The **Concrete** Centre™

Thermal Mass Explained

THERMAL MASS: WHAT IT IS AND HOW IT'S USED

Contents

Glossary of terms

Admittance

The admittance of a material is its ability to exchange heat with the environment when subjected to cyclic variations in temperature (see page 10). In practical terms, admittance values show the extent to which a specific floor or wall construction can absorb and release heat gains inside a building.

Decrement delay

The time lag, measured in hours, for heat to pass through a material or construction element (see page 13). In practical terms, it is the delay between the peak outer and inner surface temperature of a wall or roof typically on a summer day as the heat travels through it in a wave like motion.

Decrement factor

In simple terms, this is the ratio between the cyclic temperature on the inside surface of a wall or roof compared to its outside surface (see page 13). In other words, it describes the attenuation of heat as it travels through a wall or roof in a wave like motion.

Diurnal temperature variation

The daily temperature shift that occurs from daytime to night-time.

Diurnal heat flow

The heat that flows in and out of a building from daytime to night-time.

Mass enhanced U-value

This describes the ability, in certain climates, for heavyweight construction elements, to achieve better energy performance than suggested by their standard (steady-state) U-value.

Passive solar design (PSD)

PSD basically optimises a building's form, fabric and orientation to maximise solar gain from autumn to spring, whilst minimising it during the warmer part of the summer. At the same time, daylighting is maximised at all times.

Thermal mass

The capacity to store heat within a material (see page 4).

Cover images:
Front, main picture: St Matthew's keyworker estate, Brixton. A multi award-winning and highly energy-efficient building that combines high levels of insulation and air tightness with thermal mass and passive design features. Heating and hot water costs are around £98 per year for each flat. Courtesy of Benedict Luxmoore/arcaid.co.uk.

Back cover: Great Bow Yard, Somerset features a sunspace-based passive solar design utilising a high thermal mass solution. Courtesy of Building for Life/Design for Homes. Photography: Richard Mullane.

Introduction

The energy used for space heating accounts for around 20 to 50 per cent of a building's energy consumption [1] depending on type, and around a third of the carbon emissions from all UK buildings [2]. To lessen this impact, revisions to Part L of the Building Regulations, along with the introduction of other codes and standards, have done much to reduce fabric heat loss through requirements for greater levels of insulation and reduced air leakage. These are very effective and well understood measures. Something less well known is that reducing heat loss from a building also enhances the ability of thermal mass to further lower the space heating load when used in low energy design. This point is acknowledged in the proposed changes to Part L1 for dwellings, which reflect the increasing significance of thermal mass as we move towards more highly insulated, air tight, low energy buildings.

With the advent of a warming climate, summertime performance is also a driver for thermal mass. When it is used in combination with good ventilation and shading, it helps buildings adapt to the effects of hotter weather by reducing both the risk of overheating and the cooling load in air conditioned buildings.

Until recently, the use of thermal mass was often disregarded in favour of a largely services based solution to the heating and cooling of buildings, which is not surprising in an age when cheap energy was plentiful and the effects of climate change had yet to be felt. However, the time to re-evaluate the contribution that thermal mass can make to building performance has come. To do this, it is important to have a basic working knowledge of thermal mass and how to best use it. That is the purpose of this guide, which we hope you find useful.

Further free detailed publications on thermal mass can be downloaded from The Concrete Centre - **www.concretecentre.com/publications**.

Benefits of designing with thermal mass

Exploiting thermal mass on a year-round basis is not difficult, but does require consideration at the outset of the design process when requirements for the building form, fabric and orientation are being established. Providing this is done sympathetically, a more passive approach to design can realise benefits which include:

- Enhanced energy efficiency and carbon savings over the life of the building.
- Improved daylighting.
- Improved ventilation and air quality.
- Optimal decrement delay (time lag) and decrement factor (heat flow) for reducing heat gains in summer.
- Good summertime comfort and a reduced risk of overheating.
- A measure of future proofing against the effects of a warming climate.
- Reduction in the need for more expensive low and zero carbon technologies to meet CO_2 targets.
- Enhanced property resale value.

Oriel High School, Crawley features an in-situ concrete frame with precast concrete wall panels, insulated and rendered externally. The underside of the floor slabs at both levels, which are exposed concrete cast in situ, provides thermal mass that can be cooled overnight via opening windows to help to moderate internal temperatures when daytime external temperatures are high.

What is thermal mass?

Thermal mass, in the most general sense, describes the ability of any material to store heat.

For a material to provide a useful level of thermal mass, a combination of three basic properties is required:

1. High specific heat capacity – to maximise the heat that can be stored per kg of material.
2. High density – to maximise the overall weight of the material used.
3. Moderate thermal conductivity – so that heat conduction is roughly in synchronisation with the diurnal heat flow in and out of the building.

Heavyweight construction materials such as brick, stone and concrete all have these properties. They combine a high storage capacity with moderate thermal conductivity. This means that heat transfers between the material's surface and the interior at a rate that matches the daily heating and cooling cycle of buildings. Some materials, like wood, have a high heat capacity, meaning that their thermal conductivity is low, which limits the rate at which heat is absorbed. This combination, which results in low thermal mass, can be useful in other ways (see page 13). Steel can also store a lot of heat, but in contrast to wood, steel possesses a very high rate of thermal conductivity, which means heat is absorbed and released too quickly to create the lag effect required for the diurnal temperature cycle in buildings.

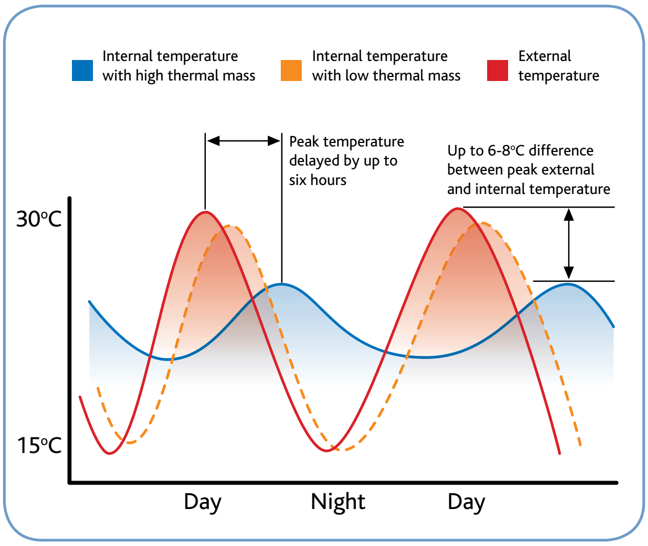


Figure 1: Stabilising effect of thermal mass on internal temperature.

Table 1: Thermal properties of common construction materials

Building material [3]	Density (kg/m³)	Thermal conductivity (W/m.K)	Specific heat capacity (J/kg.K)	Effective thermal mass
Timber	500	0.13	1600	Low
Steel	7800	50	450	Low
Lightweight aggregate block	1400	0.57	1000	Medium-high
Precast and in-situ concrete	2300	1.75	1000	High
Brick	1750	0.77	1000	High
Sandstone	2300	1.8	1000	High

Concrete and masonry steadily absorbs heat that comes into contact with its surface, conducting it inwardly, and storing it until the surface is exposed to cooler conditions and its temperature begins to drop. When this occurs, heat will begin to migrate back to the cooler surface and be released. In this way, heat moves in a wave-like motion alternately being absorbed and released in response to the variation in day and night-time conditions.

The ability to absorb and release heat in this way enables buildings with thermal mass to respond naturally to changing weather conditions, helping stabilise the internal temperature and provide a largely self-regulating environment. When used appropriately, this stabilising effect helps to prevent overheating problems during the summer and reduces the need for mechanical cooling. Similarly, the ability to absorb heat can help reduce fuel usage during the heating season by capturing and later releasing solar gains and heat from internal appliances (see pages 6-7). The seasonal use of thermal mass is explained in the next section.

Thermal mass in summer - how it works

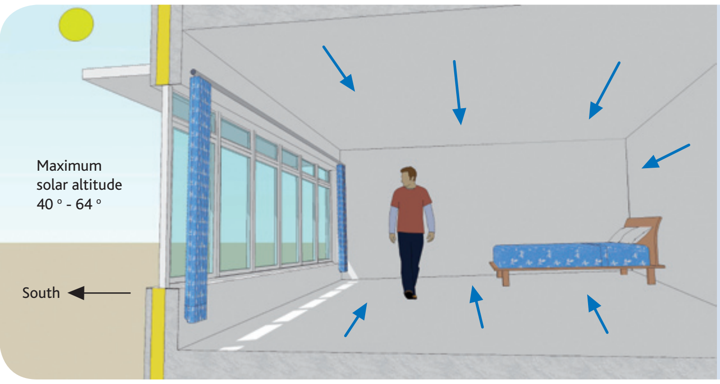
The benefit of thermal mass in residential buildings is well understood in warmer parts of Europe, but is also becoming increasingly relevant to other regions where the impact of climate change is leading to more frequent occurrences of overheating. Its application in commercial buildings is also growing, where one of the key benefits is lower running costs of air conditioning systems.

During warm weather, much of the heat gain in heavyweight buildings is absorbed by the thermal mass in the floors and walls, helping prevent an excessive temperature rise and reducing the risk of overheating. This makes naturally ventilated buildings more comfortable and in air-conditioned buildings with thermal mass the peak cooling load can be reduced and delayed. The thermal capacity of the building fabric allows a significant amount of heat to be absorbed with only a small increase in the surface temperature. This is an important quality of heavyweight construction as the relatively low surface temperature results in a beneficial radiant cooling effect for the occupants, allowing a slightly higher air temperature to be tolerated than would otherwise be possible.

By allowing cool night-air to ventilate the building at night, heat that has built up in the fabric is removed. This daily heating and cooling cycle of the thermal mass works relatively well in the UK as the air temperature at night is typically around 10 degrees less than the peak daytime temperature, making it an effective medium for drawing heat out of the fabric. This diurnal temperature variation is rarely less than 5 degrees, making night cooling reasonably dependable in the UK [4]. As the climate warms over the 21st century the diurnal variation is predicted to stay the same or increase slightly [5], however the temperature range in which it occurs will progressively shift upwards. So, towards the end of the century, the effectiveness of night cooling is likely to diminish slightly as average temperatures increase. Despite this, the combination of thermal mass and night cooling is, and will continue to be, an effective means of helping buildings adapt to the effects of a warming climate [6, 7, 8, 9].

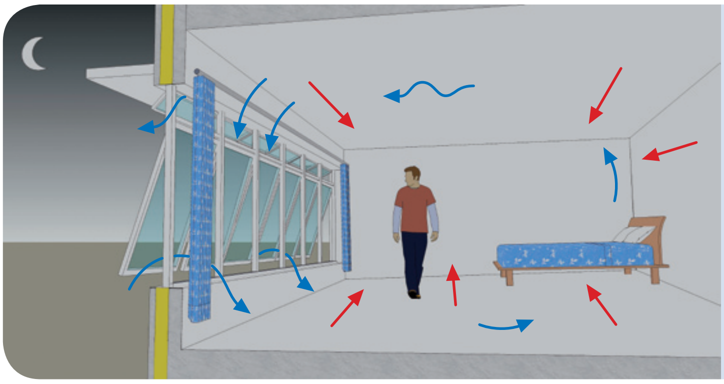
In warmer parts of the world, such as northern Australia, that experience a small diurnal temperature swing, thermal mass offers little or no benefit and the vernacular architecture uses lightweight materials.

Figure 2: Thermal mass in summer



Summer day

- During very hot weather, windows are kept shut to keep out the warm air.
- Overhangs on the south elevation can be used to keep out the high angle sun during the hottest part of the day.
- Cooling is provided by thermal mass in the floor and walls.



Summer night

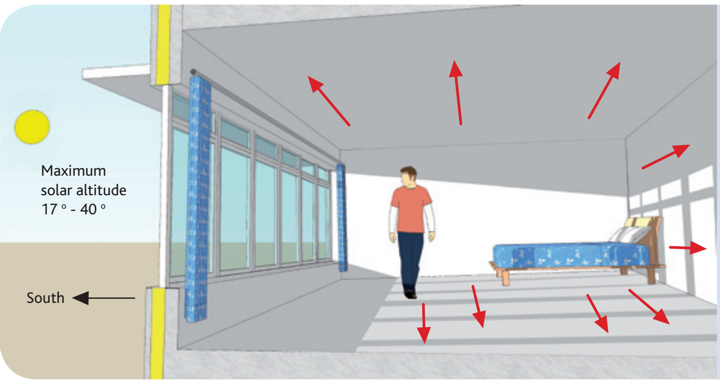
- The windows are opened at night to ventilate the building and cool the fabric.
- If another hot day is expected, the windows are closed again in the morning and the cycle is repeated.

Thermal mass in winter - how it works

The combination of tougher performance requirements and rising fuel costs, mean that we need to make the most of passive techniques to heat our homes and places of work. This requires a whole building approach to design, in which the orientation, glazing and thermal mass work together to provide comfortable, low energy solutions.

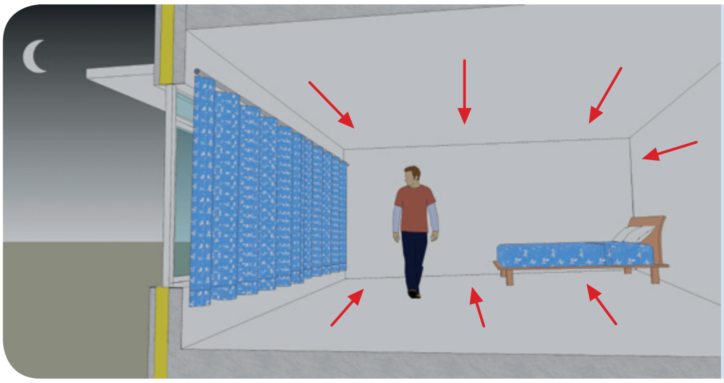
A benefit of thermal mass that is perhaps less well known in the UK is its ability to help reduce fuel consumption during the heating season when used in passive solar design. This approach to design seeks to maximise the benefit of solar gain in winter, using the thermal mass to absorb gains from south facing windows, along with heat produced by cooking, lighting, people and appliances. This is then slowly released overnight as the temperature drops, helping to keep the building warm and reducing the need for supplementary heating. By applying simple passive solar design techniques, fuel savings of up to 10 per cent can be made [10], increasing to around 30 per cent where more sophisticated passive solar techniques are adopted such as sunspaces [11].

Figure 3: Thermal mass in winter



Winter day

- During the heating season, the low angle sun can shine through south facing windows, and the heat is absorbed by thermal mass in the floor and walls.
- In the evening when the sun goes down and the temperature drops, the heat flow is reversed and passes back into the room.



Winter night

- At night, curtains are drawn and windows kept shut to minimise heat loss.
- Heat continues to be released by the thermal mass and supplementary heating is adjusted so only the minimal amount is used.
- By morning the thermal mass will have given up most of its heat and the occupants will typically have to rely on supplementary heating until later in the day.

Recent drivers for thermal mass

There are a number of recent developments that are leading to renewed interest in thermal mass and the contribution that it can make to low energy design. These include:

- The increasing threat of overheating in a warming climate and the need to mitigate this through adaptive design measures, which include the use of thermal mass.
- Proposed revisions to the calculation methodology (SAP) used in Part L1 of the Building Regulations (new dwellings), which looks set to take fuller account of thermal mass.
- Ongoing improvements in glazing and window technology, which makes passive solar design more effective (less heat loss in winter).
- Instability in energy prices, which has refocused government efforts to improve energy efficiency in buildings.
- The very low capital and running costs of passive solar systems, which can in turn reduce the need for more expensive low and zero carbon technologies.

Designing for year-round use of thermal mass with passive solar design

Passive Solar Design (PSD) basically optimises a building's form, fabric and orientation to maximise solar gain from autumn to spring, whilst minimising it during the warmest part of the summer. At the same time, daylighting is maximised at all times, adding to the overall wellbeing and comfort of the occupants. PSD costs very little to implement and can make a significant contribution to the energy efficiency of a building throughout its life, whilst incurring little or no maintenance costs.

In the UK climate, PSD is mostly used to reduce domestic heating requirements, although it is increasingly being used in non-domestic buildings, where the emphasis is often on maximising daylight without increasing the risk of overheating. PSD requires a whole-building approach to design, in which the envelope (particularly the glazing) is designed in unison with the structure's thermal mass to ensure optimal admission and absorption of solar gains during the heating season. PSD can be applied with varying levels of sophistication, including the use of both sunspaces and Trombe walls. These systems are beyond the scope of this guide, but plenty of practical information about them can be found online. At a more basic level, the general requirements for applying PSD in mainstream housing are outlined in the remainder of this section.

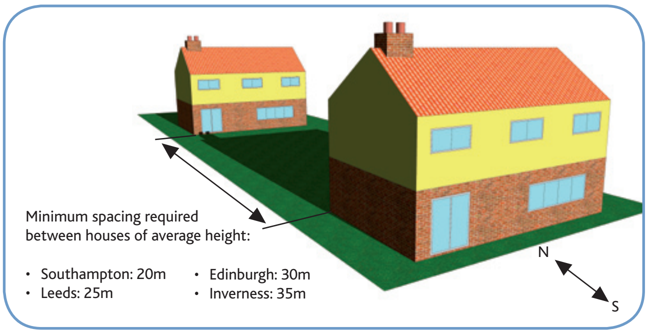


Figure 4: House spacing to avoid over shadowing [14]

South facing windows

The key objective for windows is to control the loss of heat while optimising access to available sunshine. To achieve this, the majority of the windows should face south, or within around 30° of south, with minimal overshadowing from around 9am to 3pm during the heating season. Two good sources of guidance on optimising site layout for solar gain, which are free to download are *Planning for Passive Solar Design* [12] and *Site Layout and Building Design* [13]. Conventional levels of glazing on the south elevation will provide worthwhile solar gains, but a modest increase in area improves performance. The type of glass used along with the basic house design (including shading) will determine the optimal glazed area, but typically, this should not be more than around 40 to 50 per cent of the wall to avoid overheating in summer and excessive heat loss in winter. The use of a low emissivity coating on the inner pane is an effective way of reducing heat loss and can be combined with an outer pane of low iron glass to increase light transmission and solar gains. North facing windows have a net heat loss over the course of a year and should be limited to around 15 per cent of the room's floor area, which will still provide adequate daylighting.

A roof overhang provides the simplest method of solar control for top floor windows on a south facade. For lower level windows, a balcony or brise soleil will achieve the same result. Overhangs can be supplemented with other forms of shading to provide additional control and in the case of shutters, the added benefit of secure ventilation in summer and reduced heat loss in winter.

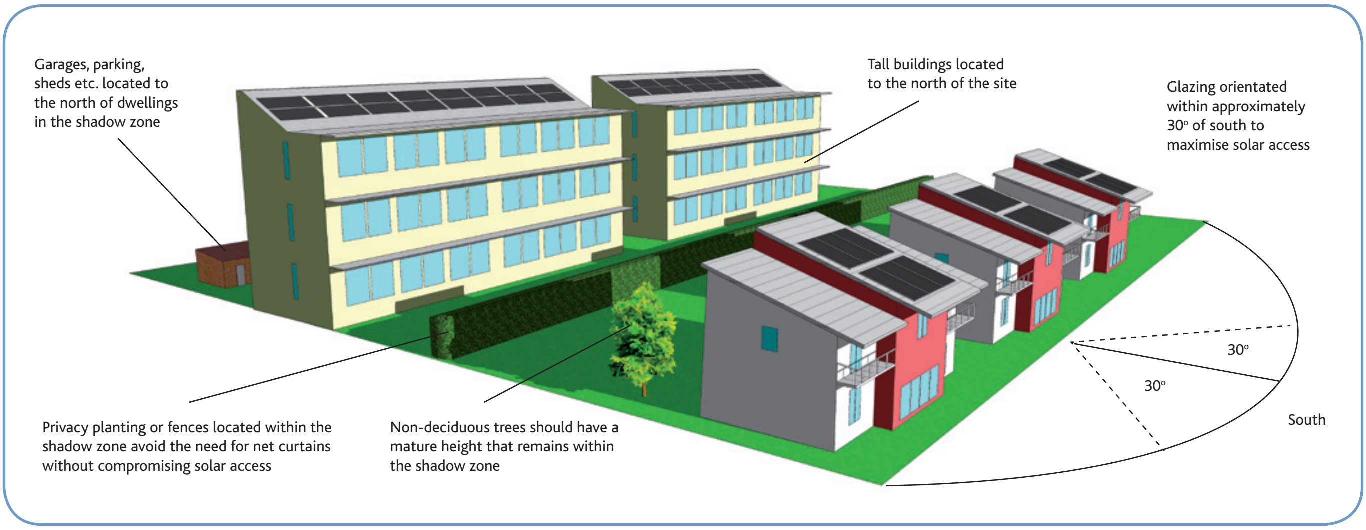


Figure 5: To maximise solar gain during the heating season, most of a building's glazing should face south or within 30° of south, with minimal overshadowing from around 9am to 3pm.

Thermal mass and insulation

Thermal mass is not a substitute for insulation, and a combination of the two is needed for effective passive design in heating climates such as the UK. The position of the insulation relative to the thermal mass is of particular importance. The simple rule is that the thermal mass must be located inside the insulated building envelope. For this reason, an outer layer of brick offers little benefit, but can help in other ways (see page 13). In practical terms, a cavity wall already satisfies the basic rule, as the insulation is located in the cavity, allowing the inner leaf of blockwork to be exposed to the room. For solid masonry walls, the insulation should be located on the outer surface, which is usual practice. The insulation for solid ground floors should ideally be located under the slab, although screed placed on top of insulation will also provide some useful thermal mass.

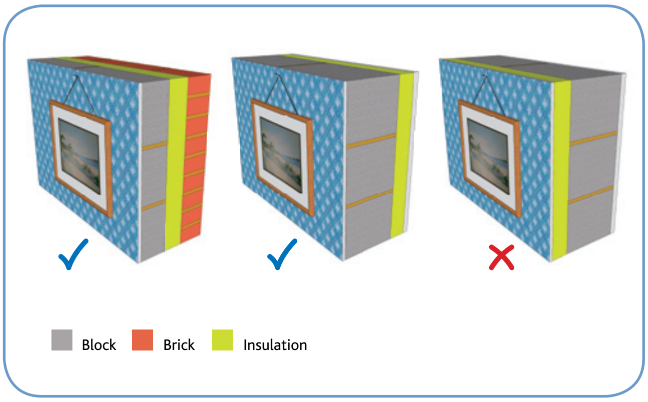


Figure 6: Locating insulation in external walls to maximise thermal mass.

There are no hard and fast rules on how much thermal mass is needed, but even a moderate amount, has been shown to provide worthwhile savings [15]. From an energy perspective, it would be difficult to have too much, and generally the more thermal mass the better, however, as with all aspects of design it is necessary to arrive at a workable balance, taking other considerations into account. As a rough guide, the surface area of the floor/walls providing the mass should be at least six times that of the glazing in the room [16], although this will to some extent be influenced by the particular properties of the mass i.e. its thermal conductivity and density. So, as the area of south facing glazing increases, more thermal mass is required to maintain a stable temperature during the summer [17]. The depth of thermal mass will also influence performance, and this is discussed later in the document (see pages 10-12).

Internal surfaces

Typically, thermal mass is provided by concrete/masonry walls and floors, but other heavyweight materials can be equally effective. It is not essential for the sun to shine directly on all internal surfaces for heat to be absorbed, as convection and radiation between surfaces will help distribute warmth throughout the space. Surfaces do not have to be a dark colour, as any small benefit in heat absorption may impact on daylighting. However, it is important that the surface of heavyweight walls and floors remain as thermally exposed as practicable.

For walls, this is best achieved with a wet plaster finish, as this will conduct heat relatively freely and offers the added benefit of providing a robust air barrier that will help minimise air leakage. Dry lining will reduce heat flow, but its impact will depend on the thermal mass potentially available in the wall. For an aircrete block inner leaf (which has a relatively low thermal conductivity), plasterboard is less of a thermal bottle-neck than for heavier weight aggregate blockwork, which has higher thermal conductivity and is more sensitive to the choice of finish. Therefore, to fully exploit the high level of thermal mass available in aggregate blocks, the use of dry lining is best avoided.

With some forms of concrete wall and floor construction, it is possible to achieve a high quality, fair-faced finish which requires little more than a coat of paint. From a thermal mass perspective, this is particularly beneficial as heat can pass directly between the room and the concrete. Although not often used in residential buildings, a fair-faced finish is more common in low energy commercial offices or schools where an exposed concrete soffit is often used to provide thermal mass.

Wherever practicable, floors should be tiled, and the use of carpet avoided, as placing carpet on a concrete floor can reduce its ability to admit heat by half [18]. A shiny or glossy floor finish will absorb less heat than a dull finish, however, this must be evaluated alongside daylighting requirements and the tendency of such a surface to absorb light. A tiled floor also works well with underfloor heating, which in turn can be particularly efficient when designed with a high level of thermal mass in the slab and a heat pump to provide a continuous source of low grade heat [11].

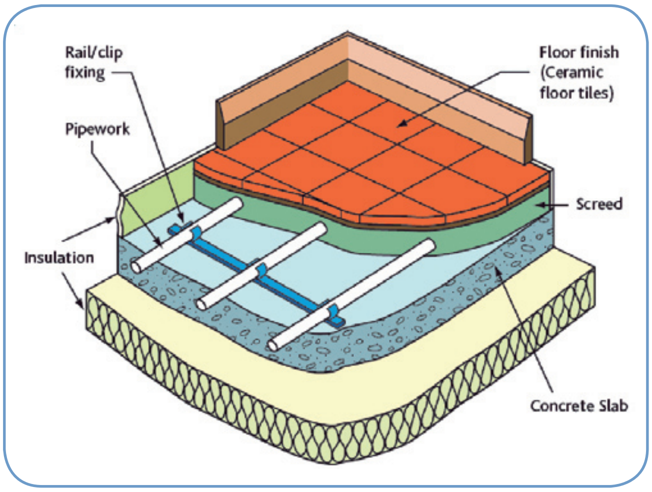


Figure 7: A tiled floor will allow a concrete floor slab's thermal mass to be fully exploited and is also suited to underfloor heating.

Internal layout

Where practicable, the most frequently used rooms should be on the south side of the dwelling, so that they enjoy the greatest benefit to be had from solar gain during the heating season. Bathrooms, utility rooms, hallways, stores etc. should be located on the north side of accommodation [19]. The cooling benefits from thermal mass tend to be slightly lower in bedrooms than for the general living spaces. So, in southern England where summer temperatures are highest, there may be some benefit in locating bedrooms on the north side. Another option that can help is to specify a concrete upper floor. Providing the mass remains reasonably accessible, this can improve year-round thermal performance. A further option is to locate south facing bedrooms on the ground floor, so they get the benefit of stack ventilation at night. A house designed to take advantage of stack ventilation will benefit from more consistent air flow, particularly on still nights. The stack effect uses the difference in air temperature at high and low level to draw cool night air into ground floor rooms, where it then travels upwards through the building and exits from windows on the upper floor(s), having absorbed heat from the building fabric on route.

Night cooling

During the hot summer months, the building fabric must be cooled during the night by ventilation to remove the heat that has been absorbed during the day. Without adequate ventilation, thermal mass has the potential in some circumstances to increase discomfort. Night ventilation requires careful design to ensure adequate air flow can be achieved, and to address any acoustic, air quality or security issues that may arise. More information on this can be found in *Thermal Mass for Housing* which is free to download from The Concrete Centre website **www.concretecentre.com/publications.**

Intermittently heated buildings

Older heavyweight buildings with comparatively low levels of insulation and minimal solar gain in winter, have traditionally required a longer pre-heat period than lightweight buildings, resulting in slightly higher fuel consumption. However, the greatly improved standard of insulation and air tightness in new construction means this is no longer the problem it once was, as the fabric remains relatively warm when the heating is off, reducing the amount of pre-heat needed to get the building back up to temperature. It is also worth noting that the pre-heat issue only applies to intermittently heated buildings, and in reality a low level of continuous heating is now the preferable option in many recent heavyweight buildings. However, in some types of intermittently occupied buildings, for example weekend holiday cottages, thermally lightweight construction will still be the best option where heating is concerned as it will enable a more rapid warm up period.

"The 21st century will see a transition to a new energy source just as has happened in previous centuries. In the 19th century a transition occurred from wood to coal, the turn of the 20th century saw the transition from coal to oil, and the end of the century saw the rapid growth in the use of natural gas in the building sector.

Which energy source will dominate as we move further in to the 21st century remains to be seen, but what is certain is that it must be a renewable source. And the use of solar energy will surely be a major energy source, particularly in the building sector."

(International Energy Agency)

Measuring and optimising the benefits of thermal mass

What are admittance values?

Describing a material or construction as having high, medium or low thermal mass gives a useful indication of its ability to store heat, but in order to know how effective a chosen material will be in practice, there are a couple of other important factors that need to be taken into account. These are firstly the length of time available to get heat in and out of the material, which is typically assumed to be 24 hours (i.e. heating during the day and cooling at night), and secondly, the resistance to heat flow at the surface of the material, which can be significant. These factors are both accounted for in admittance values, along with thermal capacity, conductivity and density. Admittance values provide a practical means of assessing the approximate in-use heat absorption performance of walls and floors etc.

From a technical perspective, admittance can be defined as the ability of a material or construction element to exchange heat with a space when it is subject to cyclic variations in temperature. Admittance is measured in W/m^2K, as U-values. However the 'K' represents something different i.e. the difference between the mean internal temperature and the actual temperature at a specific time of day. It is this dynamic temperature difference that drives heat in and out of the fabric. In contrast, the 'K' in U-values is the difference between internal and external temperature, which is assumed to be constant, which is why U-values are steady state. Another difference is that high admittance values are desirable from a thermal mass perspective, whilst low U-values will minimise heat loss.

Admittance values and U-values

Admittance and U-values are both measured in W/m^2K, but the 'K' represents different things:

For U-values K represents ($t_{inside} - t_{outside}$)
...whilst for admittance K represents ($t_{inside} - t_{mean}$)

Limitations of admittance values

Admittance values allow a comparison to be made of the heat absorption characteristics of materials in response to a simple heating and cooling cycle. However, caution must be taken if this approach is used to assess overall building performance as it can underestimate the actual peak cooling capacity of a high thermal mass structure by up to 50 per cent in comparison to more sophisticated thermal modelling techniques that use real weather data [20]. A more detailed explanation of this follows.

Effect of longer heating/cooling cycles

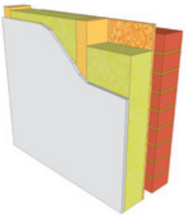
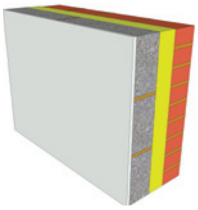
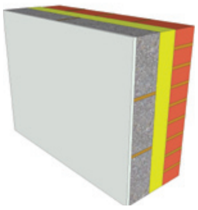
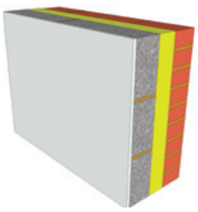
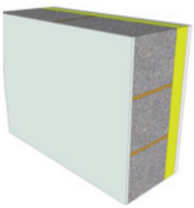
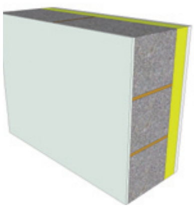
In addition to a building's daily heating and cooling cycle, there is often a cycle related to a typical UK peak design weather period (usually three to five days) and also the five working days per week cycle, from which heat will reach different depths within the available thermal mass. In the case of floors in a non-air conditioned building for example, the greater the slab depth, the longer the time period it responds to; the core of a 300mm thick concrete slab responds to the monthly average condition and draws heat in deeper over an extended period of hot weather [20]. For longer time periods these factors are important because it is the longer-term average room temperatures that define the thermal storage core temperature and hence the temperature gradient that draws heat in. It is for this reason that only a detailed thermal analysis will show the effectiveness of medium and high depth floor slabs and walls under real conditions. However, to get a rough indication of performance, the length of the heating and cooling cycle used to calculate admittance values can be increased from the usual 24 hours to a longer period. This can be seen in Figure 8, which shows admittance values for several types of external wall for time periods ranging from 24 hours to 120 hours. Unsurprisingly, the results show that admittance values decline as the period increases, however the rate of decline is less for medium and heavyweight walls because thermal mass at depths which cannot be fully exploited in a 24 hour cycle become more active during the longer cycle.

In addition to the daily heating and cooling cycle, thermal mass also responds to longer time periods e.g. the typical UK peak design weather period (usually three to five days), and the five working days per week cycle. Longer periods such as these allow thermal mass to be tapped at depths in excess of the 100mm associated with a 24-hour cycle.

Upper limit of admittance values

In naturally ventilated buildings, the resistance to heat flow at the surface of the floors and walls limits admittance values to a maximum of around 8 W/m^2K [22] even in very heavyweight construction. This is because although concrete and other heavyweight materials have moderate thermal conductivity, they are often limited by the rate of heat transfer at the surface which may act as a bottle-neck. To some extent, this can be overcome in mechanically ventilated buildings, as discussed in the section on effective slab depth in commercial buildings (see page 12).

Figure 8: Admittance and decrement values for some common types of wall construction [21]

External wall (U-value = 0.25 W/m²K)	Internal finish	Decrement delay (hours)	Decrement factor	Admittance value 24 hour cycle (W/m²K)	Admittance values for longer cycles (W/m²K)			
					48 hours	72 hours	96 hours	120 hours
Timber frame (Brick outer leaf) 	Plasterboard	7.5	0.56	1.00	0.69	0.45	0.38	0.35
	Wet plaster	-	-	-	-	-	-	-
Masonry cavity wall (100mm aircrete block) 	Plasterboard	10.65	0.26	1.85	1.45	1.17	0.96	0.81
	Wet plaster	10.2	0.33	2.65	1.9	1.44	1.14	0.95
Masonry cavity wall (100mm lightweight aggregate block) 	Plasterboard	11.21	0.16	2.38	2.16	1.93	1.7	1.51
	Wet plaster	10.51	0.25	4.05	3.33	2.7	2.23	1.88
Masonry cavity wall (100mm dense aggregate block) 	Plasterboard	10.67	0.13	2.65	2.49	2.29	2.08	1.88
	Wet plaster	10.00	0.23	5.04	4.28	3.54	2.95	2.5
Solid masonry (215mm aircrete block) 	Plasterboard	12.11	0.12	1.74	1.37	1.21	1.09	1.00
	Wet plaster	11.72	0.15	2.45	1.81	1.53	1.35	1.20
Solid masonry (215mm lightweight aggregate block) 	Plasterboard	11.79	0.08	2.24	2.00	1.9	1.82	1.74
	Wet plaster	11.6	0.11	3.7	3.14	2.87	2.65	2.46
Concrete sandwich panel (125mm internal concrete – precast or in-situ) 	Plasterboard	9.62	0.11	2.68	2.59	2.48	2.35	2.21
	Wet plaster	9.11	0.21	5.3	4.85	4.3	3.78	3.32

Effective slab depth in commercial buildings

As the building fabric becomes an increasingly important aspect of low energy design, floor slabs are shifting from being purely a structural element to something that contributes to a range of other design issues including aesthetics, daylighting, acoustics and thermal performance. Structural requirements will of course largely determine slab depth, although thermal mass may, to some extent, also be a factor. For a non air-conditioned building, the core of the slab will respond to daily, weekly and monthly average conditions, drawing heat deep into the concrete and making use of most, if not all of the slab (see page 10). In air-conditioned buildings, plant is generally operated on a 24 hour heating/cooling cycle which in turn governs the time available for getting heat in and out of the slab. However, it is still possible to take advantage of a large proportion of the thermal mass in the slab. This is explained below.

Using both sides

In offices with mechanical ventilation, the air supply often comes from floor outlets linked to an underfloor distribution system, where the void created by the raised floor is used to channel air around the space. In addition to reducing the need for ductwork, this approach also allows convective heat transfer between the air and the floor slab. This helps cool the air supply during the day and remove heat from the slab at night. When used in conjunction with an exposed soffit, heat can pass through both the top and bottom surfaces of the slab, increasing the overall depth of concrete in which the thermal mass can be accessed.

Enhancing heat flow at the surface

Before heat can enter the slab it must first pass through its surface, which acts as the main bottle-neck to heat flow due to a film of air (boundary layer) that covers it. This boundary layer provides a greater resistance to heat flow than the concrete itself. However, in buildings with mechanical underfloor ventilation, the system can be designed to ensure some turbulence as the air passes over the slab, which greatly reduces surface resistance and can enhance heat transfer by a factor of up to 5 [23, 24]. This allows thermal mass to be exploited at greater slab depths than would otherwise be possible. Turbulent air is also a feature of systems that use the cores in hollowcore precast concrete floor slabs to channel the supply air (e.g Termodeck®), ensuring good heat transfer particularly at bends where the change of direction increases turbulence.

Profiled soffits

In addition to reducing the weight of larger spans, profiled slab soffits (e.g. coffered, troughed, wave form etc.) provide an increase in surface area which improves convective heat transfer with the slab, allowing greater use of the thermal mass.

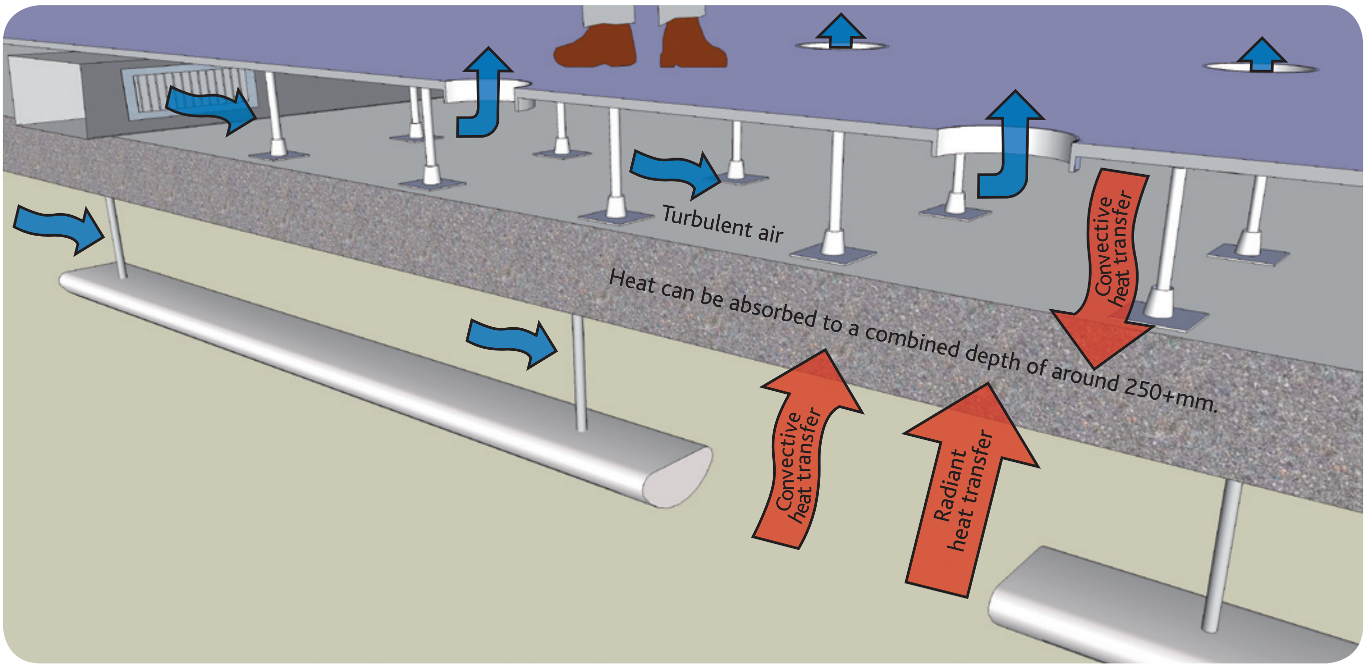


Figure 9: Combining an exposed soffit with optimised underfloor ventilation can enable thermal mass to be reached at a total slab depth of around 250mm or more.

What are decrement factors and decrement delay?

Like U-values and admittance, decrement is a term that represents a specific characteristic of construction materials, and is related to thermal mass. It describes the way in which the density, heat capacity and thermal conductivity of a wall for example, can slow the passage of heat from one side to the other (decrement delay), and also attenuate those gains as they pass through it (decrement factor).

Decrement delay

Designing for a long decrement delay of around 10 to 12 hours will ensure that during the summer, peak heat gains passing from the outer to inner surface will not get through until late evening/night, when the risk of overheating has moderated, and the relatively cool night air can offset the effect of a warmer surface. Shorter periods can still be helpful but effectiveness reduces with decreasing delay, and a value of less than around six hours is of limited benefit.

Medium and heavyweight walls insulated to current standards will slow the passage of heat by around 9 to 12 hours (see Figure 8), which provides an optimal level of decrement delay. Lighter-weight construction typically provides a shorter period ranging from just a few hours up to around 7 or 8 hours (usually in walls with a masonry outer leaf).

Decrement factors

As well as delaying heat flow on summer days, the thermal characteristics of a wall or roof construction will also determine the amount of heat that gets through. This is represented by the decrement factor, which is basically the ratio between the cyclical temperature on the inside surface compared to the outside surface. For example, a wall with a decrement factor of 0.5 which experiences a 20 degree daily variation in temperature on the outside surface, would experience a 10 degree variation on the inside surface. So, to minimise the solar gains that pass through the fabric, low values are best. Medium and heavyweight walls insulated to current standards have a low decrement factor of around 0.3 to 0.1 (see Figure 8). Using the previous example, a decrement factor of 0.1 would cause the inside surface temperature to vary by only two degrees over the day. For lightweight walls, the decrement factor will typically be in the order of 0.5 to 0.8, with the lower end of this range often found in walls with a masonry outer leaf.

Heat gains through windows and from internal sources

In well insulated lightweight construction the risk of overheating can be more acute, since the balance of heat flows is much finer and only a small excess of heat gain over loss can cause overheating [25]. So, the decrement factor and delay are particularly important, and it is possible to enhance these by using cellulose (wood-based) insulation, which has a relatively high heat capacity and density compared to most other forms of insulation. However, for all types of building, delaying and reducing gains passing through the fabric is only part of the solution, as instantaneous heat gains through windows and from internal sources must still be managed. In addition to good shading and ventilation, the impact of these gains will be reduced through the presence of internal thermal mass to help soak them up (see Figure 10 and page 5), which is a key benefit of medium and heavyweight construction.

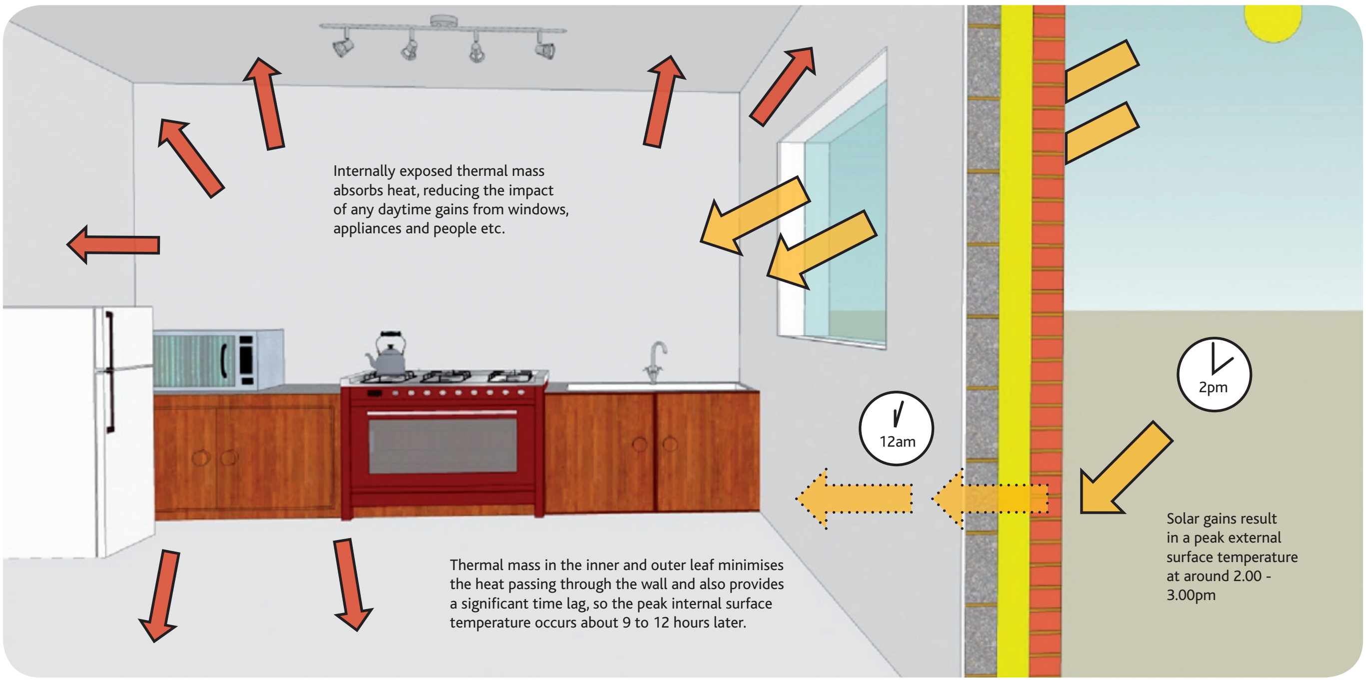


Figure 10: On hot days, the internal thermal mass of a concrete/masonry wall helps counter the effects of heat gains from windows and internal sources. At the same time, the overall mass of the wall reduces and slows external heat gains passing through it, helping ensure they do not occur until late evening/night when the risk of overheating has moderated.

What are mass enhanced U-values?

U-values indicate the rate of heat flow through a construction element for a given difference between internal and external temperature, which is assumed to be constant, i.e. steady state. Generally this will give a good indication of the insulating properties of a wall, roof or floor, but can be less accurate in climates where the outdoor temperature may cycle above and below the internal temperature over a 24 hour period. In this situation, the actual heat loss of a heavyweight external wall can be less than its U-value would suggest. The reason for this is because the heat flow through the wall is not constant (steady-state), nor is it only in one direction i.e. from inside to outside. The direction will in fact change each time the external temperature cycles above or below the internal temperature. In this situation the performance of the wall is no longer simply a question of how much insulation it contains, but is also influenced by its level of thermal mass; at night, when the temperature drops, heat begins to flow through the wall to the outside. But the presence of thermal mass will slow this process (decrement delay) and, the following day when the temperature outside becomes greater than that inside, the direction of heat flow is reversed allowing some of the heat retained by the thermal mass to flow back into the room.

This mass enhanced effect is real and a heavyweight wall can thermally outperform a lightweight wall with the same steady-state U-value. However, the effect is only significant when the outdoor temperature cycles above and below the indoor temperature in a 24 hour period [26]. An investigation looking into the significance of mass enhanced U-values in the UK climate is currently underway at the National Physical Laboratory (NPL) in Teddington. Please contact The Concrete Centre for more information.

Part L of the Building Regulations and the Code for Sustainable Homes

For buildings other than dwellings, Part L of the Building Regulations (Conservation of Heat and Power) takes into account the effects of thermal mass. However, for dwellings the calculation methodology (known as SAP) used to evaluate Part L compliance assumes a fixed, comparatively low level of thermal mass for all types of construction. This assumption is currently being evaluated as part of the revision process that Part L is undergoing during 2009. Initial feedback suggests that thermal mass will be more accurately accounted for in the methodology. In support of this are draft changes to the Energy Performance of Buildings Directive (EPBD) which, in contrast to the current edition, would explicitly require national calculation methodologies such as SAP to take account of thermal capacity and passive solar systems. As a consequence of these changes, the revised edition of Part L1 for dwellings, which will be introduced in 2010, is likely to offer more incentive to optimise building form, fabric and orientation as a low cost design measure for reducing CO_2 emissions.

Enhanced Part L compliance will give additional points in the Code for Sustainable Homes, but perhaps less apparent are the indirect Code points that thermal mass may help to score. This relates to the potential for an increase in window area for enhanced daylighting, without increasing the risk of summertime overheating to an unacceptable level. Solutions that provide thermal mass are also more likely to offer high levels of flood resilience, security and air tightness.

Summary

Performance requirements for building materials continue to increase, driven by a need to design for higher levels of energy efficiency and other factors such as the effects of climate change. Meeting these challenges requires a whole-building approach to design in which the materials, structure and systems work in unison to maximise overall performance. The thermal mass in concrete meets this challenge. It can both improve energy efficiency in summer and winter, whilst also providing a degree of adaptation to our warming climate.

Realising these benefits is not difficult, but does require a basic appreciation of how to use thermal mass, and the way it can work with orientation, solar gain, ventilation and shading to enhance thermal performance in a passive way.

This simple guide touches on the basic principles of designing with thermal mass, and explains its dynamic properties, which in addition to absorbing internal heat gains, also delays and reduces the effect of external gains as they pass through the building fabric.

The challenging performance targets for new buildings are more easily and cost effectively met with materials that perform multiple functions. In this respect, concrete has a good deal to offer as it can help meet requirements for acoustic separation, fire resistance, flood resilience, durability and of course, enhanced thermal performance.

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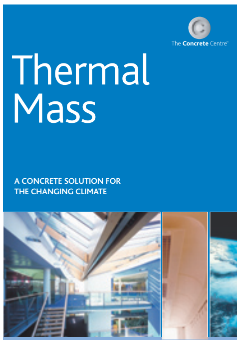
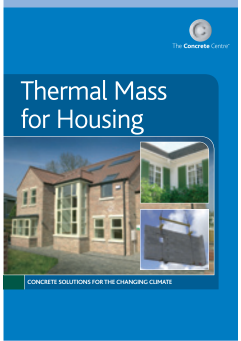


Thermal Mass

Our climate is already changing and will continue to change significantly within the lifetime of buildings designed today. This publication provides a general guide to understanding thermal mass and fabric energy storage (FES). It outlines the application of FES techniques using cast in-situ and precast concrete floor slabs in non-domestic buildings and gives readers full references to facilitate further reading.

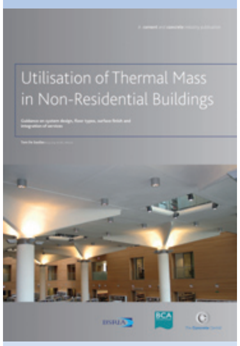
- Publication date: 2005
- Ref: TCC/05/05
- Free – PDF download available



Thermal Mass for Housing

This guide provides information on the simple, passive design techniques that can be applied in masonry and concrete dwellings to take advantage of their inherent thermal mass on a year-round basis. Reading this document, it will quickly become apparent that the design of a typical house needs very little alteration to reap this benefit, and that there are negligible capital cost implications.

- Publication date: 2006
- Ref: TCC/04/05
- Free – PDF download available



Utilisation of Thermal Mass in Non-Residential Buildings

This guide provides detailed guidance on the use of thermal mass as a sustainable method of cooling which avoids or reduces the need for air conditioning. This publication will assist designers wishing to exploit thermal mass and includes chapters on concrete floor options, integration of services, acoustic considerations and surface finish options. The guide also includes a number of case studies.

- Publication date: 2007
- Ref: CCIP-020
- Price: £45

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