SUSTAINABLE BENEFITS OF CONCRETE STRUCTURES

EUROPEAN CONCRETE PLATFORM

Published by the European Concrete Platform ASBL
Editor: Jean-Pierre Jacobs
1050 Brussels, Belgium

Layout & graphic design: Geert Joostens bvba JO-OP
Printing by the European Concrete Platform ASBL

Foreword

Sustainability lies at the heart of construction and design. A sustainable approach of construction brings lasting environmental, social and economic benefits to a construction project. From that perspective, concrete achieves high valuable properties as a construction material limiting the impacts of a building or infrastructure on its surroundings.

Acknowledgements

This was originally written and published in 2007 by the Environmental Working Group of Betonikeskus ry, in Finland, under the title **Environmental properties of concrete structures**.

We thank Laetitia Dévant for her work Europeanizing the book, the English Centre for the translation, the British Precast (particularly Martin Clarke and Chrissie Walton), Gillian Bond and Brian O'Murchu for their revisions, and Geert Joostens for his inspired and insightful design.

We pay all due respect to all the people from the European Concrete Platform ASBL that made that project possible by contributing to the work.

TABLE OF CONTENTS

FOREWORD

A reliable, universal, durable and versatile construction material that can endure for centuries, concrete can contribute to an environmentally secure future for present and future generations.

Concrete has a lot to offer. As a construction material, it can emulate traditional stone motifs or alternatively can be used to create modern, contemporary buildings.

Complex and inspirational designs are possible at an affordable cost, without unduly taxing the environment.

It is the unique combination of functional and aesthetic properties that has made concrete the primary construction material worldwide. Concrete is therefore deeply rooted in our everyday life.

As a responsible industry, the concrete sector actively promotes the objectives of sustainable construction to generate public awareness. Using materials responsibly is one of the great challenges of our time.

Through its ongoing research and collaboration with the relevant authorities, the concrete industry is improving its performance, particularly in terms of cleaner production and new and improved concrete specifications.

Sustainable construction has been identified as one of the Lead Markets by the European Commission.

Therefore, the construction sector is committed to delivering higher quality buildings for European citizens and businesses alike, which will enhance quality of life and working conditions and reduce their impact on the environment.

The concrete industry is also responding to current concerns about climate change and energy efficiency.

According to the Energy Performance of Buildings Directive (2002/91/EC), "the residential and tertiary sector, the major part of which is buildings, accounts for more than 40% of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions". Thanks to its thermal mass properties, a concrete building consumes between 5 to 15% less heating energy than an equivalent building of lightweight construction.
The long service life of a concrete building also increases its eco-efficiency.

Assessing the sustainability of a project is a complex task. The key to success is to develop a "holistic view" that takes every aspect of the structure and its performance into consideration.

For construction, for example, due to the very long service life of concrete structures, their in-use phase is far more important than the production and the disposal phases. However, without forgetting those last two aspects (chap. 2 and 6), this book focuses on the commonly recognised "three pillars" of sustainable construction, i.e. social (chap. 3), environmental (chap. 4) and economic aspects (chap. 5) in the use phase of a building.

Addressing a wide audience, from construction professionals to dedicated consumers, this book identifies the many benefits of concrete and the unique contribution our industry can make in facing the challenges ahead.

CONCRETE IN CONSTRUCTION

1.1 ACHIEVING SUSTAINABLE CONSTRUCTION WITH CONCRETE

Concrete is an essential material with a worldwide estimated consumption of between 21 and 31 billion tonnes of concrete in 2006[1], concrete is the second most consumed substance on Earth after water[2]. A world without concrete is almost inconceivable!

Concrete is made from coarse aggregates (gravel or crushed stone), fine aggregates (sand), water, cement and admixtures. These constituents are mostly available locally and in virtually unlimited quantities. Primary materials can be replaced by aggregates made from recycled concrete. Waste materials from other industries can be used to produce additions like fly ash, slag and silica fume.

Concrete is one of the more sustainable building materials when both the energy consumed during its manufacture and its inherent properties in-use are taken into account.

The cement and concrete sectors work together to continually reduce their impact on the environment through improved manufacturing techniques, product innovation and improved specification.

1.1.1 Benefits of concrete in sustainable construction

Sustainable construction was recently identified by the European Commission as one of the Lead Markets. Buildings account for the largest share of the total EU final energy consumption producing about 40% of greenhouse emissions during their service life. The construction sector can improve that rate thanks to innovation and technology.

Sustainable development is commonly defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[3]. It incorporates the environmental, economic and social considerations often referred to as "the three pillars" of sustainability.

These "three pillars" were given equal weighting at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro on 3-14 June, 1992.

Consideration of all three factors gives a more holistic view of performance. This fact is now under consideration at European level by CEN Technical Committee TC350, whose task is to give effect to the full definition of sustainable construction by including social and economic factors as part of a standardised European sustainability assessment methodology.

The built environment is fundamental to a sustainable society as construction, by definition, involves the use of natural resources.

Knowledge and awareness during the construction phase and effective management of energy throughout the life of the building can deliver significant energy savings and CO_2 reductions, while maintaining the quality of the building and the safety and comfort of its occupants.

The aim of sustainable construction is for "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles"[4]. The European construction sector is developing strategies to mitigate the environmental impacts of construction activities. To be successful, everyone involved in the construction chain must understand and apply an agreed set of principles to drive the sector towards:

- The improvement of environmental properties of its products and to decreasing environmental risks
- The creation of benefits for society
- The improvement of people's safety
- The preparation for impending legislation in social, economic and environmental areas
- More responsibility towards society
- Effective cost savings
- A better image of the sector.

The concrete sector is therefore heavily involved in this challenge. It has adopted life-cycle thinking and implemented sustainable goals to improve the durability, safety and health aspects of concrete construction. It also agreed to using raw materials efficiently, conserving energy in buildings and processes, promoting recycling and ensuring the occupational safety of the personnel.

[1] WORLD BUSINESS COUNCIL ON SUSTAINABLE DEVELOPMENT, Concrete Recycling - A Contribution to Sustainability, Draft version, 2008

[2] ISO, ISO/TC 71, Business Plan, Concrete, Reinforced concrete and pre-stressed concrete, 08/07/2005

[3] BRUNDTLAND G., Our Common Future: The World Commission on Environment and Development, Oxford University Press, Oxford, 1987

[4] KIBERT C., First International Conference on Sustainable Construction, Tampa, 1994

CONCRETE IN CONSTRUCTION

AN ECO-EFFICIENT CONCRETE STRUCTURE
is one where

- total environmental impacts are minimised during its entire life-cycle
- the structure is designed and properly built to suit its intended use

and where concrete uses

- constituents that are produced with reduced environmental impacts
- cement produced using modern manufacturing techniques, recycled raw materials and alternative sources of energy
- the optimal amount of cement to obtain the required strength and longevity

Some associations, such as the British Precast Concrete Federation[5], have launched a sustainability charter that encourages the contracting parties to improve their performance, progressively integrating sustainable thinking into every aspect of the manufacturing process.

1.1.2 Eco-efficient concrete structures

A life-cycle approach is the standardised method of identifying and assessing the environmental effects of construction products over their life-cycle (extraction, processing, transportation, use and maintenance, and disposal).

There are many ways to optimise the eco-efficiency and life-cycle economy of concrete projects, such as recycling or using industrial by-products during manufacture, or by using design strategies that utilise the thermal properties of concrete. Buildings can also be designed so that they can be easily serviced and altered.

A) BUILDINGS

Concrete is an established construction material that is used to erect buildings across Europe - a geographical area where it is estimated that people spend more than 90% of their time indoors[6]. This figure underlines the significance of buildings in everyday life, and the important consideration that has to be given to construction materials when making long-lasting choices with far reaching consequences.

An enormous range of concrete products are available in the market place and these cost effective products can be used to make daily life healthier, safer and more comfortable. The most common uses of concrete in buildings are:

- Floors for ground or upper floor levels
- Structural frames (e.g. beams, columns, slabs)
- External and internal walls, including panels, blocks or decorative elements with a whole selection of colours and finishes
- Roof tiles
- Garden paving (concrete slabs or blocks, which are virtually everlasting in that type of use).

"Dense concrete" is invariably used in the construction of industrial and commercial buildings and all infrastructural projects. This type of concrete is strong and durable, resists fire, and has good sound insulation and vibration absorption properties and thermal properties as a result of "thermal mass".

"Lightweight concrete", in the form of concrete masonry blocks, are used mainly in the construction of houses and apartments. Because of their inherent properties, concrete blocks used as partition walls typically do not require additional sound or fire protection.

Concrete-framed buildings can be designed with a variety of appearances to blend in with the environment.
Courtesy of TORHO S.A. (Barcelona, Spain). Photo: Fin Serck-Hanssen.

B) INFRASTRUCTURES

Concrete is well suited to civil engineering construction since it is able to withstand moisture and varying weather conditions, mechanical wear and tear, and high temperatures. Concrete also absorbs sound, reduces temperature swings and provides protection against different types of radiation and rising sea levels.

[5] http://www.britishprecast.org/

[6] FRANCHI M., Towards Healthy Air Dwellings in Europe, The THADE report, EFA Project 2002-2004, 2004.

[7] THE INTERGOVERNEMENTAL PANEL ON CLIMATE CHANGE, Evidence of Human-caused Global Warming "Unequivocal" http://unep.org Documents.Multilingual/Default.asp?DocumentID=499&ArticleID=5506&l=en

CONCRETE IN CONSTRUCTION

The effects of "climate change" vary throughout Europe. The more frequent occurrence of weather extremes such as floods, storms, extreme heat and drought have been attributed to human activities[7]. Recent floods in the United Kingdom are attributed to a combination of saturated soils, paved areas, and urban development in inappropriate areas. There are indications that some infrastructure may need to be adapted to counter the threats posed by the new environmental conditions. Concrete is the ideal material to provide these much needed defences against flooding and rising sea levels.

The inherent durability and strength of concrete can be used to protect communities against the worst effects of climate change. The building and shoring up of dams in New Orleans, USA is an example of concrete's capacity as a defence against extreme climatic events.

Its resilience to the effects of flooding is a major benefit when building in flood-prone areas. Sustainable drainage systems, such as water permeable concrete paving, reduce the potential effects of flooding on new and existing urban developments, while protecting and enhancing ground water quality.

Concrete safety barriers are now being used on all motorways in the UK. They are designed to achieve an essentially maintenance-free serviceable life of not less than 50 years. Courtesy of Britpave.

Other concrete applications are:

• Roads, bridges, increasingly road central safety barriers and tunnels. Building a road pavement in concrete offers several benefits, especially in tunnels where temperatures in fires can reach extremely high levels (greater than 1000°C) and last for hours. The Mont-Blanc fire disaster, in 1999 in France, lasted 53 hours and burnt at 1000°C, causing 39 casualties and damage to many vehicles. Concrete is the material of choice for road pavements as it is incombustible, does not give off harmful emissions in a fire and provides maximum safety for people, facilities and the surroundings[8].

• Power plants, many of which use and store potentially dangerous nuclear fuels, are constructed almost entirely of concrete for safety and security reasons.

• Other common industrial applications such as silos, storage tanks and water treatment and run-off catchment systems.

Example of the Sillogue Water Tower.
Courtesy of P.H.Mc Carthy Engineers, Dublin, Ireland.

[7] THE INTERGOVERNEMENTAL PANEL ON CLIMATE CHANGE, Evidence of Human-caused Global Warming "Unequivocal" http://unep.org/Documents.Multilingual/Default.asp?DocumentID=499&ArticleID=5506&l=en

[8] THE EUROPEAN CONCRETE PLATFORM, Improving fire safety in tunnels: The concrete pavement solution, April 2004.

CONCRETE IN CONSTRUCTION

• Concrete is used in large volumes in wind farms as a base for wind turbines as it can dampen the huge eccentric loads and the stresses and strains caused by the high velocity rotation of the wind turbine blades.

Precast concrete is often used for wind turbines - its high level of weather resistance and inherent stiffness help provide a stable and resilient structure that generates electricity, which is a renewable resource. Courtesy of British Precast

• In agriculture, large volumes of concrete are used to build large slurry tanks for animal effluent, with generous support from the European Parliament under the "Control of Farmyard Pollution Scheme".

1.1.3 Environmental Products Declarartions[9]

In the late 1990s, both professionals and consumers in the construction sector started asking for more environmental information about construction products such as the use of natural raw materials, consumption of energy and emissions. Industry responded by providing Environmental Product Declarations (EPDs) in a first attempt to communicate the performance of the products in a credible and understandable way.

As mentioned previously, the "three pillars" of sustainable construction are taken into account when evaluating the integrated assessment of the building performance. Along with the environmental side, the social responsibility (health, comfort, safety) and the economic growth aspects (affordability, stable value over time) are then considered.

1.2 Aesthetics and architecture

Today, many government institutions and multi-national corporations require landmark buildings that embody the corporate image of the institution or company. More often than not, concrete is the chosen material because it combines function and practicality with a contemporary appearance and the ability to express complex and dynamic forms. Concrete is the essence of permanence and performance - a material with limitless possibilities.

Concrete is a stone-like material that can be cast into virtually any shape or form. Concrete's long-span capabilities can be used to create large open spaces, suitable for providing office or retail accommodation. Beams and columns can be made "extra slim" by pre-stressing the steel reinforcing. Coloured and textured surfaces can be provided at a very competitive cost.

From the designer's perspective, concrete can be used to create a variety of shapes. Gently curved buildings such as the Sydney Opera House, the Chiesa Dives in Misericordia in Rome, the Sagrada Familia in Barcelona and Le Corbusier Church at Ronchamp show the gentle, flexible side of concrete. The language of concrete can be either lyrical or stark, and its plasticity can be used as a starting point for graphic or sculptural themes. The kaleidoscope of possibilities is almost endless.

The Academic Biomedical Cluster, Utrecht University, Netherlands sought a modest, intelligent and sustainable building to make optimal use of a deep, south-facing site. The slim structure and glazed facades (approximately 430 panes) allow indirect sunlight deep into the building. The structure is visible throughout the building and connects the public spaces on two lower levels with educational facilities on three upper levels. Courtesy of Photography© Christian Richters, Architect: EEA architecten, Erick van Egeraat.

[9] http://www.environdec.com/pageId.asp

CONCRETE IN CONSTRUCTION

La Grande Arche, Paris.
Architect: Johann Otto von Spreckelsen;
Construction System: marble cladding;
Completed by Paul Andreau.
Courtesy of The Concrete Centre.

World Trade Centre in Sevilla, Spain.
Courtesy of ANDECE.

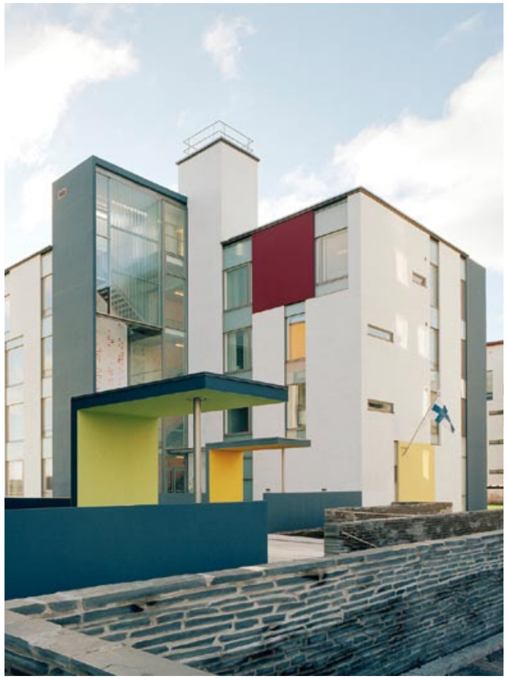
As a functional and economical material, concrete used to be concealed by finishes or simply used as a foundation to support the whole building. More recently, however, concrete has found its own creative form, its own language and power, and its own method of expression. In the 1980s, many new concrete developments were initiated. Very quickly, co-operation between architects and concrete technologists led to improving techniques for constructing and finishing concrete. Following great progress, and with continuing success in developing concrete as an expressive architectural material, increased emphasis is now firmly focused on improving life-cycle costs and reducing environmental impacts.

Today, concrete is no longer limited to buildings and infrastructure. Combined with art, technology, design and manufacturing skills, concrete is currently in vogue as an interior material for kitchens, bathrooms, etc., particularly because it can be easily cast, coloured, textured or polished. Development work is currently focused on sound insulation, moisture technology, environmental impact, flexible structural solutions and appearances/finishes.

The interior of a shop with concrete columns and staircase.
Courtesy of the Concrete Centre.

Developments are taking place in the area of coloured concrete, creating greater design freedom based on technology and software. Various types of ventilated facades are also being investigated as solutions that permit unrestricted design of joints and large surfaces.

Graphical concrete techniques offer added potential for choice in facades.
Wall facade in Germany.
Copyright: Betonmarketing Süd, 2004 (Foto: Guido Erbring)



Residential buildings,
prize winning for facades.
Finland.

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

Heidelberg Cement's Ketton works, Rutland, UK - one of the most efficient cement works in Europe - which produces some 0.8 million tonnes of cement a year. Courtesy of Heidelberg.

2.1 EXTRACTION AND MANUFACTURING OF PRIMARY RAW MATERIALS

2.1.1 Cement

Cement is a finely ground, non-metallic, inorganic powder, which, when mixed with water, forms a paste that sets and hardens. The most important use of cement is in the production of concrete, acting as the binder, gluing together the other ingredients of concrete.
It typically makes up about 12% of the entire concrete mix. Cement is a hydraulic binder, i.e. it hardens when water is added. There are 27 types of common cement, which can be grouped into five general categories and three strength classes: ordinary, high and very high. Some special cements exist, such as sulphate resisting cement, low heat cement and calcium aluminate cement. The cement industry in the 27 European Union Member States currently produces around 270 million tonnes of cement a year.

Cement plants are usually located adjacent to quarries which produce sufficient quantities of raw materials from which the basic constituents of cement (limestone and clay) are extracted.

The cement manufacturing process is essentially made up of two phases. First, clinker is produced from raw materials using a dry, wet, semi-dry or semi-wet process according to the state of the raw material. During the second phase, cement is produced from cement clinker.

During the first phase of the manufacturing process, raw materials are delivered in bulk, crushed and homogenised into a mixture which is fed into a rotary kiln - a rotating pipe 60m to 90m long and up to 6m in diameter. The kiln is heated by an internal flame that burns at 2000°C. The kiln is slightly tilted to allow for the materials to slowly progress to the other end, where it is quickly cooled to 100-200°C.

Four basic oxides used in the correct proportions make cement clinker: calcium oxide (65%), silicon oxide (20%), alumina oxide (10%) and iron oxide (5%). When mixed to form the "raw meal" or slurry these will combine when heated at a temperature of approximately 1450°C. New compounds are formed: silicates, aluminates and ferrites of calcium. Hydraulic hardening of cement is due to the hydration of

these compounds. The final product of this phase is called "clinker" which is stored in large silos.

The second phase is handled in a cement grinding mill. Gypsum (calcium sulphates) and possibly additional cementitious materials (such as blast furnace slag, fly ash, natural pozzolanas, etc.) or fillers are added to the clinker. All constituents are ground to produce a fine and homogenous cement powder which is stored in silos before being dispatched either in bulk or as a bagged product.

The cement industry is making efforts to increase the proportion of constituents other than clinker in cement (the EU average clinker to cement ratio is 0.8). Replacing clinker with secondary materials or by-products derived from other industries - such as granulated blast furnace slag from the steel industry, fly ash from coal-fired power generation and natural pozzolans or limestone from quarries - allows for a CO_2 reduction depending on the proportion of these materials.

ENVIRONMENTAL PROFILE OF CEMENT

Releases from the cement kiln come from the physical and chemical reactions of the raw materials and from combustion of fuels.

The main constituents of the exit gases from a cement kiln are CO_2 (carbon dioxide), NO_x (nitrous oxides) and SO_2 (sulphur dioxide).

The exit gases also contain small quantities of chlorides, dust, fluorides, carbon monoxide, and even smaller quantities of organic compounds and heavy metals. Cement dust in the exit gases from cement kilns is removed by filters (normally electrostatic precipitators or bag filters) and the dust is returned to the process.

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

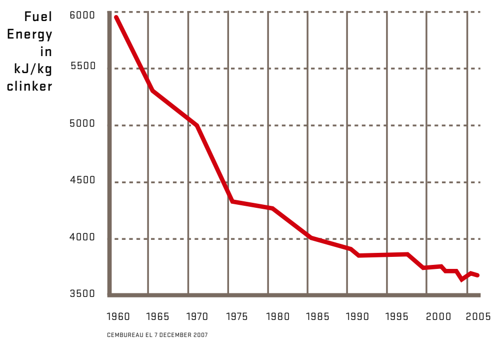
cement kilns is removed by filters (normally electrostatic precipitators) and the dust is returned to the process.

CO_2 emissions are both raw material-related and energy-related. Raw material-related emissions are produced during limestone decarbonation ($CaCO_3$) and account for about 60% of total CO_2 emissions. Energy-related emissions are generated both directly through fuel combustion and indirectly through the use of electrical power.

Energy consumption in the cement industry has declined significantly over the past 50 years. This is mainly attributable to improvements in plants and process technologies.

For several years the clinker specific fuel energy consumption has remained stable at 3,500 -3,700 MJ/t clinker. Each tonne of cement that is produced requires 60-130 kg of fuel oil or an equivalent fuelling amount depending on the cement type and the process used. Each tonne also requires an average 110 kWh of electricity. The energy bill represents over 25% of total production costs in the cement industry and is subject to a good deal of uncertainty in view of fluctuating energy prices. Not surprisingly, therefore, the European cement industry has, over the last 40 years, made considerable efforts to reduce energy consumption. Through techno-logical change and investment, the European cement industry has significantly reduced its specific energy needs (i.e., the energy required to produce one tonne of cement).

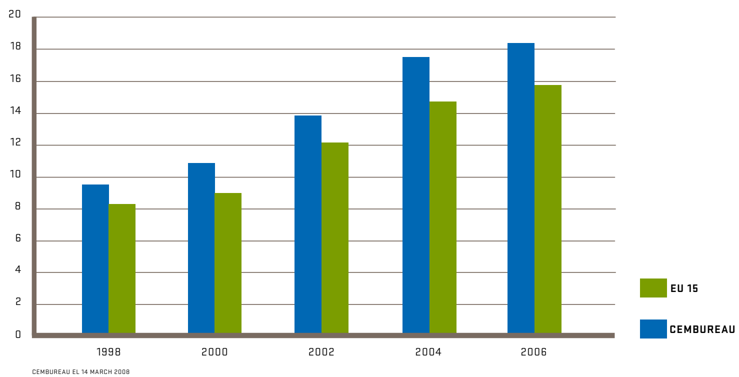
EU CEMENT INDUSTRY (average)



Cement manufacturing: the underneath chart indicates the reduction in fuel energy consumption from 1960 to 2005 (CEMBUREAU).

Now, the cement industry is close to the limit of what can be achieved through such technical improvements and rationalisation. In 1993, an independent study commissioned by the European Commission assessed the potential for further improvements at 2.2%. Information recently published by the Cement Sustainability Initiative (CSI)[10] confirms that existing clinker[11]-making technologies do not provide further potential for significant improvement in terms of energy-efficiency. More details on this report can be found on the website of the World Business Council for Sustainable Development (www.wbcsd.org).

% OF ALTERNATIVE FUELS USED IN THE CEMENT INDUSTRY 1998-2006



The increase in 8 years of the use of alternative Fuels in the Cement industry (CEMBUREAU)

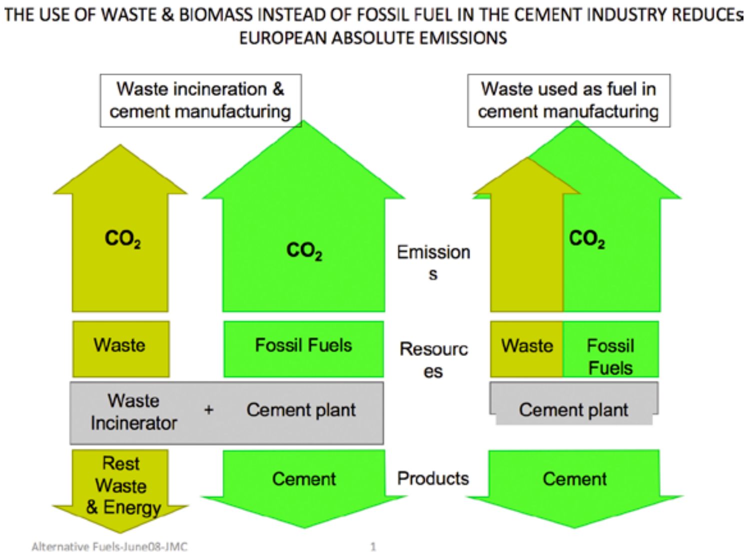
The cement industry is, therefore, committed to the use of alternative fuels. First of all, the use as alternative fuels in cement production benefits the environment by preserving non-renewable fossil fuels such as coal or oil. Secondly, alternative fuels contribute to lower overall CO_2 emmisions by preventing waste not to be incinerated or landfilled with corresponding greenhouse gas emissions and environmental impact.

The use of alternative fuels is a well proven and well established technology in most of the European cement industry and this has been the case for more than 20 years. In 2006, the volume of waste used as an alternative fuel represented about 7m tonnes. Waste materials utilised as alternative fuels by the cement industry in

[10] The Cement Sustainability Initiative launched its "Getting the Numbers Right" (GNR) project to obtain current and robust data for CO_2 and energy performance of clinker and cement production at regional and global levels across cement companies worldwide.

[11] Clinker, one of the main constituents of cement, is produced from raw materials (mainly limestone and clay) which are heated by a 2000°C flame in rotary kilns.

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS



clude used tyres, rubber, animal meal, waste oil and household RDF (refuse-derived fuel)[12].

2.1.2 Aggregates

The aggregate sector represents in Europe around 13,500 companies with 28,000 sites producing 3bn tonnes of aggregates a year. Europe provides over 23% of the worldwide production of sand, gravel and crushed rock.

Like the whole concrete sector, many aggregates sites are based in rural regions where secure jobs are scarce. The aggregates sector therefore sustains European society not only through the end-uses of its products, but also through its input to the local communities in which it operates, bringing development to the life of those areas.

Aggregates and recycled materials from construction and demolition waste are relatively low cost products and average delivery distance is less than 39km. In environmental and economic terms, local sites serve local markets. Of all minerals, aggregates are the most unless they are specialised aggregates, for example, ones with a high polished stone value, which is essential for skid resistance on roads as therefore saves lives and reduces accidents. On average, the price doubles at a radius of delivery of about 40km. Local sourcing is therefore a key criterion. Aggregates are needed mainly by the construction industry in the following proportions:

Image of a lightweight aggregate.
Courtesy of Concrete Centre

- 400 tonnes of aggregates for an average home
- 3,000 tonnes of aggregates for a school
- 30,000 tonnes of aggregates for 1km of motorway
- 90,000 tonnes of aggregates for 1km of high-speed railway track.

"No construction without aggregates" is an everyday truism. The construction industry represents almost 11% of the EU gross domestic product and the aggregates industry is an important supplier to the construction industry as aggregates are used in homes, offices, schools, hospitals and transport networks as well as power station desulferisation, flood defence and geology dictates.

In order to achieve a sustainable supply, access to potential resources must be maintained. Access should therefore not be denied unnecessarily by artificial constraints, such as environmental designations where the apparent environmental advantage of not extracting is outweighed by the economic and social need for the minerals. These constraints could also result in a negative environmental impact due to extended transport. A holistic approach and a sustainable minerals planning policy are therefore required.

[12] For more information please refer to the CEMBUREAU publication: Sustainable cement production. CO-processing of alternative fuels and raw materials in the European cement industry www.cembureau.eu.

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

A) CONTRIBUTION TO BIODIVERSITY AND NATURA 2000

In the environmental field, the aggregates industry acknowledges its role as land managers to prepare sites for environmental, agricultural, recreational, landscape or other community use during and after the operations working in close consultation with local communities.

With over 28,000 sites across Europe, the European aggregates industry is uniquely placed to make a significant contribution to the promotion of biodiversity, both during and after operations, to restore extraction sites that provide an ideal location for rare plants and other flora to flourish

Mineral extraction, unlike other forms of industrial development, involves the temporary use of land and it is incumbent on operators to work in a professional and sustainable manner. This includes respect for the land, appropriate conservation of habitats and heritage, and a commitment to reinstating the extracted sites for, commercial or recreational use. Promotion of biodiversity must, therefore, be central to operational and closure practices.

Aggregates cannot be extracted without some impact on the environment. Over many years, member companies have developed environmental awareness and understanding, while monitoring and mitigating the environmental impact. This process has not been achieved solely by the companies themselves, but also by working with partners such as non-governmental organisations (NGOs).

Those collaborations and partnerships with NGOs provide an opportunity to identify, create and enhance the habitats and ecosystems within which many companies operate. NGOs can assist with increasing knowledge and experience to create appropriate habitats and ecosystems best suited to their location, while the extractive industry can provide the technology, expertise and commitment to restore such sites.

With the increased awareness as to the importance of restoration and biodiversity, the European Aggregates Association (UEPG) has collected numerous case studies demonstrating the significant achievements in this area[10]. The industry is currently developing a biodiversity guide to assist and encourage companies to further increase their contribution and support.

The aggregate industry supports the objectives of Natura 2000[14] and is committed to contributing to nature and biodiversity conservation.

However, the way Natura 2000 is implemented in some EU member states sometimes lacks clarity, and incorrectly considers Natura 2000 areas as “no-go-areas”, although activities of the non-energy extractive industry might be allowed under certain circumstances. This may have a significant impact on the delivery of aggregates resources, which are needed to deliver essential buildings and infrastructure.

B) RECYCLING

The aggregates industry has launched a study on the recycling of construction and demolition waste that outlines the advantages and challenges for the industry. The following factors have an impact on the profitability of recycling:

- Shortage of natural material deposits on the market
- Significant and constant building and civil works activity
- Direct implication of upstream and downstream actors
- Support from public authorities to purchase high quality products
- Taxation scheme adapted to local conditions.

Recycled aggregates have an environmentally-friendly image as they contribute to save natural resources, reduce use of landfill sites and reduce negative effects of transport. However, they still suffer from a low acceptability due to a reluctance of some building designers and managers as well as a lack of support from public procurement.

Overall, the aggregates sector has made significant progress over the years in its economic, environmental and social performance and now has a much clearer understanding of its sustainability performance. The sector can draw on successful initiatives

[13] A biodiversity database containing these case studies will be uploaded on the UEPG website: www.uepg.eu

[14] www.natura.org

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

such as the partnership with IUCN/Countdown 2010[15] to halt the decline in biodiversity and the sector's contribution to the EU Sustainable Development Indicators (SDIs)[16].

2.1.3 Admixtures

Modern concrete contains, in addition to cement, gravel, sand, additions and air, one or more admixtures. Admixtures are chemicals added in very small amounts to concrete to modify the properties of the mix in the plastic and/or the hardened state. They are normally supplied as an aqueous solution to facilitate accurate addition through a dispenser. Today approximately 80% of ready mixed and precast concrete production ismodified with a concrete admixture.

The quantity of admixture added is usually based on cement content and for most admixtures is in the range of 0.2 to 2.0% by weight. In terms of active chemical this amounts to less than 0.15% of a typical concrete mix. Even at this low content they have a powerful effect, modifying the water requirement, rheological properties, pumpability and setting properties in the fresh state, and specific hardened concrete properties such as strength, resistance to freeze-thaw cycles and de-icing salts, sulphate resistance and other durability parameters.

The main sustainability benefits of admixture use are:

- Optimised mix design - reducing embodied carbon dioxide, water content and energy by enhancing the effectiveness of the cement component
- Increased fluidity - reduces vibration noise and energy requirements during placing
- Reduced permeability - increases the durable life of the concrete
- Reduced damage from harsh environments - including marine, freeze-thaw and sub zero situations
- Improved quality - better finish and reduced service life repair.

According to EN 934-2, concrete admixtures are classified into the following categories:

- Water reducing/plasticising
- High-range water-reducing/superplasticising
- Water retaining
- Air-entraining
- Set accelerating
- Hardening accelerating
- Set retarding
- Water resisting.

All other varieties of admixtures fall into the speciality category - their functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing and colouring.

Of the different concrete admixtures described above, plasticisers and superplasticisers are the most widely used, representing approximately 80% of European admixture consumption.

Generally, admixtures are processed organic chemicals and there-fore have an inherent environmental impact. The admixture manufacturing process has been subject to an environmental inventory that has enabled Environmental Product Declarations to be produced covering over 80% of admixture production in the European Union. Because the admixture dose is so small, the actual direct increase they make to the overall environmental impact of the concrete is so low (less than 1%) that under ISO14000 series rules it can be ignored. However, by using the admixture to optimise the mix constituents, a net improvement in the water use and global warming potential of the concrete can be in the order of 10 to 20%. Additionally, some admixtures are derived from sustainable raw material sources, such as corn or wood, and in the latter case the chemicals are produced from a by-product of paper pulp manufacture that was in the past a waste material that had to be disposed of.

[15] http://www.countdown2010.net

[16] http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1998,66119021,1998_66292168&_dad=portal&_schema=PORTAL

Although all admixtures are chemically based, the admixtures themselves are generally harmless and safe to handle, requiring no hazard labelling. However, all are supplied with safety data sheets detailing what to do in the event of contact, spillage or other incidents.

Admixtures are generally produced locally to their use, reducing transport impact and providing local employment, hence contributing to the socio economic aspects of sustainable construction. Manufacture is under factory-controlled conditions in mixing vessels. In most cases heating is not required so energy requirements are low. By purchasing raw materials in bulk, packaging waste is reduced to a minimum, and mixer cleaning water can usually be recycled so process waste is almost zero, too. By supplying to concrete manufacturers by tanker into fixed storage facilities, admixture packa-ging is also minimised. Most deliveries are also optimised by a 'milk round' top up system.

Stringent testing has shown that admixtures are bound into the concrete and do not leach out into the environment in significant quantities during the life of concrete. Admixtures have been approved for use in concrete that is in contact with drinking water following tests to show that they do not migrate from the concrete to taint, or otherwise affect it.

Testing for admixtures in an end-of-life scenario has shown that, even when old concrete is crushed and stockpiled, the admixture leaching rate is so slow that the admixtures biodegrade quicker than they can reach significant concentrations in the natural environment below the stockpile.

Admixtures are essential to the production of durable concrete. A concrete mix that has been optimised with admixture will generally outperform most other construction materials in terms of embedded environmental impact, durability, fire and flood resistance, noise and vibration attenuation, and temperature control due to thermal mass and many other properties.

2.1.4 REINFORCED STEEL

Reinforced concrete is a composite material comprising concrete and steel. While concrete provides the material's compressive strength, steel provides its tensile strength in the form of embedded reinforcing bars and mesh. Steel reinforcement plays a key role in reinforced concrete structures as it ensures ductile behaviour (i.e. bendability) in earthquakes, for example. Reinforcing bars are usually formed from ridged carbon steel, the ridges giving frictional adhesion to the concrete. The amount of steel used in reinforced products is relatively small. It varies from 1% in small beams and slabs to 6% for some columns, according to purpose and design conditions.

The steel used in reinforced concrete utilises 100 percent recycled scrap steel as feedstock. At the end of its life, all reinforcing steel can be recovered, recycled and used again. The embodied energy values of reinforcing steel are based on the energy used to melt and reform it - unlike those for structural steel which are mostly converted in a very energy-intensive process from iron ore. The energy input per tonne of reinforced steel is less than half of that for structural steel.

Steel reinforced concrete can be used for any type of structure (bridges, highways, runways) and buildings. But it is generally used for applications carrying heavy loads such as footings, foundation walls and columns. The cast in situ concrete "body" and shop-fabricated steel "musculature" of steel reinforcing bars work together to create one of the most durable and economical composite materials.

Three characteristics make steel and concrete work well together:

- They have similar coefficients of thermal expansion. Therfore, a reinforced concrete structure will experience minimal internal stress as a result of differential expansions or contractions of the two interconnected materials caused by temperature changes.
- When the cement paste within the concrete hardens, it conforms to the surface details of the steel, permitting any stress to be transmitted between the different materials.
- The alkaline chemical environment provided by calcium car-

bonate (lime) causes a passivating film to form on the surface of the steel, making it much more resistant to corrosion than it would be in neutral or acidic conditions.

An attractive alternative to reinforced steel is the use of fibres for reinforcement. This option appears quite sustainable as, made of glass, aramid and carbon, fibres reinforced polymer (FRPs) composite materials are six times stronger than steel, one-fifth the weight, non-corrosive and non-magnetic. They are used to reinforce the sections of infrastructures, such as concrete bridges, that corrode and deteriorate over time and usually require early maintenance.

2.2 USE OF SECONDARY RAW MATERIALS

2.2.1 Additions in concrete

By-products from other industries or electric generating processes can be used as additions in the manufacture of concrete. Fly ash, blast furnace slag and other mineral admixtures can substitute cement in the concrete mix. They offer the advantage of saving energy, improving the quality of the concrete mix and reducing its cost. They also provide a way of taking part in the necessary process of waste management for the concrete industry.

Fly ash is a fine, glass-like powder obtained from the gases of burning coal in power stations and is separated from combustion gases by electrostatic precipitators. Pulverised fly ash (PFA) can act as fine aggregate or as a substitute for cement as it enables the properties of both fresh and hardened concrete to be controlled.

Blast furnace slag is produced when iron is smelted. Ground blast furnace slag (GBBS) has latent hydraulic properties. It can, to some extent, replace Portland cement as, when it is mixed with cement, the slag is activated and acts as part of the concrete binder. Unlike Portland cement, blast furnace slag does not need to be heated separately. It is also suitable for pouring large structures as it reduces the temperature rise in comparison with using only cement.

Silica is a fine-grained pozzolana. It is a by-product of producing silicon metal or ferrosilicon alloys. Due to its chemical and physical properties, it is a very reactive pozzolana. It increases the strength and durability of concrete substantially, along with its density, chemical and moisture resistance.

Concrete standards restrict the overall amount of additions that can be used. Several studies have been carried out in the last 10 years to determine whether it would be possible to increase the amount of additions from the limits set in the concrete standards without affecting the quality of the concrete. The advantages of using larger quantities of additions are obvious: it would further reduce the amount of energy and the quantity of primary raw materials used in concrete's manufacture.

When comparing the environmental loading of concrete, concrete's strength and durability must be taken into account since its strength develops more slowly and its durability is reduced with an increased quantity of additions.

2.2.2 Recycled aggregates

Concrete can be made using other materials rather than naturally occurring aggregates. Crushed concrete is an example. But first, steel reinforcement and impurities such as insulation must be removed, and the concrete must be thoroughly crushed. Just as with naturally occurring aggregates, crushed concrete needs to be graded. Some 20-30% of total aggregate may be replaced by good quality crushed concrete

Crushed glass and brick can also be used in concrete but, because of their poorer strength and durability characteristics, are more suitable for indoor use. Waste rocks from mining can also be used as aggregate.

2.3 THE MANUFACTURING PROCESS

The different steps in concrete manufacture are receiving and storing raw materials, warming aggregates and water if necessary, measuring ingredients, mixing cement and water together, adjusting the consistency of the mix and controlling its quality. Nowadays, this is a fully automated process that does not cause hazardous emissions.

[14] http://www.eurofer.org

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

Concrete is manufactured according to predetermined proportions (kgs/m^3 of concrete) or 'mix'. The properties of fresh and hardened concrete depend on the relative volumes of the constituent materials. The ingredients (water, aggregate, cement and additions) are weighed before being put into the mixer, where it mixed for some 60 to 90 seconds.

Concrete factories, their equipment and procedures vary according to the product they specialise in. All of them have a concrete mixer and a raw material silo. The quality and quantity of recyclable material varies considerably according to the process in each factory. A few examples of different production processes are described below.

Precast concrete elements are factory made under strict controls. The manufacture of structural elements is automated to a considerable extent.
Courtesy of British Precast and Bond van Fabrikanten van Betonproducten in Nederland (BFBN).

Recycling processes during manufacturing

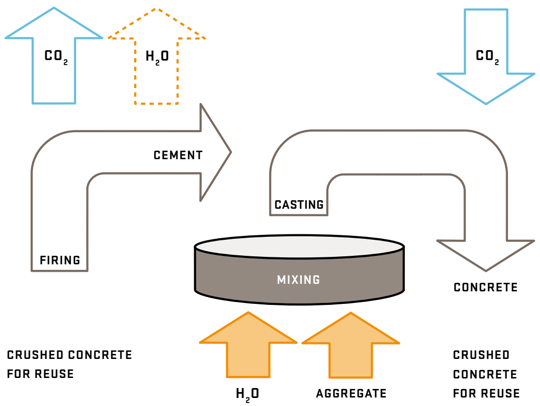
The surplus fresh concrete arising from concrete manufacture is separated into coarse aggregate and cementitious slurry by washing. The slurry is further separated from solid matter in settling tanks. Water is recycled throughout the process.

Water is recovered in several ways; from washing concrete mixers, conveyor belts and the drums of concrete trucks, from the separation of surplus concrete, from cutting, grinding and washing hardened concrete. It contains varying amounts of very fine particles, generally smaller than 0.25mm. Prior to its reuse, the amount of solid matter in it must be checked to ensure that it is not too high. Water from concrete plants is not hazardous to the environment.

Aggregate recovered from washing water is just as suitable as natural aggregate for ground works such as road building. Washed aggregate can also be used for concrete manufacture.

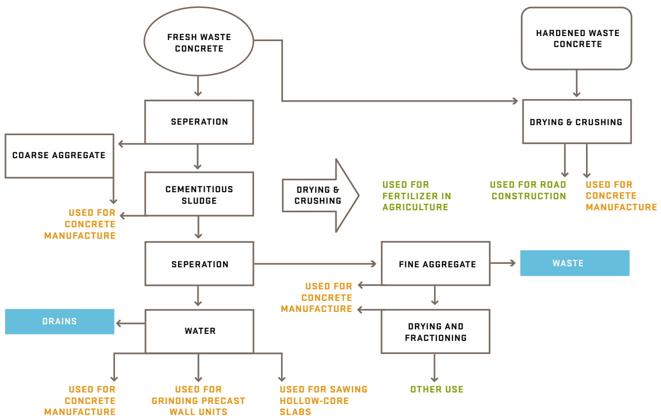
The solid material in process water in the concrete industry is allowed to settle out so the water can be recycled for concrete manufacture. Courtesy Betoni, Finland.

CONCRETE RECYCLING



Cementitious recyclable fine waste materials, which may be runny or solid, can be used as an agriculture agent within certain limits. According to legislation, cementitious recyclable fine waste materialscan be used as a liming agent if its neutralising power exceeds 10% calcium. Sludge from sawing and grinding concrete in connection with grinding hollowcore slabs and other concrete products is particularly suitable for raising the pH of soil.

A small quantity of surplus concrete is always left over in concrete manufacture, and crushed concrete is left behind when buildings are demolished. Hardened concrete does not end up as waste on landfill sites, but is recycled for a wide range of uses.



Recycling of fresh and hardened concrete.
Source: BetoninSuomen Betonitieto Oy, 2005

2.3.1 Examples

Manufacturing hollowcore slabs

Hollowcore slabs are poured with low-slump concrete on a casting bed about 100-150 metres long using a slip-forming process without separate moulds. The steel strands that act as reinforcement in the hollowcore slabs are pre-tensioned before the slabs are cast.

The product is compacted by the pouring machine. Openings and recesses are made in the fresh concrete after pouring, and the concrete removed can be used again in the process.

Manufacture of lightweight aggregate concrete blocks

The raw materials for lightweight concrete blocks include various grades of lightweight aggregate, sand, pulverised fuel ash, cement and water. In the manufacture of insulated blocks, polyurethane insulation is inserted between the components of the block.

The materials are mixed together and the dry-mix is measured into the block moulds. The moulds are vibrated continuously to give the product the correct degree of compaction. The slabs are conveyed on a casting bed to be gently cured at about 40°C or are left indoors at about 20°C for 24 hours.

Lightweight concrete blocks are widely used in foundations and external walls for small houses because they are easy to lie and easy to work with. Courtesy of BFBN.

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

2.3.2 Transportation

A key principle of sustainability is that a product should be consumed as near as possible to its production place. This is not only to minimise the need for transport and its associated environmental, economic and social impacts, but also to support the local economy and society, and to prevent the export of the associated environmental impacts of production to another location with less stringent environmental and social protection legislation.

Transportation is an essential phase of concrete production and it is a crucial phase as concrete may lose some of its properties during transportation. Some special care is given to the homogeneity obtained when mixing concrete so that it stays the same while being transported to the final place of deposition. The truck mixer retains concrete's fluid condition through agitation, or turning of the drum until delivery.

Ready mixed concrete is a fresh product that must be cast within 30 minutes after its arrival on the building site. The time for transport is also extremely limited - to one hour and 30 minutes.

The concrete industry is aware that road transport is the most carbon-intensive option. It uses alternative transportation methods, such as rail and ships, when the journey is longer.

2.4 SOCIAL ASPECTS OF CONCRETE MANUFACTURE

2.4.1 Steering safety through corporate social responsibility

In recent years, the focus was put on environmental aspects when addressing the question of sustainable development and construction. Even then, the tools used to measure environmental performances have often lacked scientific rigour. For example, a life-cycle assessment period of "60 years" for buildings has been used to the detriment of concrete structures that can typically endure for 150 years and in some cases, indefinitely. Therefore, the social and economic aspects of sustainability have been almost ignored, which has created a distorted working definition of sustainability.

To be successful in business, a company needs to consider the whole framework in which it operates; its customers, employees, shareholders, local communities and other stakeholders. The overall benefits of commercial activities are very much related to the welfare of employees, and, in particular, to their health and safety in the workplace. When an accident occurs, it is already too late to take countermeasures.

The concrete industry has always placed importance on the welfare of its employees. Recently, efforts have been stepped up to improve health and safety performance. In modern cement and concrete plants across Europe, the risk to employees or site operatives has been greatly reduced.

For example, some partners of the European Concrete Platform (BIBM, CEMBUREAU, and UEPG) participated in the Multisectorial Dialogue Platform for Respirable Crystalline Silica (SiO_2) promoted by the European Commission. The sectors concerned reached an agreement in 2006 over the reduction of workers' exposure to crystalline silica dust in the manufacturing process (NEPSI)[18]. This agreement aims at protecting individuals' health when exposed to respirable crystalline silica in their workplace, preventing and minimising the exposure by applying good practices.

The European concrete industry has a proactive attitude and produces a practical safety bulletin for concrete suppliers. This bulletin has, for example, specified the health risks of wet concrete, due to its alkalinity. Special protective clothing must be worn to prevent the skin from coming into continuous contact with the fresh wet concrete.

The industry makes strenuous efforts to reduce the noise produced by its activity and mitigate the effects on workers. In many of the newer factories, quieter machines have been installed. For example, the latest casting machines for hollowcore slabs use shear compaction instead of vibration compaction because of the lower noise levels and higher product quality. But in some situations, concrete manufacture may still cause noise levels of over 85dB, and at some work stations noise may exceed the 100dB level. The use of hearing protection is therefore essential inside factories, and the employers ensure that all workers are aware of this.

[18] http://www.nepsi.eu

THE MANUFACTURING PROCESS OF CONCRETE AND CONCRETE PRODUCTS

When concrete is being placed, it is usually compacted by vibration. The damaging effects of vibration on the hands are reduced by using mechanised vibration methods. Through innovative developments such as self-compacting concrete (SCC), the concrete industry continues to try to limit those health hazards. SCC is placed without the need for compaction using vibrating pokers, which can cause a painful condition known as "white finger"[19]. SCC is manufactured using "superplasticisers" and by increasing the amount of fine aggregates in concrete.

Self-compacting concrete is extremely fluid. It needs no vibration to compact and is easier to place, which is better for workers' health and safety and saves time.
Courtesy of BFBN.

Another new development is the use of vegetable oil based shuttering oils. As biodegradable and non toxic oils, they are safer and more sustainable than standard mineral oils, which are not biodegradable and may contain toxic components that are potentially damaging to human health (particularly lung damage and skin irritation) and to the environment.

[19] Vibration white fingers: injury triggered by continuous use of vibrating hand-held machinery that can affect nerves, joints, muscles, blood vessels or connective tissues of the hand and forearm.

THE LUXURY OF A SAFE, HEALTHY AND COMFORTABLE CONCRETE STRUCTURE

3.1 THE BEST CHOICE FOR THERMAL COMFORT[20]

The use of energy in buildings accounts for a large share of the total end use of energy in Europe (40%). This is more than either the transport or industrial sectors, which are the second and third biggest consumers respectively. "Two thirds of energy used in European buildings is accounted for by households; their consumption is growing every year as rising living standards are reflected in greater use of air conditioning and heating systems."[21]

Concrete's thermal mass can be used to avoid or reduce temperature swings in the building and to eradicate the need for energy-guzzling air conditioning systems.

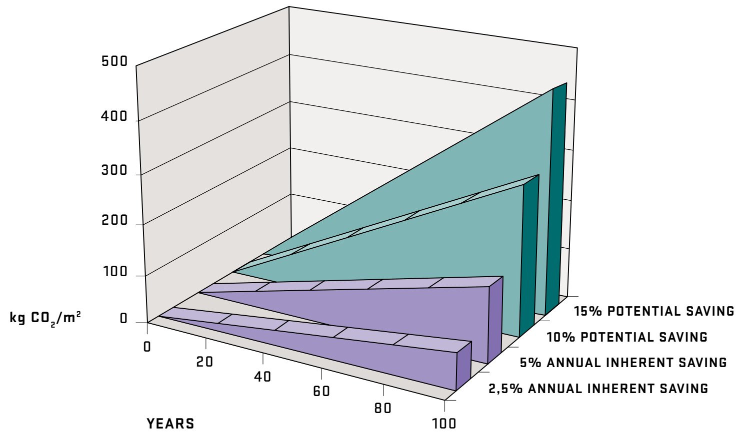
Concrete walls and floors are effective storage heaters, absorbing free heat from the sun during the daytime and releasing heat at night. Concrete stores heat in the winter and cools buildings in the summer, creating optimum comfort conditions for the occupants. Dense, heavyweight concrete provides the highest amount of thermal mass.

Research results demonstrate that buildings with high levels of thermal mass, passive solar features and effective ventilation controls perform extremely well as regards energy efficiency[22].

The effect of concrete's thermal mass[23]:

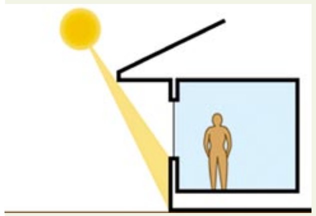
- Optimises the benefits of solar gain, thereby reducing the need for heating fuel
- Reduces heating energy consumption by 2–15%
- Smoothes out fluctuations in internal temperature
- Delays peak temperatures in offices and other commercial buildings until the occupants have left
- Reduces peak temperatures and can make air conditioning unnecessary
- Can be used with night-time ventilation to eliminate the need for daytime cooling
- When combined with air conditioning, it can reduce the energy used for cooling by up to 50%
- Can reduce the energy costs of buildings
- Makes best use of low-temperature heat sources such as ground source heat pumps
- The reductions in energy use for both heating and cooling cuts CO_2 emissions
- Will help future-proof buildings against climate change.

ANNUAL CO_2 SAVINGS



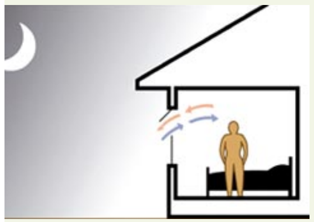
Lifetime consequences of small annual improvements in energy savings. Note: the inherent savings come automatically with a heavyweight building. The potential savings are obtained if the building and installations are specifically designed for maximum energy efficiency.

Thermal mass during the summer



Daytime

On hot days the windows are kept shut to keep the hot air out, and shading should be adjusted to minimise solar gains. Cooling is provided by thermal mass. If temperatures are less extreme, windows may be opened to provide ventilation.



Night-time

If it has been a hot day, the occupant opens windows to provide night cooling of the thermal mass.

[20] For details, refer to the European Concrete Platform publications:
Concrete for energy-efficient buildings.
The benefits of thermal mass, April 2007.

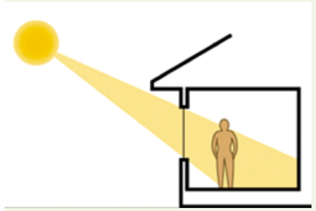
[21] http://ec.europa.eu/energy/demand/legislation/doc/leaflet_better_buildings_en.pdf

[22] HACKER J.N. ET AL., Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change, ARUP Report, Energy and Buildings 40, pp. 375-384, 2008.

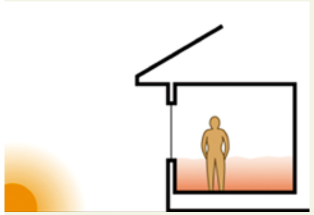
[23] TAMPERE UNIVERSITY OF TECHNOLOGY, Thermal mass of buildings - Summary of research reports and results, Report 174, 2003.
To go further: KALEMA T. ET AL., Nordic Thermal mass - Effect on Energy and Indoor Climate, Report 184, Tampere University of Technology, Tampere, 2006.

THE LUXURY OF A SAFE, HEALTHY AND COMFORTABLE CONCRETE STRUCTURE

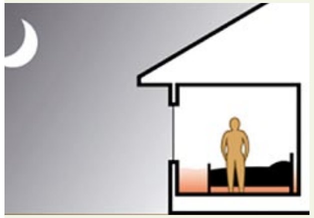
Thermal mass during the heating season



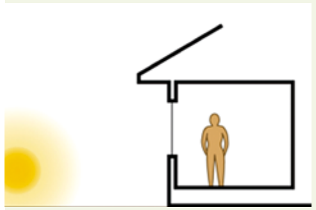
10 am to 5 pm
Sunlight enters south-facing windows and strikes the thermal mass. This heats the air and thermal mass. On most sunny days,r solar heat can help maintain comfort from mid-morning to late afternoon.



5 pm to 11 pm
After sunset, a substantial amount of heat has been stored in the thermal mass. This is then slowly released, helping to maintain comfortable conditions in the evening.



11 pm to 7 am
The occupant adjusts the heating so only minimal supplementary heating is needed. Good airtightness and insulation minimise heat loss.



7 am to 10 pm
The early morning is the hardest time for passive solar heating to maintain comfort. The thermal mass has usually given up most of its heat and the occupant must rely on supplementary heating.
However, good airtightness and insulation help minimise this need.

Passive cooling in summer, and storage and release of free energy gains in winter.
Courtesy of The Concrete Centre.

Under-floor heating works best when installed in a concrete structure, so that the heat energy is stored in the construction. It is then given up steadily to the indoor air. With under-floor heating installed in a concrete slab, most of the energy needed for heating and hot water can be obtained from night-time electricity, which is usually much cheaper than daytime supply.

3.2 HIGH INDOOR AIR QUALITY

The issue of indoor air quality is a major health concern for many European citizens as it can lead to serious health problems, including respiratory diseases such as asthma and lung cancer. Recognising that European citizens spend much of their time indoors, legislators are looking at ways to improve indoor air quality as a matter of priority.

A number of factors can contribute to poor indoor air quality; tobacco smoke, high volatile organic compound (VOC) levels, odours from products used for cleaning, personal care or hobbies, and combustion from burning oil, gas, kerosene, coal, wood, etc.

Concrete contains low to negligible levels of VOCs, compounds that degrade indoor air quality. VOCs generally emanate (in the form of gas) from new building products.

Polished concrete floors are particularly inert and are more hygienic than other types of floor finish. Concrete floors will not harbour allergens produced by dust mites, sustain mildew or give off harmful VOCs. Exposed concrete walls do not require finishing materials.

Further measures can reduce the level of VOCs in concrete construction, such as using low-VOC materials for form release agents, curing compounds, damp-proofing materials, wall and floor coatings and primers, membrane sealers and water repellents.

Concrete promotes a healthier indoor air quality since it is an inert material that does not require volatile organic-based preservatives. It is naturally waterproof and fire-resistant, so no special coatings or sealers are needed.

3.2.1 Concrete as an air barrier

Concrete acts as an effective air barrier. It absorbs comparatively small amounts of moisture at a slow rate, and does not degrade or rot as a result of moisture absorption. Concrete not only retains its structural stability when exposed to moisture but can even attain its highest strength properties when submerged in water for a long time. Concrete's moisture resistance limits the amount of moisture that can enter a building or a wall through infiltration, and provides better conditions for heating, ventilating and air conditioning systems,

THE LUXURY OF A SAFE, HEALTHY AND COMFORTABLE CONCRETE STRUCTURE

[24] For details, refer to the European Concrete Platform publications: Comprehensive fire protection and safety with concrete and Improving fire safety in tunnels. The concrete pavement solution

thereby improving indoor air quality.

In the case of sudden moisture ingress such as flooding, it is usually sufficient to dry out the building without the need for demolition or reconstruction. Alternative materials such as timber cladding or other wooden components that become wet almost always need to be replaced.

Moisture and mould damage in buildings is fairly common. The incidence of moisture damage increases steadily with indoor air humidity, typically caused by a number of factors related to the users' activities and habits. Appliances using gas and a lack of maintenance are some of the common causes of moisture damage.

3.3 CONCRETE FOR A RESISTANT, SAFE AND SECURE BUILDING

3.3.1 Concrete's strenght and structural stability

High crushing strength is a particular characteristic of concrete. Strength is chosen according to intended use and can be varied by adjusting the mix, particularly the water-cement ratio. As knowledge and materials technology develop, it is possible to increase the compressive strength of concrete. The average tensile strength in low-strength grades is about 10% of the compressive strength, and in the higher strength grades about 6%.

By using high-strength concrete (over 60MPa), the dimensions of the structure can be reduced. As part of the "high-strength concrete development project", it was estimated that doubling the strength of the columns reduces the cost/load-bearing ratio by about 25%.
A significant proportion of this comes from reducing the use of materials, so that as far as environmental impact is concerned it is advantageous to use high-strength concrete. Moreover, it has the advantage of improving the service life of the structure.

3.3.2 Naturally providing protection and safety against fire[24]

Fire is a rapid, progressive chemical reaction that releases heat and light. Once a spark or heat source is provided, combustible substances can burn in the presence of oxygen. Concrete's excellent and proven fire resistance properties protect human life, property and the environment in case of fire.

Concrete offers "concrete solutions" to all of the fire protection aims set out in European legislation, benefiting everyone from building users, owners, businesses, residents, insurers, regulators and firefighters. Whether it is used for residential buildings, industrial warehouses or tunnels, concrete can be designed and specified to remain robust in even the most extreme incidents of fire.

Everyday examples and international statistics provide ample evidence of concrete's fire protecting properties. Building owners, insurers and regulators are making concrete the material of choice, increasingly requiring its use over other construction materials as concrete offers superior performance on all relevant fire safety criteria, easily and economically.

Using concrete in buildings and structures offers exceptional levels of protection and safety in case of fire:

- Concrete does not burn, and does not add to the fire load
- Concrete has high resistance to fire, and stops fire spreading
- Concrete is an effective fire shield, providing safe means of escape for occupants and protection for firefighters
- Concrete does not produce any smoke or toxic gases, so helps reduce the risk to occupants
- Concrete does not drip molten particles, which can spread the fire
- Concrete restricts a fire, and so reduces the risk of environmental pollution
- Concrete provides built-in fire protection - there is normally no need for additional measures
- Concrete can resist extreme fire conditions, making it ideal for storage premises with a high fire load
- Concrete's robustness in fire facilitates firefighting and reduces the risk of structural collapse
- Concrete is easy to repair after a fire, and so helps businesses recover sooner
- Concrete is not affected by the water used to quench a fire
- Concrete pavements stand up to the extreme fire conditions encountered in tunnels.

THE LUXURY OF A SAFE, HEALTHY AND COMFORTABLE CONCRETE STRUCTURE

3.3.3 Resistant to external extreme events

Concrete has the ability to absorb energy from shocks. Safety is second nature to concrete. It widely covers what is required by design codes such as Eurocode 2[25], which makes provisions for buildings and civil engineering works constructed in concrete.

Evidence of this resilience can be seen in the fact that concrete can resist break-ins, break-outs and massive impacts, even from jet planes. Traffic separation barriers are made from slip-formed or precast concrete, absorbing the impact from vehicles and slowing them down. Concrete barriers deliver the following key sustainability benefits[26]:

- 80% less embodied CO_2 than competing systems
- Minimum material usage and waste
- Non-polluting in service
- Fully recyclable
- Virtually maintenance-free over its 50 year service life
- Reduction of traffic congestion and associated emissions
- Enhancement of the road users and workers' safety

Concrete construction is clearly advantageous where buildings or infrastructures are threatened by bomb blasts or chemical explosions.

3.4 BUILT-IN SOUND INSULATION AND PROTECTION AGAINST VIBRATION

Another advantage of "massive" concrete is its ability to dampen vibration and reduce sound transmission. The quiet comfort that today's homeowners require can be realised through concrete, even when a building is situated close to noise sources such as roads, railways or airports.

There are regulations throughout Europe governing the sound insulation requirements for airborne (e.g. loud speech) and impact sound (e.g. footsteps), particularly for residential buildings.
Airborne sound insulation depends on the mass and stiffness of the structure, so concrete construction is the best way of guaranteeing good sound insulation.

To effectively insulate against airborne sound, it is important that the construction is sealed and that sound cannot pass through ducts, gaps in the construction or joints. Even small gaps in the construction can greatly compromise sound insulation.
In this regard, properly built, massive construction is more reliable than lightweight construction, which does not in itself have good sound dampening properties and by its very nature tends to introduce voids in the construction. A 250-300mm thick hollowcore floor and 180mm thick walls will give sufficient insulation in almost all cases.

Floor finishes have a large bearing on structural/impact sound resistance. A standard in situ concrete slab, 250mm thick, will satisfy most European regulations, which generally require a sound reduction level of 53dbs (European requirements). Equally, hollowcore floor slabs weighing a minimum of 500kg/m^2 with a soft floor covering or composite woodblock flooring will meet European requirements.

From the point of view of acoustics and resident satisfaction, a floating concrete floor is the best alternative. Concrete floors are an effective solution to annoying, low-pitched sounds. With intermediate floors of lightweight construction, the low-frequency sounds that come from footsteps, for example, may disturb residents even though the standards for impact sound insulation are met.

Concrete walls are used to create an effective sound barrier, particularly against traffic. As a mouldable material, concrete can easily be made into the optimum shape for sound attenuation. Equally the surface can be smooth to reflect sound or indented if sound reflection needs to be reduced.

[25] http://www.europeanconcrete.eu/index.php?option=com_docman&task=cat_view&gid=25&Itemid=30

[26] BRITPAVE, Sustainability Benefits of Concrete Step Barriers, http://www.concretebarrier.org.uk/

ENVIRONMENTAL PROPERTIES OF CONCRETE STRUCTURES IN-USE

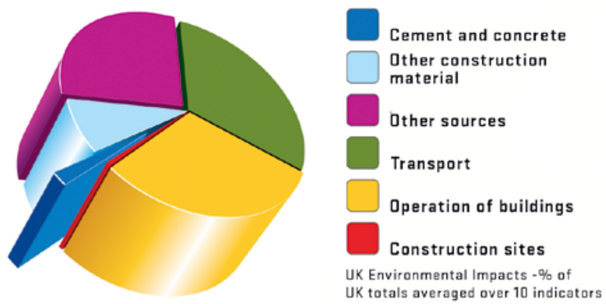
4.1 CONCRETE BUILDING' IMPACT OVER THEIR WHOLE LIFE-CYCLE

Life-cycle analysis (LCA) evaluates the environmental impact of a structure from its inception to its demolition: extraction, manufacture, construction, use, maintenance, demolition and recycling. This holistic approach has to be taken into account when assessing the environmental impact of a structure.

Concrete performs very well when accurate and holistic comparisons are made with other building materials. In the energy efficiency field, for example, the energy savings of concrete structures (5-15%) in the in-use/operational phase easily offset the amount of energy consumed in their manufacture and installation (4-5%).

Usually, some 80-90% of the energy used during a building's life-cycle is consumed during the in-use phase. Therefore, the greatest potential for energy savings occurs during this period. Up to 30-45MT of CO_2 a year[27] could be saved by 2010 by applying more ambitious standards to new and refurbished buildings. Therefore, to save energy and CO_2 we must concentrate primarily on the in-use phase.

Some 10-20% energy is consumed in the construction phase. At the extraction and demolition stages, very little energy is consumed a few per cent at most. The ratio of energy consumption between the construction and use phases depends on the duration of the period under examination (usually 50-100 years). Because concrete structures are extremely durable, they have a very long service life.



The UK concrete environmental impacts. Courtesy of The Concrete Centre.

Efforts are being made to reduce the consumption of heat energy during a building's use. Some EU Member States are progressively implementing stricter heat insulation regulations at regular intervals, and these efforts are already bearing fruit. For example, in the UK, a house built in 2007 is 40% more energy efficient than one built in 2002[28]. However, the changes usually apply to new buildings only. Furthermore, the building stock in the EU amounts to 21bn m^2 [29] and is continuously growing, as the rate of new construction is 1% a year compared to a demolition rate of 0.5%. Despite the new energy saving measures, the energy consumption of the entire building stock is increasing continuously and it may take a very long time to improve energy efficiency at this rate. Greater efforts are therefore needed to reduce energy consumption in buildings. Cutting the energy consumption in the building sector will become more important than ever with rising energy prices.

Naturally, sustainable building solutions should be investigated as part of building design and particularly those aspects that contribute to low energy consumption during use. A short-sighted vision limited to minimising the environmental loading at construction phase can easily lead to increased energy consumption at the in-use phase, or a short service life for the building.

4.2 ENERGY EFFICIENT BUILDINGS

The need to preserve energy in European buildings presents a serious challenge. There is a particular need to invest in the renovation of older buildings to bring them up to modern standards of thermal efficiency. In Europe today, only 1,000 new dwellings a year[30] are built to "Passiv Haus" (passive house) standards, although a number of European governments are themselves setting targets of achieving 100% "zero carbon" new dwellings by 2016. Many European governments are increasingly looking to the building sector to help meet Kyoto targets.

4.2.1 The Energy Performance of Buildings Directive (EPBD)

The EU estimates that about 41% of end-use energy consumption takes place in the residential and commercial sectors. The EPBD

[27] http://ec.europa.eu/energy/demand/legislation/buildings_en.htm

[28] http://www.leonardo-energy.org/drupal/taxonomy/term/54

[29] http://www.eeb.blog/org

[30] http://wwww.europeanpassivehouses.org/ and http://www.passive-on.org/en

is capable of realising an estimated 28% of energy savings in the building sector, reducing total EU energy consumption by around 11%[31]. The lack of energy efficiency in buildings costs Europe an estimated €270 bn every year[32]. For national economies, investments in energy savings in buildings would result in net annual cost reductions, making such measures economically sound. However, to achieve this objective, it is crucial that all stakeholders are involved, from governments and industry to final consumers.

The Energy Performance of Buildings Directive came into force in 2006. It is the main legislative instrument affecting energy use in the EU building sector and it commits the Member States to the following measures[33]:

- Introducing a method of calculating overall buildings' energy efficiency
- Setting minimum requirements for the overall energy efficiency of new buildings and of large existing buildings (over 1,000m²) subject to major renovations (for the whole building or parts of it thereof)
- Requiring energy certificates when commissioning, leasing or selling the building
- Regular inspections of ventilation systems
- Consideration of alternative energy maintenance systems in new buildings of over 1,000m².

This Directive is currently being recast by European institutions, who review different points to broaden its scope by:

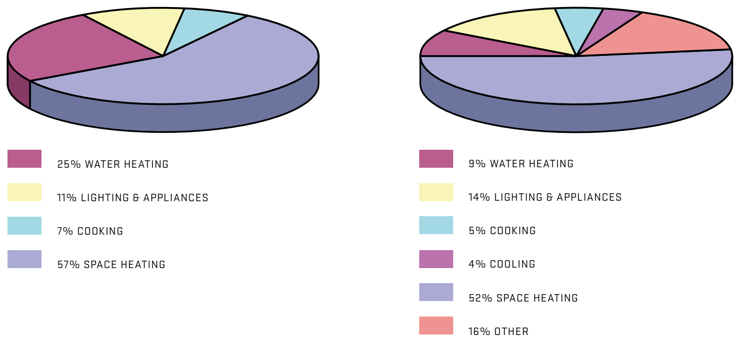
- Improving the quality of buildings by strengthening certification schemes and inspections
- Expanding the role of the public sector to demonstrate new technologies and methods
- Lowering the 1000m² threshold (or abolishing it) so that more buildings fall within its scope
- Proposing minimum performance requirements (kWh/m²) for new and renovated buildings and some components, with a target for new buildings to approach the level of 'passive houses' from 2015
- Considering binding requirements to install passive heating and cooling technologies
- Proposing measures for Member States to provide financing for highly cost effective investments and promoting the concept of low-energy consumption houses[34].

4.2.2 Energy savings on heating and cooling

Energy consumption during the service life of a building is divided into heating energy and electricity consumption, which account for 42% and produce about 35% of total European greenhouse emissions[35]. This is in addition to energy consumed by maintenance and repairs.

Energy used for heating forms the major part of energy consumption. In office buildings it can be substantial and is added to by the need to power computers, copying machines, etc., and the need to cool the building.

The energy consumption of a building is directly affected by its structure; large glazed facades, for example, will usually increase the need for heating in winter and cooling in summer. Heating energy consumption in a building is affected by the thermal insulation of the external envelope, the mass of the building, the ventilation and how well sealed (or airtight) it is.



EU building energy consumption for residential and commercial buildings.
Source: www.intuser.net

[31] EUROPEAN COMMISSION, Action Plan for Energy Efficiency: Realising the Potential, 2006.

[32] BOERMANS T., PETERSDORFF C., U-Values - For Better Energy Performance of Buildings, Report established by ECOFYS for EURIMA, 2007. http://www.eurima.org/europeandU

[33] http://www.buildingsplatform.org/

[34] http://www.cepi.eu/

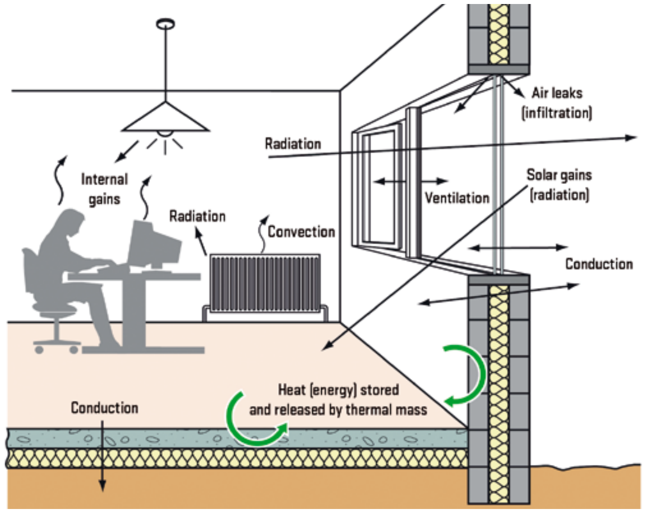
[35] EUROPEAN COMMISSION, Accelerating the Development of the Sustainable Construction Market in Europe, Report of the Taskforce on Sustainable Construction Composed in preparation of the Communication "A Lead Market Initiative for Europe", 2007.

ENVIRONMENTAL PROPERTIES OF CONCRETE STRUCTURES IN-USE

The importance of sealing a building grows as the thermal insulation of the external envelope improves and as heat recovery from the ventilation is increased. Better sealing in a house built entirely in concrete can save an average of 10% heating energy compared with a house built in timber.

The energy savings can be further increased by switching from passive ventilation to active (or mechanically assisted) systems. For example, hollowcore slabs can act as ventilation ducts and store surplus heat or coolness. In the latter case this lowers maximum temperatures in summer and reduces the need for cooling. The mechanical cooling power requirement and the energy consumption reduces and in some cases the mechanical cooling can be left out altogether by using the thermal mass of the hollowcore slabs. This gives substantial savings both in construction and running costs.

Developed for office buildings, this system can provide energy savings of 7-10% compared with conventional variable air volume (VAV) systems and cooling beam solutions.



Heat (energy) flows within a building

- Heat is gained by solar radiation, and internal gains from lighting, heating, and the occupants and their equipment
- Heat is lost via air leaks, ventilation, radiation through windows and conduction (transmission) through walls, windows and floors
- Heat is stored and released by the thermal mass of the building

4.3 A NON-POLLUTING CONSTRUCTION MATERIAL

The health and environmental aspects of building products, and particularly the quality of indoor air, top the rankings in various EU action programmes. The different Member States and their officials have regulations and assessment procedures for these matters; the Commission is currently harmonising these by introducing new legislation.

The third 'essential requirement' of the Construction Products Directive (currently under revision and to be transformed into a Regulation) concerns "Hygiene, Health and the Environment"[36]. It covers emissions from hazardous substances and their monitoring in places where construction products are used. The Construction Unit of the European Commission[37] has drawn up a mandate for launching harmonisation of standards for measurement, testing and assessment procedures. On this basis, as many procedures as possible will be harmonised to suit products and product groups in the same use environment. Emissions from building products to indoor air are also under examination along with depositing substances into the ground and into surface and ground water.

4.3.1 Emissions to soil and water

In the case of concrete, several studies conducted in different European countries have shown that the release of constituents into groundwater is low. The chemical analysis on hundreds of samples, with tens of formulations containing different sorts of cements and granular materials, including recycled ones, show dissolved substances at levels much lower than the very stringent limits set by the World Health Organisation for drinking water[38]. Only sulphate ion ($SO_4^{=}$) is regularly found at high concentrations, but always much lower than the levels found in many popular brands of mineral waters.

4.3.2 Emissions to indoor air

Emissions to the air are produced by substances that can become gaseous at temperatures and in conditions existing in buil-dings. The components of concrete products are inert materials. Small quantities of organic chemical products can be used to enhance the

[36] http://ec.europa.eu/enterprise/construction/internal/cpd/cpd_en.htm#a1

[37] http://ec.europa.eu/enterprise/construction/index_en.htm

[38] WORLD HEALTH ORGANIZATION, Guidelines for Drinking Water Quality, First Addendum to Third Edition, Volume 1, Recommendation, 2006. http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf

ENVIRONMENTAL PROPERTIES OF CONCRETE STRUCTURES IN-USE

production of the concrete, but they are entrapped in the concrete matrix and cannot migrate to the surface. Traces of mould release agents, made from non-toxic vegetable oils, can also be present for a short period at the surface of the products, but disappear within a few days after production.

A) RADIATION AND RADON

The principal source of ionising radiation to which humans are exposed is radon gas. Local geology and natural release of radon from the ground is normally the dominant influence on radon and radioactivity levels in buildings. Indoor radon levels vary widely throughout Europe and views as to radon's significance also vary in different countries. Where guidelines for indoor radon levels have been set, the levels generally present no difficulties for normal concrete building materials. On the contrary, radon intake from the ground can be substantially reduced by the use of concrete and suitable building construction design.

B) CONCRETE STRUCTURE AGAINST RADON

The radon content of indoor air can be influenced by the choice of foundations. In areas where exceptionally high radon concentrations have been measured, choice of foundations is key to the success of anti-radon measures.

Basic practices for achieving radon safety are:

- Ventilate below the lowest slab (crawlway/undercroft)
- Provide a continuous slab foundation, without joints
- Where the slab is cast separately inside the plinth/foundation walls, special care must be taken to ensure that the joint between the slab and the plinth is airtight.

The basic approach to foundations and the choice of materials can affect the number of technical solutions that have to be employed to cater for potential radon problems, and this affects costs.
For structures built directly onto the ground, the best solution is to make the ground or basement slab and the foundations as dense, airtight and homogeneous as possible, with minimum points that have to be sealed. In buildings where there is an undercroft below the lowest floor slab, the space must be ventilated so that the radon can escape to the outside air. This type of slab must also be airtight.

ECONOMIC ASPECTS OF CONCRETE STRUCTURES

5.1 SERVICE LIFE OF CONCRETE STRUCTURES OR BUILDINGS

"Service life" means the period of time a building can be expected to withstand normal conditions, if properly maintained. The expected service life of a building is usually relatively long with many 100-year-old buildings still fully operational.

There are roughly 150m dwellings within the EU. Of these, 32% were built before 1945, 40% between 1945 and 1975, and the remaining 28% were built since then[37]. From a sustainability perspective, a long service life is highly desirable, not only for the ecological and economic aspects, but also for the cultural reasons.

The basis for calculating the durability of concrete construction has been developed over many decades. Accurate durability assessment is the key to establishing a reliable way of ensuring an adequate service life and establishing it in a standard.

The 'Rion-Anterion' suspension bridge in Greece is a structure that calls for a long service life. The bridge is 3km long and the centre span is 560m long.
Courtesy of FIB.

Concrete paving slabs can be used to construct long lasting and attractive pedestrian areas in urban environments.
Courtesy of Fédération de l'Industrie du Béton (FEBE), Belgium.

The design service life for concrete structures is set at a minimum of 50 years and up to 200 years. There is 95% likelihood that the designed service life will be reached. In practice, this means that, depending on the design parameters, the average actual service life is substantially greater than the design service life, often more than double.

The designer should aim for the optimum overall package with regard to service life; insuring that the various design options and components act in harmony with each other. Thus in designing and building concrete structures, the service life can be influenced by the following choices:

- Strength grade and water/cement ratio
- Quantity and quality of cement
- Concrete cover on reinforcement
- Air-entrainment and porosity
- Shape of the structure and the method of construction
- Density of the concrete and maintenance.

Internal concrete structures are, in principal, everlasting as there are no mechanisms that will damage indoor concrete in normal conditions. Their service life is assumed to be 200 years.

[37] http://www.eurima.org

ECONOMIC ASPECTS OF CONCRETE STRUCTURES

Dutch buildings made of precast concrete units. The concrete roof tiles used for the roof finish ensure a long service life for the building. Courtesy of BFBN.

5.2 A CONCRETE SOLUTION TO AFFORDABLE HOUSING

The whole life costing of a building is defined in the draft International Standard, ISO 15686 Part 5 as: "the economic assessment considering all agreed projected significant and relevant cost flows over a period of analysis expressed in monetary value. The projected costs are those needed to achieve defined levels of performance, including reliability, safety and availability".

Costs include the costs of construction, use (including energy consumption, insurance premiums and interruption costs if the building cannot be used during repairs following flood or fire damage) and maintenance, renovation, alteration and demolition, plus the costs of financing. Concrete buildings are more cost effective than other alternatives, especially in terms of use and renovation costs, and because of the long service life of concrete structures compared with other building materials.

Improving the energy efficiency of a building not only reduces emissions of carbon dioxide and other hazardous substances, but also heating and cooling costs. The energy consumption of a standard single-family house can be about 100-120kWh/m^2.

A 'low-energy' house uses less than half the amount of energy used for heating compared with a conventional house. Heating a low-energy house consumes between 30–70kWh/m^2 according to national requirements. In Austria, the current legislation for energy index is 65kWh/m^2 whereas in France, the new legislation proposes a target for new buildings of 50kWh/m^2 for 2012. By using current technology and notably off-the-shelf solutions, lower energy consumption levels can be reached more easily.

According to some comparisons, a well sealed and well insulated house built of lightweight concrete blocks can save €75,000 to €130,000 in energy bills over 50 years, compared with a standard house built of lightweight construction[40]. Since energy costs represent a major proportion of living costs (10% of household spending[41], it has a significant impact on the family budget.

[40] TECHNICAL RESEARCH CENTRE OF FINLAND (VTT), Low energy concrete block house – Comparison calculations on energy consumption of single family houses, Report RTE627/05, Espoo 2005

[41] EUROPEAN COMMISSION, Facing the challenge of higher oil prices, COM (2008)384, 13/07/2008.

ECONOMIC ASPECTS OF CONCRETE STRUCTURES

Concrete construction has also been developed for low-energy construction. For example, a U-value of 0.15 can be obtained for wall construction using standard products. Proper sealing of concrete con-struction is also a requirement for low-energy construction.

Both one-family houses and multi-storey residential houses are now tested and built with low-energy or zero-energy technology in many European countries. Almost all of these are constructed of concrete.

Another interesting aspect of concrete is its lighting efficiency. Concrete walls and floors have reflective properties, which can reduce costs associated with both indoor and outdoor lighting. This can be increased by using white cement that will result in a higher reflectance (0,75) compared to about 0,35 for ordinary concrete[42].

5.3 ADAPTABILITY OF BUILDINGS

Designing a flexible structure that can be easily altered, extended or subdivided is one of the objectives of sustainable design. To be sustainable, a building must be capable of adapting to change throughout its service life.

If at all possible, these considerations should be taken into account at the early design stage. The costs associated with "future proofing" the building at construction stage are only a fraction of the costs incurred when changes are implemented at a later stage.

Building flexibility can be facilitated at relatively low cost by adequate provision for additional services. In relation to the load bearing structure, it is desirable to provide large open spaces that can be subdivided if required.

The designer should be able to anticipate any possible need for extra capacity and decide, for example, at what point additional openings may be required, and whether better fire resistance or thermal insulation will be required in the long term.

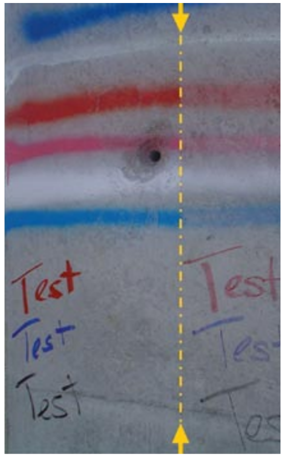
Anticipating changes calls for much greater input from the designer, because simply over dimensioning everything is not sustainable. A sound principle is to think about possible alternative uses for the building at the design stage.

As far as flexibility is concerned, the advantages of concrete are its high load-bearing capacity combined with long span capability. Inherent fire resistance and sound insulation are other important attributes.

This German house was built entirely in concrete by the German cement and concrete industry. This attractive building was specifically designed to provide flexible living space to meet the occupants' future needs.
Picture from Germany, Home for life (copyright: Betonmarketing Nord, 2006).

5.4 LIMITED COSTS TO REPAIR AND MAINTAIN

Concrete structures require very little maintenance. However, the structures must be inspected on a regular basis in accordance with good building maintenance practices. Often, a regular wash down of the structure with non toxic substances such as soapy water will be sufficient. Indoors, concrete will last almost indefinitely. Outdoors, it may have to withstand the stress of frost action, and casual vandalism in the form of graffiti. Concrete surfaces can be partially protected against the latter with 'anti-graffiti' finishes.



The difference between wall zones protected or not by "anti-graffiti" finishes.
Courtesy of Béton[s]- le Magazine.

[42] http://www.concretethinker.com/solutions/Lighting-Efficiency.aspx

ECONOMIC ASPECTS OF CONCRETE STRUCTURES

Concrete surfaces do not require painting, but if they are painted, they will require repainting on an ongoing basis. The elastic joints between precast concrete facade units typically need to be overhauled and replaced every 20 years or so. If the concrete surface is allowed to deteriorate, repair mortar can be applied. If concrete reinforcement begins to corrode, repairs consist of removing the deteriorated concrete, treating the surface of any steel and filling the concrete surface. Concrete can also have its alkalinity restored to ensure the preservation of steel.

END-OF-LIFE

6.1 DEMOLITION, REUSE AND RECYCLING

About 200 million tonnes of construction and demolition waste (C&DW) is generated every year in Europe. Concrete is an excellent construction material for long-lasting and energy efficient buildings, but still has to adapt to the constant changes of human needs that may generate waste. Fortunately, at the end of its life cycle, concrete can be recycled for minimum environmental impact.

The goal of "zero landfill" of concrete can be achieved if the structure is carefully planned and designed, and if the building undergoes successful renovation and demolition. Recovered concrete from C&DW can be crushed and used as aggregate. It is mainly used for road bases and sub-bases, but new concrete can also be made using a percentage of recovered waste material.

Recovered waste material and crushed waste concrete can be used in road construction. Credits: Photothèque CERIB.

Concrete can be reused in various ways and on a large scale, and, on occasions, in its original form. An example of the latter is to leave the concrete structure in place while modernising the inside space or façade/curtain wall of the building. Such an approach conserves natural resources, and prevents environmental impacts from waste disposal and extraction, manufacturing and transportation of virgin materials.

An example of successful reuse is the Mehrow Residence near Berlin This new family housing reused the complete walls, floor plates and ceilings from a demolished an 11-storey tower block. The only significant energy cost arose from the transportation of the five tonne panels and the use of a portable crane to lift them into place on site. The reuse of precast panels, free of charge, avoided the environmental impacts associated with disposal and saved material costs[43].

A recycled concrete panel house can be up to three times more energy efficient and approximately 30-40% cheaper than building a structural frame with virgin materials[44].

Another form of recycling is where concrete structures are built of precast units using bolts or welded joints that are designed to be dismantled; units can be dismantled with little or no damage. In the Netherlands, where construction demolition is well organised and recovery levels are extremely high, construction systems have been developed so that the entire building can be dismantled and delivered to another site.

A building's demountable skeleton in the Netherlands. Courtesy of BFBN.

[43] For details, visits http://www.architectmagazine.com/industry-news-print.asp?sectionID=0&articleID=384249

[44] http://www.sustainableconcrete.org.uk/

Another example is precast construction where some of the units can be reused and the rest of the structure crushed. Crushed concrete can be used either as hardcore for road construction or as aggregate in the manufacture of new concrete. If a maximum of 20% of the total aggregate used in the manufacture of new concrete is crushed concrete, the properties of the new concrete will be almost the same as concrete made with "normal" aggregate.

Crushed concrete is mainly used in earthwork constructions, to construct roads, streets, yards and parking areas, but it can also be used as backfilling for pipe excavations, environmental construction, foundations for buildings, etc. For these types of applications, recycled concrete is particularly useful as recycled aggregates often have better compaction and density properties and are generally cheaper than virgin material[44].

A regular quality control system has been organised for crushed concrete to detect the presence of any hazardous substances and the possibility of chemical leaching into the environment.

Recycling gives a new life to concrete. Surplus fresh concrete can be successfully recycled; it can either be used to make new concrete, or used as it is, or in separated form. Most waste process water can be recycled and cementitious sludge makes good soil treatment when crushed because of its high lime content.

The above techniques reduce natural resource exploitation and transportation costs as old concrete can be recycled on demolition or construction sites, or close to urban areas where it can be directly reused. Material can be recovered from landfill sites and redeployed as required.

[45] WORLD BUSINESS COUNCIL ON SUSTAINABLE DEVELOPMENT, op. cit.

GLOSSARY OF TERMS

Aerated concrete: concrete containing small bubbles or pores added during the manufacturing phase to protect the concrete against freeze-thaw. The pores improve frost resistance by allowing any water inside the concrete room to expand.

BAT: Best available techniques.

Durability: "capability of a building or its parts to perform its required function over a specified period of time under the influence of the agents anticipated in service"[47].

Eco-efficiency: "eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensty througout the life-cycle to a level at least in line with the Earth's estimated carrying capacity"[48].

Emissions: indoor emissions emanating from building materials and interior finishes. There are two types of emissions:

1.Primary emissions: the natural evaporation of impurities from new building materials and interior finishes that are easily recognisable by their characteristic odour. Significant evaporation may continue for several weeks, up to six months at the most.

2.Secondary emissions are triggered by an outside agent, usually moisture, causing the product to deteriorate.

Heavyweight construction: building shell made of dense materials such as concrete or masonry bricks, for which dead loads are relevant in the total load of the structure.

High-strength concrete: the maximum resistance of a concrete sample to applied pressure. The limits have greatly evolved in the last few years thanks to progress in material technology and a greater demand. In the 1950s, 34N was considered high strength, and in the 1960s compressive strengths of up to 52N were being used commercially. Compressive strengths approaching 138N have been used in in-situ buildings.

Inert: chemically unreactive, permanent.

Life-cycle: "consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal"[49].

Life-cycle assessment (LCA): "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life-cycle"[50].

Lightweight construction: building shell made of less dense materials, such as timber or steel, for which live loads are predominant in the total load of the structure.

Passiv Haus (passive house) standards: ultra-low energy building design system that uses efficient building envelopes to drive down energy consumption in structures. The standard is voluntary but implies an extremely rigorous set of requirements that must be met in order to be classified as a Passive House.

Sandwich element: multi-layer precast concrete unit commonly used for the external walls of buildings. A sandwich element is made up of three different parts:

- a precast concrete external panel
- a layer of insulation
- a precast concrete internal panel.

Service life: "period of time after installation during which a building or its parts meets or exceeds the performance requirements"[51]

U-value: "the amount of heat loss that occurs through an element of construction such as a wall or window (in $W/m^2.K$). The lower the U-value the less energy is lost and the better is its insulating characteristics"[52]

[47] Definition given by ISO 6707-1 & ISO 15686-1.

[48] Definition given by the World Business Council on Sustainable Development http://www.wbcsd.org/

[49] Definition given by ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines.

[50] Ibid.

[51] Definition given by ISO 6707-1 & ISO 15686-1 & ISO/CD 15392.

[52] Definition given by EURIMA in BOERMANS T., PETERSDORFF C., op.cit.

Volatile organic compounds (VOCs): "organic chemical compounds that under normal conditions are gaseous or can vaporise and enter the atmosphere. VOCs include such compounds as methane, benzene, xylene, propane and butane. Methane is primarily emitted from agriculture (from ruminants and cultivation), whereas non-methane VOCs are mainly emitted from transportation, industrial processes and use of organic solvents"[53]. Over 900 VOCs have been identified[54].

[53] Definition given by the European Environment Agency http://www.eea.europa.eu/

[54] ENVIRONMENTAL HEALTH PROTECTION AGENCY (EPA). Report to Congress on Indoor Air Quality. vol. II, Assessment and control of indoor air pollution. Report N. EPA/400/1-89-001C, 1989.

BIBLIOGRAPHY

BOOKS

BOERMANS T., PETERSDORFF C., **U-Values - For Better Energy Performance of Buildings**, Report established by ECOFYS for EURIMA, 2007.

BRUNDTLAND G., **Our Common Future: The World Commission on Environment and Development**, Oxford University Press, Oxford, 1987.

CEMBUREAU, **Sustainable cement production. CO-processing of alternative fuels and raw materials in the European cement industry.**

ENVIRONMENTAL HEALTH PROTECTION AGENCY (EPA), **Report to Congress on Indoor Air Quality. vol. II, Assessment and control of indoor air pollution**, Report N. EPA/400/1-89-001C, 1989.

EUROPEAN COMMISSION, **Accelerating the Development of the Sustainable Construction Market in Europe**, Report of the Taskforce on Sustainable Construction Composed in preparation of the Communication "A Lead Market Initiative for Europe", COM (2007) 860.

EUROPEAN COMMISSION, **Action Plan for Energy Efficiency: Realising the Potential**, 2006.

EUROPEAN COMMISSION, **Facing the challenge of higher oil prices**, COM (2008)384, 13/07/2008.

EUROPEAN CONCRETE PLATFORM, **Comprehensive fire protection and safety with concrete**, April 2007.

EUROPEAN CONCRETE PLATFORM, **Concrete for energy-efficient buildings. The benefits of thermal mass**, April 2007.

EUROPEAN CONCRETE PLATFORM, **Improving fire safety in tunnels. The concrete pavement solution**, April 2004.

FRANCHI M., **Towards Healthy Air Dwellings in Europe**, The THADE report, EFA Project 2002-2004, 2004.

HACKER J. ET AL., **Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change**, ARUP Report, Energy and Buildings 40, pp. 375-384, 2008.

ISO, ISO/TC71, **Business Plan, Concrete, Reinforced concrete and Prestressed concrete**, 08/07/2005.

ISO 14040.2, Draft: **Life Cycle Assessment - Principles and Guidelines.**

KALEMA T. ET AL., **Nordic Thermal mass – Effect on Energy and Indoor Climate**, Report 184, Tampere University of Technology, Tampere, 2006.

KIBERT C., **First International Conference on Sustainable Construction**, Tampa, 1994.

TECHNICAL RESEARCH CENTRE OF FINLAND (VTT), **Low energy concrete block house – Comparison calculations on energy consumption of single family houses**, Report RTE627/05, Espoo 2005.

TAMPERE UNIVERSITY OF TECHNOLOGY, **Thermal mass of buildings – Summary about research reports and results**, Report 174, Tampere, 2003.

WORLD HEALTH ORGANIZATION, **Guidelines for Drinking Water Quality**, First Addendum to Third Edition, Volume 1, Recommendation, 2006.

WORLD BUSINESS COUNCIL ON SUSTAINABLE DEVELOPMENT, **Concrete Recycling – A contribution to sustainability**, Draft Version, May 2008.

BIBLIOGRAPHY

WEBSITES

http://www.architectmagazine.com/industry-news-print.asp?sectionID=0&articleID=384249

http://www.assurre.eu/uploads/documents/pub-32_en-efd92a8a-a387-435a-9fb5-f9d3f743d513.pdf

http://www.cembureau.eu

http://ec.europa.eu/energy/demand/legislation/doc/leaflet_better_buildings_en.pdf

http://ec.europa.eu/energy/demand/legislation/buildings_en.htm

http://ec.europa.eu/enterprise/construction/internal/cpd/cpd_en.htm#a1

http://ec.europa.eu/enterprise/construction/index_en.htm

http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1998,66119021,1998_66292168&_dad=portal&_schema=PORTAL

http://www.concretebarrier.org.uk/

http://www.bibm.eu/

http://www.britishprecast.org/

http://www.buildingsplatform.org/

http://www.cembureau.be/

http://www.cepi.eu/

http://www.concretecentre.com/

http://www.concretethinker.com/solutions/Lighting-Efficiency.aspx

http://www.countdown2010.net/

http://www.eea.europa.eu/

http://www.eeb.blog/org

http://www.efca.info/

http://www.environdec.com/pageId.asp

http://www.ermco.eu/

http://www.eurima.org/europeandU

http://www.europeanconcrete.eu/

http://wwww.europeanpassivehouses.org/

http://www.itn.is/ncr/publications/doc-21-10.pdf

http://www.leonardo-energy.org/drupal/taxonomy/term/54

http://www.natura.org/

http://www.nepsi.eu/

http://www.nordicinnovation.net/

http://www.passive-on.org/en

http://www.sustainableconcrete.org.uk/

http://www.uepg.eu/

http://unep.org/Documents.Multilingual/Default.asp?DocumentID=499&ArticleID=5506&l=en

http://www.wbcsd.org/

BRIEF HISTORICAL REVIEW OF CONCRETE[55]

7,000BC	Israel	Building of a concrete floor uncovered in 1985.
3,000BC	Egyptians	Building pyramids out of mud mixed with straw to bind dried bricks. They also used gypsum and lime mortars.
	Chinese	Cementitious materials used to build the Great Wall.
300BC to AD476	Romans	First to develop Pozzolana cement by grinding lime and volcanic ash together with water to create the binding agent that hardens stones together. Use of admixtures such as animal fat, milk and blood to increase the properties of cement. Building of the Pantheon, which still exists today!
Middle Ages		Concrete use disappears with the fall of the Roman Empire.
1759		Milestone in concrete's history: Eddystone Lighthouse (Corn wall, UK). John Smeaton invented a waterproof concrete as he found that the calcination of limestone containing clay produced a lime that hardened under water. The lighthouse was then able to withstand sea attacks.
1817		Louis Vicat (FR) introduced the first artificial cement (calcining synthetic mixtures of limestone and clay).
1824		Joseph Aspdin (UK) obtained the patent for Portland cement (burnt a mixture of finely ground clay and limestone in a lime kiln until carbon dioxide was driven off). The burning process changes the chemical properties of the materials, creating stronger cement than that which uses plain crushed limestone. Portland cement is the cement most commonly used today in concrete production.
1836		First use of tensile and compressive tests (GER).
1867		J. Monier (FR) reinforced flower pots with wire. Introduction of reinforced concrete combining the tensile strength of metal and the compressive strength of concrete enabling it to withstand heavy loads. Concrete was then able to act as supporting structure in building construction, capable of resisting not only compression, but also tension. It is no longer used solely in buildings, but also in public works and infrastructure.
1900s		Introduction of precast concrete.
1970s		Introduction of fibre reinforcement.
1980s		Introduction of superplasticisers as admixtures.
1985		Introduction of silica fume as a pozzolanic addition.
1988		Introduction of Self-Compacting Concrete (Japan) to reduce labor in the placement of concrete, by eliminating or reducing the need for vibration to achieve consolidation.
End 1980s		Introduction of High-Performance Concrete.
1997		Introduction of Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC) which comprises a cementitious fibre containing matrix. The compression resistance of such concrete is generally greater than 150 Mpa, for example 250 Mpa. The fibres are metallic, organic or a mixture thereof.

[55] http://www.sustainableconcrete.org.uk/main.asp?page=36