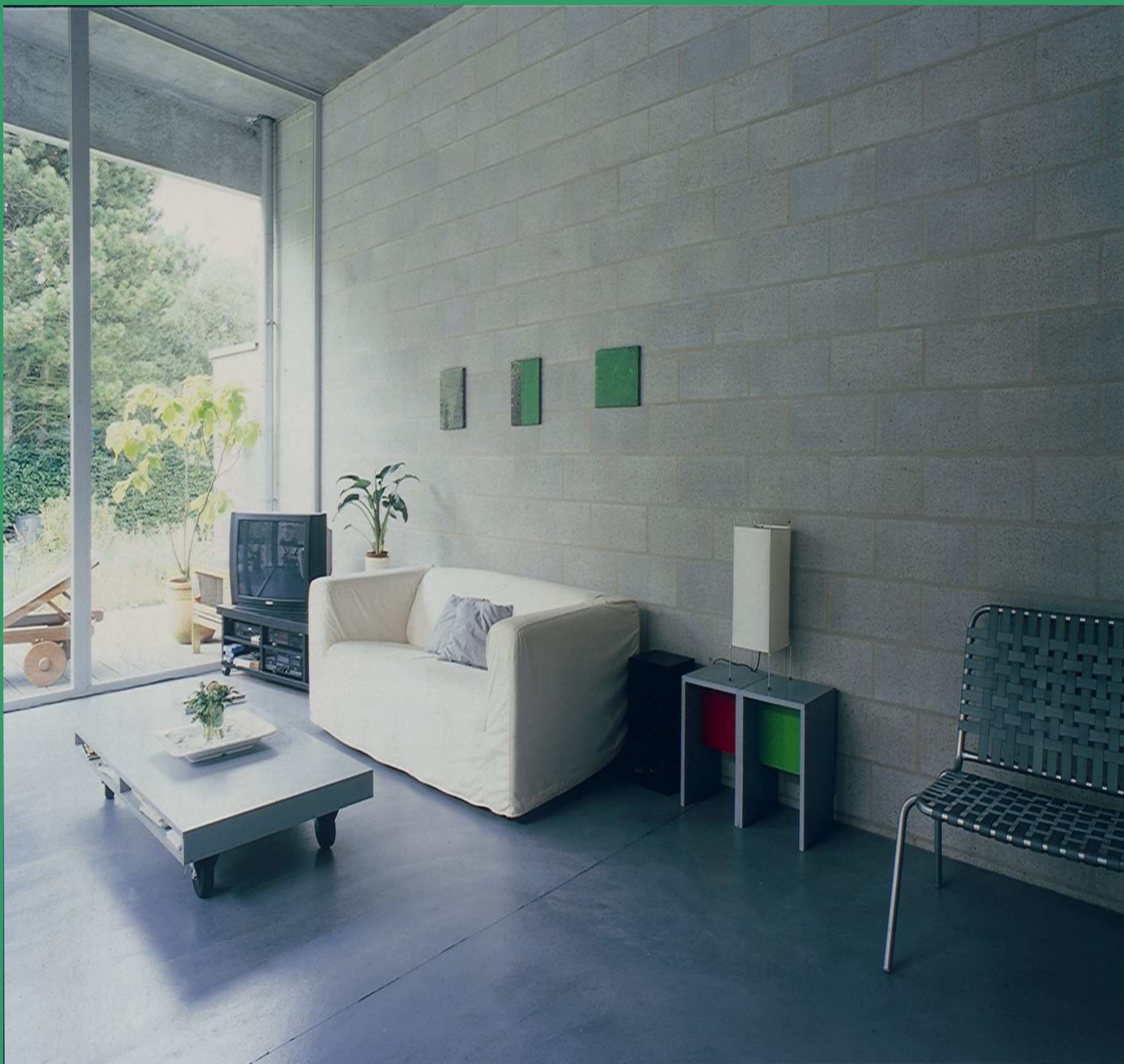
Concrete for energy-efficient buildings

The benefits of thermal mass



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Front cover image
A concrete house in Marke, Belgium takes advantage of solar gain and thermal mass to provide energy efficiency and year-round comfort.
(*Courtesy of Architect – Ansfried Vande Kerckhove, Photographer – Jasmine Van Hevel, Belgium*)

Concrete for energy-efficient buildings: The benefits of thermal mass

This document was produced by CEMBUREAU, BIBM and ERMCO. Aimed at designers, specifiers, regulators and building owners and users, it shows how concrete can be used both to reduce the speed of climate change and to minimise the effects it will have on our built environment.

Contents

By choosing concrete, energy efficiency is improved and thermal comfort enhanced

1. ENERGY EFFICIENCY BENEFITS OF CONCRETE BUILDINGS

Concrete is an established, dependable and well-understood building material that is used across Europe for a range of building types. Its most common applications in buildings are:

- Floors at ground or upper floor levels.
- Structural frames (i.e. beams, columns and slabs).
- External and internal walls, including panels, blocks or decorative elements.
- Roof tiles.

Concrete is extremely versatile in terms of its structural and material properties, which is one of the reasons for its success. The majority of buildings use heavyweight, or dense concrete, which is known for its strength, fire protection, sound insulation and, increasingly, for its thermal mass.

The Energy Performance of Buildings Directive

Concrete offers a very effective solution to the requirements of the Energy Performance of Buildings Directive (Directive 2002/91/EC of 16 December 2002), which came into force in 2006 and aims to reduce Europe's energy consumption. This Directive is having a significant impact on the way buildings are designed and constructed, with Member States implementing the EPBD either directly or through changes in existing building regulations.

The Directive:

- Places minimum requirements on the energy performance of buildings.
- Requires that this is checked in completed buildings.
- Imposes a system of energy certification for buildings.
- States that passive heating and cooling concepts should be accounted for.
- Insists that energy performance must not impinge upon the quality of the indoor environment.

Figure 1a
A model house near Hamburg, Germany entirely built in concrete by the German cement and concrete industry. This attractive building was specifically designed to provide flexible living space to meet the needs of the occupants.
(Courtesy of Betonbild, Erkrath, Germany)

The benefits of thermal mass

The main energy benefit of using concrete in buildings is its high thermal mass that leads to thermal stability. This saves energy and produces a better indoor environment for building users.

The thermal mass of concrete in buildings:

- Optimises the benefits of solar gain, so reducing the need for heating fuel.
- Reduces heating energy consumption by 2 – 15% (see Section 5).
- 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 emissions of CO_2, the main greenhouse gas.
- Will help future proof buildings against climate change.

It can be seen that the EPBD takes an integrated approach to the problem of energy consumption in buildings, and, for this reason, designers and clients are becoming increasingly conscious of the energy-performance properties of construction materials.

How concrete can help buildings meet the EPBD

Research on the energy performance of both real and theoretical concrete buildings has shown that there are advantages to be gained in all European climates provided that concrete's thermal mass is considered within building design. If this effect is accounted for properly within the EPBD's permitted calculation procedures, a 2 – 15% advantage in energy consumption can be gained in a heavyweight building, compared with a lightweight equivalent (see Section 5).

The research also established that a heavyweight building maintains comfortable indoor conditions for an extended period (days) compared with a lightweight building (hours), during hot as well as cold ambient conditions. An intelligent combination of heating, ventilation, solar shading, building structure and night cooling, can further improve the utilisation of concrete's thermal mass, producing concrete buildings that are better adapted to increasing temperatures and helping them to remain comfortable without the need for air conditioning.

The fact that the Directive lends its support to passive heating and cooling concepts, and specifically acknowledges the valuable contribution of thermal mass, are welcome developments.

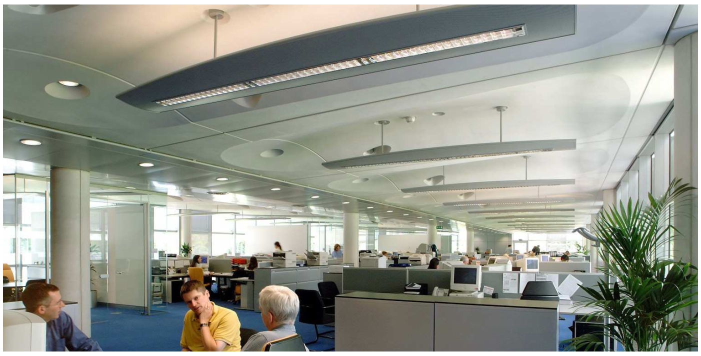


Figure 1b:
A comfortable office environment is provided by using concrete's thermal mass to full advantage: Toyota Headquarters, UK.
(*Courtesy of the Concrete Society, UK)*

Using concrete in buildings benefits everyone

Building occupants and owners

The energy savings made possible by the thermal mass in concrete can reduce heating and cooling bills; a significant contributor to the running expenses of buildings. This can help support social equity through the provision of more affordable housing costs. Additionally, the thermal stability provided by concrete will help provide a more comfortable home in the years ahead when the effects of climate change increase. This could contribute to improved resale value. Other benefits include lower investment costs associated with simpler heating, ventilation, and cooling systems (HVAC) systems.

The environment

The reduction in greenhouse gases resulting from energy savings associated with thermal mass during a building's life is a fundamental advantage. Because a large proportion of global CO_2 emissions come from buildings and these buildings have long lifetimes, even a relatively small decrease in energy consumption has a significant impact.

Energy savings accumulate over a building's lifetime

Based on typical European energy prices in the 2nd quarter of 2006, research on residential buildings found that the energy savings from using heavyweight construction methods would equate to around EUR 60 per year based on a house of around 70 – 80 m^2 in size. Since energy prices do not appear to be stable and if the dramatic price rises of recent years continue, then it will become critical to optimise heating and cooling installations by utilising thermal mass more effectively.

In practice, of course, energy savings will be affected by user behaviour, such as closing windows and shutters, but there is no doubt that even a small improvement due to building design will accumulate, year after year, leading to substantial savings over a building's lifetime.

Energy savings result in significant reductions in CO_2 emissions

Figure 1c indicates how even a modest annual saving in energy used will result in significant reductions in CO_2 emissions. Furthermore, recent UK research has found that a mediumweight masonry/concrete home that fully utilises its thermal mass can pay back its additional embodied CO_2 compared with an equivalent timber-framed house within 11 years and then continue to provide energy and CO_2 savings over the life of the building (Hacker et al 2006).

The embodied CO_2 of a material, construction element or building is the CO_2 emitted from the processes associated with its production, including the mining of natural resources, manufacturing of materials and transportation.

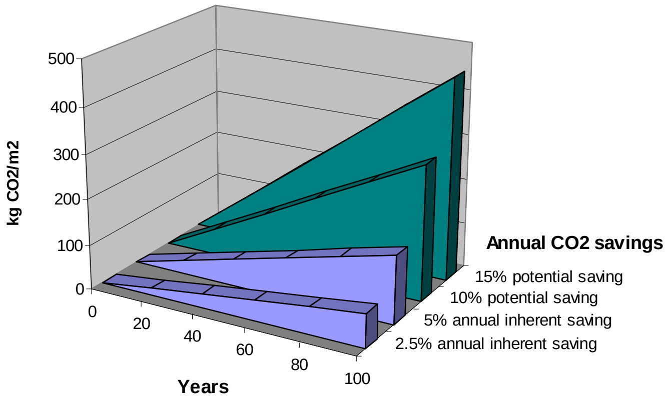


Figure 1c:
Lifetime consequences of small annual improvements in energy savings.
Note: The **inherent** savings come automatically with a heavyweight building. The **potential** savings are obtained if the building and installations are specifically designed for maximum energy efficiency.

The contribution that concrete's thermal mass has to play in improving the internal environment of buildings will grow as the effects of climate change become more marked, helping to future proved buildings well into the current century.

This publication explains how specifying heavyweight concrete construction can help to improve energy efficiency and enhance the thermal comfort properties of buildings.

Figure 1d:
Concrete block masonry house in Bonheiden, Belgium.
(Courtesy Architect – Gie Wollaert, Photographer – FEBE, Belgian Precast, Association, Belgium)

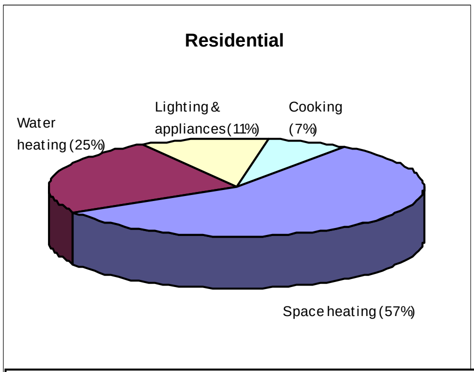
Figure 1e:
Energy efficient apartment building in Dublin, Ireland.
(Courtesy of Concrete Development Group, Ireland)

Energy performance depends on striking a balance between reducing consumption and maintaining comfort

2. EFFICIENT ENERGY USE IN BUILDINGS

It is crucial to reduce energy consumption in buildings because of the significant role this can play in combating unsustainable levels of energy use. European figures show that the energy used for the heating, lighting and cooling of buildings accounts for over 40% of the primary energy consumed. This makes the occupation and use of buildings the largest single source of EU greenhouse gas emissions, mainly in the form of carbon dioxide. Figure 2a shows the proportion of energy used within the EU for different functions in both residential and commercial buildings.

Having pledged to reduce its greenhouse gas emissions to 1990 levels by 2010, the European Union sought to introduce a mechanism to reduce the energy used in buildings. As a result, the EU Directive on Energy Performance of Buildings or EPBD (Directive 2002/91/EC of 16 December 2002) has been enforced in Member States since January 2006 so that the EU could ensure new buildings would use less energy. This is discussed further in Section 4.



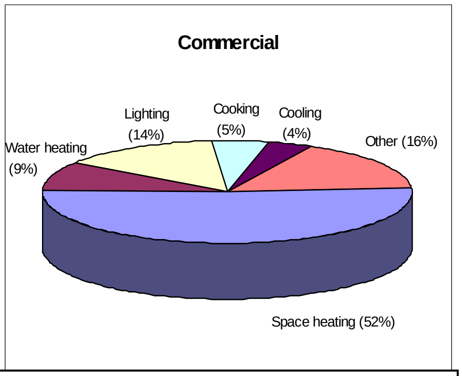


Figure 2a:
EU building energy consumption for residential and commercial buildings
Source www.intuser.net

Assessing energy use in buildings

To comply with such legislation and create energy-efficient, comfortable buildings, all the relevant energy flows and the factors or parameters that are important (including thermal mass) need to be taken into account. The energy consumption of a building can be calculated using simple hand calculation methods, based normally on statistical outdoor temperatures at a specific location, thermal insulation (U-value) and expected ventilation rate, or via computer programmes that model thermodynamic flows (i.e. transmission, radiation and convection) mathematically.

The EPBD takes a holistic and integrated approach to design, allowing a number of different methods to be used. It permits both simplified 'quasi-steady state' methods as well as detailed, 'dynamic' calculations, but the complexity inherent in energy flows means that computers are being used more often to perform design simulations (Figure 2b). Many dedicated energy software programmes exist, but not all will be applicable to all situations; for example some focus on residential buildings, others can be used only in particular countries or climatic regions.

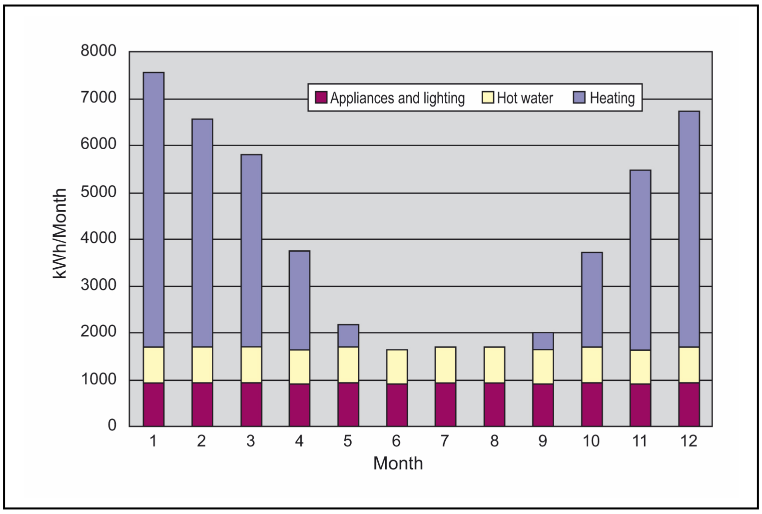


Figure 2b: Monthly energy use of a theoretical residential building calculated with Stockholm climate by Consolis programme

The impact of climate change

Changes in the world's climate have the potential to affect indoor thermal conditions throughout Europe. With growing evidence of the effects of climate change on the built environment, De Saulles T (2005) reports that new research shows that many existing offices and residential buildings will experience overheating towards the middle of the 21st century (CIBSE, 2005). Indeed, research carried out by Arup R&D suggests that London will be as hot as Marseilles in 2080 (Arup, 2004).

For this reason, buildings need to be designed to safeguard health and comfort for the future – designing to current standards may not be enough to combat the effects of climate change. Heavyweight buildings provide good thermal stability, which is a robust and environmentally friendly solution to the problem, reducing, or in many cases eliminating, the need for mechanical cooling. Research has shown that buildings with high levels of thermal mass, passive solar features and effective ventilation control perform extremely well (Arup & Bill Dunster Architects, 2004). This approach to design may be the only way to future-proof new buildings, so concrete and masonry products can help provide comfortable living, now and in the future.

Energy flows within a building

The basic principles of energy flows within buildings are shown in Figure 2c. It is important for us all to understand how these various flows interact within a building to form the indoor climate that we experience. In fact, it is the effective management of these flows that helps reduce energy consumption – a critical aspect of building regulations in respect of energy performance.

Energy (such as heat) is transported by transmission (conduction), air movement (convection) and/or radiation.
Transmission is dependent on the thermal insulation or conversely the conductivity of a material or construction.
Air movement is controlled through ventilation. It is also caused by infiltration due to air leaks; buildings are becoming more airtight to avoid such unplanned flows.
Radiation primarily affects the glazed parts of a building and will vary with latitude and orientation.
The direction and size of energy flows will vary during the day, throughout the year and from place to place, depending on the external and internal climatic conditions; the presence of people and

equipment will have an effect too. The ability of building materials to store and release energy by using their thermal mass has a significant effect on the energy performance of a building. This is brought about either by natural ventilation, which needs no mechanical assistance, or by active methods, such as forcing air or water through coils or ducts in concrete slabs. The concept of thermal mass is explained in more detail in Section 3.

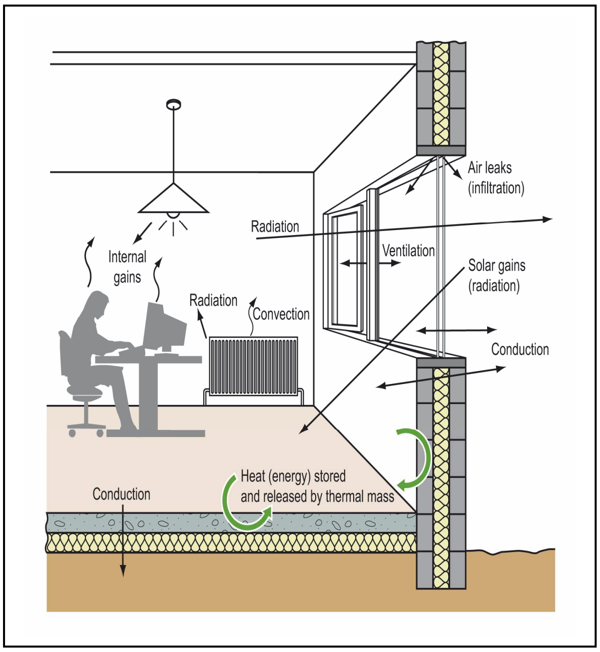


Figure 2c:
Heat (energy) flows within a building.
Heat is gained by solar radiation, and internal gains from lighting, heating, and the occupants and their equipment.
Heat is lost via air leaks, ventilation, radiation through windows and conduction (transmission) through walls, windows and floors.
Heat is stored and released by the thermal mass of the building.

Looking at it practically, there are two important aims relating to energy performance:

1. To minimise the amount of energy that a building consumes.
2. To ensure that the building maintains a level of thermal comfort that is appropriate for its occupants.

Concrete helps buildings to achieve both of these aims, as Section 3 explains in detail.

Figure 2d:
Section through a very highly insulated external wall with a heavyweight concrete inner leaf for good thermal mass. This provides excellent year-round thermal performance by creating an optimised combination of energy flow and storage.
(*Photo taken during study tour at BedZED, UK)*

Figure 2e:
"ITCLAB" located in "Km Rosso" (red kilometre), the new energy efficient Italcementi's research and innovation centre designed by Richard Meier in Bergamo, Italy.
(Courtesy of Italcementi, Italy)

Concrete's thermal stability helps provide energy efficient, future-proof buildings

3. CONCRETE AND ENERGY USE IN BUILDINGS

By utilising concrete's thermal mass, energy consumption can be reduced by tempering the need for heating and cooling in a building. The thermal inertia provided has the effect of smoothing out temperature peaks or troughs and delaying the onset of peaks in internal temperatures, so maintaining a more stable, comfortable indoor environment. (see Figure 3a). This is recognised in the methodology provided in EN ISO 13790, which supports the EPBD (see Section 4)

How thermal mass works

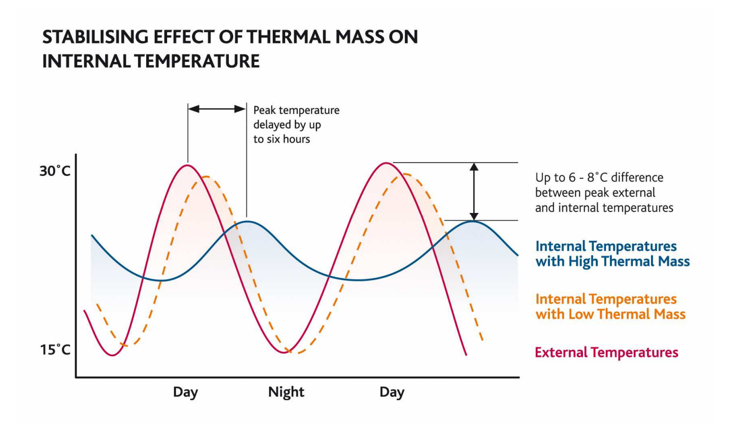


Figure 3a
The influence of thermal mass on comfort.
(From The Concrete Centre publication, Thermal mass for housing, UK).

As a heavyweight material, concrete acts as a store (or buffer) during the heating season by utilising free heat gains, such as solar radiation and heat from occupants, storing this energy and then releasing it later in the day (see Figure 3b). Conversely, the ability of concrete to be cooled at night, and then release this coolness into the building's interior during the day is another important way in which concrete can contribute to thermal comfort during the summer.

Dense, heavyweight concrete provides the highest level of thermal mass. Lightweight, insulating concrete providing a lower, but nevertheless worthwhile level. Thermal mass has long been known to have a positive influence on energy use and thermal comfort in buildings, but this aspect has not been incorporated into building energy codes until relatively recently (see Section 4).

During the course of a day, the level of thermal mass provided by a material will determine the depth to which heat will penetrate and, as a result, how well it acts as a thermal store.

Thermal mass during the summer

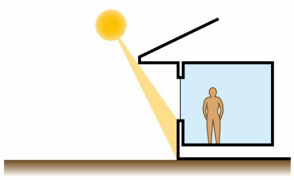
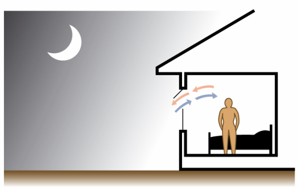
	**Daytime** On hot days the windows are kept shut to keep the hot air out, and shading should be adjusted to minimise solar gains. Cooling is provided by thermal mass. If temperatures are less extreme, windows may be opened to provide ventilation		**Night-time** If it has been a hot day, the occupant opens windows to provide night cooling of the thermal mass.

Figure 3b **(continued on page 9)**
Passive cooling in summer, and storage and release of free energy gains in winter. *(Courtesy of The Concrete Centre, UK)*

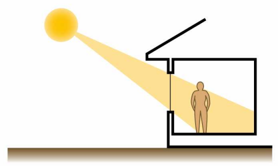
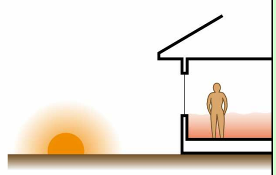
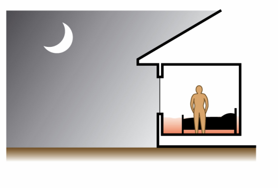
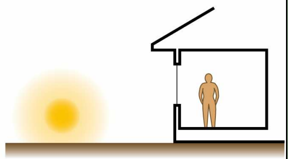
Thermal mass during the heating season			
	**10.00 am to 5.00 pm** Sunlight enters south-facing windows and strikes the thermal mass. This heats the air and thermal mass. On most sunny days, solar heat can help maintain comfort from mid-morning to late afternoon.		**5.00 pm to 11.00 pm** After sunset, 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.
	**11.00 pm to 7.00 am** The occupant adjusts the heating so only minimal supplementary heating is needed. Good airtightness and insulation minimise heat loss.		**7.00 am to 10.00 am** 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.

Figure 3b continued
Passive cooling in summer, and storage and release of free energy gains in winter. *(Courtesy of The Concrete Centre, UK)*

To illustrate concrete's high capacity for storing heat, a simple comparison can be made between wall types: A heavyweight blockwork wall with a plaster finish can absorb around seven times more heat than a typical timber frame wall with a plasterboard finish. This means that on hot summer's day, the additional capacity to soak up heat in a heavyweight dwelling can have approximately the same cooling effect as running two standard portable air conditioning units.

Making the most of thermal mass

Concrete's thermal mass works best in buildings where there is a regular cycle of temperature variation, typically over the course of a day. For example, in schools or offices where the peak internal heat gains are substantial and coincide with peak solar gains, the buffering effect of the concrete helps to reduce and delay the onset of peak temperatures. The evening drop in temperature when the building is unoccupied presents the opportunity for night cooling of the concrete, to prepare it for the next day.

The presence of internal finishes such as plasterboard and carpet will, to some extent, reduce thermal mass by acting as an insulating layer. Consequently, it does not necessarily follow that a structurally heavyweight building will automatically provide a high level of thermal mass; this depends on the extent to which the structural concrete elements can thermally interact with the occupied space, i.e. exchange heat with the surrounding environment. Ideally, insulation in external walls should be placed behind the concrete inner leaf (e.g. in the cavity), and the insulation in ground floors is located below the slab. Beyond this, the simple rule is that, as far as practicable, the surface of the concrete should be left thermally exposed by using finishes such as paint, tiles or wet plaster. A simple rule-of-thumb is that the mass must be 'visible' to the internal heat source to be effective.

Whilst some types of concrete wall construction may use interior insulation in conjunction with a thermal break, a significant level of thermal mass can still be achieved within such a building through the use of concrete floors.

In climates with temperatures that remain very hot or cold over a long period of time, such passive means of using thermal mass become less effective, and so active (mechanically assisted) options become more useful. In this case, energy is transferred by water in coils or air in ducts (see Figure 3c). Concrete's high thermal conductivity is beneficial in distributing the heat from the air or water, via the slab, to the room itself. This approach is also useful where high internal heat gains are experienced, for example in offices containing a quantity of IT or other equipment, as the cool air/water can improve the ability of the slab to absorb heat.

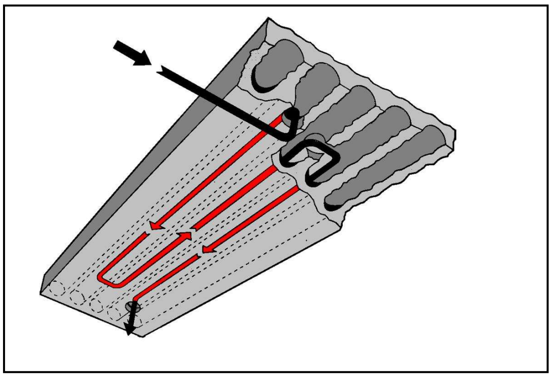


Figure 3c
The Termodeck System. Here mechanical ventilation passes low velocity air through the cores of a hollowcore slab in a serpentine pattern, which ensures prolonged contact between the air and concrete for good heat transfer. In each slab, three of the five cores are generally used in this way, and an air supply diffuser is located on the underside of the slab i.e. soffit. *(Drawing courtesy of Termodeck®, Sweden)*

Studies on thermal mass

The thermal mass effect is well known and a useful overview was compiled by a team from Tampere University in Finland (Hietamäki et al. 2003), which examined 28 international publications on the subject and drew a number of conclusions. These included:

- There is a **2 – 15% saving in heating** energy due to thermal mass, with a typical saving in North-European climate conditions of 10% when comparing light and heavyweight buildings.
- When no cooling is used in the summer, the highest indoor air temperatures in a heavyweight building are **3 – 6 degrees lower** than those in an equivalent lightweight building; thus high thermal mass can reduce the need for cooling.
- Night ventilation of office buildings can decrease or prevent the use of mechanical cooling. When coupled with high thermal mass, this **decreases the energy needed for cooling by up to 50%.**
- The combination of high thermal mass and improved airtightness in single-family homes can result in a **20% reduction** in heating energy consumption compared with a lightweight equivalent.

An additional Norwegian study evaluated the summer performance of a single-family house with night ventilation and an office building with night ventilation or with active cooling with different operating regimes (Dokka T H, 2005). The simulation used Norwegian climate data that was applied using a commercially-available, dynamic energy modelling tool. The results indicated that the heavyweight residential building would have required approximately 7% less heating energy than the lightweight building and that concrete's thermal mass exerted a major influence on thermal comfort. For the office, the difference in heating energy required was about 10%, and in the case of active cooling, the lightweight building required over 30% more cooling energy. With passive cooling enhanced by night ventilation in the lightweight building, there was still excessive overheating, with 179 hours of the occupied period experiencing temperatures above 26 °C. The results of recent research on this subject are reported in Section 5 of this publication.

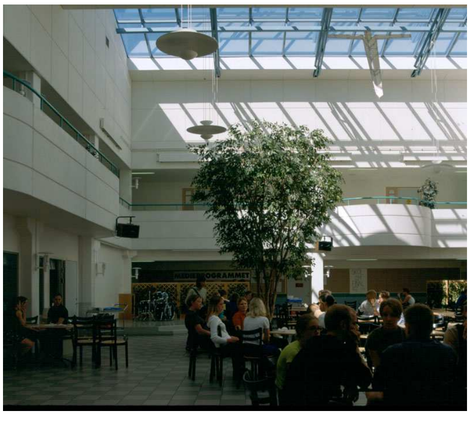


Figure 3d:
Energy efficient high school in Gislaved, Sweden, built in 1993 with the TermoDeck system and extended in 2006 representing a total area of 12,000 m^2.
(Courtesy of Strängbetong, Sweden)

The EPBD provides a common framework for calculating the energy performance of buildings across Europe and sets minimum standards in new and refurbished buildings

4. THE ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE (EPBD)

The EU Directive on Energy Performance of Buildings (Directive 2002/91/EC of 16 December 2002) came into force in member states in January 2006 so that the EU could ensure new buildings would use less energy. The occupancy and use of the 160 million buildings in the EU account for 40% of its energy consumption and as such are the largest single source of the region's CO_2 emissions. At this stage, however, this Directive applies only to buildings with a total surface exceeding 1000 m^2.

The requirements of the EPBD

The Directive contains a number of different regulations and tools on energy performance that impact on the design and operation of buildings. In this publication, the focus is on the potential contribution of concrete to the aims of the EPBD, so not all aspects of the Directive will be covered in detail here. However, in essence, the EPBD requires that governments, designers and clients take action by:

- Providing a common framework for a methodology of calculation of the integrated energy performance of buildings.
- Placing minimum requirements on the energy performance of buildings, including that required for cooling.
- Requiring that measured energy use is checked in completed buildings and that they are compliant.
- Allowing a CO_2 indicator to be included in the assessment of energy performance, which promotes the use of alternative energy sources (such as solar panels).
- Stating that passive heating and cooling concepts should be employed.
- Stating that good energy performance must not conflict with the quality of the indoor environment.
- Imposing a system of energy certification of buildings, which increases awareness of the issue and improves the market value of energy efficiency (see Figure 4a).

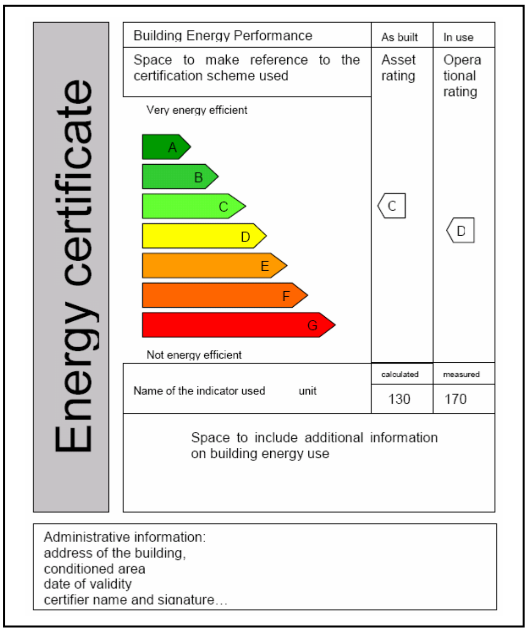


Figure 4a: An impression of how a building energy certificate might look *(Courtesy of www.eplabel.org)*

In previous energy performance calculations, designers and energy specialists were usually required to design according to prescribed, elemental U-values for the building's shell – its floor, walls and roof. In some countries, a more holistic 'Energy Performance' (EP) regulation was used (the calculated energy consumption of the building, usually expressed in kWh/m^2) and this has been adopted in the new Directive. This step from elemental U-values to the EP principle opens the possibility of including aspects such as thermal mass and airtightness in the assessment of energy performance of buildings.

The EPBD takes a broad view of energy performance and introduces an integrated energy performance criterion, whereby aspects such as thermal mass may be taken into account in design. As a minimum, the Directive requires that the following aspects should be considered:

- Thermal characteristics of the building (i.e. its external envelope/shell and internal walls), including airtightness.
- Heating installations and hot water supply, including their insulation characteristics.
- Air conditioning systems.
- Mechanical ventilation systems.
- Built-in lighting installations (mainly in non-residential buildings).
- Position and orientation of the building, including outdoor climate.
- Passive solar systems and solar protection.
- Natural ventilation.
- Indoor climatic conditions, including the designed indoor climate.

Predicting energy use within a building

To be able to implement the Directive, a number of standards are required. The most important is perhaps EN ISO 13790 *Thermal performance of buildings – Calculation of energy use for space heating and cooling* (CEN 2005), which defines the assessment of thermal mass and airtightness, thereby setting down how to predict the energy use of a building. EN ISO 13790 allows a simplified 'quasi-steady state' method as well as detailed 'dynamic' calculations.

Dynamic methods model the true thermodynamic behaviour of a room or a building, but rely on extensive, detailed design and climate data, so can be time consuming. However, with easier access to hourly climate data and development of more user-friendly software, dynamic modelling is becoming more popular.

The quasi-steady state method is a simpler approach and takes into account the benefits of thermal mass, which makes it ideal for use in the early design phases, when strategic decisions on building materials are being made. It assesses thermal mass by quantifying free energy gains (e.g. heat from solar radiation and occupants) and bought energy, more of which can be utilised in a heavyweight building, which therefore requires less bought energy than a lightweight building. The way in which this is calculated is shown in Figure 4b, from which it can be seen that a greater proportion of free energy gains can be used in a heavyweight building. This is an important aspect of EN ISO 13790.

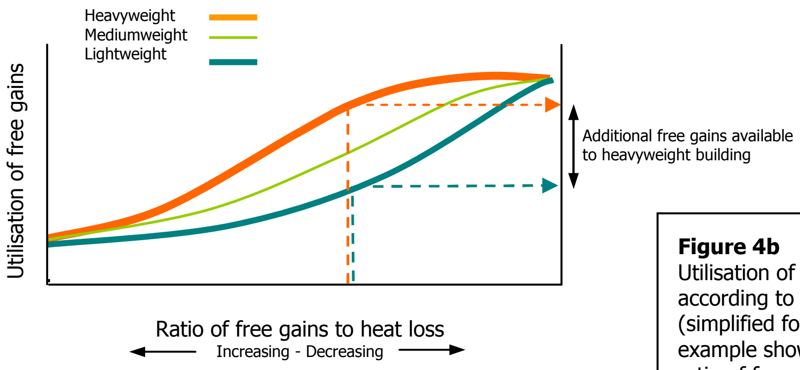


Figure 4b
Utilisation of free energy gains according to EN ISO 13790 (simplified for this guide). The example shows that, for a given ratio of free gains to heat loss, a heavyweight building provides a higher utilisation than a lightweight building.

Concrete's contribution to the thermal stability and energy efficiency of buildings has been demonstrated clearly through new research

5. DEMONSTRATING CONCRETE'S ENERGY EFFICIENCY

To establish the extent to which concrete maintains a stable indoor climate whilst minimising energy consumption, a number of tests (Johannesson et al, 2006) (Johannesson G, Lieblang P, and Öberg M). were carried out using a theoretical building design. The aim was to investigate the energy balance in residential and office buildings in various European climates (from Sweden to Portugal), for both heavyweight and lightweight options. A simple, two-storey building design was developed, which is shown in Figure 5a, being suitable for both residential or office use. Two different configurations were used: the heavyweight option included concrete floors, internal and external walls, whereas the lightweight option used typical timber or light steel frame components throughout except for a concrete ground floor slab. However, in both instances the thermal insulation used was identical, so that the influence of thermal mass could be examined accurately.

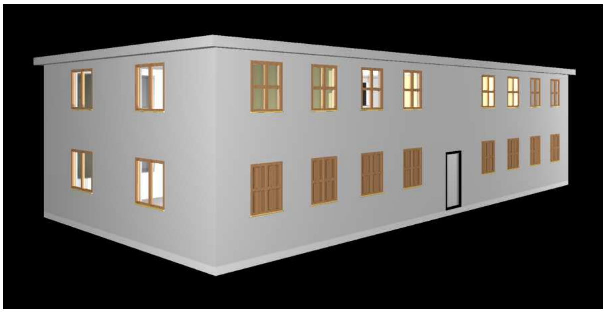


Figure 5a: A view of the theoretical building used for the energy tests

Calculating theoretical energy performance

A range of computer programmes for calculating energy use in building are available, many of which were developed in response to the formulation of EN ISO 13790. Five programmes from Denmark, Germany and Sweden were used in the research on concrete and energy performance. Three are based on the quasi steady state method, one is a general dynamic programme and one uses both computational methods in parallel.

The results of these tests using the five theoretical building design options show that a heavyweight concrete building offers a significant advantage in terms of energy performance when compared with an equivalent lightweight construction. All five programmes showed a clear performance advantage for the heavyweight building option.

For residential construction with a neutral window orientation the heavyweight concrete building required 2 – 9% less primary or bought energy (1.5 to 6 $kWh/m^2/year$) compared with a similar lightweight option. The advantage for the heavyweight option increased when more windows were oriented towards the south. Figure 5b shows that a heavyweight building with south facing windows requires less cooling energy than a lightweight building with neutral window orientation. In other words heavyweight buildings permit maximum utilisation of solar energy with a minimum of comfort problems.

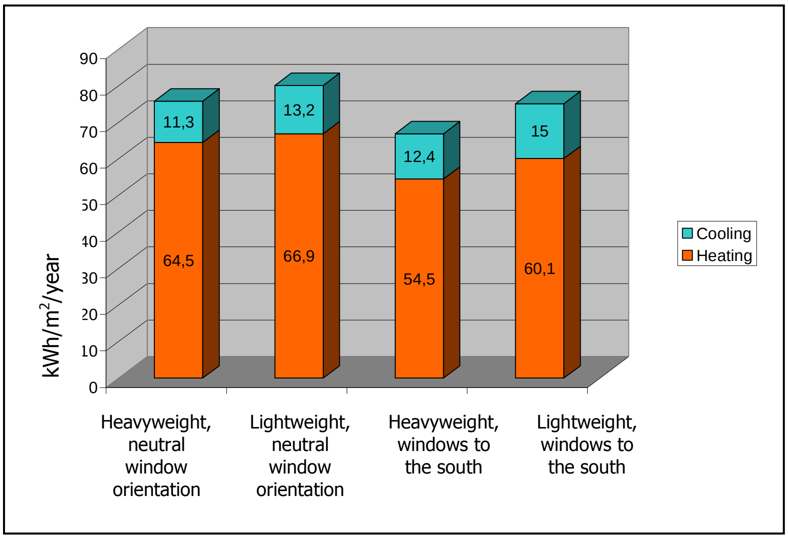


Figure 5b: Typical results from a calculation of required heating and cooling energy in a heavyweight and lightweight building model as shown in Figure 5a. In this case the example modelled was a residential building in Stockholm, Sweden.

Concrete's performance advantage was even more impressive in the office building scenario (7 – 15%), where the thermal mass effect was very apparent. The office design included air conditioning (to cope with large internal heat gains from staff and office equipment), but the heavyweight option made use of its thermal mass to minimise the need for cooling and thereby performed much better than the lightweight equivalent. It was found to be difficult to assess thermal comfort using quasi-steady state programmes, but by taking the resultant reduction in cooling energy as a proxy for thermal comfort, then the heavyweight option performed 10 – 20% better than the lightweight option.

In both cases, if thermal mass had been taken into account in the initial design of the building, along with use of ventilation and expectations with regard to indoor temperatures, then the energy savings could have been further increased.

In summary, the programmes provided consistent results for both the absolute energy use and the relationship between heavyweight and lightweight buildings. Dynamic and quasi-steady state methods all produced similar results for the concrete buildings, but displayed less consistent results for the lightweight options. This may be because their lower thermal stability results in poor predictability from test scenarios of their real behaviour.

Concrete's advantages confirmed by work on real buildings

However, to confirm the overall validity of the results above, a number of real buildings (see Figure 5c) in a range of different climates were analysed using the same computer programmes. A range of structural alternatives, both heavy and lightweight was considered, and site-specific climate data was included.

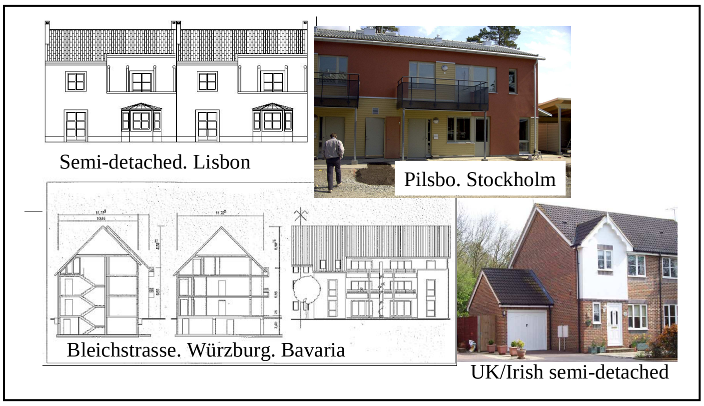


Figure 5c: A variety of European buildings were analysed using the computer programmes that applied the effect of both a lightweight and a heavyweight versions.

Figure 5d:
Torre Verde (Green Tower), an energy efficient twelve-storey residential concrete building (7,200 m^2), constructed in Lisbon, Portugal. Monitoring has shown that it emits around 24 tonnes less CO_2 per year than a conventional building of the same size. The solar thermal system supplies 70% of the heat required by the domestic hot water consumption of the building.
(Courtesy of Tirone Nunes, SA, Portugal)

The results of this validation study are summarised in Table 1 and were broadly in agreement with the test data provided by the five software programmes, but an interesting observation was made in respect of intermittent space heating of buildings. There is typically little difference between heavy and lightweight constructions when subjected to intermittent heating cycles, but only where the temperature drop between successive heating cycles is minimised by effective insulation and adequate airtightness.

Table 1: Example from real building studies. Annual energy use (kWh/m^2)

Building type	**Energy use**	**Heavyweight**	**Lightweight**
UK/Ireland semi-detached. Average of 9 locations	Heating**	34	35
Semi-detached. Lisbon	Heating*	17	19
	Cooling	27	32
	Total	44	51
Multifamily, Würzburg	Heating*	51	55
Semi-detached, Stockholm	Heating	78	81

Key
* Constant heating regime
** Average of constant and intermittent heating to take account of the common use of intermittent heating in these countries

Figure 5e:
A cast in situ town house in Brussels, Belgium
(*Courtesy Architect – Joël Claisse Architectures; Photographer – Jean-Paul Legros, Belgium*)

Figure 5f:
Kvernhuset Youth School in Fredrikstad, Norway.
An energy efficient building utilising ready mixed concrete to obtain energy savings and featuring many other sustainable solutions.
(Courtesy of Photographer: Terje Heen - Municipality of Fredrikstad)

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Figures 6a & 6b:
EDIFICIO ECOBOX, FUNDACIÓN METRÓPOLI for a sustainable future, energy efficient concrete office building in Madrid, Spain.
(Courtesy of architects Vicente Olmedilla and Ángel de Diego, Spain)