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Cleaner Technology Solutions in the Life Cycle of Concrete Products

By

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ABSTRACT

The objective of the Brite Euram project "Cleaner Technology Solutions in the Life Cycle of Concrete Products" (TESCOP) was to develop and test cost-effective cleaner technologies for the concrete industry. Based on life cycle inventories (LCI) and on political scenarios, i.e. a listing of all environmental impacts in the life cycle, and priority lists of environmental parameters, decisions on development of cleaner technologies have been made. Examples of cleaner technologies are environmental evaluation of admixtures and repair products, and water saving and pH-regulation in concrete manufacturing.

Keywords: Admixtures, carbonation, cleaner technology, CO_2 emissions, energy, life cycle inventory, repair products, residual products, water saving.

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BACKGROUND, OBJECTIVES AND FACTS ABOUT TESCOP

Background

Concrete is globally one of the most important building materials. The environmental impact per cubic meter is not high, but the total effect is significant because of the large volumes produced. Even small improvements will have a significant effect (1).

A "holistic" approach is needed to achieve real environmental improvements in the construction sector. A building or any other structure has to be considered as a product. Consequently the total environmental impact associated with the "product" during the entire life cycle has to be considered.

This means that it is no longer sufficient to address environmental issues associated with the production of the individual building materials. The environmental impacts associated with the use and disposal of a structure have to be considered. The energy consumption and CO_2 emissions associated with the use of a structure are generally much larger than the energy consumption and CO_2 emission associated with production of the individual construction materials. Use, maintenance and durability are therefore important aspects, which have to be considered.

The European concrete industry is faced with new challenges. Legislation, environmental levies, voluntary agreements and demands from the customers mean that the industry must continuously improve its environmental performance by developing and implementing cleaner technology. There is often an economic benefit from these activities. Costs savings may be achieved by e.g. reducing the energy consumption, saving water, improving the working environment or even reducing the amount of environmental levies paid.

These developments mean that new qualifications are needed for the actors in the concrete construction sector. It is not enough for the individual producers to know the environmental performance of their own materials. Knowledge of the total environmental performance from cradle to grave is needed. These data are fed into life cycle inventories (LCIs) to create a "holistic" understanding of the environmental impacts in the life cycle of a construction.

A united business effort is needed, involving the relevant actors in the construction sector.

Objective

The main industrial objective of the TESCOP project was to develop and implement cost-effective cleaner technologies to fulfil environmental requirements in the concrete industry and to reduce the environmental impact of products based on concrete. LCI was to be developed as a tool to target the areas where cleaner technologies would give the largest environmental benefit.

Facts about TESCOP

TESCOP (an abbreviation for Cleaner Technology Solutions in the Life Cycle of Concrete Products) is a Brite Euram project partly funded by the European Commission. The project was carried out from March 1997 to September 2000. The budget was 2.7 mio. EURO. Partners in TESCOP were:

- Danish Technological Institute, Concrete Centre (institute, co-ordinator, Denmark)
- Aalborg Portland A/S, (cement producer, Denmark)

- Danish Concrete Element Association, (pre-cast concrete producers, Denmark)
- Volker Stevin Construction Europe (contractor, the Netherlands)
- Intron (institute, the Netherlands)
- Italcementi(cement producer, Italy)
- Conphoebus (consultant, Italy)
- Contento Trade (consultant, Italy)
- Premix (concrete producer, Greece)
- Alteren (consultant, Greece)

The TESCOP project is an effort to demonstrate the use of life cycle inventories (LCIs), i.e. a listing of all environmental impacts in the life cycle, as a tool to guide the development of cleaner technologies, involving partners from the European concrete construction sector.

RESEARCH APPROACH

LCIs combined with the concept of "political scenarios" have been used to determine the areas where the effect of the cleaner technologies is largest.

LCIs of 12 selected European concrete-based products and applications have been prepared to establish an overview of the environmental state-of-the-art for concrete in Europe. This overview shows where in the life cycle of concrete products the largest environmental impacts are, and consequently also where the environmental effect of developing cleaner technologies is greatest.

An LCI includes many environmental impacts. To select areas for cleaner technology development, some of the most important environmental impacts have to be selected. This has been done by use of "political scenarios".

Environmental priorities vary from country to country according to a number of factors such as climate, availability of raw materials, water supply, energy costs, power production methods (coal combustion, nuclear power, hydroelectricity) etc. Environmental priorities are set not only by scientific but also by political considerations. A "political scenario" is in the present study defined as a priority list of environmental impacts to be reduced or improved, prepared for individual countries or regions based on literature studies and interviews with the relevant authorities.

OVERVIEW OF RESULTS

The results are:

- a method which focuses cleaner technology development on areas which represent significant environmental impacts and that are politically highly prioritised.
- 14 cleaner technologies for concrete products

The method consists of an LCI model, a large amount of environmental data collected on concrete products, political scenarios and LCIs of 12 concrete-based products.

A clean technology is defined as a technology or strategy that reduces an environmental impact or improves the overall environmental profile of a product.

Life cycle inventories

The LCI model is based on the draft ISO standards 14040-14042 (2), the SETAC model, the Dutch CML method and the Danish experience from environmental projects (3)

The life cycle of concrete products was divided into 5 phases in which environmental data were collected and assessed covering the concrete product from cradle to grave:

- Phase 1: Extraction and processing of component raw materials
- Phase 2: Concrete production
- Phase 3: Construction and re-building/extension of buildings and structures
- Phase 4: Operation and maintenance
- Phase 5: Demolition and waste treatment/recycling.

Environmental in- and output within the following data categories were collected and expressed per process unit.

Input: raw materials used and energy used

Output: emissions to air water and soil and waste.

The output of the processes, for instance the amount of concrete produced or the amount of demolished concrete was also registered.

LCIs were prepared for 12 selected concrete products, two examples are shown in the chapter "Examples of and experience with LCIs" The 12 selected concrete products were:

- In-situ cast deck and pre-cast beam for a bridge
- In-situ cast tunnel
- Pre-cast elements for a tunnel
- Pre-stressed hollow core slab
- A floor element made in the Italian way
- Pipe for sewer system, diameter 300 mm
- Pipe for sewer system, diameter 900 mm
- Structural framework made of pre-cast beams, columns, slabs and foundation
- Structural framework made of in-situ cast beams, columns and floors
- Flags and pavers
- In-situ cast pavement
- Non-supporting wall made of lightweight concrete

Political Scenarios

Political scenarios were established for the four participating countries and for the EU. A global political scenario was set up in addition. The scenarios were established based on interviews with national and European environmental and energy authorities and researchers. Reviews of literature concerning environmental impacts have also been carried out and public debate and discussion has been monitored and evaluated to define the scenarios. A number of pre-defined environmental impacts were ranked in three groups: high, medium and low (Table 1).

Significant differences between the political environmental priorities in the four countries were found. There was, however, agreement that the four principal environmental impacts were:

- CO_2
- Depletion of scarce resources (mainly water)
- Waste
- Substances harmful to health and environment

Working environment was not included in the priority groups because no clear-cut way of quantifying this parameter has been developed. This increasingly important subject has, however, been included in the selection and evaluation of cleaner technologies in a qualitative manner.

Cleaner technologies

The 14 cleaner technologies developed are described in Table 2. The cleaner technologies represent a broad spectrum of solutions aimed at reducing or improving different environmental impacts such as water consumption, hazardous substances in waste water, working environment, materials resource consumption, energy consumption, substances harmful to health and environment, CO_2 emission and NO_x emission. The cleaner technologies represent solutions in all five life cycle phases, however with a focus on life cycle phase 2 – concrete production.

Some of the 14 cleaner technologies are already in use, others have been pilot tested or laboratory tested whilst a few were performed as desk studies only.

EXAMPLES OF AND EXPERIENCE WITH LCIs

Figure 1 shows the accumulated CO_2 emissions for a 300-mm sewer pipe through the entire life cycle. It can be seen that approximately 80% of the CO_2 emission is derived from the production of cement. The production of the sewer pipe, the placing and other processes do not contribute significantly. There is no contribution for the last two life cycle phases due to the fact that there is no maintenance and repair in the lifetime of a sewer pipe. Furthermore, the sewer pipes will not be disposed of but will instead be left underground.

As another example, the CO_2 emission during the lifetime of a non-supporting wall is shown in Figure 2. The wall has the function of separating two rooms inside an apartment. The thickness is 100 mm and the density of the lightweight concrete used is 1200 kg/m^3. Cement is still the largest CO_2 contributor, accounting for approximately 60 % of the total emission. This is significantly less than the case with the sewer pipe.

The production of lightweight aggregate (LWA) i.e. expanded clay accounts for approximately 10 % of the total CO_2 emission. This is under the assumption that the fraction of lightweight aggregate with grain size below 2 mm is considered a residual product from the production of the larger fractions. This fraction is hence assigned zero CO_2 emission. Other noticeable environmental impacts are production of reinforcement steel, electricity and thermal energy consumption during production of the wall.

There is no contribution in life cycle phase 4, operation and maintenance CO_2 – emissions derived from the use of the building (heating, electricity etc.) are not considered. Other studies have calculated that this contribution is many times larger the contribution from the production of the concrete structure itself (4).

If crushed after demolition concrete may be assumed to carbonate fully within some years. Eventually the total amount of CO_2 liberated from calcium carbonate during the production of cement will be fully reabsorbed by the concrete. This effect is assigned to life cycle phase 5 with up to 40% of the CO_2 released from cement production being incorporated into the concrete. The two investigated scenarios, i.e. no carbonation and full carbonation, represent end members. The actual situation is supposed to be somewhere in between.

LCI can be a useful tool for evaluating concrete products and for focusing cleaner technology development on areas that represent significant environmental impacts. However, the results have to be carefully interpreted, as they are influenced by a number of different assumptions and conditions such as:

- Whether or not a raw material is considered to be a residual product. By convention, the environmental impacts of residual products are considered to be nil, as the impact is assigned to the primary product. Fly ash and silica fume are generally considered to be residual products with zero environmental impact.
- The quality and the accessibility of the input data.
- Whether or not carbonation should be included. The concrete will eventually reabsorb the same amount of CO_2 that was originally released from the calcination, over a period of time depending of the physical characteristics of the concrete.

In addition, account must be taken of differences in the system boundaries and functional units when comparing the LCIs of different concrete products or when comparing the LCIs of a concrete product with a product made of another building material.

EXAMPLES OF CLEANER TECHNOLOGIES

Evaluation of admixtures and repair products

The objective was to analyse admixtures and repair products used in the Danish concrete industry with regard to impacts on health and environment. Elimination of substances harmful to health or environment is given a high priority by the Danish Environmental Protection Agency according to the Danish political scenario (Table 2). The analysis was carried out by the Danish Technological Institute.

The basis for the evaluation is to completely avoid substances with an impact on the working environment and the external environment. It means that the evaluation criteria go beyond the level required by law. A special focus has been on the list of unwanted substances issued by the Danish Environmental Protection Agency, (5).

The analysis is made on the basis of information provided from an international manufacturer of products for the building industry. Five commonly used products have been chosen within the groups: plasticizing, superplasticizing, new generation superplasticizing and air entraining agents. The manufacturer has provided information, e.g. safety data sheets, technical facts, information about the composition and content of chemical substances, tests and environmental impacts related to production etc. Supplementary information about the substances has been obtained in order to find possible threshold limit values and other requirements or guidelines.

The products are evaluated with regard to working environment and external environment aspects.

The working environmental aspects are only related to the use of the products, i.e. when the admixtures are mixed with the other concrete constituents or when the repair products are applied or used for coating. Persons using the products, even for a short period, can be exposed:

- Through inhaling particles and dust
- Through inhaling fumes
- Through skin or eye contact

As it is assumed that some staff will be exposed to one or more of the products over prolonged periods or repeatedly, it is relevant to include the effects of such contacts.

The overall focus is on the external environmental aspects of the use and discharge of the products. This means that the impact on the external environment in connection with waste in the form of discarded building components and remains of the products after use will be considered. It is assumed that there is no impact on the external environment during the service life of the component.

Regarding waste in the form of discarded building components the most important impacts will be:

- Possible emissions/evaporation of environmentally harmful substances
- Possible leaching of environmentally harmful substances to soil and subsoil water
- Other types of hazardous waste

All the mentioned impacts are evaluated and gathered in a table, from which it is possible to compare the products. As an example the information for admixtures is shown in Table 3.

The evaluation shows that a majority of the products contains substances, which are harmful either to health or the environment. It is preferable to find substitutes with less harmful effects. If that is not possible, necessary precautions, e.g. ventilation, are required. It must be noted that the evaluation is based on the available information and in some cases not all the necessary information is available; the evaluation should therefore be taken with reservations.

The strict evaluation criteria, which go beyond the level required by law, can be used by companies that wish to obtain an environment-friendly profile. In (6) it is stated that the release of substances harmful to health or environment from concrete admixtures by leaching and by release of volatile constituents under normal conditions is extremely small.

Recycling of water

The main objective of this task has been to develop a water recycling system for concrete unit production leading to reduced water consumption and a reduced environmental impact from the discharge of wastewater (3). The Danish Concrete Unit Association in co-operation with the Danish Technological Institute, a pre-cast concrete producer and authorities have carried out the work.

In connection with an application for an environmental permit on behalf of a pre-cast concrete producer, the treatment and contents of the wastewater have been investigated. The Local Authority sets a number of requirements for wastewater. The county is responsible for the discharge directly to the environment and the council is responsible for the discharge to the public sewer system.

Before the water recycling system was implemented all the production wastewater percolated into the ground. The county authorities have demanded a complete stop to all percolation of wastewater. However, rainwater can still be percolated.

The municipal demands for the facilities comprised a well for measurements and an oil separator placed immediately before the connection to the sewer. The producer should aim at replacing substances on the list of unwanted substances of the Danish Environmental Protection Agency, (5) and mineral substances.

Today concrete slurry is added to the hardened concrete waste at a maximum of 10 %. The municipal authorities demand that storage of concrete slurry must only take place on consolidated ground. Since there has been no trace of oil in the concrete slurry, the municipal authorities have allowed the slurry to be treated together with other concrete waste.

A system has been designed in which all the production wastewater will be reused. Rainwater is accumulated from the roofs and added to the treated production wastewater when required. Rainwater is the only source of fresh water.

Tests have shown that it is possible to pump production wastewater containing large amounts of concrete slurry from the tank where it was very difficult to dig the slurry out by hand. The system is therefore designed with pumps and pressure hoses for transport of the production wastewater to the sedimentation tank. The hoses are designed with a station for cleaning when required.

After sedimentation the water is pumped into an accumulation tank to which rainwater is added when needed. The water is constantly in motion to maintain homogeneous quality. The rainwater/production wastewater mixture is tested and neutralised according to the demands for mixing water for concrete.

Pumping water will result in a minor increase in the use of energy, but less energy is expected to be used for maintaining the system; i.e. the energy consumption is estimated to be the same as before. The water consumption will be reduced 100 % meaning that tap water will only be used in the office buildings and for personal hygiene. The outlet wastewater from production will be reduced with 100 % meaning that the only wastewater from the plant is sanitary wastewater. All chemicals from production will be recycled resulting in no pollution to the local recipient.

CONCLUSIONS AND ACHIEVEMENTS

The cleaner technologies developed constitute important information about how to reduce the environmental impacts in the concrete industry. LCIs and political scenarios have proven their effectiveness as a tool to guide the development of cleaner technologies in areas that are politically highly prioritised and which represent significant environmental impacts.

The achievements for the concrete industry are as follows:

- Improved competitiveness resulting from lower costs and an improved environmental profile through the developed cleaner technologies.
- Increased awareness of environmental issues.
- A comprehensive catalogue of environmental data and LCI results for concrete products, probably one of the largest in Europe.
- Increased focus on the effect of carbonation (CO_2 – uptake) of concrete products in LCIs.

The achievement for society is a basis for reductions of environmental impacts such as energy, CO_2 emissions and waste through the implementation of the developed cleaner technologies in the concrete industry

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Table 1 Political scenarios divided into groups of high priority, medium priority and low priority (3)

	High priority	**Medium priority**	**Low priority**
Denmark	- CO_2 - Resource (water) - Fossil fuel (oil) - Substances harmful to health or environment (chemicals, heavy metals)	- SO_2, NO_X - Local supply of resources as sand, stone, gravel, chalk and lime - Resource (recycling of waste of building industry) -	- VOC (only relevant related to the working environment)
The Netherlands	- Resource (energy) - CO_2 - Secondary materials/resources/land use/recycling	- Resource (water) (water only has a high priority concerning water use by building owner, showers, etc.) - NO_X, SO_2 - Substances harmful to health or environment (heavy metals)	- Indoor climate/radon - VOC (only relevant related to working conditions)
Italy	- CO_2 - NO_X - Waste	- CH_4 - N_2O - Resource (water)	- VOC (only relevant related to the working environment) - Substances harmful to health or environment (heavy metals)
Greece	- Resource (Energy)	- Fossil fuel (coal) - CO_2, CH_4, N_2O - Resource (water) - Solid waste - Substances harmful to health and environment (heavy metals) - Resources	- SO_2, NO_X
European Union	- Substances harmful to health or environment (toxic chemicals, heavy metals) - CO_2, CH_4, N_2O - Resource (water) -	- SO_2, NO_X - Selective demolition - Water quality	- VOC (only relevant related to the working environment) - Waste (increased reuse, recycling, minimised depositing, selective demolition)
International	- CO_2 - Resource (water) - Water quality	- Secondary raw materials, recycling/waste minimisation	- Resource (energy)

Table 2 Overview of cleaner technologies (3)

Cleaner Technology	Life cycle phase	Environmental impact to be reduced/improved	Level of development
Recycling water for use in concrete unit production. A system has been designed in which all production wastewater is reused. Rainwater is the only source of fresh water.	2	• Water consumption • Hazardous substances in waste water	In production
Self-compacting concrete. Development of methods for mix design and testing. Demonstration of use in precast unit production and in in-situ production.	2 + 3	• Working environment • Material resource consumption	In production / pilot production
Industrialised construction process. Optimisation of design by use of 3D design. Evaluation of form oils and development of electrical spraying devices. Control of concrete hardening. Industrialising tunnel production.	3	• Material resource consumption • Waste • Working environment	Desk study / pilot production
Steel and concrete. Optimisation of material consumption.	1 + 3	• Material resource consumption	Desk study
Belite rich clinker. Development of cement based on belite rich clinker. The cement has low early and high 28-days strength.	1	• CO_2 emission • NO_x emission	Laboratory testing
Lightweight aggregate from waste. Experimental production of granulates from cast iron waste.	1 + 4	• Energy	Laboratory testing / desk study
Planning building components for demolition	5	• Waste	Desk study
Energy saving in concrete production plant. Energy audit of main feeder line, flag making machine, batch mixer and conveyer belt.	2	• Energy	Mapping and desk study
Ready mix concrete logistics. IT solution to manage and monitor order processing and transport.	2	• Material resource consumption • Waste	In production
Water recycling tanks plant. System to separate waste concrete into the individual materials for recycling in the concrete production.	2	• Water • Material resource consumption	In production
Modular photovoltaic systems for in situ energy supply. Feed electric load from a photovoltaic system as a replacement for ordinary power supply.	3	• Energy	Mapping and desk study
Chemicals in admixtures and repair materials. Development and demonstration of an evaluation form.	2 + 4	• Substances harmful for health and environment	Desk study
Separate grinding systems. Development of two separate grinding circuits one for clinker and gypsum and for slag resulting in an improved performance of the cement.	1	• Waste • Energy • Material resource consumption	Laboratory testing / pilot production
Direct use of waste in concrete. Testing of waste used as aggregate and waste used as additive.	2	• Waste • Material resource consumption	Laboratory testing

Table 3 Environmental evaluation of admixtures, (3)

<table>
<tr><th colspan="3">Product
(active component)</th><th>Plasticizing agent
(lignosulfonate)</th><th>Superplastiz-icing agent
(melamine resin)</th><th>Super plasticizing agent
(sulphonated naphtalene polymers)</th><th>New enhanced super plasti-cizing agent
(acrylic polymers)</th><th>Air entraining agent
(vinsol resin and surfactants)</th></tr>
<tr><td colspan="2" rowspan="4">A. Working Environment</td><td>Emission of dust</td><td>Not relevant</td><td>Not relevant</td><td>Not relevant</td><td>Not relevant</td><td>Not relevant</td></tr>
<tr><td>Volatile substances</td><td>No</td><td>Formaldehyde</td><td>Formaldehyde</td><td>Formaldehyde*</td><td>No</td></tr>
<tr><td>Corrosive/ irritating effects</td><td>Mild irritant</td><td>Mild irritation</td><td>No</td><td>No</td><td>Strong irritant</td></tr>
<tr><td>Chronic effects</td><td>None</td><td>May be carcinogenic, skin irritation</td><td>May be carcinogenic, skin irritation</td><td>Mild skin irritation</td><td>May cause allergy</td></tr>
<tr><td rowspan="4">B. External Environment</td><td rowspan="2">Discharge of building components</td><td>Hazardous substances</td><td>None</td><td>None</td><td>None</td><td>None</td><td>None</td></tr>
<tr><td>Disposal</td><td>None</td><td>None</td><td>None</td><td>None</td><td>None</td></tr>
<tr><td rowspan="2">Discharge of product</td><td>Hazardous substances</td><td>None</td><td>Formaldehyde</td><td>Formaldehyde</td><td>Formaldehyde*</td><td>None</td></tr>
<tr><td>Disposal</td><td>None</td><td>None</td><td>None</td><td>None</td><td>Alkaline material</td></tr>
</table>

* According to the safety data sheet the product does not contain free formaldehyde. A leaching test according to UNI 10820/99 has however shown that the product contains free formaldehyde, though a very small amount.

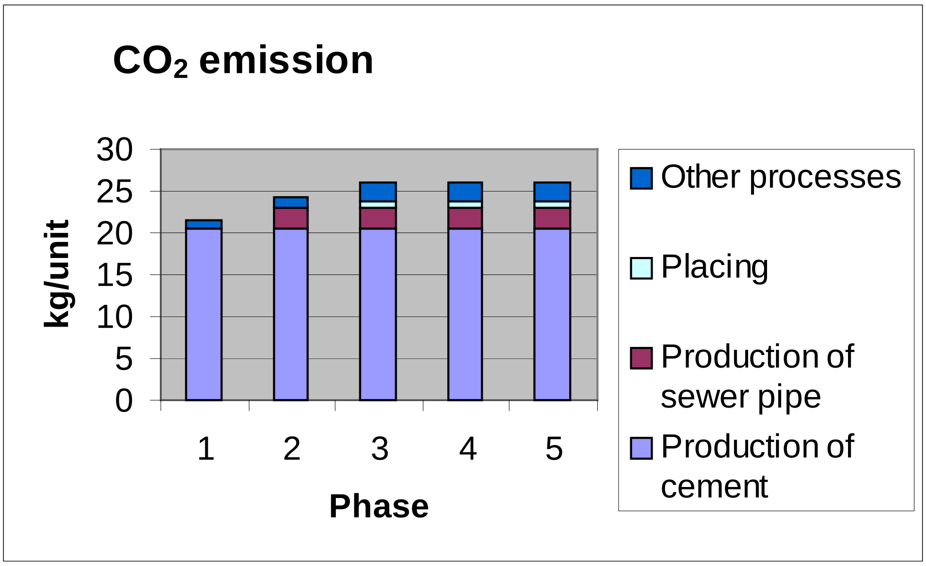

Fig. 1. Accumulated CO_2 emission in the entire life cycle for a 300-mm sewer pipe, (3).

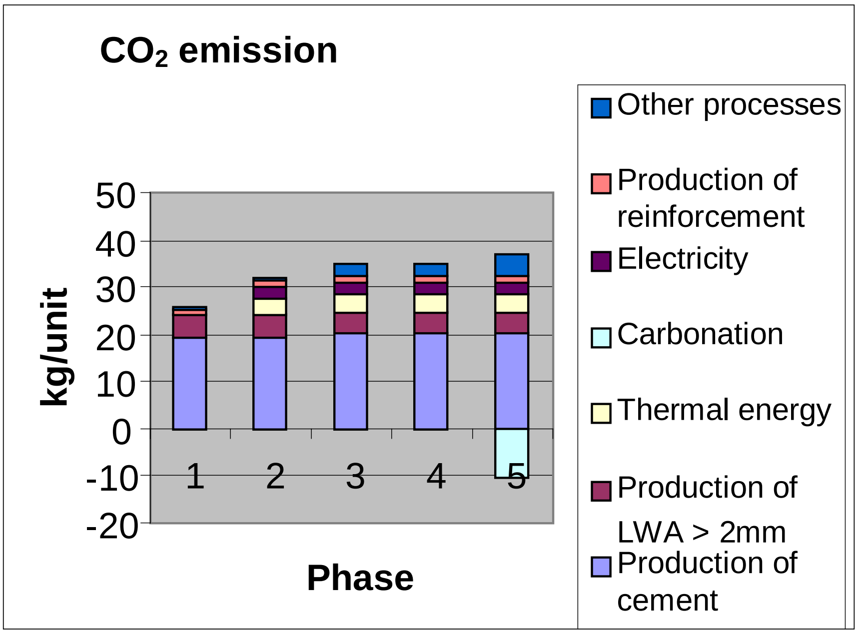

Fig. 2. Accumulated CO_2 emission in the entire life cycle for a lightweight wall, (3).