# Concrete for energy-efficient buildings

## The benefits of thermal mass

22 December

EUROPEAN CONCRETE PLATFORM

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COVER

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ERMCO

# EUROPEAN CONCRETE PLATFORM

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**Front cover image**
A traditionally built house in the UK uses brick and block construction to provide all the benefits of thermal mass
(*Courtesy of Gusto Homes*)

# 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 (EC, 2003), which came into force in 2006 and aims at 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**
Heavyweight construction coupled with a design that incorporates sun spaces makes the most of solar gain and thermal mass. at BedZED, a zero energy development in London. (*Photo taken during study tour at BedZED*)

## 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.

**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%.
- Smoothes out fluctuations in internal temperature.
- Delays peak temperatures in offices and other commercial buildings until the occupants have left.
- Can be used with night-time ventilation to eliminate the need for daytime cooling.
- When combined with air-conditioning, it can reduce energy use for cooling by up to 50%.
- Can reduce the energy costs of buildings.
- Makes possible the 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. Annual energy savings continue to accumulate, year after year, leading to substantial savings over a building's lifetime.

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 increased 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 for further into the 21st century.

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

**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)*

### Using concrete in buildings has benefits for everyone

**For professionals, including architects, engineers, developers, design and build contractors, and owners** the main benefit of concrete in buildings is the thermal stability that provides low energy cost and superior indoor climate. Other benefits are the improved resale value of the building and decreased investment costs associated with simpler heating, ventilation, and cooling systems (HVAC) systems.

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

**For occupants**, energy consumption constitutes a large share of the operating cost and thus the total housing cost; so energy savings can help to support social equity through affordable dwellings. 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.

## 2. EFFICIENT ENERGY USE IN BUILDINGS

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

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 building.

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 (EC, 2003) 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.

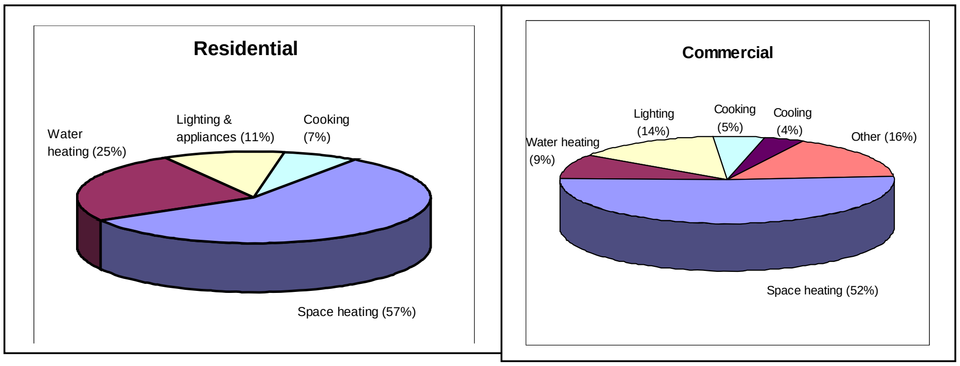

**Figure 2a**
EU building energy consumption for residential and commercial buildings
*Source www.intuser.net/ufes35.php.*

### 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 programs 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 programs exist, but not all will be applicable to all situations; for example some focus on residential buildings or can be used only in particular countries or climatic regions.

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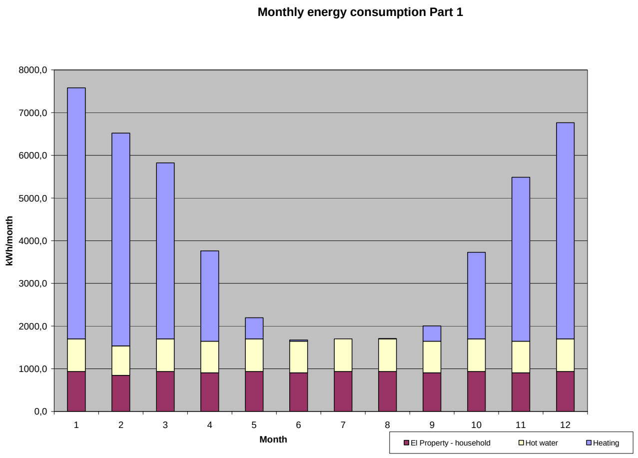


**Figure 2b:**
Monthly energy use calculated by Consolis program

## 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 (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 primary (bought) energy consumption – a critical aspect of building regulations in respect of energy performance.

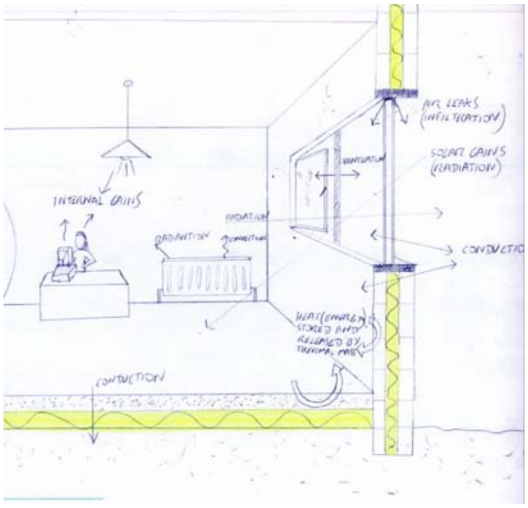
Energy (such as heat) is transported by transmission (conduction), air movement (convection) and/or radiation.

**Transmission** is dependent on the thermal insulation or conversely the conductivity of a material or construction.

**Air movement** is either controlled (through ventilation) or 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 passive (free) means, which need 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.



Designer – outer wall to be brick coloured, inner, grey. Inside of room to be white, with coloured carpet.

**Figure 2c**
Heat (energy) flows within a building.
**Heat is gained** by solar radiation, air infiltration and internal gains from lighting, heating, and the occupants and their equipment.
**Heat is los**t 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.

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

1. To minimise the amount of primary (bought) 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)*

Concrete's thermal stability helps provides 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

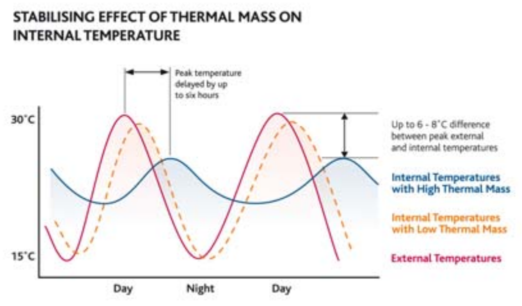


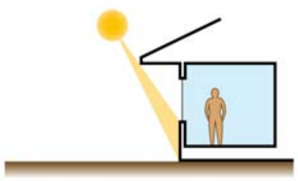
**Figure 3a**
The influence of thermal mass on comfort and energy use.
*From TCC publication, Thermal mass for housing.*

As a heavyweight material, the thermal mass of 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.

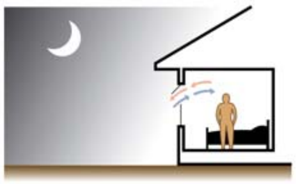
Dense, heavyweight concrete provides the highest level of thermal mass, with lightweight, insulating concrete providing a lower, but nevertheless worthwhile level. Thermal mass has long been known to have a positive influence on energy use and thermal comfort in buildings, but this aspect has not been 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.

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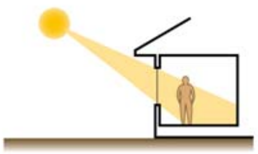
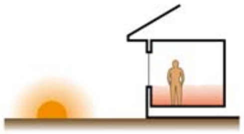
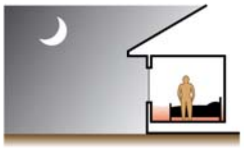
**Thermal mass during the heating season**



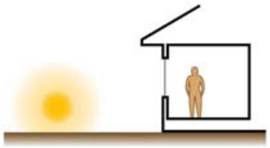
**10.00 am to 5.00 pm**
Sunlight enters south-facing windows and strikes the thermal mass. This heats the air and thermal mass. On most sunny days, solar heat can help maintain comfort from mid-morning to late afternoon.



**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 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.

**Figure 3b**
Storage and release of free energy gains in winter and passive cooling in summer *(courtesy of The Concrete Centre)*

## Making the most of thermal mass

Concrete's thermal mass works best in buildings where there is a regular cycle or temperature variation, perhaps 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 slabs, to prepare them 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. It is therefore important that the insulation in external walls is 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.

In climates with temperatures that remain very steady 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.

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.

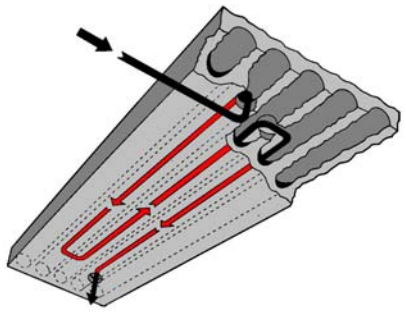


**Figure 3c**
The Termodeck System. – here mechanical ventilation passes low velocity air through the cores of a hollowcore slab in a serpentine pattern, which ensures prolonged contact between the air and concrete for good heat transfer. In each slab, three of the five cores are generally used in this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

## 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 redcue 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.

Please can Mats clarify all this ? Did the building have air-conditioning?

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 cooling energy than the lightweight building and that concrete's thermal mass exerted a major influence on thermal comfort. For the office the difference was nearly 20% for the active cooling case. Despite the use night of night ventilation in the lightweight office there was still excessive overheating, with 179 hours of the occupied period above 26ºC. The results of recent research on this subject are reported in Section 5 of this publication.

**Figure 3d:**
Energy efficient masonry town housing in Dublin, Ireland. (C*ourtesy of The Concrete Centre*)

# 4. THE ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE (EPBD)

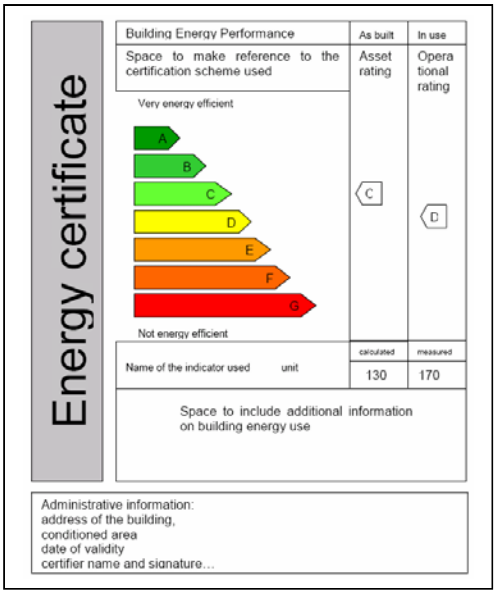
The EPBD provides a common framework for calculating the energy performance of buildings across Europe and sets minimum standards in new and refurbished buildings

The EU Directive on Energy Performance of Buildings (EC, 2003) 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.

## The requirements of the Energy Performance of Buildings Directive

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 photovoltaic 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).



Energy certificate

| Building Energy Performance | As built | In use |
|---|---|---|
| Space to make reference to the certification scheme used | Asset rating | Operational rating |
| Very energy efficient<br>A<br>B<br>C<br>D<br>E<br>F<br>G<br>Not energy efficient | C | D |
|  | calculated | measured |
| Name of the indicator used unit | 130 | 170 |

Space to include additional information on building energy use

Administrative information:
address of the building,
conditioned area
date of validity
certifier name and signature…

**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 (of thermal insulation) 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:

Optional list

- 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 subtracting this from the amount of primary energy purchased (bought energy). For example, a heavyweight building utilises more of the free gains and so requires less bought energy than a lightweight building. The way in which this is done is shown in Figure 4b, from which it can be seen that a greater proportion of free gains can be used in a heavyweight building. An important aspect of EN ISO 13790 is the way in which it takes account of thermal mass and free solar and internal heat gains.

Is this an acceptable simplification of the Mats' original diagram, which was hard to understand and not suitable for intended audience?

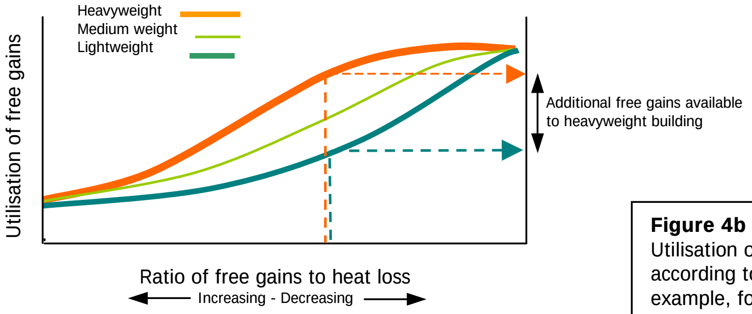


**Figure 4b**
Utilisation of free energy gains according to EN ISO 13790. For example, for a certain ratio of free gains to heat loss, a heavyweight building provides a higher utilisation than a lightweight building.

The net heat gain is the heat gained less losses due to poor insulation and air leaks.

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

Is this the quasi steady state method mentioned in previous chapter?

I don't understand this

## 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) 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.

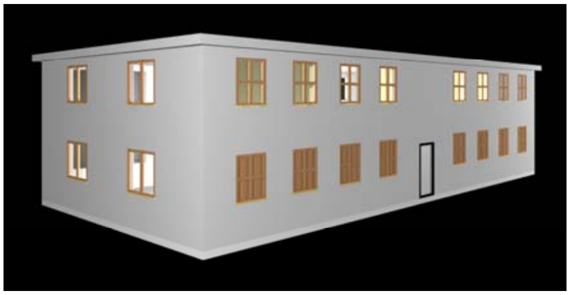


**Figure 5a**:
A view of the theoretical building used for the energy tests

### Calculating theoretical energy performance

A range of computer programs for calculating energy use in building are available, many of which were developed in response to the formulation of EN ISO 13790. Five programs from Denmark, Germany and Sweden were used in the research on concrete and energy performance. Three are based on the simplified utilization-factor method, one is a general dynamic program 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 programs 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, and was also somewhat greater in coastal locations with longer periods of moderate temperature fluctuations (compared with an inland climate). 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 utilization of solar energy with a minimum of comfort problems.

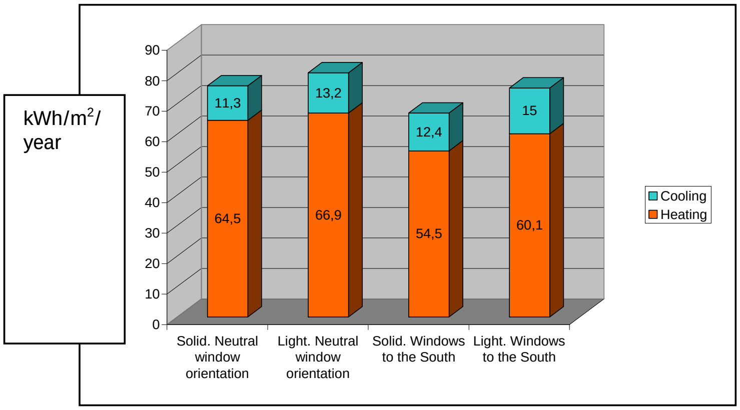


**Figure 5b:**
Typical results from calculation of required heating and cooling energy a heavyweight or lightweight building model as shown in Figure 5a. In this case the example modelled was a residential building in Stockholm.

**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 programs, 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 programs 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 programs. A range of structural alternatives, both heavy and lightweight was considered, and site-specific climate data was included.

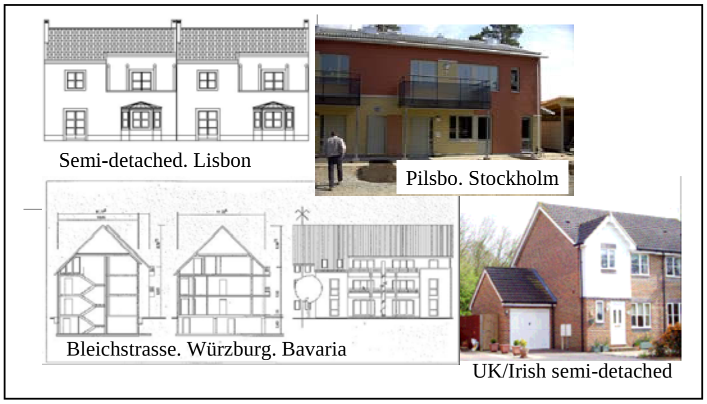


**Figure 5c**:
A variety of European buildings were analysed using the computer programs that applied the effect of both a lightweight and heavyweight version.

This picture would be better separated - would be nice to get **photos** of all

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 programs, 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.

What about Stockholm??

**Table 1:** Example from real building studies. Annual energy use [kWh/$m^2$]

| **Building type** | **Energy use** | **Heavyweight** | **Lightweight** |
|---|---|---|---|
| Semi-detached. Lisbon | Heating* | 17 | 19 |
| | Cooling | 27 | 32 |
| | Total | 44 | 51 |
| Bleichstrasse. Würzburg | Heating* | 51 | 55 |
| UK/Ieland semi-detached. Average of 9 locations | Heating** | 34 | 35 |

*Constant heating regime

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

**Figure 5d:**
A brick and block house with a basement, Manchester, UK. *(Courtesy of the Basement Development Group*)

## 6. BENEFITS OF ENERGY-EFFICIENT CONCRETE BUILDINGS

Concrete has a proven case – and there are many buildings across Europe that demonstrate its good energy performance

The results of the research study on concrete's performance described in Section 5 indicated that heavyweight construction can offer typical energy savings of 2 – 9% for a residential building and 7 – 15% for an office, when compared with a lightweight equivalent. Overall, these results were in good agreement with other research discussed in *Studies on thermal mass* on page 9. These savings may not appear substantial, but with rising energy prices, they could soon grow into considerable sums for the average building occupier.

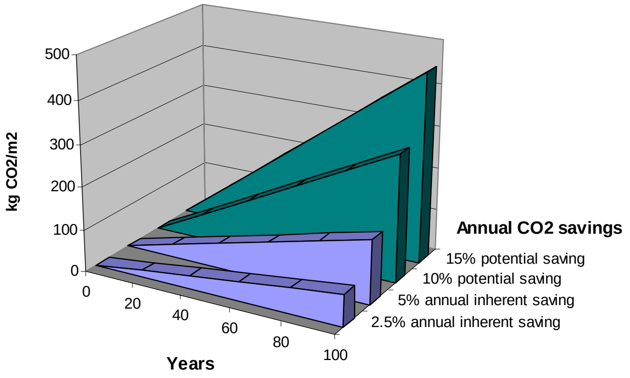
Based on typical European energy prices in the 2nd quarter of 2006, the energy savings found in the residential test would equate to around EUR 60 per year based on a house of around 70 – 80 $m^2$ in size. Since energy prices do not appear to be stable and if the dramatic price rises of recent years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

**Figure 6a)**
Relative price increase of gas and electricity in Sweden
*From Mats' fig 10)*
Figure removed as nothing more pan-European provided

### Energy savings accumulate over a building's lifetime

In practice, of course, energy savings will be affected by user behaviour, such as closing windows and shutters, but over the life-cycle of a building there is no doubt that even a small improvement due to building design will accumulate to become a substantial saving. Every year, concrete's incremental advantage adds up to a massive performance benefit that no one can afford to ignore. Figure 6a indicates how even a modest annual saving can mount up over time. Furthermore, recent UK research has found that a medium-weight masonry/concrete home that fully utilises its thermal mass will 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 their production, including the mining of natural resources, manufacturing of materials and transportation.



Not clear what potential saving or inherent means – Mats to explain, please.

**Figure 6a)**
Lifetime consequences of small annual improvements (BASED ON MATS' FIG 11).

The implementation of the EU Directive Energy Performance of Buildings (EPBD) has heightened awareness of the problem of buildings accounting for much of the energy used in Europe today. With its requirements on minimum energy performance, system of energy certification and stringent checking procedures, the EPBD is setting higher standards for buildings. Nevertheless, it is delivering this change in a balanced and sensible manner by insisting that energy performance must not impinge upon the quality of the indoor environment. 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.

As a heavyweight building material, concrete has a high thermal stability, which enables it to maintain an even, comfortable indoor climate while consuming only a minimal amount of primary (bought) energy. This attribute is extremely valuable in reducing both the economic and environmental costs associated with energy use in buildings. It is also helpful in maintaining a steady, comfortable indoor temperature – particularly for buildings with high daily temperature variations, such as schools and offices. Concrete buildings offer superior comfort conditions and can reduce or even eliminate the need for air conditioning by optimising the use of passive, solar gains.

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-proof our buildings well into the current century.

**Figure 6b**
Energy efficient flats in Dublin
(*Courtesy of The Concrete Centre*)

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**Figure 7a**
A cat taking advantage of solar gain in a thermally efficient house. (*Courtesy Gillian Bond*)