Grey Energy of Buildings Materials

Dr. arch. Sophie Trachte

13th October 2012
Challenges

«A development which meets the needs for the generations of the present without compromising the capacity of the future generations to answer theirs » Brundtland Report, 1987

Impacts of the building sector in Europe:

- 50 % of natural resources depletion;
- 45 % of energy consumption;
- 40 % of waste production;
- 30 % of greenhouse gas emissions;
- 16 % of water consumption

Source: Traité d’architecture et d’urbanisme bioclimatique, Observ’ER, Paris, 2005
Challenges

Building sector is a key sector in Europe...

...it is also a major consumer of energy...

...it consumes a lot of resources...

... BUT it offers a great potential for improvement, especially in terms of greenhouse gases emissions and use of resources (recycling potential)

The choice of materials is a fundamental step:

- Buildings material is the base, the substance which will give shape and form to architecture;
- Selecting and assembling materials to create a building is a complex process based on a variety of constraints and knowledge and on different scales of time and space.
With the objective of designing energy efficient buildings in a sustainable way:

- **Improve comfort, well-being and quality of life while limiting/reducing environmental impacts**

  - **Scale of time:**
    From the design to the demolition, from extraction of raw materials to end of life;

  - **Scale of space:**
    From the interior of a room to the global scale of the planet, through the public space, the city blocks and the city
Life cycle
The life cycle of a building material can be considered as the set of transformations undergone by the material from the extraction of raw materials to the end of life and waste treatment.
Building materials and life cycle

Extraction of raw materials:
Nature of raw materials
Type of resources used - availability / renewal
Footprint

Production / transformation:
Type of raw materials used
Type and amount of energy used
Type of transformations

End of life
Deconstruction ➞ demolition
Type of treatment
Valorization / recycling

Implementation
Type of assembly
Reversibility / Flexibility
Implementation and additives
Impact on health (workers)

Life in use
Lifespan of buildings materials
Preservation of performances
Impact on health (occupants)
Building materials and environmental impacts

Consumption of non energy resources
Type of resources, availability, renouvellement

Consumption of energy resources
Embodied energy, grey energy, renewable and non-renewable energy

Environmental impacts:
Pollution of atmospheric air, waters and soils
Landscape changes, loss of biodiversity

Health impact (workers/occupants):
Use of toxic materials (production, implementation)
Emission of physical and chemical pollutants...

Waste production
Recycling potential, existence of recycling options
Type of assembling
Quantification and evaluation of environmental impacts

« LCA provides a method to quantify and evaluate the potential environmental impacts of a product from the extraction of raw materials to its disposal at end of life, through the phases of production, distribution and use »

EN ISO 14040: Environmental management– Life cycle analysis– Principles and framework, 2006

• Norme EN ISO 14040: LCA - principles and framework
• Norme EN ISO 14044: LCA - Requirements and guidelines
Function
The function of a painting is to protect and color a wall

Functional unit
Quantification of the function
Covering 1m² of wall over 5 years

Reference flow
Quantity of the product analyzed and/or substances used to meet the needs of the functional unit
2 liters, 5 or 10 liters

Limits of the system
Defining the limits of the study (steps included):
• Cradle to gate
• Cradle to grave
Building materials and life cycle analysis

According to ISO standard 14044, the potential environmental impacts to be mandatory covered are:

- **Natural resources depletion (energy and non energy resources)**
- **Global warming**
- **Acidification**
- **Eutrophication**
- **Stratospheric ozone depletion**
- **Photochemical ozone creation**

Some potential impacts are not necessarily taken into account:

- Impact of human activities on landscape
- Impact of nuisances caused by human activities: noise, odors
- Impact of the potential toxicity of products emitted or used on environment or on human health

**LCA is not intended to cover all environmental issues: only what is quantitative (measurable) and extensive (summable) is taken into account**
Embodied energy [kWh/kg product]

Embodied energy is the energy required by the production process of a product.

Embodied energy = process energy requirement

Embodied energy is the energy consumed by all of the processes associated with the production of a building material, from the mining and processing of natural resources to manufacturing, transport and product delivery.

Embodied energy does not include the operation and disposal of the building material.
**Grey energy** [MJ/kg product]

Grey energy is the energy required by all the transformations undergone by a product throughout its life cycle.

Grey energy, calculated in primary energy, can be divided into 4 types of energy:

- **Primary renewable energy**
- **Primary non renewable energy (NRE)**
- **Primary energy « material »** : this energy takes into account the energy stored in materials and theoretically recoverable at end of life.
- **Primary energy « process »** : this energy takes into account the energy used in operations of processing, operating and transportation over its life cycle.

<table>
<thead>
<tr>
<th>Type of primary energy</th>
<th>Renewable</th>
<th>Non renewable</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATERIAL</td>
<td>Primary renewable energy « material »</td>
<td>Primary non renewable energy « material »</td>
<td>Total of primary energy « material »</td>
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<tr>
<td>PROCESS</td>
<td>Primary renewable energy « process »</td>
<td>Primary non renewable energy « process »</td>
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<tr>
<td>TOTAL</td>
<td>Total of primary renewable energy</td>
<td>Total of primary non renewable energy</td>
<td>GREY ENERGY</td>
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<td>Matériaux et composants</td>
<td>Densité $\rho$ kg/m$^3$</td>
<td>Ressources (DAR) fabrication kg antim.-Eq/kg</td>
<td>Energie grise fabrication MJ/kg</td>
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Comparison – grey energy and heating energy

Comparison over 50 years
UCL: Sophie Trachte / Catherine Massart
Comparison – grey energy and heating energy

- Two cases of walls composition were selected:
  - [✔] with an important GWP
  - [✖] with a low GWP

- The wall compositions were analyzed over 50 years taking into account average lifetime of used materials.

- “Cradle to gate” phase, replacement and “end of life” phase were analysed.

- Life cycle inventory values have been selected among 3 databases: ECOSOFT, KBOB/ECO-BAU/IPB and ECOINVENT.
Comparison – grey energy and heating energy

<table>
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<th></th>
<th>Passivhaus Standard</th>
<th>Low energy Standard</th>
<th>EPB</th>
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<tr>
<td>Energy per m²/yr</td>
<td>10 kWh/m²/year</td>
<td>15 kWh/m²/year</td>
<td>38 kWh/m²/year</td>
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</table>

### Comparison over 50 years

- Grey energy - building materials
- Operational energy: heating

Comparison over 50 years

UCL: Sophie Trachte / Catherine Massart
Grey energy and transport
Grey energy and transport

**Grey energy (MJ/tpkm)**
- Camion 16t
- Camion 28t
- Camion 40t
- Camionnette (<3.5t)
- Train de marchandises
- Navigation intérieure
- Navigation haute mer
- Avion de fret europe
- Avion de fret intercontinental

**GWP (kgCO2equ./tpkm)**
- Série 1
- Série 2
- Série 3
- Série 4
- Série 5
- Série 6
- Série 7
- Série 8
- Série 9

**Acidification (kgSO2equ./tpkm)**
- Série 1
- Série 2
- Série 3
- Série 4
- Série 5
- Série 6
- Série 7
- Série 8
- Série 9

**Photochemical ozone (kg ethylène.equ./tpkm)**
- Série 1
- Série 2
- Série 3
- Série 4
- Série 5
- Série 6
- Série 7
- Série 8
- Série 9
Grey energy and transport

Does « local » building material really limit the impact of transport?

1: Belgium – 90 km
2: Benelux – 200 km
3. Neighboring regions – 500 km
4. Neighboring countries – 1000 km
5. Close Europe – 2000 km
6. Wider Europe – 4500 km
7. World – 10 000km
Grey energy and transport

*Energy* consumption calculated per ton multiplied by the **number of km covered**

The mode of transport influences more the environmental impact that the distance
Grey energy and transport

- Siberian wood: 10,000 km by road (truck)
- Brazilian wood: 10,000 km by sea (90%) and road (10%)
- German wood: 500 km by road (truck)
- German wood: 500 km by train
Environmental product declaration (EPD)

Environmental product declarations are statements prepared under the responsibility of buildings materials/ products manufacturers according to the standard ISO 14025

Information sheets - verified by an independent third party - in which the manufacturer provides, based on a life cycle analysis, quantitative data on the environmental impact of the product
- cradle to gate
- cradle to grave

OBJECTIVE:
To compare two products with the same functional unit
Example:
1m² of concrete or terracotta roofing tile
## Grey energy – assessment tools

<table>
<thead>
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<th>Impact environnemental</th>
<th>Unité par UF</th>
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<td>Energie primaire totale</td>
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<td></td>
<td></td>
<td>Energie renouvelable</td>
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<tr>
<td></td>
<td></td>
<td>Energie non renouvelable</td>
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<td>2</td>
<td>Épuisement des ressources</td>
<td>Kg équivalent Antimoine</td>
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<td>3</td>
<td>Consommation d’eau totale</td>
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<tr>
<td>4</td>
<td>Déchets solides valorisés total</td>
<td>kg</td>
</tr>
<tr>
<td></td>
<td>Déchets dangereux</td>
<td>kg</td>
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<tr>
<td></td>
<td>Déchets non dangereux</td>
<td>kg</td>
</tr>
<tr>
<td></td>
<td>Déchets inertes</td>
<td>kg</td>
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<tr>
<td></td>
<td>Déchets radioactifs</td>
<td>kg</td>
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<tr>
<td>5</td>
<td>Changement climatique</td>
<td>Kg équivalent CO2</td>
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<td>6</td>
<td>Acidification atmosphérique</td>
<td>Kg équivalent SO2</td>
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<tr>
<td>7</td>
<td>Pollution de l’air</td>
<td>m³</td>
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<tr>
<td>8</td>
<td>Pollution de l’eau</td>
<td>m³</td>
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<td>9</td>
<td>Destruction de la couche d’ozone stratosphérique</td>
<td>kg équivalent CFC</td>
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<tr>
<td>10</td>
<td>Formation d’ozone photochimique</td>
<td>kg équivalent éthylène</td>
</tr>
</tbody>
</table>
Grey energy – assessment tools

Checklists

www.bre.co.uk
www.ecobau.ch
www.nibe.org
www.baubook.info
Grey energy – assessment tools

LCA Softwares

www.envestv2.bre.co.uk
www.ecobat.ch
www.ibo.at
www.catalogueconstruction.ch
Case study – comparison between blocks

> Performances physiques

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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</thead>
<tbody>
<tr>
<td>épaisseur totale [m]</td>
<td>0.335</td>
<td>0.34</td>
<td>0.46</td>
</tr>
<tr>
<td>Coeff. de transmission thermique U [W/m²K]</td>
<td>0.193</td>
<td>0.194</td>
<td>0.192</td>
</tr>
<tr>
<td>Inertie thermique [kJ/m²K]</td>
<td>306</td>
<td>308</td>
<td>308</td>
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<tr>
<td>Affaiblissement acoustique dB</td>
<td>&gt; 55 dB</td>
<td>&gt; 65 dB</td>
<td>&gt; 65 dB</td>
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> Composants

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<th>[m]</th>
<th>Composants</th>
<th>durée de vie</th>
<th>remplacement</th>
<th>élimination</th>
<th>description technique</th>
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<td>0.02</td>
<td>enduit au plâtre</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td>Le bloc de béton choisi a une densité de 2000kg/m³</td>
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<td>0.14</td>
<td>bloc béton (90%)</td>
<td>&gt; 50</td>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
<td></td>
<td>mortier ciment (10%)</td>
<td>&gt; 50</td>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
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<td>0.17</td>
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<td>2</td>
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<td>4</td>
<td>0.005</td>
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<td>30</td>
<td>1</td>
<td>2</td>
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</table>

Density
- Concrete : 2000kg/m³
- Terra cotta : 1000kg/m³
- Cellular concrete: 650kg/m³
Case study – comparison between blocks

> Performances physiques

<table>
<thead>
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<th>C</th>
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<td>0.34</td>
<td>0.46</td>
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<tr>
<td>Coeff. de transmission thermique U</td>
<td>0.192</td>
<td>0.192</td>
<td>0.195</td>
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<tr>
<td>Inertie thermique</td>
<td>166</td>
<td>166</td>
<td>168</td>
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<tr>
<td>Affaiblissement acoustique</td>
<td>48 dB</td>
<td>62 dB</td>
<td>62 dB</td>
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> Performances physiques

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<td>123.5</td>
<td>125.5</td>
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<tr>
<td>Affaiblissement acoustique</td>
<td>41 dB</td>
<td>57 dB</td>
<td>57 dB</td>
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</tbody>
</table>
Case study – comparison between blocks

Environmental performances (over 50 years: production/ replacement/ elimination)

Grey energy: 288,76 MJ/m²
GWP: 37,38 kgCO₂/m²
AP: 0,0792 kgSO₂/m²
POCP: 0,0027 kgC₂H₂/m²

Grey energy: 446,26 MJ/m²
GWP: 37,12 kgCO₂/m²
AP: 0,0892 kgSO₂/m²
POCP: 0,0052 kgC₂H₂/m²

Grey energy: 554,19 MJ/m²
GWP: 47,64 kgCO₂/m²
AP: 0,0735 kgSO₂/m²
POCP: 0,0029 kgC₂H₂/m²
Case study – comparison between blocks

Resources depletion

<table>
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<tr>
<th>[m]</th>
<th>Composants</th>
<th>Quantité [kg]</th>
<th>Nature</th>
<th>Caractéristique</th>
<th>Origine</th>
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<tr>
<td>1</td>
<td>enduit au plâtre</td>
<td>52</td>
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<tr>
<td>2</td>
<td>bloc béton (90%)</td>
<td>252</td>
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<tr>
<td>2</td>
<td>mortier ciment (10%)</td>
<td>23.80</td>
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<td>3</td>
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<td>10.2</td>
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<td>4</td>
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<tr>
<td>2</td>
<td>bloc terre cuite plein (90%)</td>
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<td>bloc béton cellulaire (97%)</td>
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Architecture et climat

13th October 2012
Case study – comparison between blocks

Recycling potential

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<th>Composants</th>
<th>Recycled content</th>
<th>Recyclabilité</th>
<th>Moyen d’assemblage</th>
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<td>3</td>
<td>isolant EPS (polystyrène expansé)</td>
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<tr>
<td>4</td>
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<th>Situation filière</th>
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<td></td>
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<tr>
<td>2</td>
<td>bloc terre cuite plein (90%)</td>
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<tr>
<td>2</td>
<td>mortier ciment (10%)</td>
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<tr>
<td>3</td>
<td>isolant EPS (polystyrène expansé)</td>
<td></td>
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<tr>
<td>4</td>
<td>enduit à résines synthétiques</td>
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<td></td>
<td></td>
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<tr>
<td>2</td>
<td>bloc béton cellulaire (97%)</td>
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<td>mortier colle (3%)</td>
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<td>isolant EPS (polystyrène expansé)</td>
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<td>4</td>
<td>enduit à résines synthétiques</td>
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Case study – comparison between walls

> Performances physiques

<table>
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<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>Épaisseur totale</td>
<td>0.335</td>
<td>0.34</td>
<td>0.46</td>
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<tr>
<td>Coeff. de transmission thermique U</td>
<td>0.193</td>
<td>0.194</td>
<td>0.192</td>
</tr>
<tr>
<td>Inertie thermique</td>
<td>306</td>
<td>308</td>
<td>308</td>
</tr>
<tr>
<td>Affaiblissement acoustique</td>
<td>&gt; 55 dB</td>
<td>&gt; 65 dB</td>
<td>&gt; 65 dB</td>
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</table>

> Composants

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th>durée de vie</th>
<th>remplacement</th>
<th>élimination</th>
<th>description technique</th>
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<tbody>
<tr>
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<td>0.02</td>
<td>enduit à la chaux</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td>Le bloc de béton choisi a une densité de 2000kg/m³</td>
</tr>
<tr>
<td>2</td>
<td>0.14</td>
<td>bloc béton (90%)</td>
<td>&gt; 50</td>
<td>0</td>
<td>1</td>
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<tr>
<td>2</td>
<td></td>
<td>mortier ciment (10%)</td>
<td>&gt; 50</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.17</td>
<td>laine de roche (panneau rigide)</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.01</td>
<td>enduit minéral ciment</td>
<td>30</td>
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<td>2</td>
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</tbody>
</table>
Case study – comparison between walls

> Performances physiques

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<thead>
<tr>
<th></th>
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<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epaisseur totale</td>
<td>[m]</td>
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<tr>
<td>Coeff. de transm. thermique U [W/m²K]</td>
<td>0.190</td>
<td>0.192</td>
<td>0.191</td>
</tr>
<tr>
<td>Inertie thermique [kJ/m²K]</td>
<td>76.44</td>
<td>98.22</td>
<td>72.81</td>
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<tr>
<td>Affaiblissement acoustique dB</td>
<td>&gt; 45 dB</td>
<td>&gt; 45 dB</td>
<td>&gt; 45 dB</td>
</tr>
</tbody>
</table>

Remarque:
La composition serait davantage efficace d'un point de vue acoustique en rajoutant une couche isolante dans la cloison technique (intérieure).

> Composants

<table>
<thead>
<tr>
<th>A</th>
<th>[m]</th>
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<th>description technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.015</td>
<td>plaque de carton plâtre</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td>Excepté la structure portante, l'ensemble des composants est remplacé au bout de 30 ans.</td>
</tr>
<tr>
<td>2</td>
<td>0.06</td>
<td>lattage bois 30 x 60 (traité)</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.02</td>
<td>panneau OSB</td>
<td>30</td>
<td>1</td>
<td>2</td>
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</tr>
<tr>
<td>4</td>
<td>0.002</td>
<td>pare-vapeur PE</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.18</td>
<td>chevronnage 70 x 180 (traité)</td>
<td>&gt; 50</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.16</td>
<td>laine de roche (matelas)</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.02</td>
<td>panneau MDF</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
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<tr>
<td>8</td>
<td>0.04</td>
<td>laine de roche (panneau rigide)</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td></td>
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<tr>
<td>9</td>
<td>0.01</td>
<td>enduit minéral ciment</td>
<td>30</td>
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<td>2</td>
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</tbody>
</table>
Case study – comparison between walls

Environmental performances (over 50 years: production/renovation/élimination)

**Grey energy:** 288,76 MJ/m²  
**GWP:** 37,38 kgCO₂/m²  
**Acidification:** 0,0792 kgSO₂/m²  
**Photochem. Ozone:** 0,0027 kgC₂H₂/m²

**Grey energy:** 2451,27 MJ/m²  
**GWP:** -87,37 kgCO₂/m²  
**Acidification:** 0,0889 kgSO₂/m²  
**Photochem. Ozone:** 0,0016 kgC₂H₂/m²
Case study – comparison between walls

Resources depletion

<table>
<thead>
<tr>
<th></th>
<th>[m]</th>
<th>Composants</th>
<th>Quantité (kg)</th>
<th>Nature</th>
<th>Caractéristique</th>
<th>Origine</th>
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<tbody>
<tr>
<td>B</td>
<td>1</td>
<td>0.02 enduit à la chaux</td>
<td>56</td>
<td>❌</td>
<td>✅</td>
<td>✅</td>
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<tr>
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<td>0.14 bloc béton (90%)</td>
<td>252</td>
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<td>✅</td>
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<tr>
<td></td>
<td>2</td>
<td>mortier ciment (10%)</td>
<td>23.80</td>
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<td>✅</td>
<td>✅</td>
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<tr>
<td></td>
<td>3</td>
<td>0.17 laine de roche (panneau rigide)</td>
<td>34</td>
<td>⬧</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.01 enduit minéral ciment</td>
<td>30</td>
<td>⬧</td>
<td>✅</td>
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<tr>
<th></th>
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<th>Caractéristique</th>
<th>Origine</th>
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<tbody>
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<td>✅</td>
<td>✅</td>
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<tr>
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<td>✅</td>
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<tr>
<td></td>
<td>5</td>
<td>0.18 chevronnage 70 x 180 (traité)</td>
<td>18</td>
<td>⬧</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td></td>
<td>5</td>
<td>0.16 laine de roche (matelas)</td>
<td>32</td>
<td>⬧</td>
<td>✅</td>
<td>✅</td>
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<tr>
<td></td>
<td>7</td>
<td>0.03 laine de roche (panneau rigide)</td>
<td>6</td>
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<td>✅</td>
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<tr>
<td></td>
<td>6</td>
<td>0.02 panneau MDF</td>
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<td>✅</td>
<td>✅</td>
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Recycling potential

**Case study – comparison between walls**

### Recycling potential

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<tr>
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<td>🍁</td>
<td>🍁</td>
<td>🍁</td>
</tr>
<tr>
<td>2</td>
<td>bloc béton (90%)</td>
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<td>🍁</td>
<td>🍁</td>
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<tr>
<td>3</td>
<td>mortier ciment (10%)</td>
<td>🍁</td>
<td>🍁</td>
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<td>🍁</td>
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<tr>
<td>4</td>
<td>laine de roche (panneau rigide)</td>
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<td>panneau OSB</td>
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<td>🍁</td>
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<tr>
<td>5</td>
<td>chevronnage bois 70 x 180 (traité)</td>
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<td>🍁</td>
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<tr>
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<td>laine de roche (matelas)</td>
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<td>🍁</td>
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Thank you for your attention
Questions?

Architecture et Climat
www-climat.arch.ucl.ac.be
sophie.trachte@uclouvain.be