related distances

6.4. Impact of waste treatment of life cycle GHG emissions

Construction and demolition waste (C&DW) represent important volumes in Europe and in Belgium especially : According to Sydmonts et al (1999)[23] "core" C&DW[11] represent annual amounts of respectively 180 and 7 millions tonnes. This gives about 480 kg and 700 kg per capita respectively.

On the European level about 28% of the waste is either recycled either reused.

The question of building waste treatment in link with the global GHG life cycle emission has been dealt with taking into consideration the relative importance of each material in these emissions. As shown in § 7, the materials having the main impact are concrete, bricks, plaster for the conventional houses and wood for alternative options. This paragraph will focus on those materials in particular.

For the first type of materials (**mineral materials**), most of related waste after being crushed can be recycled as a substitute for newly quarried aggregates engineering fill and road sub-base. The use of such C&DW-derived aggregates in new concrete is much less common and technically much more demanding.

Such recycling allows to avoid landfil and natural resource exploitation.

In Belgium 80 crushers/recyclers with a 5 10^6 t/yr capacity and 40 sorting facilities exist in Flanders. None exist in Brussels and 12 recycling plants exist in Wallonia with a 0.9 10^6 t/yr capacity.

[11] Core C&DW refer to mix of materials obtained when a building or piece of civil engineering infrastructure is demolished. They however exclude road plannings, excavated soil, external utility and service connections and surface vegetation."

As for energy and CO_2 issue, the impact can be considered as of small effect : inert waste landfilling is a zero GHG emission (except transport and machinery on the site). On the other side, C&DW need to be crushed before being recycled which represents a similar energy consumption than raw material crushing.

For those types of waste it so makes sense to neglect the effect of such waste treatment on the life cycle GHG emissions.

An other option exist now to recycle concrete blocks. It consists in crushing the blocks and mixing the crushed material with some waste like plastics. The mixture is then fired and used to prepare new building blocks.

As for reuse, there exist some possibilities for material like bricks, wood. Brick reuse requires an intensive treatment : mortar has to be removed and bricks have to be selected. Moreover reused bricks can not be used for facing because they generally can't stand frost.

As for **wood**, elements like beams, doors can be reused. For other wood elements reuse is more difficult due to protection treatment (mulching for instance is not possible). The most interesting solution is an energy use with gazeification installations equipped with purification systems. Such applications have gained interest (see for instance research by Unit Therm – UCL). When such a solution is used wood combustion will emit carbon stored in the wood (0.5 t C/t wood), which reinforces the fact that wood from deforested areas is a huge CO_2 emitter.

In accordance with 6.2.1, this emission can be considered as zero if wood was supplied by a sustainable managed forest. In the other case this emission has to be accounted for.

7. Environmental performance per product

7.1. Introduction

The evaluation of the environmental performance of a product requires to evaluate all the environmental impacts associated with the whole life cycle of the product ie from cradle to grave.

This environmental performance is here restricted to GHG emissions and refers to the current situation. In this sense it is a static analysis. A dynamic analysis will be performed in chapter 8 where evolution of technologies will be taken into account.

The analysis that will be described here below is made in two steps :

Firstly we make a systematic comparison of different architectural and material options for the different **building elements**. This comparison will be done both in terms of Material Consumption per Product (MCP) and in terms of Indirect GHG Emissions per Product (IGEP). Indirect GHG emissions refer to all emissions over the life cycle excluding emissions from heating. As explained below (see 7.2.2) houses compared are conceived have the same thermal insulation levels.

The evaluation of the IGEP is based on the knowledge of GHG emissions factors related to the material process fabrication, the waste treatment and material transport. Table 40 shows the average life cycle emission factors for the different materials used in the building sector. They include process emissions, material transport emissions and waste treatment.

The functional unit used for the different elements is given in Table 39.

Secondly we combine the output data for the different building element to represent the construction of new **houses** having different characteristics and calculating MCP and IGEP coefficients for the houses selected.

Element	functional unit
Foundation	Soil surface (m^2)
External wall	Wall surface (m^2)
Internal wall	Wall surface (m^2)
Roof	Roof surface (m^2)
Window	Window surface (m^2)

Table 39 : Reference units used for the different elements

	transport emissions (t CO2/t)	process emission factor (t CO2/t)	total emission factor (t CO2/t)
blocks concrete	0.03	0.10	0.13
prefab concrete elements	0.03	0.22	0.25
ready mixed concrete	0.03	0.13	0.16
Cement	0.03	0.72	0.75
Mortar	0.03	0.17	0.20
cement glue	0.04	1.73	1.77
cellular concrete	0.03	0.15	0.18
Brick	0.06	0.20	0.26
sawn wood	0.04	0.15	0.19
wood panel	0.04	0.70	0.74
rock wool	0.04	2.20	2.24
argex	0.06	0.15	0.21
flax	0.04	0.02	0.06
plaster	0.32	0.00	0.32
tiles	0.06	0.20	0.26
artificial slates	0.04	0.20	0.24
natural slates	0.07	0.01	0.08
gravel	0.02	0.01	0.03
stone	0.07	0.01	0.08
PS	0.04	2.20	2.24
PU	0.04	2.20	2.24
PVC	0.04	2.20	2.24
steel	0.08	1.55	1.63
aluminium	0.08	10.00	10.08
flat glass	0.06	0.70	0.76
wool glass	0.06	0.94	1.00
lime	0.03	0.70	0.73
roughtcast	0.04	0.15	0.19

Table 40 : indirect CO2 emission factors
Source : Gielen, IW, NIBE

7.2. Material Input and Indirect GHG emissions per building element unit

7.2.1. Foundation

From the three foundations systems described in 4.1.1, sole and slab foundations are considered to be relevant for our analysis. The third system, pile foundation, is exceptionally implemented for single family houses.

For the sole foundation the strength will depend on the weight of the house to be built. It is however to be noted that in practice, architects generally do not perform detailed calculation of this strength as a function of the house weight. Standard deepness and thickness of the soles are used at least for “conventional” houses, namely concrete, expanded clay masonry.

The estimations of MCP and IGEP values for these foundations are made on the basis of the standard dimensions given in 4.1.1.

For lighter materials like cellular concrete and wood the strength of the foundation can be lower. Here we consider that the deepness is 30% lower than for the previous “strong” foundations”.

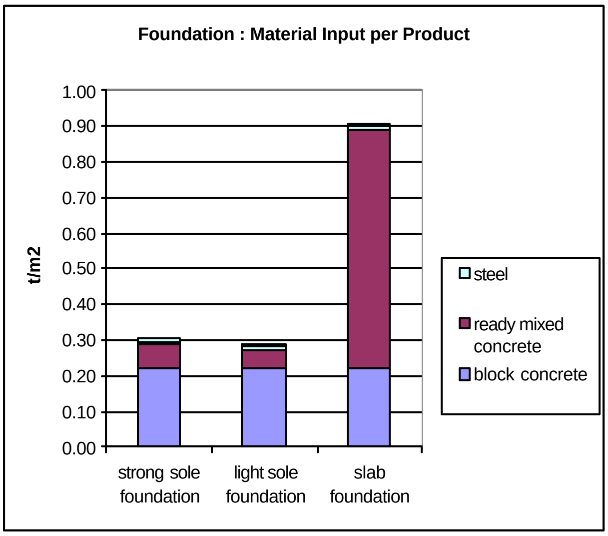
Slab foundation systems are generally implemented for unsteady soils and heavy buildings so that there is no reason to make a distinction within this kind of system.

The calculation presented here include the sole, the soil and the masonry.

Figure 21 illustrates the MCP and IGEP values for the three different foundation systems. It shows a large difference in material and emission intensities between sole and slab systems. In all cases concrete represents the bulk of material intensity. The Block concrete consumption is the same in all cases because it relates to the masonry of the empty space. Steel consumption is low compared to concrete.

Material intensities for the two sole foundations (heavy and light) are lightly different. This small difference (about 5%) is due to the fact that the only difference between both is linked to the soles themselves. The other elements (masonry and soils) are equivalent. The values in this figure correspond to average intensities over soil surfaces between 100 m^2 and 300 m^2.

These mean values do not actually represent the influence of the soil surface. The material consumption’s and so the Indirect emissions do not vary linearly as a function of the surface. This is shown in Figure 22 that illustrates the influence of the soils surface to the IGEP value for the two soles foundations.



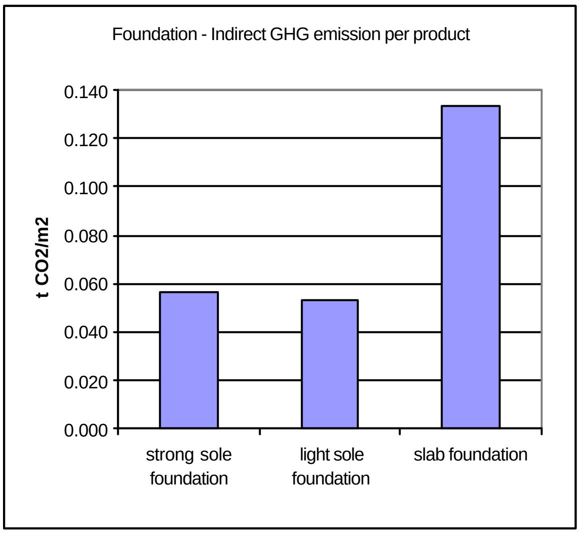


Figure 21 : Material Intensity and Indirect GHG emission per unit of foundation

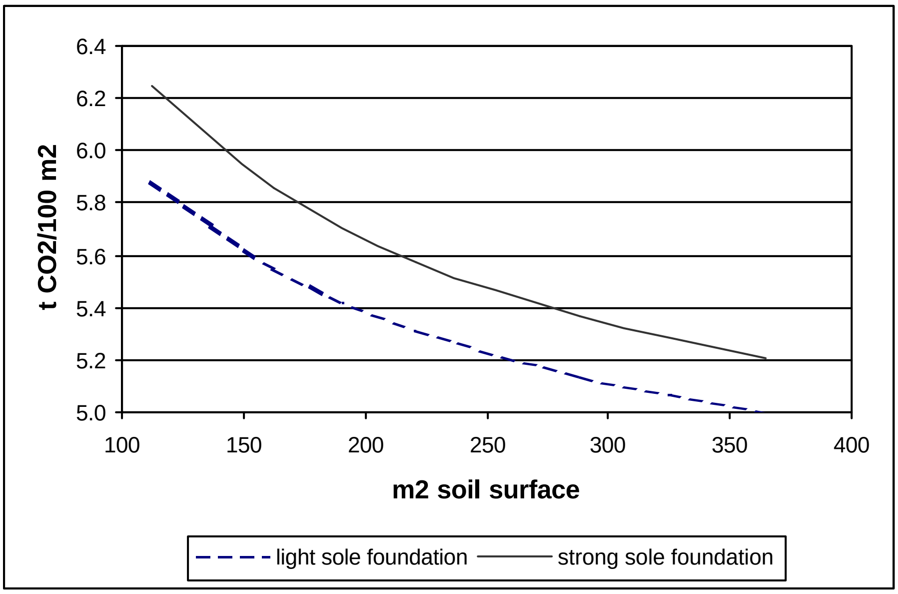


Figure 22 : Indirect GHG emission per unit of foundation as a function of soil surface

7.2.2. External Walls

As shown in Table 5, a large set of materials are available for the construction of external walls. Comparisons can be done between different options in terms of both MCP and IGEP. This comparison makes sense only with consideration of the thermal insulation.

For this reason all options considered are supposed to have a thermal conductivity $k \sim 0.50$ (see Appendix II Building thermal insulation).

A total of 11 options have been considered. Their respective components are presented in Table 41 from the interior side to the exterior side.

Options 1 to 5 refer to the most common practices. The first is composed of a brick loading wall and brick facing. Options 1 to 4 have a block concrete loading structure. Options 1 and 2 are characterised by the use of steel for reinforcement. Options 4 and 5 differ from option 3 only in the thermal insulating material. These two options are considered in order to evaluate the influence of the choice of synthetic insulating materials in the total IGEP value (Polyurethane is used for the option 3 while rockwool – RW - and glass wool – GW - are used for the options 4 and 5 respectively).

Options 6 to 11 differ from the first five options in their lower concrete use due to the substitution of the loading structure by other material (stone, argex, cellular concrete or wood). Options 6, 9 and 11 do not use brick for facing.

The last option is a "full biomaterial" option : wood is used for the skeleton and cladding while flax is used as a thermal insulation.

	1 brick wall + reinforc.	2 Brick&concrete wall + reinforc.	3 Brick&concrete wall	4 Brick&concrete wall + RW	5 Brick&concrete wall + GW	6 Stone + concrete wall	7 Brick & argex	8 Brick & cellular concrete	9 Cellular concrete + roughcast	10 Brick & wood	11 Wood
cladding	plaster										wood panel
loading structure	brick	concrete block					argex block	cellular concrete	cellular concrete	wood skeleton	wood skeleton
steel reinforcement	x		-								
thermal insulation	PU panel			rock wool	glass wool	PU panel		-	-	PU panel	flax
facing	brick					stone	brick	brick	roughcast	brick facing	wood facing
ventilated layer	x								-	x	

Table 41 : Description of the external wall options considered

brick wall + reinforc.	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
masonry brick	14.0	0.45	0.31	3.21	1.35	0.189	0.0378
steel for reinforc.						0.002	0.0023
PU panel	4.5	0.03	1.61	1.61	0.04	0.002	0.0040
facing brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.080	0.0138
air	2.0		0.08	0.17			
complete layer			2.15	0.47		0.395	0.0954

Brick&concrete wall + reinforc.	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
concrete block	19.0	0.85	0.22	4.47	1.65	0.314	0.0314
steel for reinforc.						0.002	0.0023
PU panel	4.2	0.03	1.50	1.50	0.04	0.002	0.0037
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.080	0.0138
air	2.0		0.08	0.17			
complete layer			1.95	0.51		0.519	0.0887

Brick&concrete wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
concrete block	19.0	0.85	0.22	4.47	1.65	0.314	0.0314
PU panel	4.2	0.03	1.50	1.50	0.04	0.002	0.0037
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.080	0.0138
air	2.0		0.08	0.17			
complete layer			1.95	0.51		0.517	0.0863

Brick&concrete wall + RW	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
concrete block	19.0	0.85	0.22	4.47	1.65	0.314	0.0314
rock wool	6.0	0.04	1.50	1.50	0.04	0.002	0.0053
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.080	0.0138
air	2.0		0.08	0.17			
complete layer			1.95	0.51		0.518	0.0879

Brick&concrete wall + GW	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
concrete block	19.0	0.85	0.22	4.47	1.65	0.314	0.0314
glass wool	6.0	0.04	1.50	1.50	0.09	0.005	0.0049
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.080	0.0138
air	2.0		0.08	0.17			
complete layer			1.95	0.51		0.521	0.0876

Stone + concrete wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
concrete block	19.0	0.85	0.22	4.47	1.65	0.314	0.0314
PU panel	4.0	0.03	1.43	1.43	0.04	0.002	0.0035
stone	22.0	2.00	0.11	0.11	2.70	0.594	0.0030
mortar						0.101	0.0175
air	2.0		0.08	0.17			
complete layer			1.87	0.53		1.020	0.0703

Table 42 : Characteristic of the external wall options and MCP and IGEP value

Brick & argex	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m_2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
argex block	14.0	0.35	0.40	2.50	1.00	0.140	0.0210
PU panel	3.8	0.03	1.36	1.36	0.04	0.002	0.0033
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.063	0.0108
air	2.0		0.08	0.17			
complete layer			1.99	0.50		0.327	0.0727

Brick & cellular concrete	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m_2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
cellular concrete	20.0	0.13	1.60	0.63	0.40	0.080	0.0120
brick	9.0	0.75	0.12	0.12	1.25	0.113	0.0225
mortar						0.063	0.0108
air	5.0		0.17	0.17			
complete layer			1.92	0.52		0.265	0.0603

Cellular concrete + roughcast	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m_2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
cellular concrete	30.0	0.13	2.40	0.42	0.40	0.120	0.0180
mortar						0.067	0.0115
roughcast	1.2	0.10	0.12	0.12	1.00	0.012	0.0018
complete layer			2.55	0.39		0.209	0.0463

Brick & wood	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m_2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
PU panel	4.5	0.03	1.61	1.61	0.04	0.002	0.0040
wood skeleton						0.008	0.0011
wood panel	2.7	0.08	0.34	0.34	0.60	0.016	0.0113
brick facing	9.0	0.75	0.12	8.33	1.25	0.113	0.0225
mortar						0.013	0.0023
air	2.0		0.08	0.17			
complete layer			2.17	0.46		0.161	0.0562

Wood	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m_2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
wood panel	1.4	0.08	0.17	0.17	0.60	0.008	0.0057
flax	7.0	0.05	1.49	1.49	0.03	0.002	0.0000
wood skeleton						0.008	0.0011
wood panel	1.4	0.08	0.17	0.17	0.60	0.008	0.0057
wood facing					0.50	0.069	0.0104
air	2.0		0.17	0.17			
complete layer			2.00	0.50		0.095	0.0229

Table 42 (follow) : Characteristic of the external wall options and MCP and IGEP value

Detailed estimations of MCP and IGEP for all options are given in Table 42 where the thickness, the material conductivity per unit of thickness, the thermal resistance and the thermal conductivity are given for the different layers. The material density is also given. Last two columns give the MCP and IGEP values.

These results show the respective share of each layer in terms of material and GHG emission compared to the total wall thickness. They also show the large differences in the total MCP and IGEP from one option to the others.

Figure 23 shows how IGEP values compare from one option to others. Five first options have similar performances (around 0.09 t $CO2/m^2$). Options 6 and 7 are similar even materials used are different (about 0.07 t $CO2/m^2$). Then options 8, 9 and 10 reveal decreasing IGEP values from 0.06 to 0.045 t $CO2/m^2$. Full wood option has the best performance (0.023 t $CO2/m^2$).

These results show that a same insulation level can be achieved with very different IGEP values.

It is also to be noted from Table 42 that for a given external wall option the improvement of thermal insulation do not change significantly the global IGEP value : for case 2 for instance, if the PU panel thickess is doubled (8.4 cm) than the IGEP value for the wall increases by 4% only (92.4 kg/m^2)

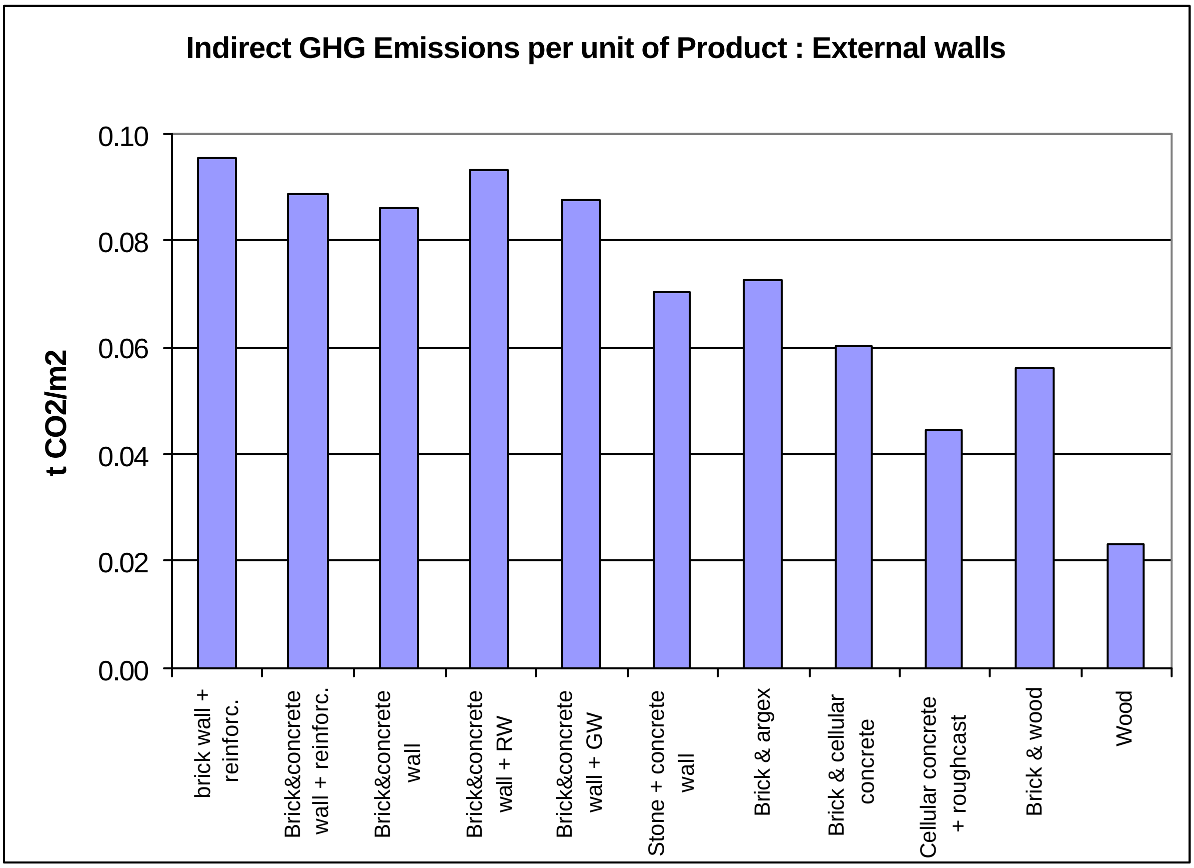


Figure 23 : Indirect GHG emissions per unit of external wall surface

7.2.3. Interior walls

The same exercise has been done for interior walls. Here however the insulation criteria doesn't play any role. In this case cladding, loading or non loading walls (including mortar) are to be considered. Six cases are considered based on same materials as considered for external walls.

The results are shown in next table where the thickness, density as well as MCP and IGEP values are given. Loading and non loading walls are distinguished and the total values (complete layer) are calculated with weighting factors of 0.33 and 0.67 respectively.

The results show a large variation of MCP and IGEP coefficients from option to option.

brick wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	2.0	-	-	-	1.00	0.020	0.0300
mortar						0.040	0.0069
brick (loading)	19.0				1.35	0.257	0.0513
brick (non loading)	14.0	-	-	-	1.35	0.189	0.0378
complete layer						0.2712	0.0791

concrete wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	2.0	-	-	-	1.00	0.020	0.0300
mortar						0.040	0.0069
concrete block (loading)	19.0				2.00	0.380	0.0380
concrete block (non loading)	14.0	-	-	-	2.00	0.280	0.0280
complete layer						0.3729	0.0682

argex wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	2.0	-	-	-	1.00	0.020	0.0300
mortar						0.040	0.0069
argex block (loading)	19.0				1.20	0.228	0.0342
argex block (non loading)	14.0	-	-	-	1.20	0.168	0.0252
complete layer						0.2477	0.0651

cellular concrete wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	2.0	-	-	-	1.00	0.020	0.0300
cellular concrete block (loading)	19.0				0.70	0.133	0.0200
cellular concrete block (non loading)	14.0	-	-	-	0.70	0.098	0.0147
complete layer						0.1296	0.0464

wood wall + plaster	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	2.0	-	-	-	1.00	0.020	0.0300
sawn wood	-	-	-	-	0.50	0.008	0.0011
complete layer						0.0276	0.0311

wood wall	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
wood panel	2.7	-	-	-	0.60	0.016	0.0113
sawn wood	-	-	-	-	0.50	0.008	0.0011
complete layer						0.0238	0.0125

Table 43 : Characteristic of the internal wall options and MCP and IGEP values

Figure 24 illustrates the IGEP values for the six options considered. Here again it is shown that performance improvements are possible through the choice of materials.

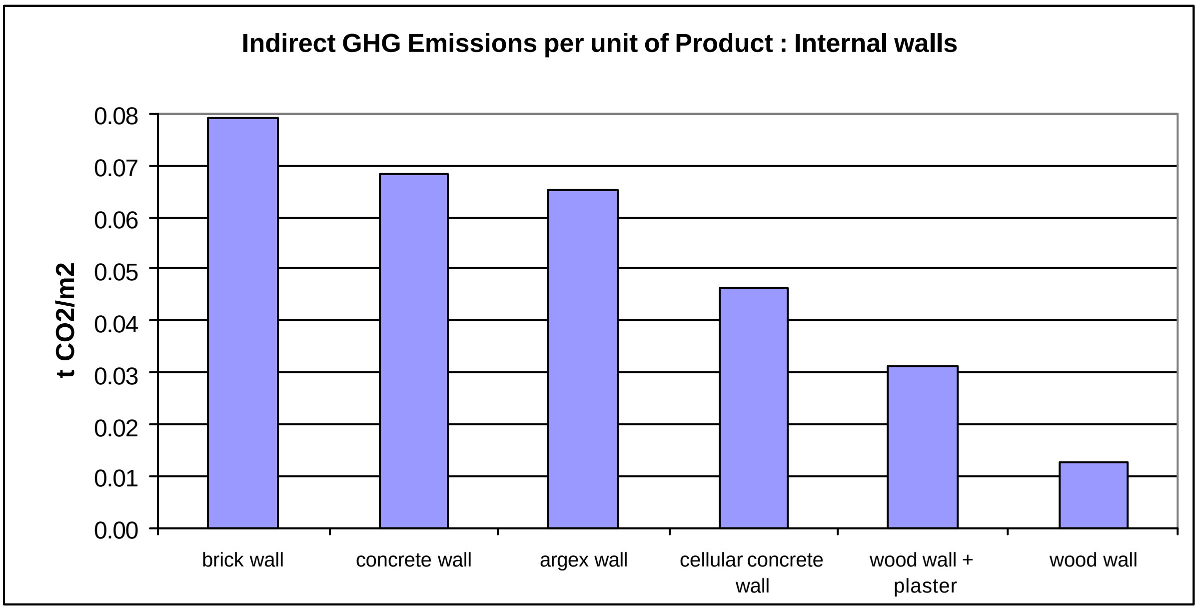


Figure 24 : Indirect GHG emissions per unit of internal wall surface

7.2.4. Roof

Roof like external wall has to be evaluated taking into account the thermal insulation properties of the materials considered. For this reason options considered here have the same thermal performances ($k=0.24\ W/m_2.K$).

Then options differ from the others in terms of roofing materials.

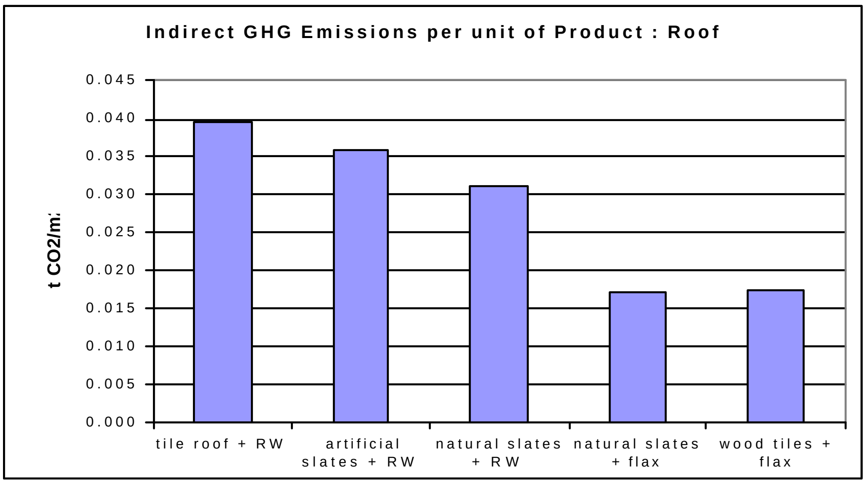


Figure 25 : Indirect GHG emissions per unit of roof

Results are presented in Table 44. They show the least performance for tile roof with Rock wool. With the same insulating material, natural slates roof has the best performance. However it is largely improved when rock wool is substituted by bio-material like flax.

Full wood option is not more efficient than the last.

tile roof + RW	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
wood skeleton	-	-	-	-	0.50	0.021	0.0019
rock wool	16.0	0.04	4.00	4.00	0.04	0.006	0.0141
tiles	-	-	-	-	1.00	0.043	0.0086
air	2.0		0.17	0.17			
complete layer			4.20	0.24			0.0396

artificial slates + RW	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
wood skeleton	-	-	-	-	0.50	0.021	0.0019
rock wool	16.0	0.04	4.00	4.00	0.04	0.006	0.0141
artificial slates	-	-	-	-	1.20	0.025	0.0050
air	2.0		0.17	0.17			
complete layer			4.17	0.24			0.0210

natural slates + RW	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
wood skeleton	-	-	-	-	0.50	0.021	0.0019
rock wool	16.0	0.04	4.00	4.00	0.04	0.006	0.0141
natural slates	-	-	-	-	1.00	0.030	0.0002
air	5.0		0.17	0.17			
complete layer			4.17	0.24			0.0161

natural slates + flax	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
plaster	1.0	0.35	0.03	35.00	1.00	0.010	0.0150
wood skeleton	-	-	-	-	0.50	0.021	0.0019
flax	15.0	0.04	4.05	4.05	0.03	0.005	0.0001
natural slates	-	-	-	-	1.00	0.030	0.0002
air	5.0		0.17	0.17			
complete layer			4.22	0.24			0.0021

wood tiles + flax	thickness (cm)	λ (W/m.K)	R_i	k_i (W/m2.K)	ρ (t/m3)	material intensity (t/m2)	t CO2/m2
wood panel	1.4	0.08	0.17	0.17	0.60	0.008	0.0041
wood skeleton	-	-	-	-	0.50	0.021	0.0019
flax	15.5	0.04	4.19	4.19	0.03	0.005	0.0001
wood shingles	-	-	-	-	0.50	0.015	0.0014
air	5.0		0.17	0.17			
complete layer			4.19	0.24			0.0033

Table 44 : Characteristic of the roof options and MCP and IGEP value

7.2.5. Floors

For floors two options are considered : one concrete floor and one wood floor. Results are given in Figure 26. It clearly shows the better performance of the second option both in terms of material intensity and in terms of indirect GHG emissions.

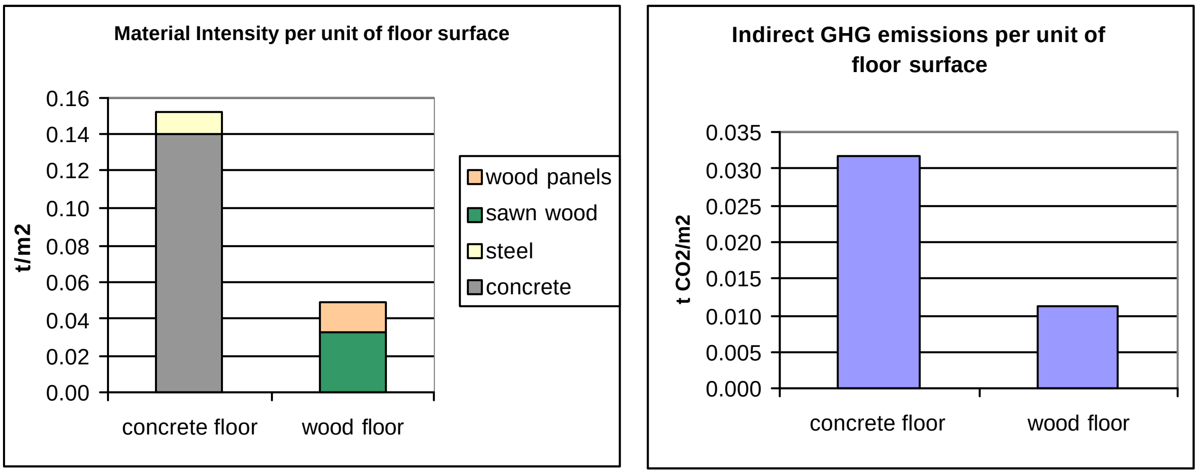


Figure 26 : MCP and IGEP values for concrete and wood floors

7.2.6. Windows

Window frames has gained a special concern regarding environmental impacts due to different reasons : They specific life time being lower than the whole life time of the building makes that they have to be replaced several times during the life of the building. Different materials (wood, PVC, aluminium, steel,…) can be used to assemble window frames, with different properties and environmental impacts.

Life cycle window frames have been done in different studies. For instance, Hendrix and Martens (1990)[24] have concluded that pinewood window frames painted with natural paint are environmentally preferable while pinewood window frames painted with acrylic-paint are cheaper. According to a study by Lindeijer et al. (1990)[25], a single, environmentally most preferable window frame cannot be determined.

The comparison made here considers three options : wood, PVC and Aluminium for the frame. For the window it is considered that double glazing is implemented (see discussion in 4.1.5).

The estimation of material intensity of window frames as expressed in kg/m2 is based on data from Kandelaars et al. (1997)[26], Gielen and data from technical documentation. They are reported in next table. Then the IGEP value is calculated.

Results are given in Table 45 and indicate the best performance for the wood window frames. PVC and Aluminium are on the same level.

	Wooden window frame	PVC window frame	Aluminium window frame
Glass	20.0	20.0	20.0
Wood	55.0	0.0	0.0
PVC	0.0	15.0	0.0
PS	0.0	0.0	1.7
Aluminium	1.0	0.0	6.8
Steel	0.0	24.5	0.0
t CO2/m2	0.029	0.084	0.085

Table 45 : Material intensity of window frames
Source : Kandelaars et al, Gielen, IW

7.3. Material Input and Indirect GHG emissions per house

7.3.1. Introduction

After the previous step that provided MCP and IGEP values for each main building elements we are now able to simulate such parameters for different types of buildings.

For this purpose we make use of relations between the element-related reference units and a defined building-related unit (either the total surface either the living surface). Theoretical relationships between both units can be built for each element on the basis of simplifying geometrical considerations. The geometrical assumptions we used for the build-up of theoretical relations are described in detail in *Appendix I :*

Relationship between material contents and house surface as well as the relationships that we deduced from these assumptions.

In view of the number of options considered for the different elements we could envisage a huge number of combinations. It makes however non sense to consider all of them here. Firstly many of them are not realistic secondly a series of options will not substantially differ with respect to their life cycle emissions.

Table 46 shows the architectural features of the houses selected in terms of their respective elements (foundations, exterior and interior walls, soils and windows).

	brick&concrete house + cellar	brick&concrete house	terraced brick&concrete house	brick house	stone & concrete house	Argex house	Cellular concrete house	wood & brick house	Wood house	renovated conventional house	renovated wood house
foundation	strong sole foundation						light sole foundation			strong sole foundation	light sole foundation
external walls	Brick&concrete wall + reinforc.			brick wall	Stone + concrete wall	Brick & argex	Cellular concrete + roughcast	Brick & wood	Wood	Brick&concrete wall + reinforc.	Wood
interior walls	concrete wall			brick wall	concrete wall	argex wall	cellular concrete wall	wood wall	wood wall	concrete wall	wood wall
roof	tile roof + RW				natural slates + RW	artificial slates + RW		natural slates + RW		tile roof + RW	natural slates + flax
soil	concrete floor							wood floor		concrete floor	wood floor
windows	PVC window frame				Wooden window frame	PVC window frame	Wooden window frame			PVC window frame	Wooden window frame

Table 46 : Description of the different representative houses

7.3.2. Material Consumption and indirect emission per house

In the next paragraphs we present the results of calculations for the MCP and IGEP successively for each case selected. Values will be given as a function of the total house surface.

7.3.2.1. Brick&concrete houses : the reference house

Being the most usually built[12], the conventional house can be considered as the reference. It is so interesting to give a detailed overview of the role of the different materials and elements in the total material consumption and in the total indirect CO_2 emission.

First we focus on a 200 m^2 total surface house to illustrate the relative importance of materials in the whole building. The total consumption for this house is around 220 ton of which 68% of block concrete. This consumption is distributed mainly between foundation (15%), walls (65%) and floors (19%) as shown in Figure 27.

[12] It is however to be noted that brick houses are also commonly built.

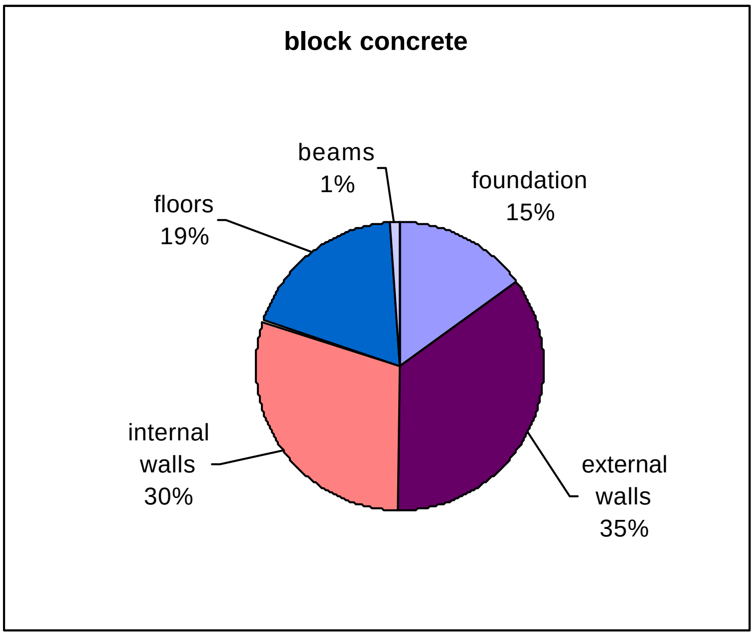


Figure 27 : Share of block concrete consumption between the different building elements

The remaining material consumption is distributed between the different building elements as shown in Figure 28.

This figure clearly shows the primary importance of walls and foundation in the total material consumption.

Regarding materials brick and mortar are the second order important materials (9% for both). Then plaster, steel and tiles intervene each for 2% to 3% of the total.

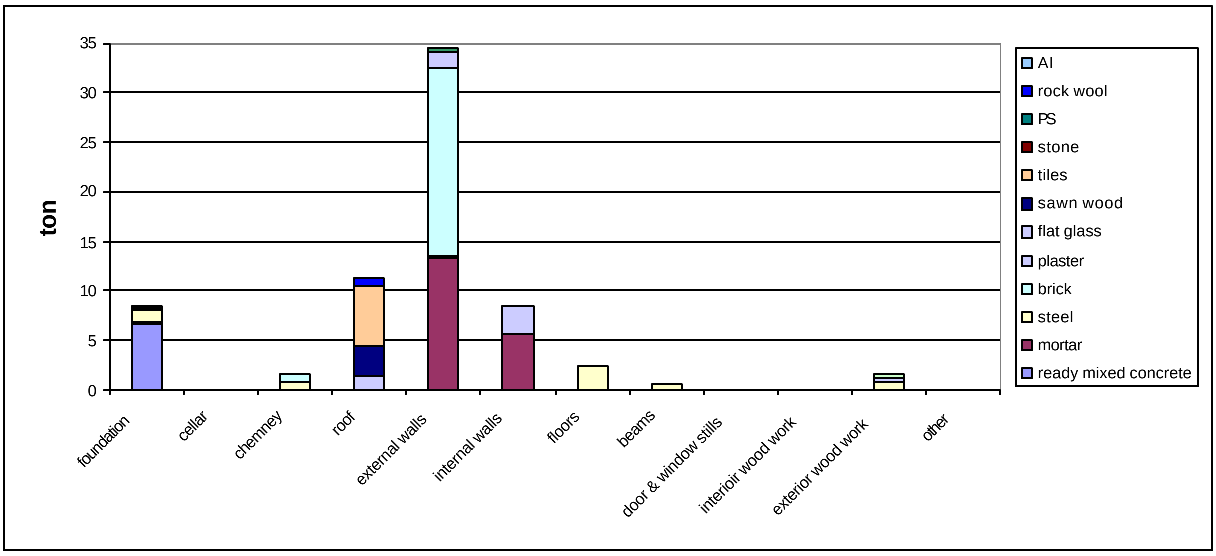


Figure 28 : Importance of the different materials for each building element for a conventional house in the total consumption (excluding block concrete)

Due to the material composition of the conventional house indirect CO_2 emission are dominated by concrete, cement (contained in mortar) and bricks. They are represented in Figure 29. The total is around 47 ton CO_2.

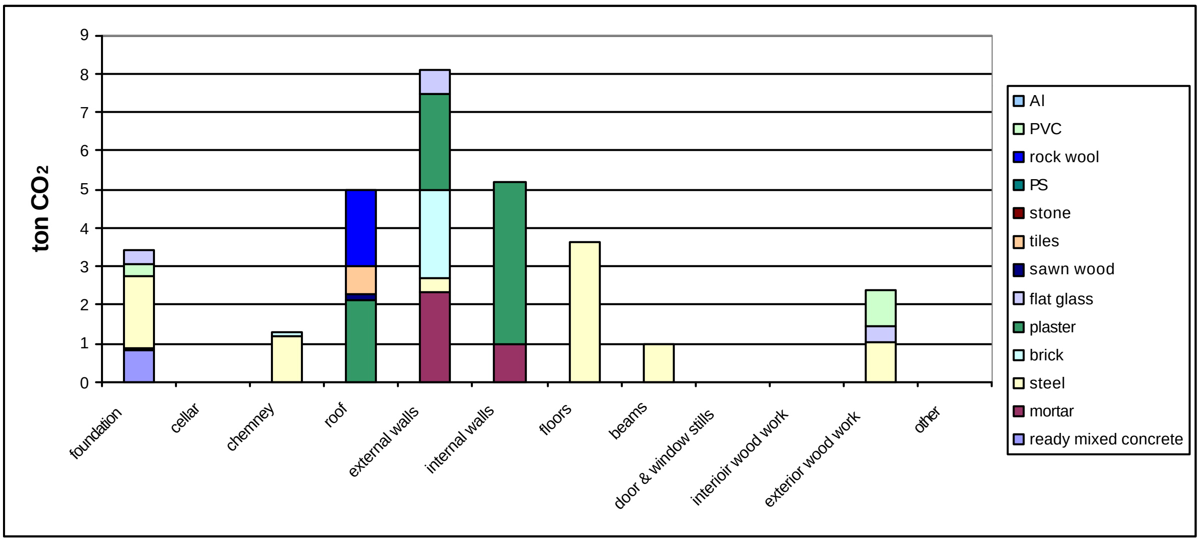
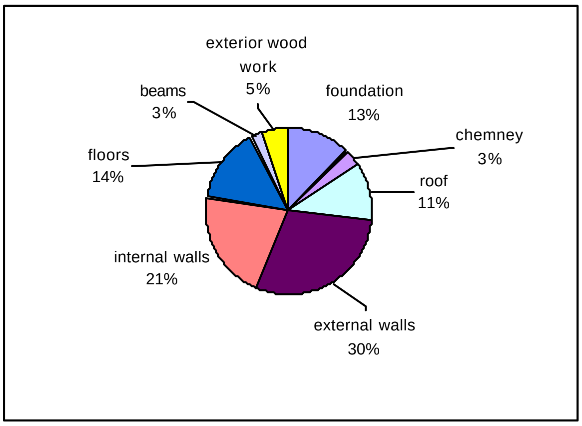


Figure 29 : Importance of the different materials for each building element for a conventional house in the **total indirect CO_2** emission



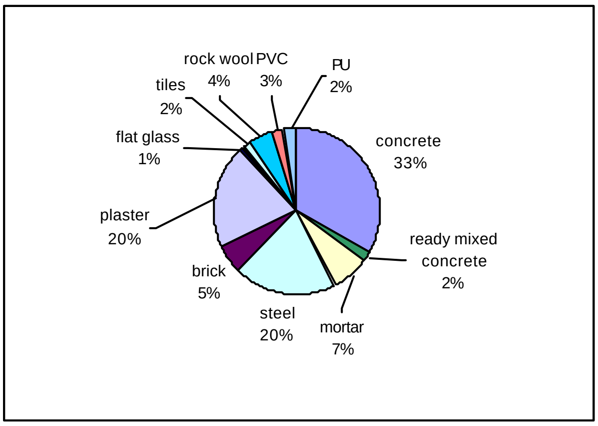


Figure 30 : Importance of the different materials for each building element for a conventional house in the **total indirect CO_2** emission between building elements (left) and between materials (right)

These results indicate the main elements of the building where changes in materials or in design may result in the greatest environmental performance improvements of the building, namely walls and concrete use.

Figure 31 and Figure 32 depict the influence of the total surface on the material consumption and indirect emission.

For a similar house with a cellar, concrete consumption is still higher : from 330 to 460 t and the IGEP varies from 59 to 83 t CO_2. This represents an increase by 24% to 13% compared with the house without cellar over the surface interval considered.

When an terraced conventional house is built CO_2 emissions vary from 43 t to 60 t which is slighly lower than for the detached house. The small difference is explained by a small difference in concrete and brick consumption for the common walls.

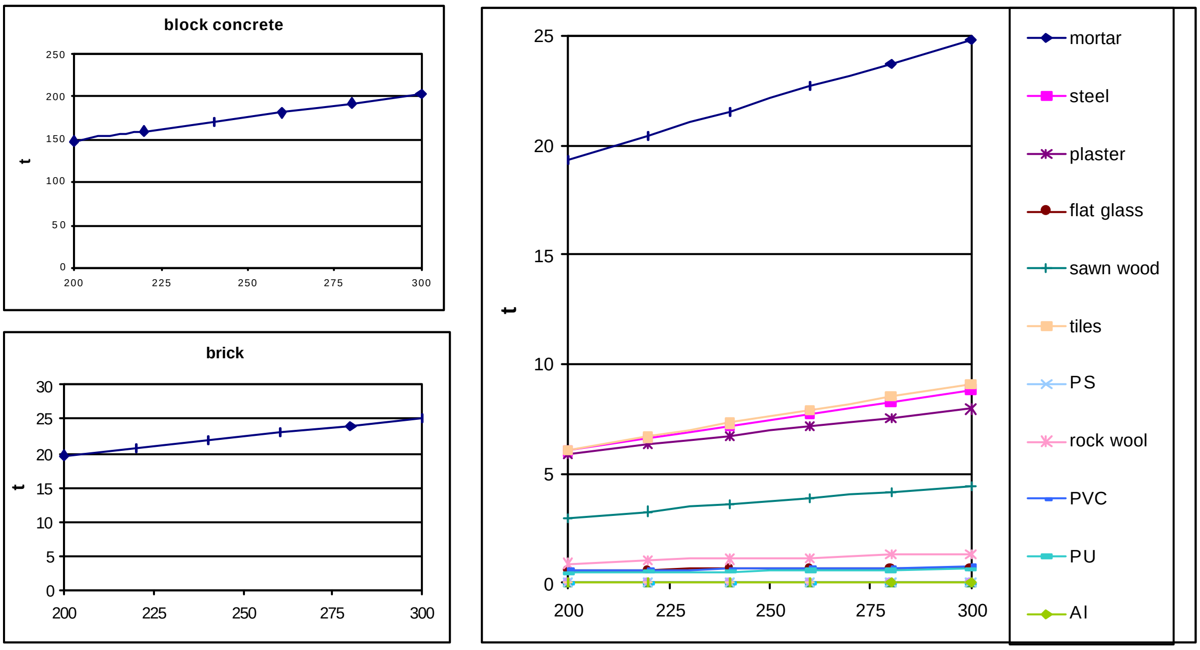


Figure 31 : Material Consumption for a brick&concrete house as a function of total house surface (expressed in m^2)

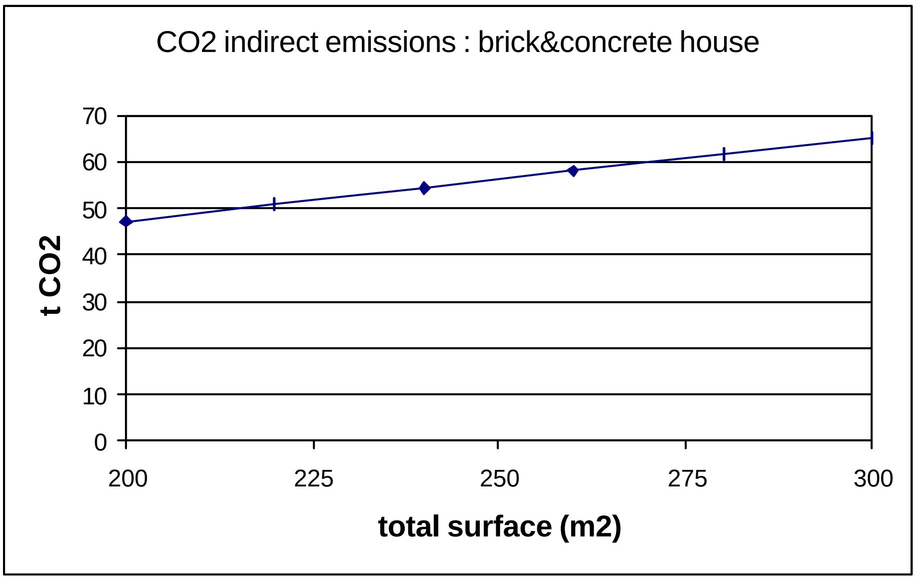


Figure 32 : Indirect CO_2 emission for a brick&concrete house as a function of the total surface

7.3.2.2. Brick house

For a brick house brick importance is higher than for the reference case. Block concrete is still important because it is used for floors.

The resulting indirect CO_2 emissions are of the same order of magnitude than for the previous case and varies from 50 to 70 t CO_2 when the total surface increases from 200 m2 to 300 m2.

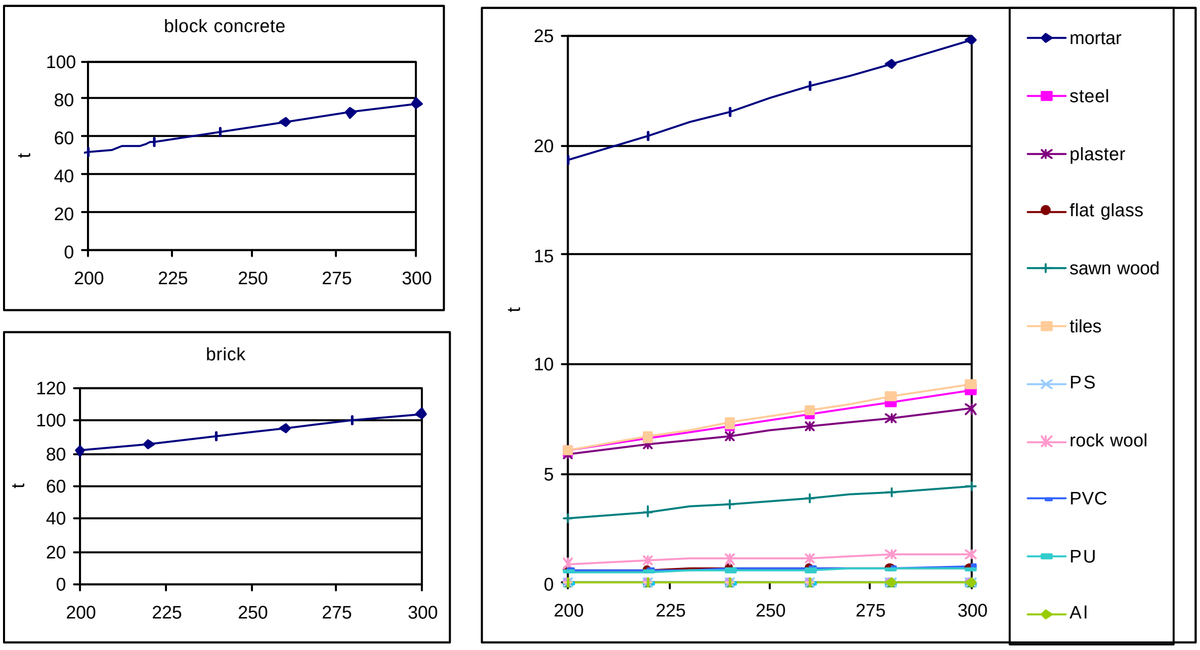


Figure 33 : Material Consumption for a brick house as a function of total house surface (expressed in m^2)

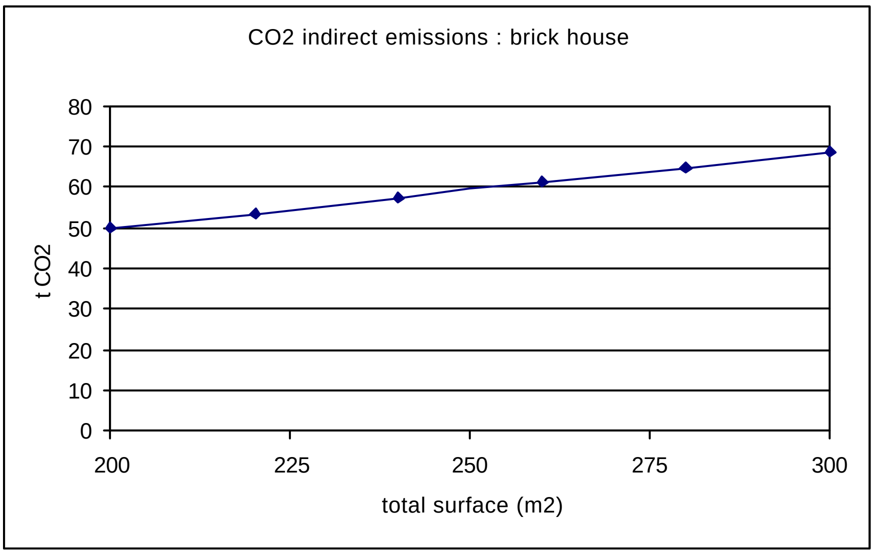


Figure 34 : Indirect CO_2 emission for a brick house as a function of the total surface

7.3.2.3. Stone and concrete house

For this case concrete remains the dominant material (50% of the 300 to 400 ton total material). Stone as a very dense material constitutes the second important material (32%), substituting brick. Mortar consumption is higher than in the conventional house due to higher consumption per m^2 wall.

The indirect CO_2 emissions are smaller than in the previous case (41 to 57 t CO_2).

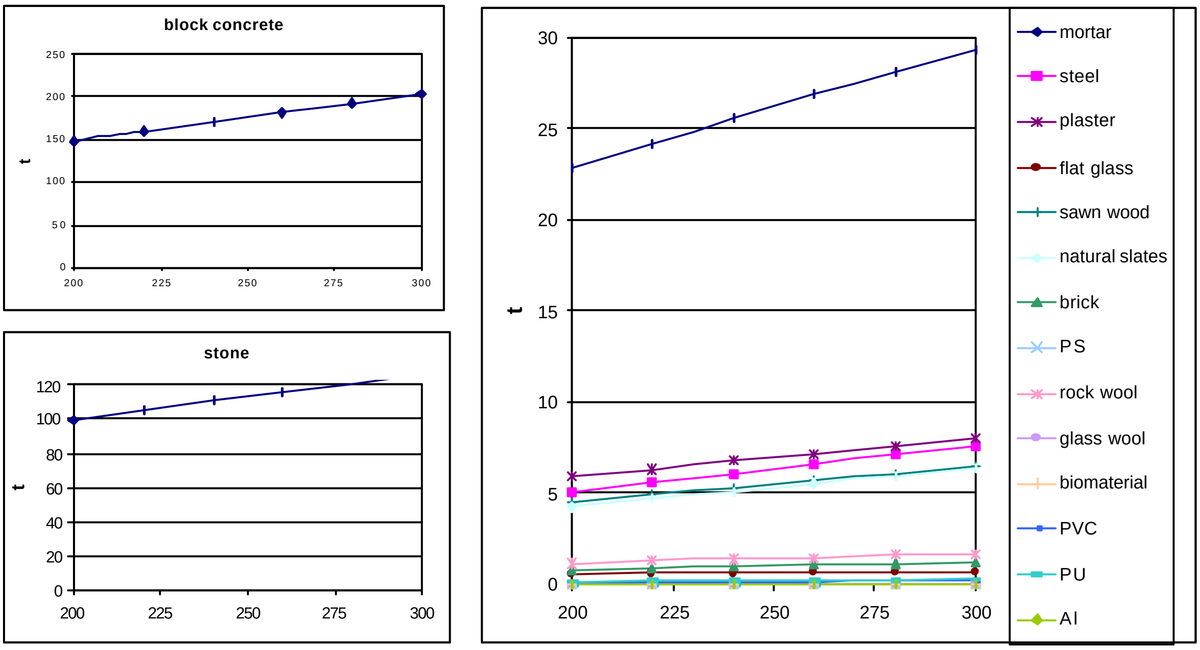


Figure 35 : Material Consumption for a stone & concrete house as a function of total house surface (expressed in m^2)

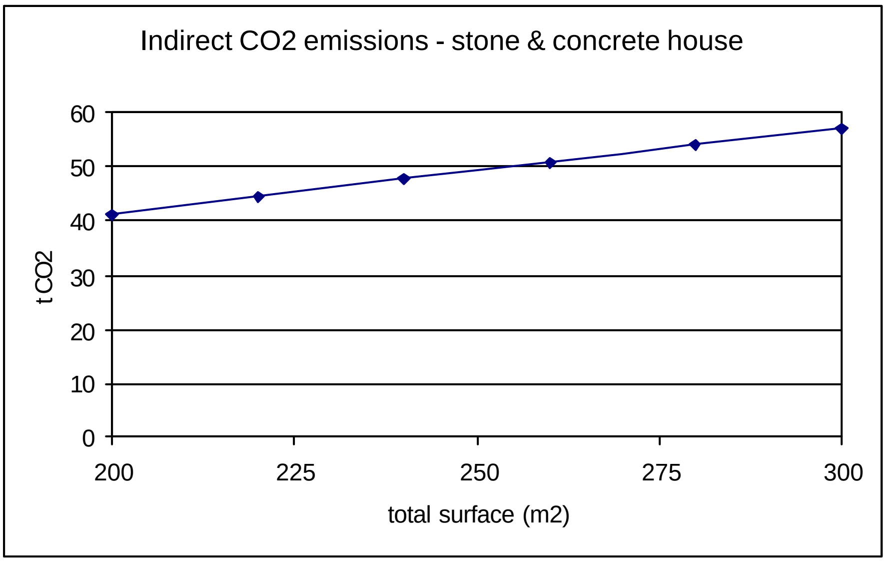


Figure 36 : Indirect CO_2 emission for a stone & concrete house as a function of the total surface

7.3.2.4. Expanded clay house

For an expanded clay house, the total material intensity varies from 165 and 230 t material which is lower than in the previous cases. Here concrete is partly replaced by expanded clay blocks for the walls. Mortar and bricks consumptions are of second order levels.

Indirect CO_2 emissions are between 43 and 60 t CO_2.Those values are very similar to those calculated for the brick&concrete house.

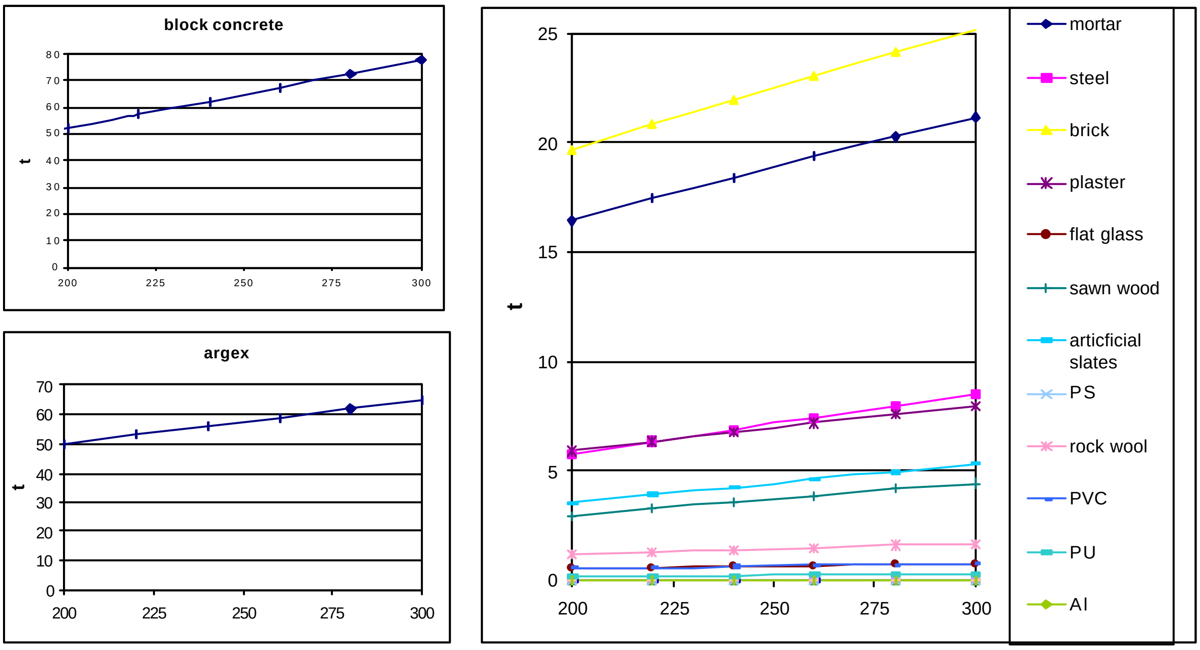


Figure 37 : Material Consumption for a expanded clay house as a function of total house surface (expressed in m^2)

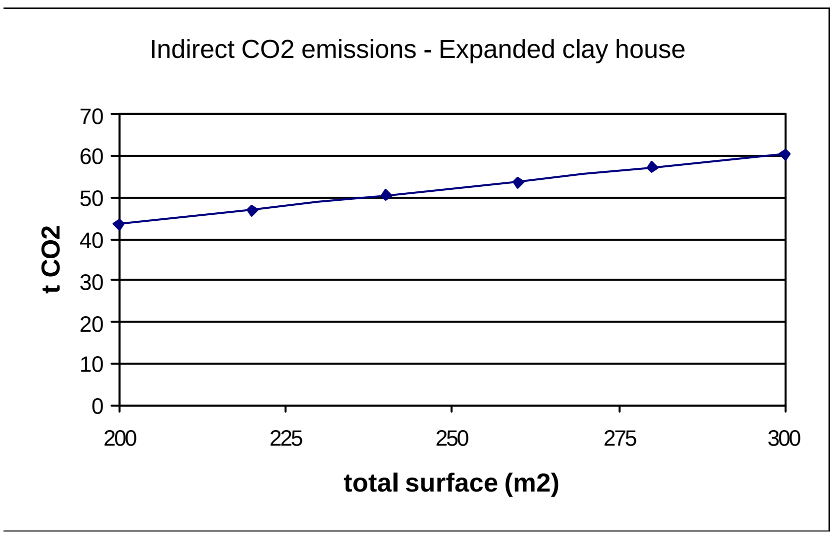


Figure 38 : : Indirect CO_2 emission for a expanded house as a function of the total surface

7.3.2.5. Cellular concrete house

For a cellular concrete house the total material consumption varies from 125 to 176 t when total surface varies from 200 to 300 m^2. The intensity in concrete is highly decreased compared to the conventional case for two reasons : firstly the walls use very few concrete blocks, secondly the foundation strength is smaller due to the fact that the house is less heavy.

The resulting indirect CO_2 emissions are from 34 to 48 ton.

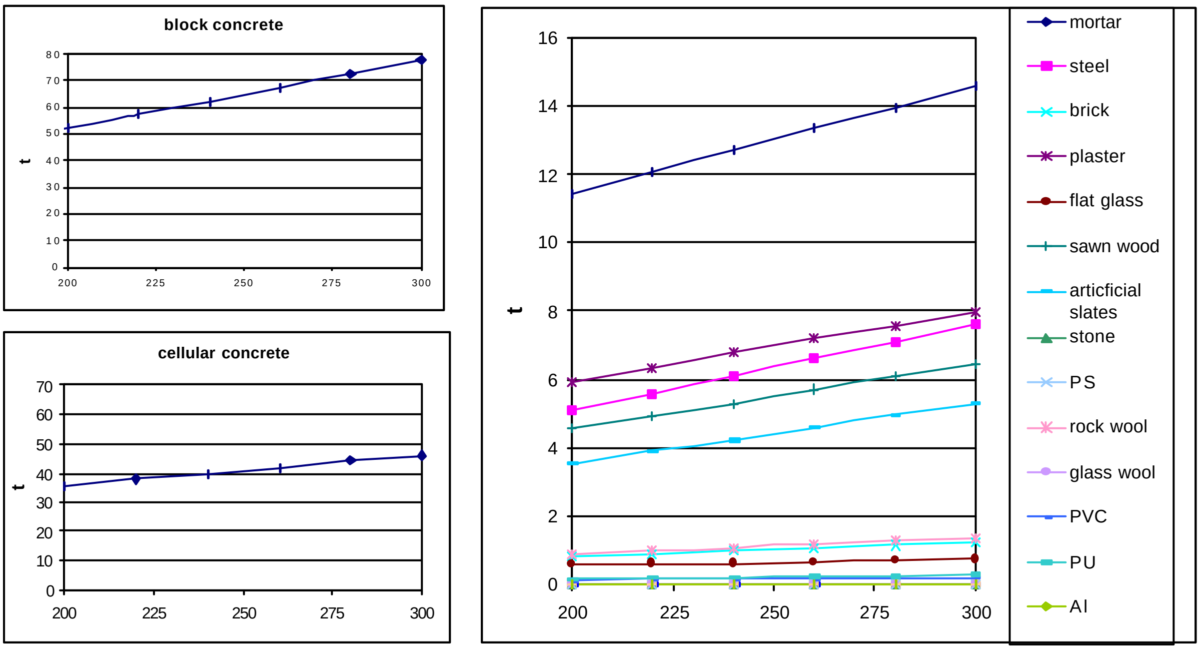


Figure 39 : Material Consumption for a cellular concrete house as a function of total house surface (expressed in m^2)

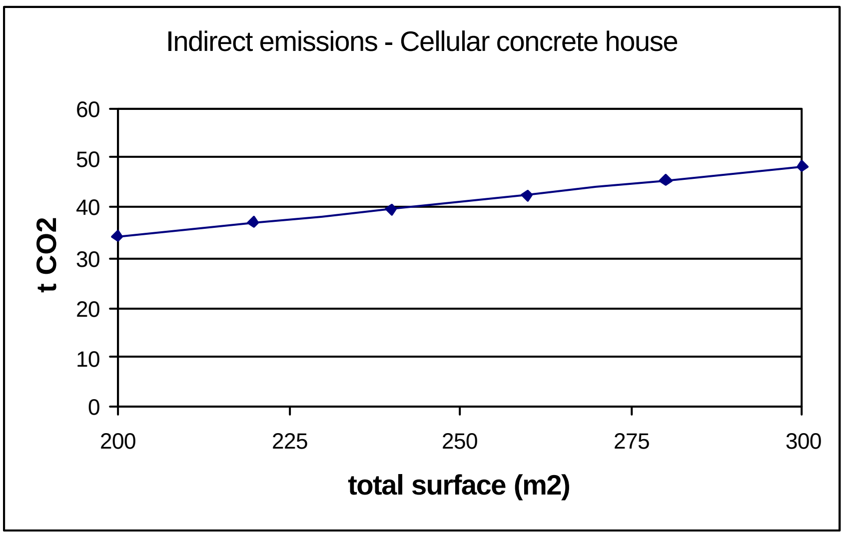


Figure 40 : Indirect CO_2 emission for a cellular concrete house as a function of the total surface

7.3.2.6. Wood & brick house

Material consumption for a typical wood & brick house varies between 83 and 120 t material for surfaces between 200 and 300 m^2. Sawn wood is the most important material before concrete (mainly used for foundations).

Due to this high wood consumption the indirect emission is highly determined by the origin of timber. If wood is supplied by a sustainable managed forest, the indirect emission varies from 27 to 37 t CO_2 . If wood originates from a deforested land the indirect emissions dramatically increase to levels from 300 to 450 t CO_2. This figure highlights the need to exclude this kind of wood due to negative impacts both on biodiversity and on climate.

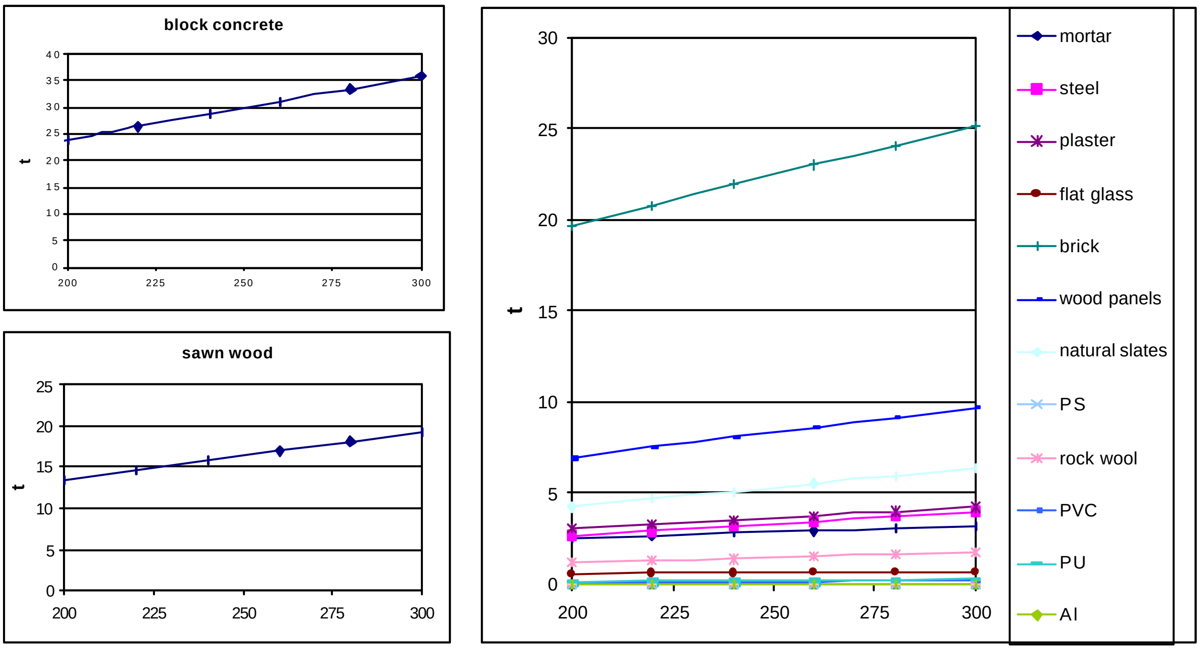


Figure 41 : Material Consumption for a wood&brick house as a function of total house surface (expressed in m^2)

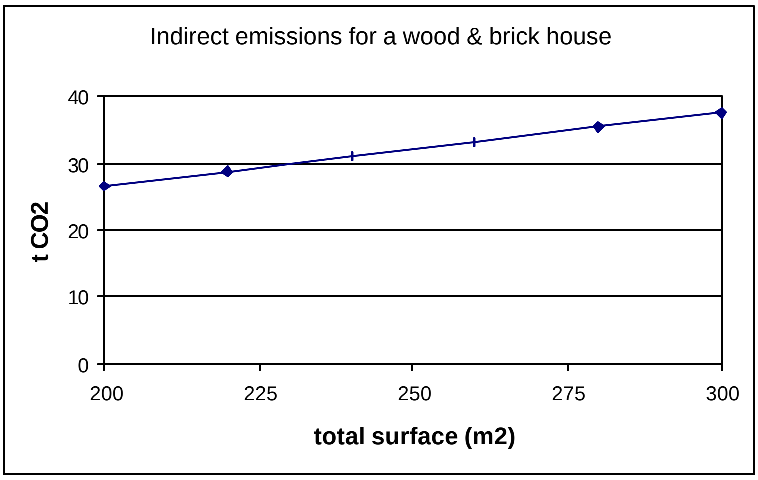


Figure 42 : : Indirect CO_2 emission for a stone & concrete house as a function of the total surface
Wood is supposed to originate from sustainable managed forests

7.3.2.7. Wood house

For a wood house (including wood facing), the material intensity is highly decreased compared to a conventional house (from 132 to 184 tons). As for wood and brick houses, wood represents the most important material. But here the consumption is increased due to the use for facing.

The indirect emissions are highly determined by the origin of timber. If wood is supplied by a sustainable managed forest, the indirect emission varies from 20 to 28 t CO_2 . If wood is coming from a deforested land the indirect emissions are dramatically increased to levels from 250 to 450 t CO_2. .

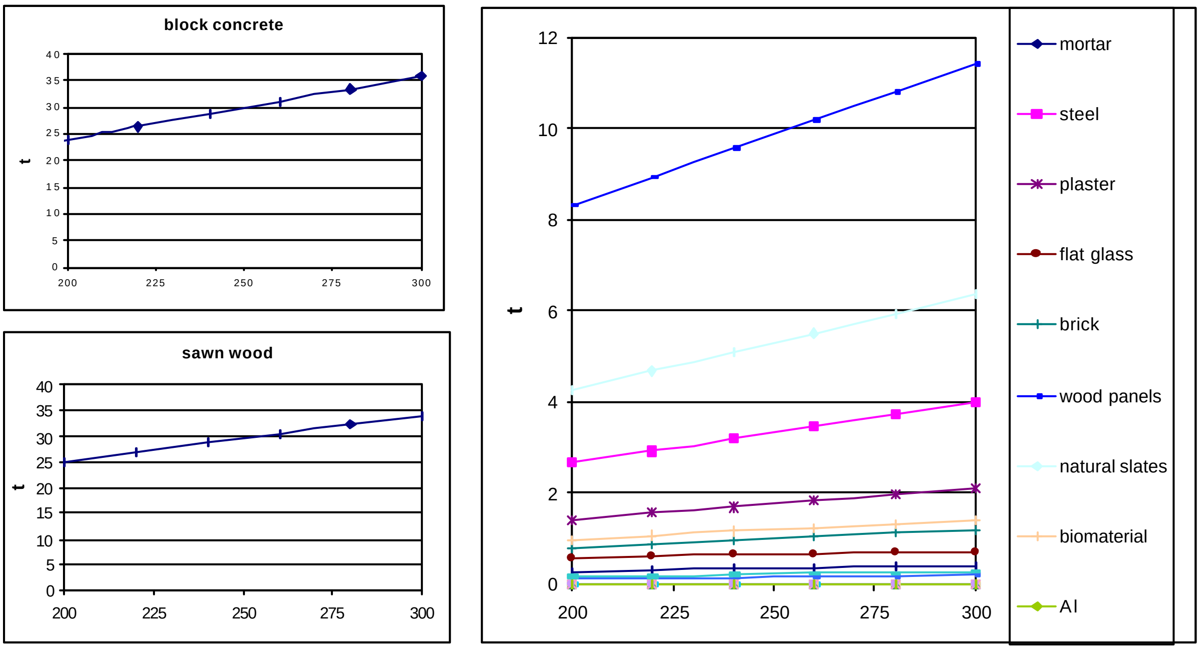


Figure 43 : Material Consumption for a wood house as a function of total house surface (expressed in m^2)

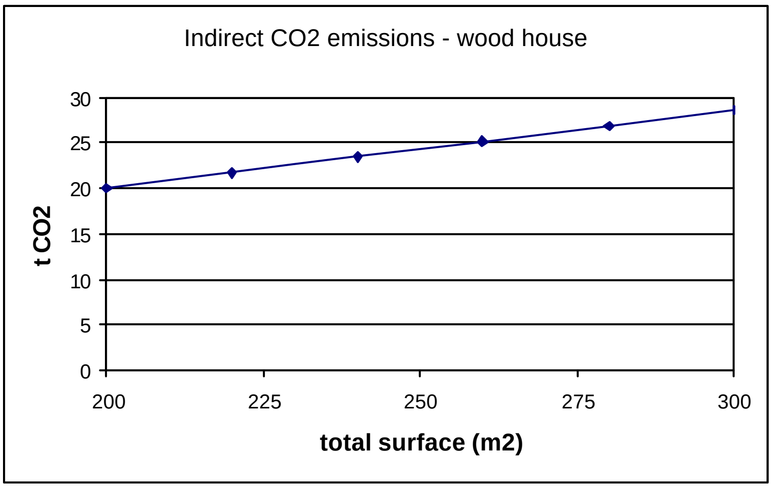


Figure 44 : : Indirect CO_2 emission for a wood house as a function of the total surface
(wood supposed to originate from sustainable managed forests)

7.3.2.8. Renovation

We consider two types of renovation : the first is a conventional renovation, the second is a wood renovation. For a renovation resulting in a 50 m2 total surface increase (resulting in a 200 m2 total surface), results are as followed :

- For the first case the material consumption is around 143 ton and CO_2 indirect emissions of 30 tons.
- For the second case the material consumption is around 20 ton and CO_2 indirect emissions of 6 tons.

7.3.2.9. Comparison between different types of houses

Comparison of MCP and IGEP values for the different cases studied is made in Figure 45.

This figures illustrates the important role of the cellar construction in the total material intensity and in the total indirect emissions.

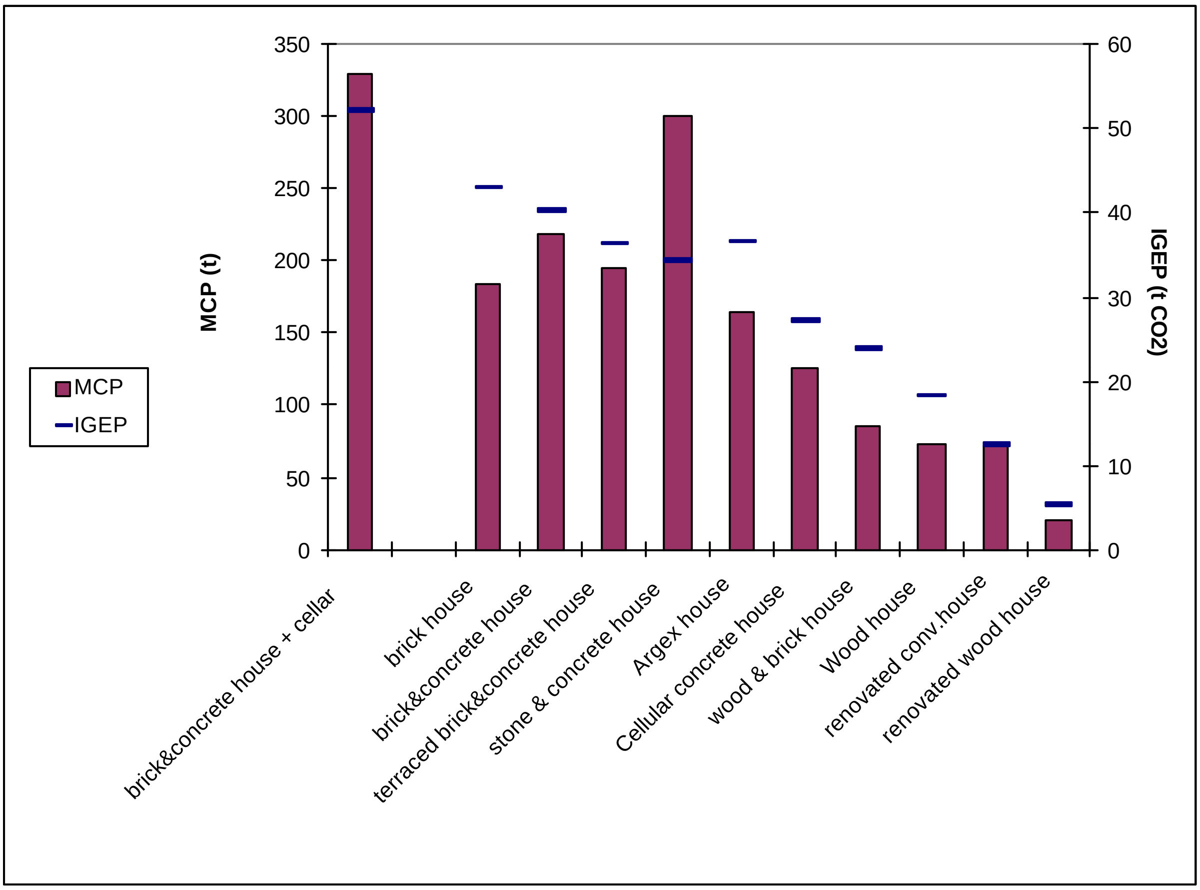


Figure 45: Comparison of MCP and IGEP values for the different cases studied for a 200 m^2 total surface.

It also shows a similar trend between material intensity and indirect CO2 emissions. Two exceptions are observed : brick house and stone&concrete house.

Then the figure suggests that compared with the reference house construction large environmental performance improvements can be gained from material substitutions : IGEP can be reduced by 10 to 15% if materials like cellular concrete, stone or expanded clay are used for new construction. Further decrease may be obtained if wood is used (from 40% to 50% decrease).

Compared with new construction renovation allows to reduce the IGEP by 70% to 87%.

This comparison indicates an important technical potential for reducing CO2 emissions. However this comparison has to be completed by a comparison with consideration of the respective possible lifetimes of the different types of houses. With that respect a large uncertainty exists : an uncertainty exists about new conventional houses but is still larger for non conventional houses. For wooden houses especially, few experience exist in Belgium notably with respect to the weather conditions. Houses in Canada appear to have quite large life time but extrapolation to the Belgian context is trucky.

Different experiences in Belgium for complete wood houses indicate a possible lifetime untill 60 years. If brick facing is used this lifetime will possibly be extended to 70 years.

Assumptions made on the lifetimes for the different types of houses are given in Table 47.

	life time (yr)
Brick house	100
Brick&concrete house	100
Terraced brick&concrete house	100
Stone & concrete house	120
Argex house	100
Cellular concrete house	90
Wood & brick house	70
Wood house	60
Conventional renovation	50
Wood renovation	40

Table 47 : Comparison of averaged yearly indirect emissions taking into account average lifetimes of different houses

Given these lifetimes, we can calculate yearly IGEP values that can be compared (see Figure 46). Results are compared with yearly IGEP values calculated for 100 years lifetime for all houses. We see that the advantage of non conventional construction is smaller especially for wood construction. Compared with the brick&concrete house, the IGEP is now 25%, 15%, 25% for cellular concrete, wood&brick and wood houses respectively.

For renovation the advantage is also reduced and emissions reductions vary from 40% to 66% for conventional and wood renovations.

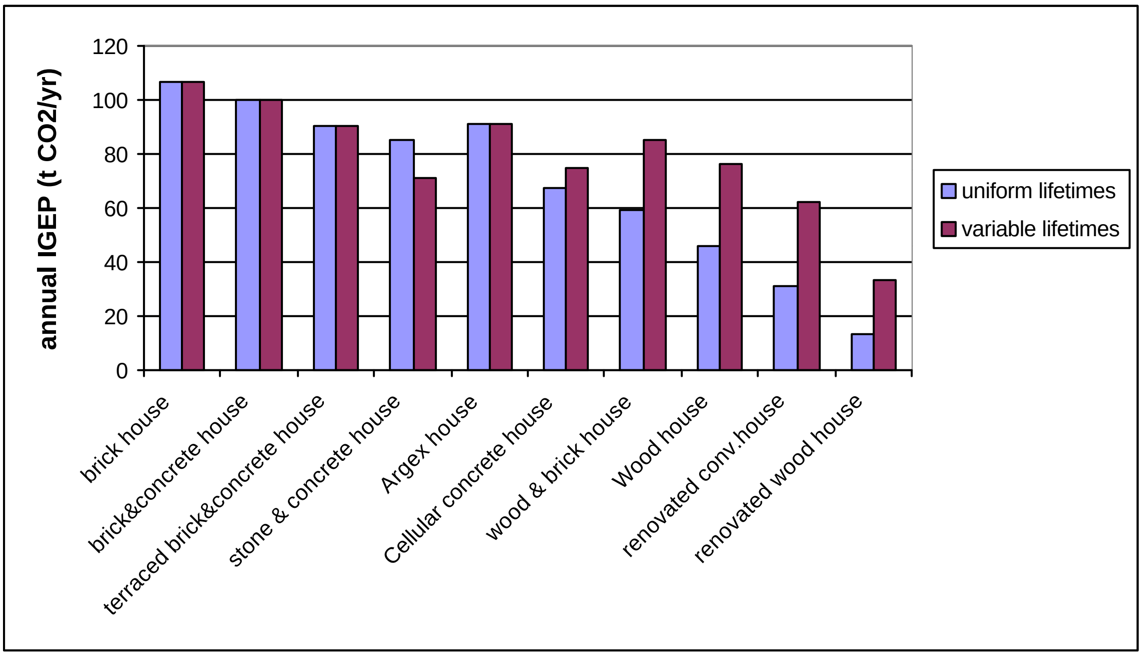


Figure 46 : Yearly indirect CO2 emissions for two sets of lifetimes assumptions : uniform lifetimes means that all houses are supposed to live during 100 years, variable lifetimes refers to assumptions in …

7.4. Indirect GHG emissions per house : comparison with direct emissions

It is interesting to compare the indirect emission as estimated for the conventional house with its direct emission namely the emission related to space heating during the life of the house.
For this purpose we consider the 200 m^2 surface house (about 120 m^2 living surface) as analysed in § 7.3.2.1 and assume that its heat demand is equivalent to 17 gasoil liter/living m^2. Then we calculate the consumption over the life of the house and the related CO_2 emission (see Table 48). Depending on the life span and on the fuel, we can estimate that the indirect CO_2 emission from the house is equivalent to 7 to 14%. Those percentages are somehow higher than figures found in other European countries reported by Gielen (3% to 12%).

The uncertainty in the estimations may explain somehow this difference. An other explanation may also be found in the difference observed related to the characteristic of the building practice in Belgium as highlighted in § 4.1.2.1.

direct CO2 emissions (tonnes CO2)	yearly	over 80 years	over 120 years
natural gaz (55 kg CO2/GJ)	4.2	337	506
gasoil (73 kg CO2/GJ)	5.6	448	672

Table 48 : Direct CO_2 emission for a 200 m^2 house

7.5. Indirect emissions from SFH construction and renovation at the Belgian level

Estimating the related indirect emissions at the level of Belgian demand for new construction and renovation requires to have an estimation of the present sharing of different types of houses in the market. Due to lacking statistical data we had to make own estimations based on expert judgements and observations. We considered that about 75% of new houses are conventional houses, that 15% are intermediary cases (expanded clay or cellular concrete) and that 4% are wooden houses. Given this share and also taking into account renovation (mostly of conventional type) the total indirect GHG emissions can be estimated to 1750 kt CO_2.

7.6. Discussion on other issues

7.6.1. Other environmental impacts

7.6.1.1. Environmental impacts of wood use

Most wood facing houses presently use cedar or larch. The interest in these two species is that they do not need preservation products. However cedar use poses problems in terms of ressource depletion and biodiversity : most of cedar is imported from native forests in West North-America or Canada. The problem is now such that a strong resistance is appearing to further exploitation of these forests. The nature of forests also implies high life cycle emissions not compatible with Kyoto Protocol.

If such wood construction is to be developed in the future other species are to be envisaged. The Centre luxembourgeois of ULB has undertaken studies to evaluate the properties of douglas as an alternative. The conclusions are very positive as regard for different critera[27] :

- density and mechanical resistance properties are suitable,
- in terms of longevity douglass is intermediary between afzelia (class 1) and spruce (class 5),
- better inertia to humidity changes than spruce,
- large increase rates : 4 to 5 m^3 roundwood can be produced after 70 years (1.7 m^3 for spruce),
- less pressure on soil (1100 stands/ha compared to 2500 stands/ha for spruce).

Small Douglass wood pieces can also be used for glulam products making which allows to valorise 2d and 3th clearing products. This solution may offer an interesting potential for the future especially with new glues less environmentally damaging.

7.6.1.2. Thermal inertia of materials

The accumulation of heat by building materials depends on its thermal capacity. The greater the thermal capacity the lower the thermal inertia is. The higher thermal capacity of wood may be viewed as a disadvantage compared with more traditional materials of with cellular concrete of expanded clay.

Combining wood with such materials may offer a solution for this problem.

material	Thermal capacity (kcal/dm3*°C)
Water	1
Steel	0.95
Wood	0.43
Brick	0.40
Concrete	0.35
Expanded clay	0.24
Cellular concrete	0.12
Polyurethane expanded	0.009
Air	0.00029

Table 49 : Thermal capacity of materials
Source : Tu bâtis, Je rénove and IW survey

8. Greenhouse gas emissions projections and potential for emissions reduction

Assessing the possible role of products, materials and technologies substitutions within the housing system in the accomplishment of the emissions reduction targets as agreed in the framework of the Kyoto Protocol, requires to develop emission scenarios up to 2010 at least.

Such scenarios have been developed under two different approaches described below :

- In the first approach scenarios are built in order to derive an estimation of the technical potential for reducing CO2 life cycles resulting from the demand for new and renovated SFH.
- In the second approach a MARKAL model has been developed for the housing system in order to evaluate a technico-economic potential.

8.1. Technical potential of emissions reduction

As a first step we made a straightforward evaluation of the evolution of the life cycle CO2 emissions resulting from the demand for new construction and renovation of SFH under a static production system. According to this assumption averaged CO2 life cycles of all materials are constant and only two parameters influence the evolution of the total

Given the housing demand as projected in the reference scenario as set up by IDD. Two alternative GHG emissions curves have been calculated at this stage, assuming no technology changes within the production system : the first one assumes a constant share of houses types (as estimated for the current situation), the second assumes an increasing contribution of intermediary houses types and wooden houses (respectively rising to 30% and 25%).

The resulting two GHG scenarios are represented in Figure 47.

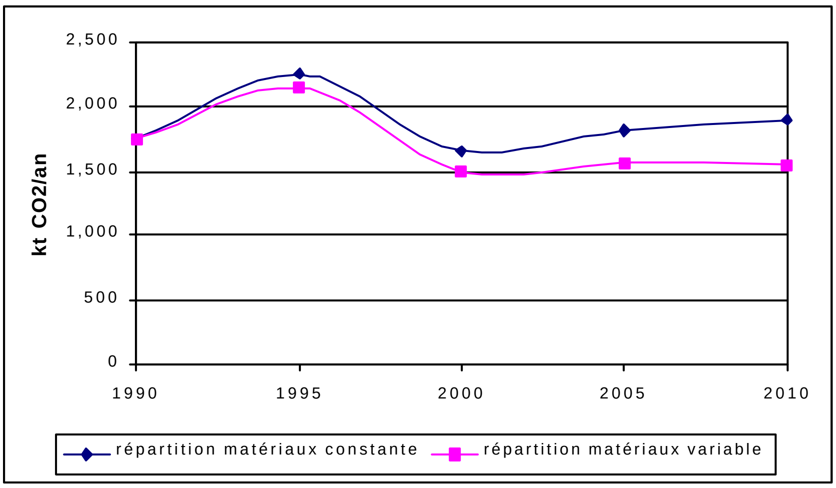


Figure 47 : Indirect CO2 emissions scenarios

The upper curve represents the first scenario and the lower the second. In the first case, GHG emissions should rise to 1900 kt while they reach 1550 kt in the second case, ie a 11% decrease compared to 1990 level.

8.2. Technico-economic potential of emission reduction

Paragraph 8.1 provided figures on the environmental performance of the different representative houses types. This comparison suggest the existence of a emission reduction potential when shifting from conventional houses (brick, brick& and concrete) to other houses types (cellular concrete, wood& brick and complete wooden houses).

This potential is however to be further assessed under a dynamic and economic approach, namely, taking into account both :

- Evolution of technology developments,

- Cost comparison of different measures to reduce the overall GHG emissions.

Such an evaluation has been made with MARKAL (see description in Nemry, Theunis, Bréchet and Lopez, 2001)[28].

This chapter will present the different steps and results of the work carried out for building GHG emissions scenarios related to SFH construction and renovation.

Firstly, the structure of the model will be described: demand considered, technologies described, constraints and description of the assumptions made in the different scenarios.

Then the different scenarios will be compared and main conclusions will be drawn upon these scenarios, discussing also the scale of the uncertainty on some parameters used.

Most of the assumptions are based on the results that were developed in the detailed description regarding:

- The description and the modelling of the demand that have been performed with IDD.
- The description of the different building systems based on existing constructions
- The analysis of the fabrication processes in Belgium for the different building materials
- The analysis of the different flows for the materials and waste concerned.

8.2.1. Definition of the system in MARKAL

8.2.1.1. Introduction

The aim of the development of a MARKAL model here is to make an assessment of the technico-economic potential of GHG emissions reduction through substitutions between SFH types for a given housing demand (and as a result substitution between materials involved in the construction and the renovation of SFH) as compared with emissions reductions through the production system, namely through eco-efficiency of technologies used to produce the materials.

8.2.2. Description of the different components

8.2.2.1. MARKAL modelling of housing construction : system definition

For the development of the modelling of the housing chain, the system has been delimited to :

- the demand for new SFH houses and renovation (including renovation with surface increase, light renovation with maintenance),
- the total residual demand for the most significant materials in the building sector (including domestic and foreign demand, so corresponding to the Belgian demand dedicated for needs different than single family houses),
- the production technologies and primary materials involved in the life cycle of the materials used for the construction and renovation of houses.

The structure of the model is summarised in Table 50.

	Residential housing
Horizon	2030 (however results will be significant for a 2020 horizon)
General definition of the system and its boundary	Product use, product elimination, material production processes and transport involved in the product preparation
Representation of the demand	Demand for new single family houses, renovated houses and house maintenance expressed in total surface
Level of description of the Belgian production system	Detailed description of the main processes encountered in Belgium and alternative technologies taking into account the industry investment plans. Exception for plastic production for which technologies are standard technologies.
Imports representation	Explicitly distinguished from Belgian processes (however of few importance given the low level of imports for most of the main building construction materials)
The level of detail of the energy system	Not explicitly described. Input data are based on scenarios performed with the Belgian energy MARKAL.
Interrelation with the overall system	Exogenous demand for materials involved in the product production but consumed by other products expressed as a residual demand
Material exports representation	Included in the residual demand (which so represent the Belgian production not dedicated to SFH construction and renovation)
Waste treatment	Incomplete accounting justified by the fact that the horizon is not far enough to take into account the demolition of houses built during the period studied and also to the fact that it may influence only slightly the energy performance of the system.

Table 50 : Structure of the product system models "Residential housing"

8.2.2.2. The demand

8.2.2.2.1. Demand for housing construction and renovation and demand processes

The demand over the period 1990-2030 for new SFH construction and renovation with surface increase is introduced exogenously in the model and is based on the reference results of the model LOCATELLI as developed by IDD.

For new construction, it is considered that a certain fraction of new SFH has a cellar and this is taken into account through a separate demand.

For “light renovation”, namely house maintenance (window replacing, roof replacing), the level of the demand is calculated as a constant percentage of the total existing houses, this percentage being based on the average lifetime of the elements to be replaced (20 years for window frames and 50 years for a roof) .

Both demands (construction and renovation) are expressed in terms of total surfaces.

In MARKAL processes that supply end-use commodities are designated as “demand process”. Regarding housing demand, demand processes consist in construction of houses of different types. As a result of the analysis of the main different houses types with regard to their material intensity and resulting life cycle emission[13]. Seven different types of houses and two types of renovation with surface increase are considered in the model. These are listed in Figure 48.

[13] In this chapter as in all the housing system description, life cycle emission actually doesn’t include emissions from heating. The houses compared here are such that they have the same insulation levels and so the same first order heat demand.

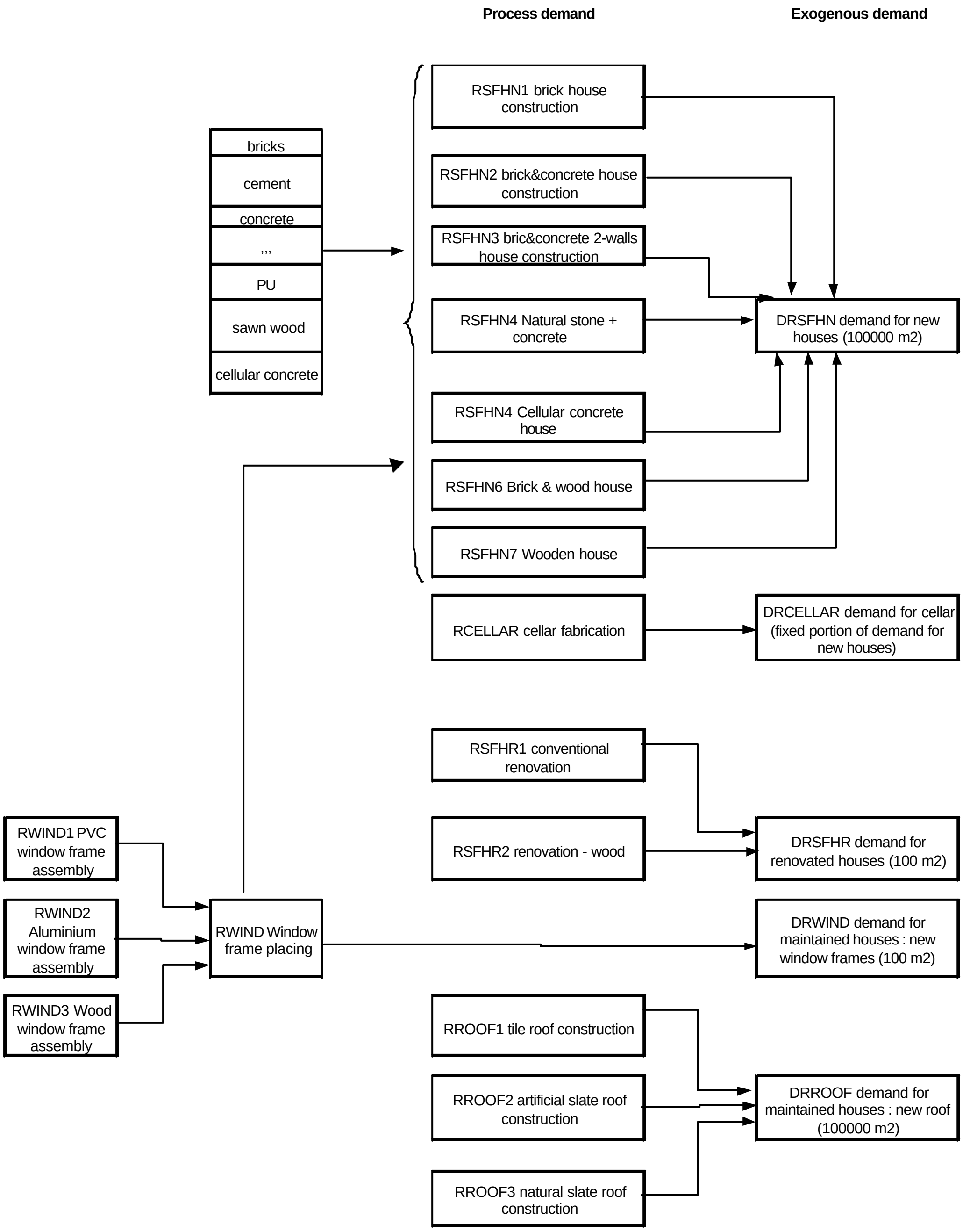


Figure 48 : Description of the demand and demand processes for the modelling of the residential housing chain

8.2.2.2.2. Residual demands

Even the MARKAL database developed here aims at modelling the housing system, the aim is also to compare the technico-economic emission reduction potential through building material substitution with the reduction potential that comes from technologies improvements. Furthermore, assessing the most realistic possible these technologies improvements requires to ensure some consistency of the system modelled and the actual industrial capacity in Belgium and the overall material flows. This consistency is especially necessary to be able to evaluate the possible influence of material substitution on technology choices under reduction target constrains and to take into account planned industrial changes.

Some materials in particular (cement or steel for instance) come from energy intensive processes and represent high CO_2 emissions at the national level. On the other side, as detailed in the analysis of the production system (IW, 2000)[14], alternatives to increase the energy efficiency exist and could be used in the future. However, material consumption by SFH new constructions will not be an enough driving force for switching these technologies.

Steel represents a special case : Single family houses represent about 6% of steel consumption so that a priori it is of small interest to represent residual demand for this material. However existing and possibly developing material flows exist with other material productions. Slag for instance is a by-product of blast furnace that can be used in the production of blast furnace cement. This inter linkage may offer possibilities to reduce GHG emissions. For this reason we choose to take into account a residual demand for steel.

For this reason we made calculations to simulate the evolution of demands for different materials for purposes other than construction and renovation of SFH. First we estimated from the analysis of material flows (IW, 2000)[15], the amount of the Belgian production o the different materials not dedicated to SFH construction and renovation.

Then evolution rates for the period 2000-2030 were used to evaluate the potential evolution of this residual demand. These rates were based on estimations done by KUL and VITO[16]. Results are given in Table 51.

Residual material demands are then given in kt from 1990 to 2000.

residual demand (increase rates)	1990-2000	2000-2005	2005-2010	2010-2030
bricks	1.56%	0.70%	0.50%	0.40%
cement	1.16%	0.70%	0.50%	0.40%
flat transformed glass	0.26%	0.70%	0.50%	0.40%
sawn wood	-0.53%	0.70%	0.50%	0.40%
wood-based panels	1.81%	0.70%	0.50%	0.40%
steel	-0.25%	0.20%	0.30%	0.10%

Table 51 : Evolution rates for material demands from 1990 to 2000 and from 2000 to 2030
Source : KULeuven and VITO

[14] Institut Wallon, 1999, Housing system analysis, Part III – Process description

[15] Institut Wallon, 1999, Housing system analysis, Part II - Material Flows Analysis

[16] KULeuven, VITO, 2000, Prospective Study of the Emissions in Belgium until 2008/2012 of the Greenhouse Gasses included in the Kyoto Protocol

residual demand (kt material)	1990	1995	2000	2005	2010	2015	2020	2025	2030
bricks	1,112	1,201	1,298	1,344	1,378	1,406	1,434	1,463	1,492
cement (production)	3,720	3,940	4,174	4,322	4,431	4,521	4,612	4,705	4,800
flat transformed glass	293	296	300	311	319	325	332	338	345
sawn wood	1,226	1,194	1,162	1,203	1,234	1,259	1,284	1,310	1,336
wood-based panels	470	514	562	582	597	609	621	634	646
steel (production)	11,040	10,900	10,762	10,870	11,034	11,089	11,145	11,201	11,257
lime	2,037	1,982	1,929	1,997	2,047	2,089	2,131	2,174	2,218

Table 52 : Residual demands of materials

8.2.2.3. Process technologies

Technologies described in the database are listed here below. Some of them are described in detail, namely with their energy and material inputs and outputs and, when relevant, with their process emissions : steel production processes, clinker production, cement, brick, wood processing especially. Others are described with less detail. This choice has been made at least for three main reasons :

- The low contribution of the material to the total life cycle emissions in the different houses considered

- The level of the Belgian production compared with imports being such that domestic production offers few improvement possibilities for reducing the GHG emissions

- A lack of more detailed information regarding costs or energy consumption.

In these cases an average emission factor is attributed to the material production based on life cycle analysis studies. They concern productions of synthetic materials (polyurethane, polystyrene, PVC), rockwool, flax, aluminium, plaster…

Industrial production	Item	Description
Bricks	CIBA	Brick production tunnel kiln
	CIBB	Brick production roller kiln
	CIBD	Tiles fabrication
Steel	CIGD	Coke oven
	CIGF	Sinter production
	CIGG	Steel blast furnace
	CIGH	Basic oxygen furnace
	CIGI	Steel : electric arc furnace
	CIGJ	Steel : cont. casting
	CIGK	Hot rolling
Clinker	CIUA	Cement clinker dry process
	CIUB	Cement clinker wet process
	CIUC	Cement clinker dry process with precalciner
	CIUD	Cement clinker dry process - CO2
Cement	CIUF	Portland cement production
	CIUG	Blended cement production
	CIUH	Blast furnace cement production
Concrete	CIUP	Ready mix concrete production
	CIUR	Concrete building blocks production
	CIUT	Cellular concrete fabrication
Other non metallic minerals	CIDA	Flat glass production
	CIQA	Gypsum production
	CIUU	Stone extraction
	CIUV	Rock wool production
	CIUX	Artificial tiles production
	CIUY	Slates extraction
	CIUZ	Gravel and sand extraction
	CMCO	Plaster fabrication
	IIUM	Quicklime production
Biomaterials	MINMNA	Wood Harvesting
	NIXB	Sawn wood production
	NIXC	Chipboard production
	MINMNZ	Flax cultivation
	IMPMNA1	Import of timber from Europe
	IMPMNA2	Import of timber from outside of Europe
	IILA	Solvay soda ask production
Others	IILB	Soda production (heavy)
	IMPIRO	Import of iron ore
	IMPMCU2	Import of natural slates
	IMPMMA	Import of aluminium
	IMPMPVC	Import of PVC
	IMPMPW	Import of PU
	IMPMSR	Import of resins
	IMPNAOH	Import of NaOH

8.2.2.4. Cost data

In the database developed costs data are represented for each technology being described in detail by investments costs, O&M and variable costs.

One comment is however to be done here :

In the MATTER study all technologies are described with their investment and O&M costs. In a comprehensive approach as followed in the MATTER approach where all product categories are modelled simultaneously it is indeed necessary to allow the model to optimize both over the supply side and the demand side under certain GHG emission constraints. This is only possible with the knowledge of investment costs.

Some observations have however to be done here :

First while energy technologies are intensively described in literature notably in the framework of different international frameworks (UNFCCC, OCDE, IEA,…) including on a economic point of view, process technologies even they are described on a technological point of view are more difficult to quantify on a economic perspective. Several elements explain these difficulties :

- Contrary to energy technologies, process technologies have gained less interest on a GES perspective, which explains why much less information is made available in literature.
- Investments in sectors are only partly described by the companies because of confidentiality.
- There is generally large variability in the costs data found in the literature and few elements are given that should be necessary to specify what makes part of the investment.
- The recent experience carried out by IW in the field of environmental expenditures has lead to this last conclusion (IW, 2000)[17].

In practice costs have been described in the current model either on the basis on existing estimations of investment cost and O&M, notably from the MATTER study either on existing data on delivery material costs.

Some consistency had to be found between both cost prices in order to reflect the actual market, especially the comparability between different building materials. This consistency was checked in a first step through a comparison of shadow prices calculated by the model for the different materials were compared with the market prices. For some materials (steel, bricks, concrete blocks especially) a great gap was observed between both prices.

This origin of this gap may be twofold :

- The level of accuracy of cost data for technologies may be low
- Some intermediary processing stages between processes described and demand are not described in the model and their cost is not taken into account, leading to some underestimate of the total averaged price of the end-use material.

[17] Institut Wallon, 2000, Bilan environnemental des entreprises en Région wallonne – Volet Dépenses environnementales – Données 1999.

When too large gaps were observed. O&M cost were adjusted to better fit market prices of the end-use materials.

8.2.2.5. Energy flows

The preparation of the MARKAL database for the building materials has to include a representation of the energy flows.

Two options were available :

- Represent the energy system on a very simplified way i.e. through the consideration of a limited set of energy fuels as used by the process described within the material system and dummy technologies characterised by mean emission factors and delivery costs **without** a description of the supply technologies.

- Represent the energy system in a more **detailed.** This could be done on the basis of the energy database as developed by VITO with some small simplifications in order to keep only the relevant technologies for the system defined.

The second solution should offer more consistency than the first one. However some disadvantages can be found :

- An automatic link between the energy database and the process technology database developed here is not so obvious on a technical point.

- The link is also difficult as a consequence of the choice of the system represented : the energy database aims to model all the energy system, including all domestic final energy demands (industry, residential, tertiary, transport), which implies to estimate residual final energy demands for sectors not concerned by the material demands included in the model. One difficulty for instance is to estimate realistic heat demands, and ensure consistency with regard to classical heat production and cogeneration.

As a result we have chosen the first option that consisted in defining different energy carriers with emission factors (based on IPCC emission factors for fossil fuels) and delivery costs.

For electricity, two types of productions have been considered :

The first production aims aim representing the electricity of the grid as produced by the evolving centralised power plants in Belgium. This average emission factor represents the resulting average emission over all the power plants. An average delivery cost is attributed. Both emission factor and costs over the period 1990-2030 have been deduced from scenarios previously built by VITO in a study on the electricity sector (VITO, 2000)[18]. Among the different scenarios developed by VITO one reference scenario was built under base case assumptions over the economic growth, the evolution of international prices of gas, coal and oil.

[18] VITO, 2000, Lange Termijn Scenarios, for Electrabel-SPE

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Emission factor (T CO_2/GJ)	0.092	0.094	0.083	0.058	0.051	0.052	0.068	0.101	0.121
Average cost (Euro/GJ)	19.4	11.2	10.2	10.1	10.1	11.0	11.5	12.5	12.1

Table 53 : Average emission factor and cost of electricity
Source : VITO

The second type of electricity production is the auto-production by the steel industry. The distinction of this production is justified by the significant use of blast furnace gas as a fuel in the electricity production resulting in a higher CO_2 emission factor than for electricity from the grid. An average emission factor of 0.117 t/GJ has been applied for all the period 1990-2030 for this production.

8.3. Description of the scenarios and results

8.3.1. Description of the scenarios

Five scenarios have been built in this study :

- Scenario BASE : in this scenario only residual demands are considered without any constraint on the CO_2 emissions.

- Scenario BASEHOUS : in this scenario, both residual demand and demand for new construction and renovations are taken into account, again without any limitation on CO_2 emissions.

- KYOTO scenario : in this scenario, only residual demands are considered and an emission reduction target is assumed for 2010 (-7.5% compared to emissions in 1990) and for 2030 (-15% compared to emissions in 2030).

- KYOTOH scenario : in this scenario, residual demands and demand for new construction and renovation are taken into account, with the same limitation as in the KYOTO scenario.

- KYOTOP scenario : same as KYOTOH but with constraints on the share between the different houses types.

The choice of these scenarios is to :

- Evaluate the scale of the life cycle emissions attributed to the SFH construction and renovation compared with the emissions produced by the residual demands.

- Estimate the cost of emission reduction resulting from process technology substitutions only.

- Estimate the possible influence of material substitution (through product – houses types – substitutions) on the overall system considered and the cost of emission reduction under such possible (free or drastic substitutions).

8.3.2. Results

<u>8.3.2.1. CO_2 emissions</u>

Total CO_2 emissions as calculated in the different scenarios are represented in Figure 49.

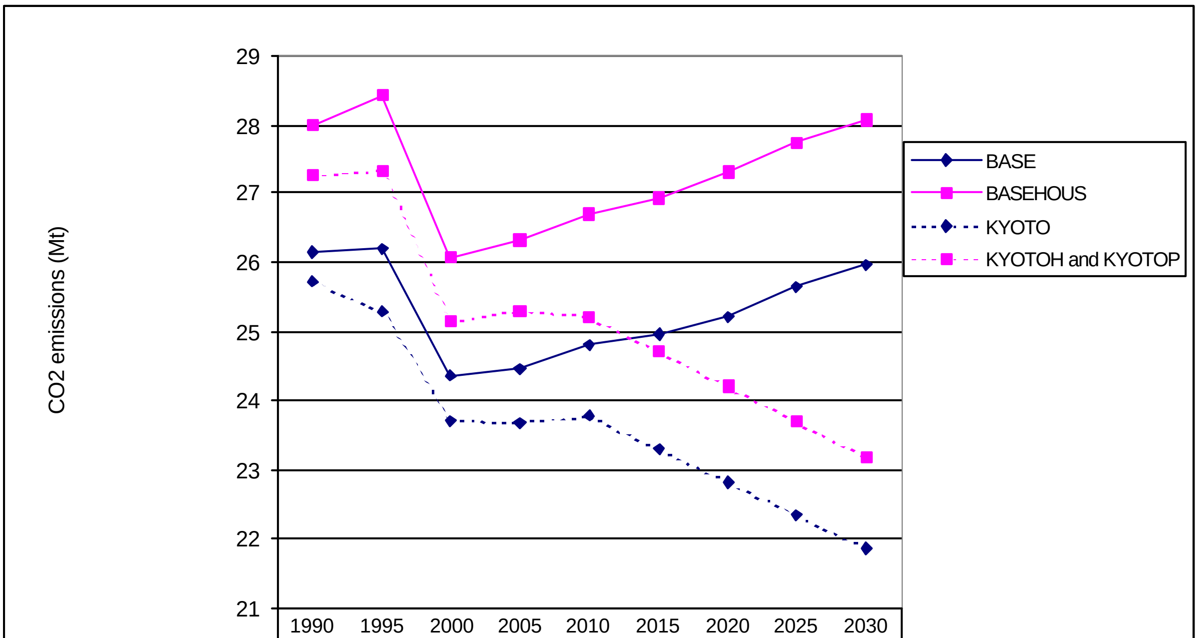
The emissions for the BASE scenario decrease substantially from 1990 to 2000 for three main reasons : on one side it reflects the trend of the decreasing average emission factor that is shown in Table 53 until 2015. On the other side it is explained by a temporary decrease of steel production in the early 90's. Finally planed investments being taken into account in the industry sectors result in a reduction of the specific emissions.

As a result, the levels of emissions in 2010 fit a –7.5% reduction target. However, for the longer term, increase of emission resumes up to 1990 levels in 2030.

The emissions in the BASEHOUS scenario allow deducing life cycle emissions from the addition of demand for new construction and renovations. As shown in Figure 49 and Table 54., emissions vary from 1855 to 2110 kt C and represent about 8% of the total emissions by the overall system.

The level of these emissions is decreased in the scenarios KYOTO, KYOTOH and KYOTOP.

The way such emissions reductions are reached is explained by a choice to different technologies as explained below.



	1990	1995	2000	2005	2010	2015	2020	2025	2030
BASE	26.158	26.196	24.351	24.465	24.802	24.953	25.221	25.65	25.968
BASEHOUS	28.003	28.42	26.078	26.315	26.708	26.918	27.299	27.75	28.077
KYOTO	25.71	25.3	23.693	23.681	23.78	23.3	22.82	22.33	21.85
KYOTOH and KYOTOP	27.27	27.34	25.143	25.285	25.22	24.71	24.2	23.69	23.18

Figure 49 : CO_2 emissions in the different scenarios

Life cycle emissions from construction and renovation	1990	1995	2000	2005	2010	2015	2020	2025	2030
Mt C	1.85	2.22	1.73	1.85	1.91	1.97	2.08	2.10	2.11
% of total emissions	0.07	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08

Table 54 : Life cycle emissions from construction and renovation

8.3.2.2. Technology and material substitutions

Given the system described, a limited set of technologies offers possibilities to reduce emission reductions. These main technologies are :

- Substitution of BOF steel production by EAF steel production
- Substitution of wet clinker production by dry clinker production with or without pre-calcination
- Substitution of roller kiln brick production by tunnel brick production
- Substitution of Portland and blended cement by blast furnace cement.

The contribution of the different technologies in the respective productions is illustrated in next figures.

For steel production, BAOF steel production remains the main production way until 2030 in both BASE and BASEHOUS scenarios while its contribution continuously decreases from 1990 to 2030 towards 58% and 55% depending on the inclusion of demand for housings.

It is to be noticed only a very small difference between scenarios KYOTOH and KYOTOP.

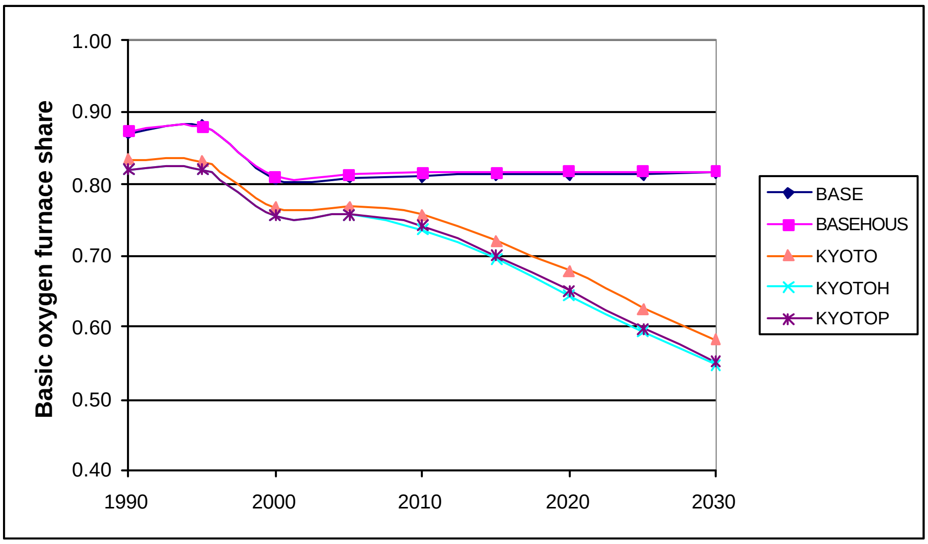


Figure 50 : Share of BOF steel production in the total production in the different scenarios

For clinker production for which it has been taken into account the investment plan of the sector for a progressive phasing out of the wet process in favour of the dry process with precalcination in the BASE scenario. The scenario BASEHOUS indicates a significant influence of the demand for SFH on the technology choice in the clinker production field. In that case dry process contributes less then in the previous case to the total clinker production. The difference is compensated by a larger contribution from the dry process with precalcination while the contribution from the wet process remains the same.

For the other three scenarios, both dry and wet processes lose importance in favour of the dry process with precalcination.

We see no difference between the KYOTOH and KYOTOP scenarios.

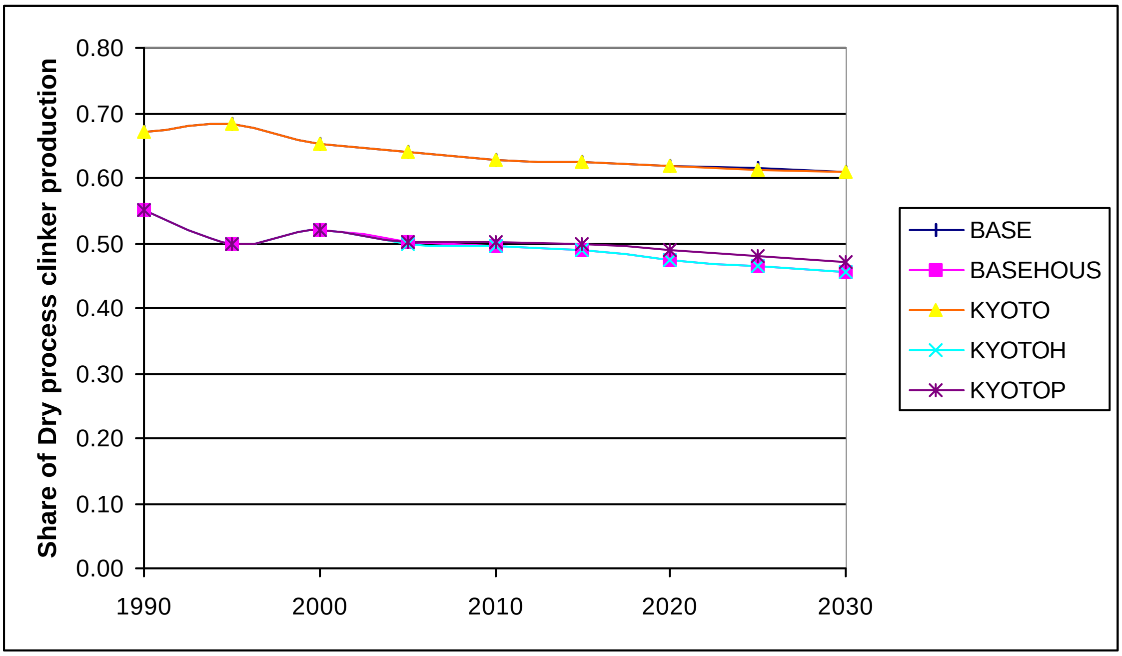


Figure 51 : Share of dry pro²cess clinker production in the total production

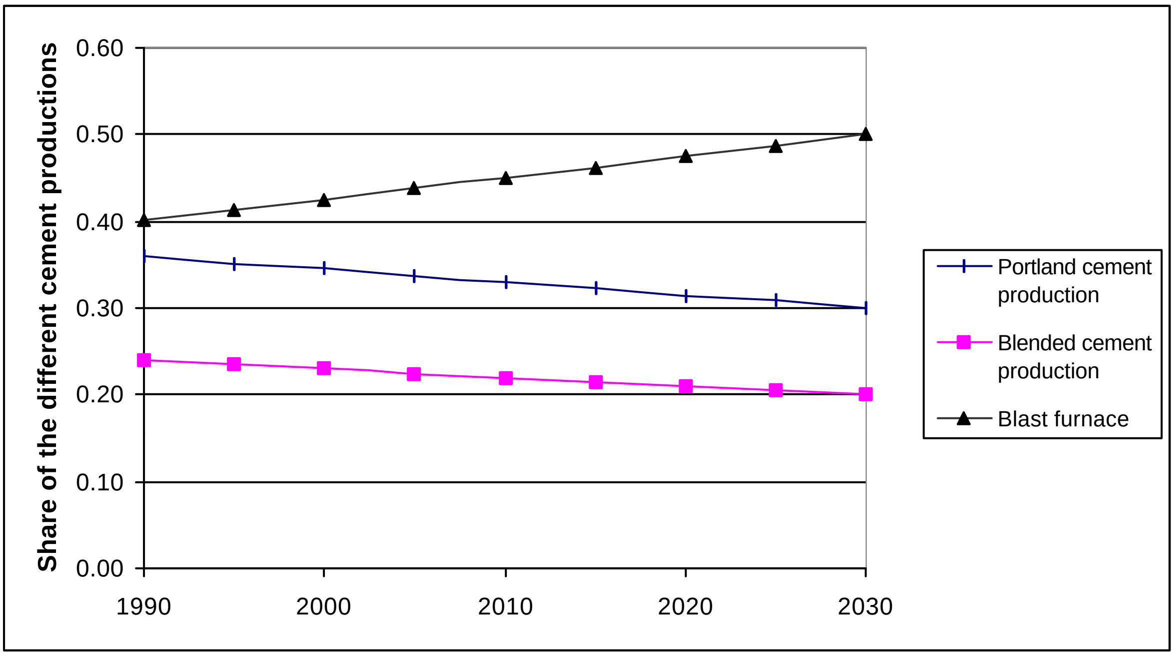


Figure 52 : Share of the different cement production (any scenario)

For cement production, all scenarios lead to the same result as shown in Figure 52. The contribution of blast furnace cement production increases steadily until 2030.

The fact that there is no difference between scenarios may be surprising with regard to the possible influence of a greater production of blast furnace on CO2 emissions as a result of a decrease of clinker consumption and hence of energy consumption. Such an option may be rather economically efficient.

This surprise comes from the evolution of the steel industry in the scenarios with emissions targets : the more the contribution of the EAF production is, the less blast furnace slag production is, becoming so less and less available for cement production.

For brick production roller kiln production remains the only process implemented until 2015 for the BASE, BASEHOUS and KYOTO scenarios. For the KYOTOH and KYOTOP scenario the technology change is observed after 2000.

There is no difference between scenarios KYOTOH and KYOTOP.

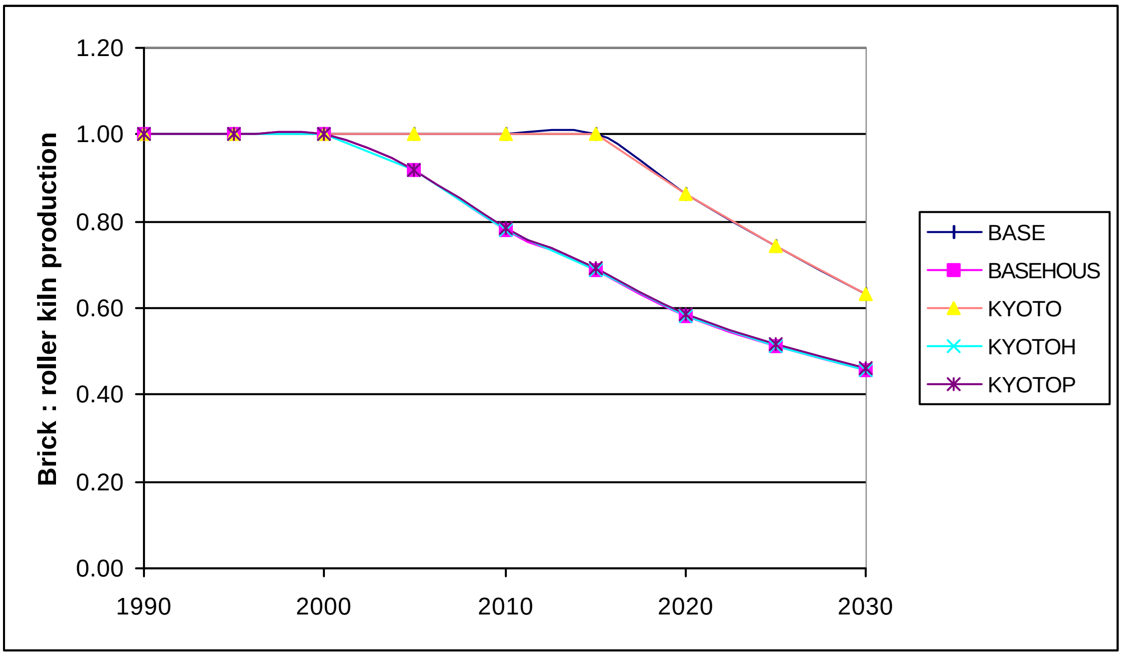


Figure 53 : share of roller kiln brick production in the total for the different scenarios

8.3.2.3. Product substitution

In the system modelled product substitution is possible through the choice of SFH types both for new construction and renovation.

The most striking result of the scenarios is the lack of difference in the contribution of the different construction types between a base case (BASEHOUS) and a scenario with targets (KYOTOH). We had to impose constraints on this share to observe a shift to more wood constructions for instance (see Figure 54).

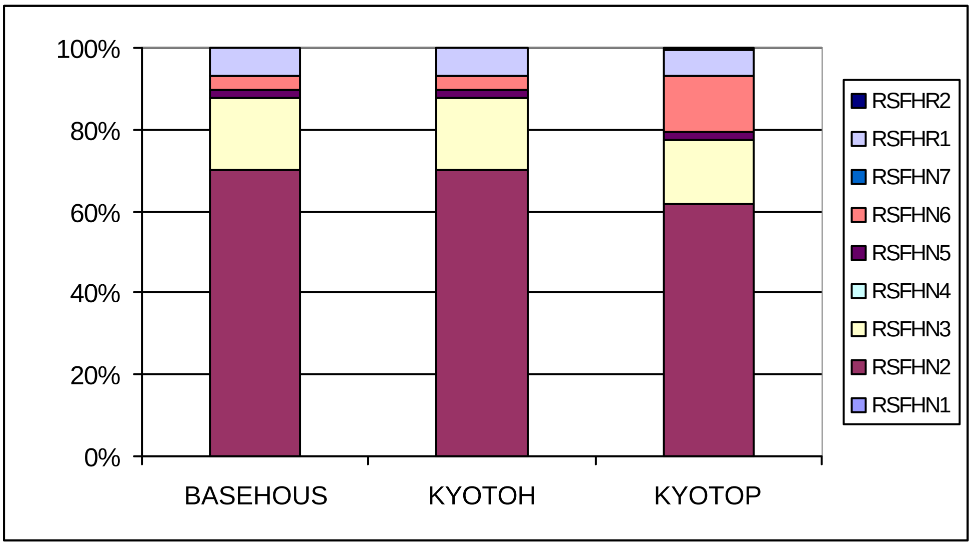


Figure 54 : Share of construction types in 2010 in the three scenarios BASEHOUS, KYOTOH and KYOTOP
RSFHN1 : brick house, RSFHN2 : brick&concrete house, RSFHN3 : brick&concrete house (terraced),
RSFH : stone&concrete house, RSFHNN : brick&wood house, RSFHN7 : wood house,
RSFHR1 : brick&concrete house, RSFHR2 : wood house

8.3.2.4. Cost of emissions reductions

Based on total cost estimated for the optimised system for all scenarios and on the total CO2 emissions, an estimation of the cost of emission reduction can be done. For this purpose we calculate the difference in cost and cumulated emissions over the period 1990-2030 between inter alia : KYOTO and BASE scenario, and between KYOTOH or KYOTOP and BASEHOUS scenario.

Next table gives the resulting costs for the reduction scenarios KYOTO, KYOTOH and KYOTOP. It indicates that the cost slightly increases when reduction efforts cover a larger volume of emissions.

When a constraint is put on the share of construction types, the costs is more than three times the costs without any constraints.

Scenario	**Total reduction over the 1990-2030 period (Mt CO2)**	**total additional cost compared with BASE or BASEHOUS scenarios (MEuro)**	**reduction cost (Euro/t CO2)**
KYOTO	-15.30	437	28
KYOTOH	-19.53	713	37
KYOTOP	-19.57	2,501	128

Table 55 : Cost of CO2 emissions reduction

8.3.2.5. Discussion of the results and uncertainty

Results described below indicate that for the system modelled, shift in technologies as a CO2 mitigation measure is more cost effective than shift in product types (here shift in construction type). In both scenarios KYOTO and KYOTOH where the model chooses freely the technologies that allow to minimise the total cost the same technology evolutions are observed. For the KYOTOH scenario we observe that the additional emission reduction to be achieved compared with the KYOTO scenario is accomplished through additional technology shifts and that no change is made on the product side.

This is due to the higher estimated price of “low emitting” houses (cellular concrete, brick&wood and wood houses) compared with the price of the more conventional houses (especially brick&concrete house). This comparison is shown in Figure 55 where the total cost price of houses are compared based on the marginal cost of the different material consumed for the construction. It suggests that among new constructions the cost of brick&house new construction is the smaller (either for detached or attached houses). Stone houses are about two times more expensive than conventional houses. Cellular concrete houses appear to be 10% more expensive while brick houses as well as wooden houses (brick&wood or full wood) are 20% more expensive.

As a result the technico-economic potential for reduction emission from product shifting is negligible compared with the technical potential.

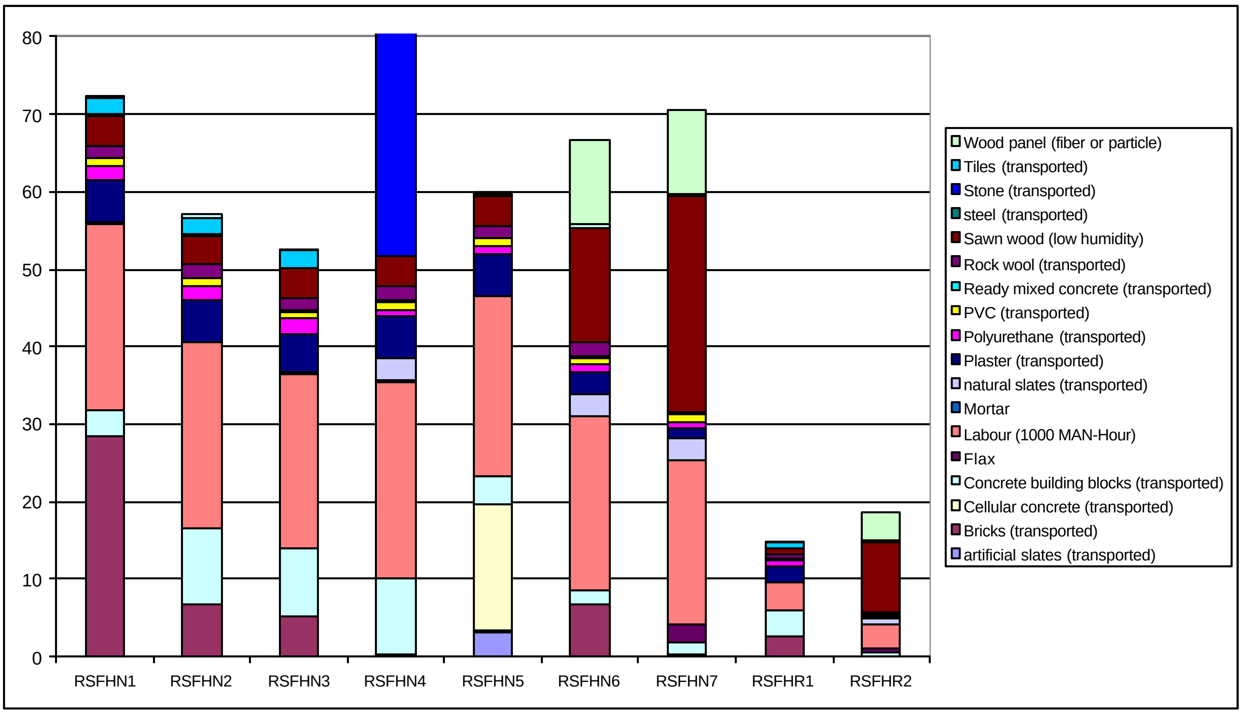


Figure 55 : Comparative prices of different types of houses
RSFHN1 : brick house, RSFHN2 : brick&concrete house, RSFHN3 : brick&concrete house (terraced),
RSFHN4 : stone&concrete house, RSFHN5 : cellular concrete house, RSFHN6 : brick&wood house, RSFHN7 : wood house,
RSFHR1 : brick&concrete house, RSFHR2 : wood house

This result indicates that on a pure economic perspective it makes sense to give priority to technology improvements as a CO_2 mitigation measure.

The result itself is however questioned by three major facts :

- The experience gained with this analysis indicated a substantial uncertainty on costs of technologies found in the literature. Despite these costs were adjusted in order to better reflect the market prices, and so better reproduce the comparative price of the different houses considered, there remain an unsolved gap between cost of technology shifts and cost of product shifts as CO_2 emissions reduction measures. Cost of technology shift depends on the comparative costs of competing technologies that may be subject to high uncertainty.

- Results may be influenced by the limitation made on the system modelled. However it is very uneasy to check this possibility.

- Then costs data assumed do not take into account a possible influence of the market development on technology costs.

Further analysis of the uncertainty of results should be fruitful. However a proper treatment of uncertainty is not straightforward with MARKAL and an intensive work should be made to overcome this limitation which is out of the scope of this study.

9. Discussion of uncertainty

One of the major difficulty encountered all along this system analysis has been the uncertainty that affected the different stages of calculations. In the framework of this project we were not able to make a detailed analysis of the uncertainty on the results regarding the evaluation of the emissions reduction potentials. Besides the influence of the evolution demand scenario assumed (see IDD, 2000)[29] we can list the different types of uncertainties and discuss their possible implications on the quality of the results.

- Representitiveness of houses types considered with respect to the actual diversity of the SFH

This issue both refers to the material composition of houses and to the architecture of the houses.

- It was out of the scope of this study to carry out an exhaustive analysis of the different houses types with respect to all possible material combinations. A larger inclusion of different houses types in the study might have allowed to highlight a more continuous transition path from conventional houses towards other types with continuous decrease of GHG emissions. Representing such a houses continuum may be had result in more economically efficient emission reductions in MARKAL.

- Representitiveness of the architectural assumptions with respect to the actual diversity of the SFH market : as shown in Annex II, uncertainty on the relationship between major building elements (exterior and interior walls) and the ground surface may reach from 20% to 25%. This uncertainty on its turn leads to uncertainty on the mean material and indirect GHG emissions uncertainty for a selected house. This uncertainty has implication on the estimation of the overall indirect GHG emissions resulting from all SFH constructions and renovation in Belgium. On the opposite this has no effect on the qualitative comparison of performances of different types of houses for a same total surface.

- Energy consumption and process emissions in the production system

Here we may distinguish two types of processes :

- For processes described with detail in MARKAL and for which mutual alternative are taken into account. In this case uncertainty present a double implication. First uncertainty may result in either in overestimation either in underestimation on advantage from shifts from technologies to others. Secondly this uncertainty may influence unjustified preferences to some defined materials by the model.

- For processes not described in detail this uncertainty may influence unjustified preferences to some defined materials by the model.

  We can estimate that the uncertainty on emissions factors is the greatest for this second category because data were based on literature information were few detail was given on the assumptions made and were data were estimated without any reference to the national situation. We estimate that the uncertainty in these cases could reach 50%.

- Uncertainty on costs

  As mentioned 8.2.2.4 and in 8.3.2.5, uncertainty on costs in general is high and has major implications on the conclusions that can been drawn about economic efficiency of the technical potential improvements as estimated in 7.4.

  While this technical potential is entirely independent on costs data the evaluation of its economic feasibility is highly determined by these data. The large uncertainty as experienced in chapter 7 represents a limitation in the interpretation of the results.

10. Conclusions

In the framework of this study we performed an detailed analysis of the SFH system in order to evaluate the life cycle emission reduction potential of construction and renovation of SFH on the level of Belgium.

The analysis has been made through different steps, going from the description of the current houses demand, through the description of different houses types, of the relevant material flows and industrial process to the evaluation of the indirect GHG emissions and the potential for emissions reductions both on a technical and restricted product perspective and on an economic perspective.

The evaluation of the demand has shown that residential housing, especially SFH represents an important demand in Belgium with some increasing trends, notably with respect to living surface.

Different building practices with respect to material composition has been described and material consumption has been quantified. This evaluation has shown the primacy of a limited set of materials in the total material intensity, especially concrete and bricks.

The analysis of the building material flows in Belgium has allowed to highlight the low levels of international trades for the most important materials (cement, concrete, brick). The situation is more complicated for steel, wood and glass as intermediary flows are more important. We could also estimate the consumption of these materials for SFH construction and renovation compared with the total domestic consumption.

The estimation of material intensities and indirect emissions indicated a high possible emission reduction potential from shifting from conventional houses to cellular concrete and wooden houses (up to 25% emission decrease). Such a potential also exists if shifting from construction to renovation (up to 66% emission decrease).

At the level of the overall Belgian market given the possible evolution demand for construction and renovation we estimated that an increase of the share of non conventional houses by up to 25% of the market, may help to reduce the indirect emissions in 2010 resulting from this demand by 6% compared with 1990 levels.

Then a technico-economic analysis has been carried on with MARKAL. This analysis lead to the conclusion that for the product system studied technology improvements at the supply side offer more economically efficient measures to reduce GHG emissions reductions than material and product shifting.

This conclusion is largely based on technology and material costs where uncertainty is high.

Appendix I :

Relationship between material contents and house surface

The purpose of this annex is to deduce the shape of the relationship between the quantities of material used for the building of the different elements (roof, exterior walls, floors, interior walls) and the ground surface (or living surface).

Let S_g be the ground surface of a house. It is possible to represent the quantities Q_{ij} of material i content in element j as functions of this surface. This can be made if we assume a reference house as a rectangle of height h, width l and length L. The roof is supposed to have a standard inclination a..

It is easy to show that quantities Q_{ir} for the <u>roof construction</u> are given by the formula :

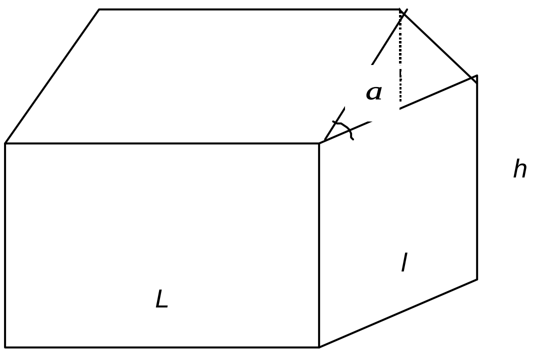
$$Q_{ir} = q_{ir} \cdot \frac{S_g}{\cos \cdot a}$$

where q_{ir} is the quantity of material per unit of <u>roof</u> surface.

Quantities Q_{if} of material used for <u>grounds</u> will depend on the floors number n_f and are simply given by :

$$Q_{ig} = q_{ig} \cdot n_f \cdot S_g$$

where q_{ig} represents the quantity of material i per unit of ground surface.



For materials used for exterior walls, it can be stated that for most material quantities will be proportional to the wall surface. If d represents the fraction of exterior walls occupied by windows, this surface is given by

$$(1-d)\cdot\left[2h(L+l)+\frac{l^2}{2}\cdot tg(a)\right]$$

if

$$l=\frac{l}{L}$$

We can deduce that :

$$Q_{iw}=q_{iw_e}(1-d)\cdot\left[2h(1+l)\cdot\sqrt{\frac{S_g}{l}}+\frac{l\cdot S_g\cdot tg(a)}{2}\right].$$

where q_{iw_e} is the quantity of material per unit of exterior wall surface.

We have also :

$$S=\frac{D^2}{4l\cdot(1+l)}$$

A similar relation can be used for interior walls..

Let's suppose that the reference house comprises interior walls having a total l_w length across width and L_w length in length[19]. Let a_l and a_L be such that

$$l_w=a_l\cdot l$$
$$L_w=a_L\cdot L$$

We will assume that the average height of the interior walls is $h+\frac{l}{4}\cdot tg\cdot a$ and that the fraction of interior walls occupied by interior doors is q. Then if q_{iw_i} is the quantity of material i needed per interior wall surface unit, the total amount of this material needed is given by :

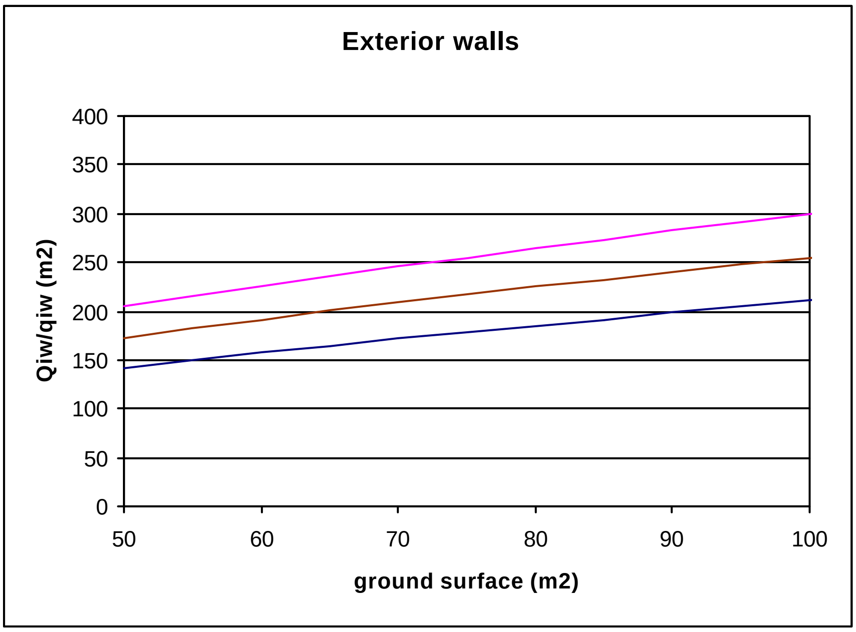
[19] Distinction should be further made between carrier and non carrier walls

$$Q_{iw} = q_{iw_i}(1-\theta)\cdot\sqrt{\frac{S_g}{\lambda}}\cdot(a_L + \lambda\cdot a_l)\cdot\left[h+\frac{tg\cdot\alpha}{4}\sqrt{\lambda\cdot S_g}\right]$$

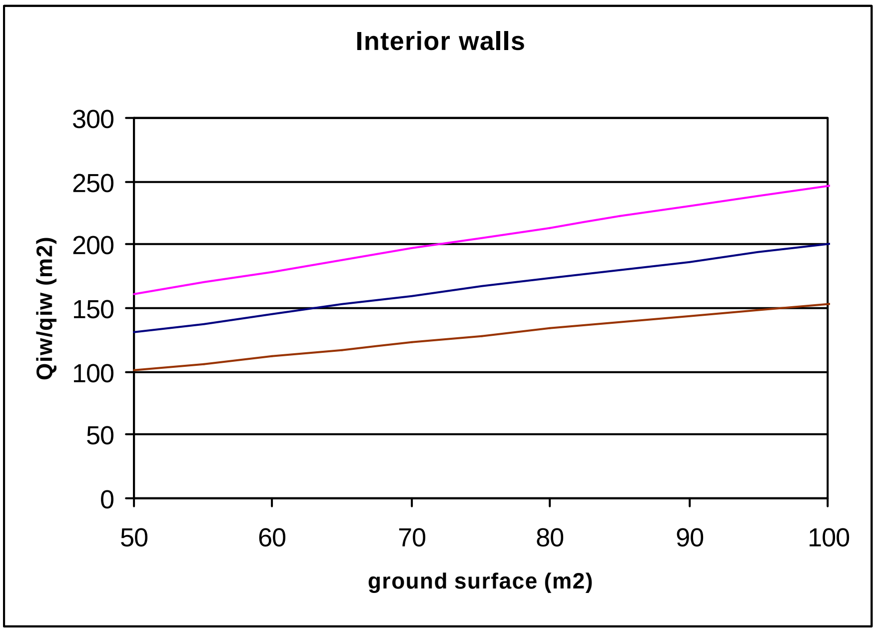
These functions can be calculated for the following values for different values of the parameters a_l, a_L, α, δ and λ. This has been done for three sets of values (see next table) supposed to represent extreme situations (min and max values) and average situation (mean values). They are illustrated in the next figures where it clearly appears that the relationship is quasi linear in the surface range represented. However, the selected parameters result in a significant dispersion of the curve : about 20% for the exterior walls and up to 40% for the internal walls.

	min	mean	max	
H	5.0	6.3	7.5	m
Alpha	0.8	0.8	0.8	
Delta	0.1	0.1	0.1	
Teta	0.1	0.1	0.1	
Lambda	0.78	0.800	0.82	
a_l	1.0	1.3	1.6	
a_L	1.0	1.3	1.6	

Assumptions made about the different geometrical parameters of SFH



Level of uncertainty on the relationship between the exterior wall surface and the ground surface



Level of uncertainty on the relationship between the interioir wall surface and the ground surface

Appendix II
Building thermal insulation

The thermal insulation of a building is the result of the thermal insulation of each component, namely, walls (exterior, interior), windows, roof, soils. Its depends on the thermal conductivity of each of those component and on the compactness of the building (heated volume divided by heat loss surface).

The global insulation level of the building is designated by the coefficient K.

On its turn, each component is characterized by its k coefficient expressed in W/m^2.K that gives the heat loss per unit of (wall or roof) surface for a 1 Kelvin temperature discrepancy between the interior and the exterior. Then the heat conduction Q across the surface is given by :

$$Q = (k + a) \cdot \Delta T$$

where DT is the difference of temperature between the internal face and the external face of the surface and a is the convective conductivity of the air strips at the internal and external surfaces of the element. For normal conditions the standard value for a is 0.17.

The k value depends on the materials used and the thickness of the different layers that compose the building element. The thermal conductivity k_i of each layer i of thickness e_i (see Figure 56) is given by

$$\frac{1}{k_i} = R_i = \frac{e_i}{l_i} + R_a$$

Where l_i is the thermal conductivity of the material (W/m.K), R_i is the thermal resistance of the material and R_a is the thermal resistance of air. For full ventilated layers the resistance is 0.17 m.K/W and for incompletely ventilated layers it is 0.08.

Then the k value of the all element is given by :

$$\frac{1}{k} = \sum \frac{1}{k_i} + \frac{1}{a}$$

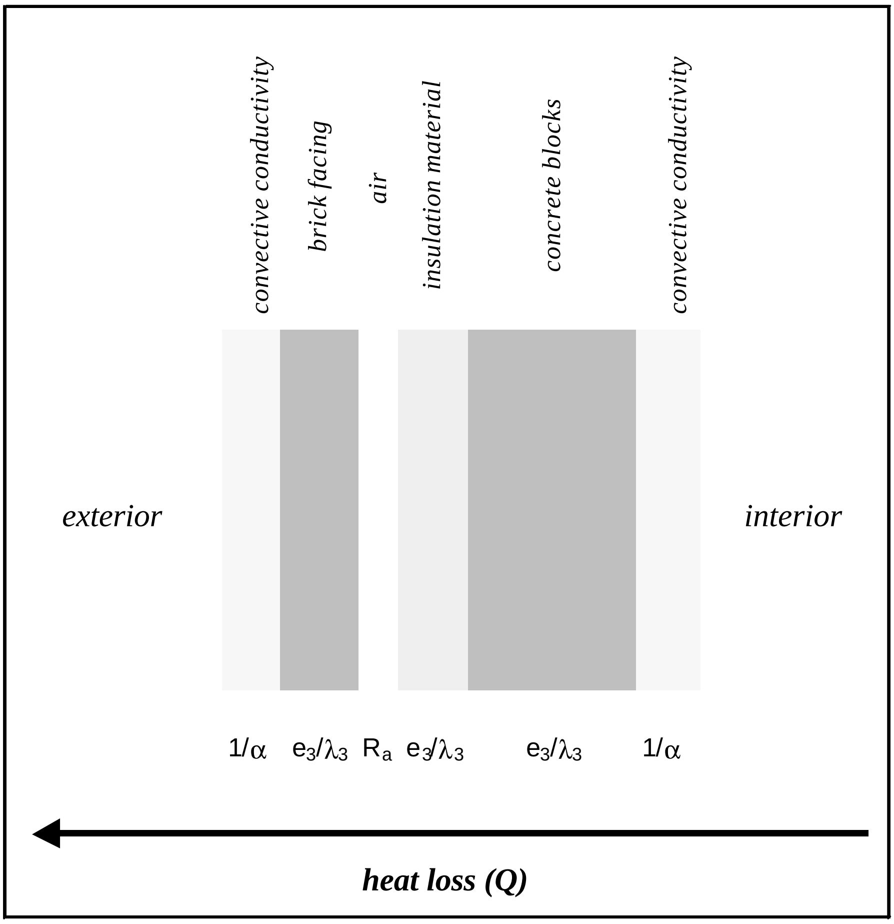

convective conductivity
brick facing
air
insulation material
concrete blocks
convective conductivity
exterior
interior
1/α e3/λ3 Ra e3/λ3 e3/λ3 1/α
heat loss (Q)

Figure 56

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