STEEL CONSTRUCTION
Thermal Mass

TATA STEEL

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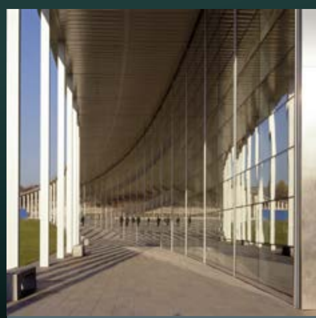



Tata Steel and the British Constructional Steelwork Association (BCSA) have worked closely together for many years to promote the effective use of structural steelwork. This collaborative effort ensures that advances in the knowledge of the constructional use of steel are shared with construction professionals.

Steel is, by some margin, the most popular framing material for multi-storey buildings in the UK and has a long track record of delivering high quality and cost-effective structures with proven sustainability benefits. Steel can be naturally recycled and re-used continuously, and offers a wide range of additional advantages such as health and safety benefits, speed of construction, quality, efficiency, innovation, offsite manufacture and service and support.

The steel sector is renowned for keeping specifiers abreast of the latest advances in areas such as fire protection of structural steelwork and achieving buildings with the highest sustainability ratings. Recent publications have provided detailed guidance on Fire Protection, CE Marking and Cost and what it means for the construction sector. Guidance is provided on all relevant technical developments as quickly as is possible.

The sector's go to resource website – *www.steelconstruction.info* - is a free online encyclopedia for UK construction that shares a wealth of up-to-date, reliable information with the construction industry in one easily accessible place.

TATA STEEL

Tata Steel in Europe
The European operations of Tata Steel comprise Europe's second largest steel producer. With the main steelmaking operations in the UK and Netherlands, they supply steel and related services to the construction, automotive, packaging, lifting and excavating, energy and power, aerospace and other demanding markets worldwide. The combined Tata Steel group is one of the world's largest steel producers, with an aggregate crude steel capacity of more than 28 million tonnes and approximately 80,000 employees across four continents.

BCSA

British Constructional Steelwork Association
BCSA is the national organisation for the steel construction industry: its Member companies undertake the design, fabrication and erection of steelwork for all forms of construction in building and civil engineering. Associate Members are those principal companies involved in the direct supply to all or some Members of components, materials or products. Corporate Members are clients, professional offices, educational establishments etc which support the development of national specifications, quality, fabrication and erection techniques, overall industry efficiency and good practice.

SCI Steel Knowledge

Steel Construction Institute
SCI (the Steel Construction Institute) has been a trusted, independent source of information and engineering expertise globally for 25 years, and remains the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. We support everyone involved in steel construction; from manufacturers, consulting and design engineers, architects, product managers, commercial directors right through to industry groups and peers.

This guide was written by the SCI for Tata Steel and the British Constructional Steelwork Association.

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Photo courtesy of SCI-Tech Daresbury

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Introduction

Thermal mass describes the ability of the fabric of a building to absorb and store heat. Used effectively, it can reduce cooling loads and, in some cases, remove the requirement to provide air conditioning. In most multi-storey buildings, the thermal mass is provided by the concrete in the upper floor slabs.

This guide is an introduction to the use of thermal mass to reduce operational energy use in non-domestic buildings in the UK. It describes thermal mass and explains how it can be used as part of a fabric energy storage (FES) strategy to achieve sustainable, energy efficient buildings.

It dispels the myth that thermal mass is only effective in heavyweight buildings with thick concrete floors and demonstrates that fabric energy storage strategies are equally effective in structurally efficient, steel-framed buildings.

Thermal mass is not a universal panacea however and FES strategies are not appropriate in all buildings. Location, form, orientation, occupancy patterns and servicing strategy can all preclude a natural or mixed-mode ventilation strategy and therefore limit the viability of a fabric energy storage solution.

Effective thermal mass solutions can be achieved with any material

www.steelconstruction.info

Article of interest:

• THERMAL MASS

What is thermal mass and how does it work?

Thermal mass describes the ability of materials within the fabric of a building to absorb, store and release heat energy and reduce the energy normally required for cooling. In non-domestic buildings thermal mass is used, together with an appropriate ventilation strategy, to cool the building without the need for air conditioning or as part of a mixed-mode strategy.

Effective thermal mass solutions can be achieved with any material selected for the structural frame as typically, only the concrete in the upper floor slabs is used to provide the thermal mass.

In FES strategies, thermal mass is utilised with a ventilation and/or cooling strategy so that heat is absorbed during the day, helping to maintain thermal comfort and prevent overheating during normal working hours. Peak internal temperatures are reduced and the peak is delayed. This delay can be particularly useful in intermittently occupied buildings such as offices and schools. This concept is shown graphically in Figure 1.

Figure 1 The effects of thermal mass on internal temperatures.

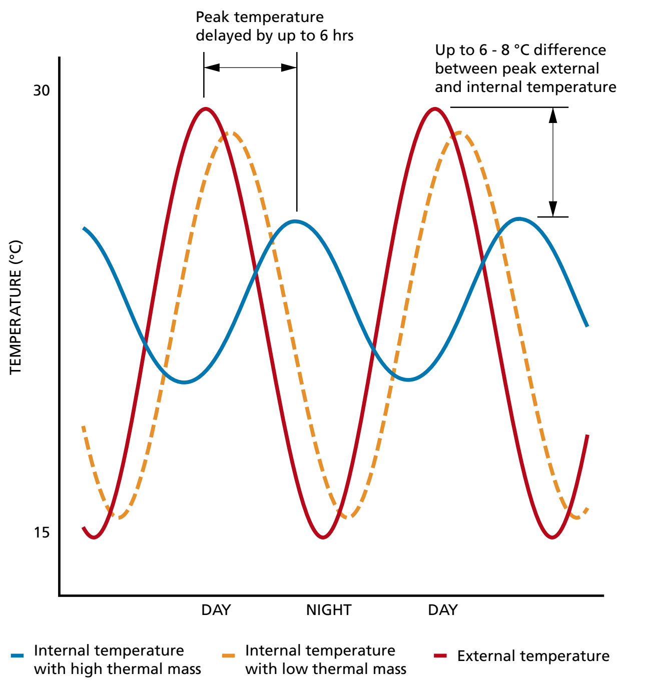
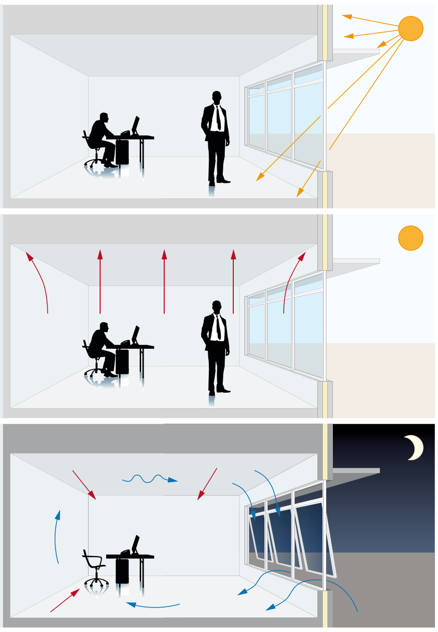


Figure 2 How thermal mass strategies work.



During the day, heat is produced in the building from solar gains, human activity and electrical equipment.

The warm air rises and is absorbed by the thermal mass in the exposed surfaces of the walls and upper floors.

At night, cool air ventilates the building, purging heat from the fabric.

This process is repeated on a diurnal or daily basis during hot weather.

At night, when the external air temperature drops, natural ventilation is used to 'purge' the stored heat energy from the building fabric so that the process can be repeated the following day. The daily variation in temperature is rarely less than 5°C in the UK, making night cooling a relatively effective way of removing the heat. Alternatively, or in addition to night purging, active measures such as mechanical ventilation and water cooling may be used.

The 'accessibility' of the thermal mass is crucial, i.e. the mass must be exposed so that heat energy can be easily exchanged with the enclosed space. In the case of walls, dry lining impedes the flow of heat into the wall and for upper floors, suspended ceilings, raised floors and floor coverings effectively isolate the thermal mass of the building and undermine an effective FES strategy.

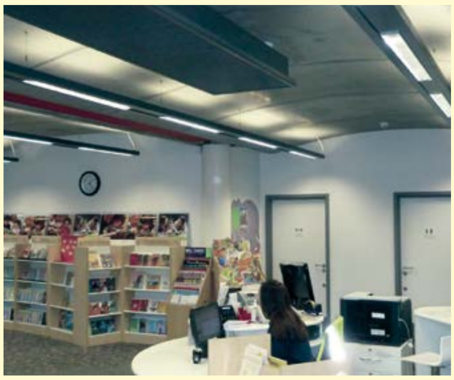
Woolwich Civic Centre, London

This six-storey steel-framed office building has strong green credentials and, through a combination of renewable energy, mixed-mode ventilation, extensive use of thermal mass and a sophisticated building management system, it has been possible to reduce carbon emissions by around 50% compared to current national standards for offices.

The frame comprises fabricated steel beams that support exposed, precast concrete barrel-vaults on their bottom flanges. Openings in the webs of the beams allow services to be distributed in the plenum above the concrete floor units.

The building's mixed-mode ventilation strategy utilises the external glazed façade to naturally ventilate the building. When necessary, extra convection cooling is provided by passive chilled beams that hang inside the curve of each vault, while a displacement ventilation system on each floor provides space heating/comfort cooling.

The building has a BREEAM 'Excellent' rating



Photos courtesy of Mott MacDonald

Cheshire Police HQ, Blacon

Mott MacDonald and Fairhurst were commissioned by Cheshire Police to design its new 2,800m^2 headquarters in Blacon, Cheshire. Sustainability and energy efficiency were key areas for this project along with cost and the need for a quick delivery.

The team opted for a steel-framed solution, rather than concrete, due to the relative cost and time savings the material offered.

The steel-framed building was designed to exploit thermal mass, providing "inertia" against temperature fluctuations.

Mott MacDonald technical director Edward Murphy, says: "Thermal mass can, if designed correctly, be just as effective within an exposed hollow floor deck, steel frame building as it can within a concrete frame.

"In this instance we chose to use steel with hollow floor deck because of the cost and time efficiencies that it offered."

As a result of using a steel frame, approximately 5% was saved on the cost of the frame and the job was completed four weeks earlier than would otherwise have been expected.

Shires House, Guiseley, Leeds

Occupied by the architects that designed it, Shires House is a three-storey office building on the outskirts of Leeds. The building has a steel frame supporting composite metal decking and structural concrete. The upper floor soffits are exposed.

The building is naturally ventilated and heated and cooled using a ground source heat pump which is coupled to a network of pipes embedded in the concrete in the ground and upper floor slabs.

Photos courtesy of Watson Batty

How much thermal mass is required?

Maximum thickness of concrete available for thermal mass is 75-100mm

BRE, the Concrete Centre and CIBSE all acknowledge that, based on a 24-hour cycle of heating and cooling, heat energy can only penetrate up to around 100mm into the exposed building element and conclude that designing thicker floors specifically to utilise thermal mass offers little benefit.

The most commonly used parameter for assessing the potential thermal mass of building elements is admittance which can be defined as the ability of a building element to exchange heat with a space when it is subject to cyclical variations in temperature. Reflecting the daily or diurnal temperature variation experienced in the UK, on which naturally ventilated FES strategies are dependent, this cycle is taken as 24 hours.

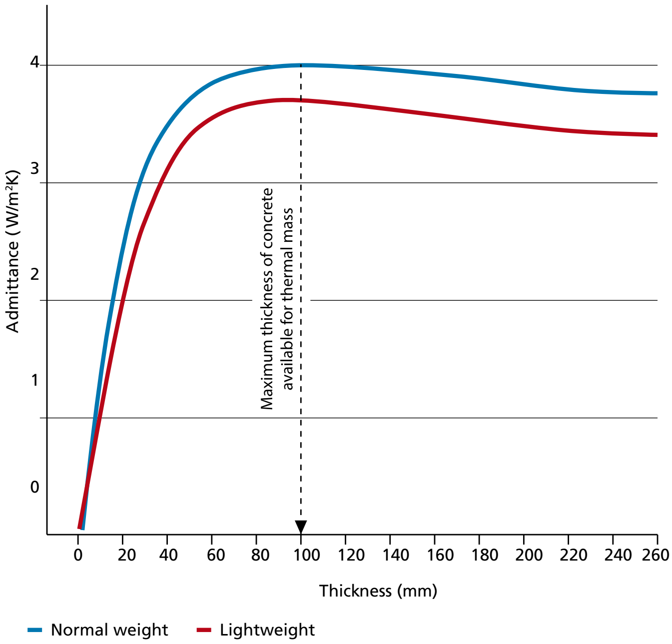
The admittance of a building element is a function of its thermal capacity, thermal conductivity, density and surface resistance. It is also a function of the depth of the material absorbing the heat and its surface resistance.

Figure 3 shows the variation in admittance with increasing depth for normal and lightweight concrete. It shows that, in a naturally ventilated building, the maximum value of admittance for a concrete slab exposed on one side is achieved with only 75-100mm of concrete.

In multi-storey buildings the upper floors are the most important element providing the greatest ‘accessible’ thermal mass. Whether the building is steel or concrete framed, the upper floors are generally concrete, either cast in-situ or precast and therefore utilising the thermal mass in the upper floors does not restrict the choice of framing material.

All of the standard floor types used in steel-framed buildings (see Figure 4) can form the basis of an effective passive or active FES system since their floor slabs are thicker than 100mm. Therefore the benefits of standard steel construction such as recyclability, speed of construction, long spans, flexibility in use, cost effectiveness, etc. can still be realised in buildings requiring a thermal mass cooling strategy.

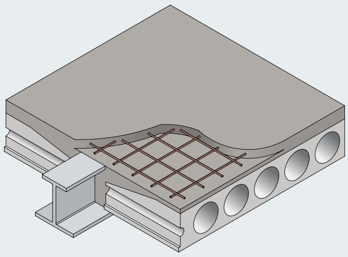
Figure 3: Thermal admittance against thickness for an exposed, flat concrete floor slab – 24 hour diurnal cycle.



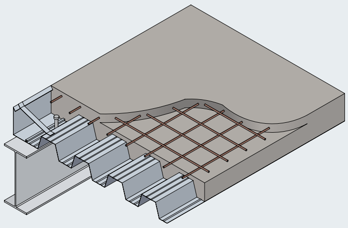
The new building was designed to meet high environmental standards and achieve a BREEAM ‘Very Good’ rating

Figure 4: Commonly used floor types in steel-framed buildings.

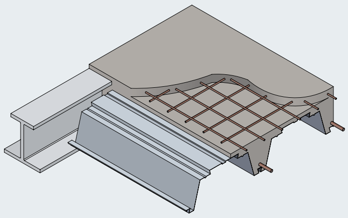
Precast concrete units. The units, which are normally prestressed, may be solid (flat or coffered) or hollow-core. Units can be supported on the top flanges of beams or on the bottom flanges of Asymmetric Slimflor Beams (ASBs). This will be designed compositely or non-compositely with the beam.



Composite slabs, comprising reinforced concrete cast on profiled steel decking. The decking may be supported on the top flange of downstand beams or on the lower flange – see shallow floor option below.



Shallow floors. A range of different shallow floor systems is available. In the UK, the proprietary Slimdek system is common and comprises composite Asymmetric Slimflor Beams (ASBs) supporting deep profiled metal decking.



Concrete in floor slabs of all steel-framed buildings will be greater than 100mm thick

St John's Square, Seaham

Part of the St John's Square redevelopment, this four-storey office building houses a public library and offices for Durham County Council.

The building has a steel frame which supports composite metal decking and concrete floor slabs.

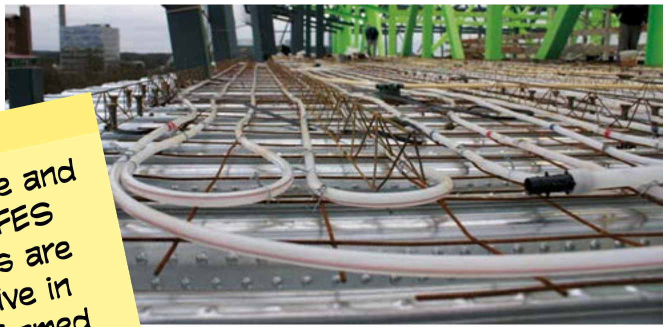
It is divided by a full height glazed atrium which promotes natural ventilation and allows natural light into the core of the building.

Natural ventilation to the building is achieved by a series of stacks which penetrate the metal decking and floor slabs culminating at rooftop level in louvred boxes. On the top floor of the building, roof lights also aid the ventilation.

In parts of the building, acoustic suspended ceiling panels were installed to improve the acoustic environment for those working in and using the building.

Photos courtesy of Ecophon.

Thermal mass as part of a wider cooling strategy


Water-cooled composite steel floors during construction

All passive and active FES systems are effective in steel-framed buildings

FES systems are generally described as either passive or active systems. All FES systems can be utilised effectively in steel-framed buildings.

Passive FES systems

Passive FES systems rely on natural ventilation to disperse the heat absorbed by the upper floor slabs. As they are dependent on wind direction and speed, they are only suitable for buildings with relatively simple requirements and low cooling loads (up to 30 W/m^2). They are easy to operate, with low capital, maintenance and operation costs.

Natural ventilation can be achieved from one side only, by cross ventilation or by stack ventilation, generally using atria. The control of the ventilation is fundamental to the optimum operation of passive FES systems.

Active FES systems

In active FES systems, the heat exchange with the structure is enhanced by mechanical ventilation, either within the core of the slab or over its surface. In practice, the methods used in the UK are mixed-mode systems combining natural and mechanical ventilation, with natural ventilation being the default mode to minimise energy consumption.

Common 'active' FES systems include:

Underfloor ventilation with exposed soffits. In this solution, the underfloor void is used as a supply plenum, allowing good heat interchange with the floor slab. When used in conjunction with exposed soffits, thermal linking on both sides of the slabs is enabled.

Exposed hollowcore slabs with mechanical ventilation. In this system, the heat exchange between the floor soffit and the occupied space is supplemented by low velocity air passage within the hollow slabs.

Water cooled slabs. In this system, heat transfer is achieved by water circulating in pipes embedded within the floor slabs. Condensation is avoided by using water at between 14-20°C and therefore water from sources such as rivers, lakes, boreholes, etc, can be used. Alternatively, the water can be chilled mechanically. The system can also be used in heating mode by circulating water at between 25-40°C.

Vanguard House, Daresbury

Vanguard House is a 3,600m^2 three-storey office and laboratory building on the Daresbury Science & Innovation Campus. The building has a steel frame which supports exposed, precast concrete hollow core slabs which incorporate an active cooling strategy.

The building is designed to use a combination of passive design and geo-thermal technologies, which include heating and cooling from a ground source heat pump which extracts constant cool water from a 120m deep borehole. The water is used to cool the building or, when necessary, to heat it via a heat pump.

Heating and cooling is delivered to the tenants' offices and laboratories by use of an active system which comprises a network of plastic piping embedded in the lower section of the precast hollow core planks.


Vanguard House achieved a BREEAM 'Excellent' rating

Photo courtesy of Sci-Tech Daresbury.

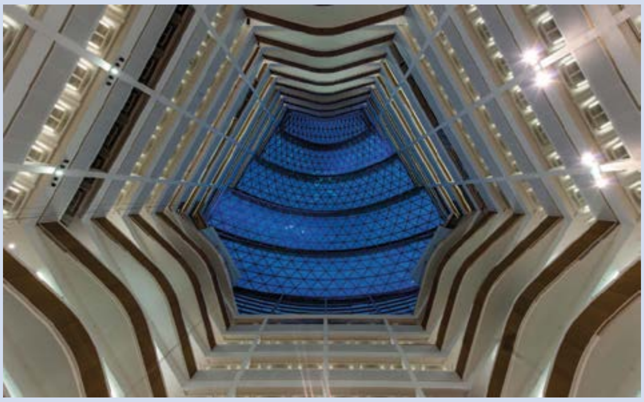
The Co-operative Group Headquarters, Manchester

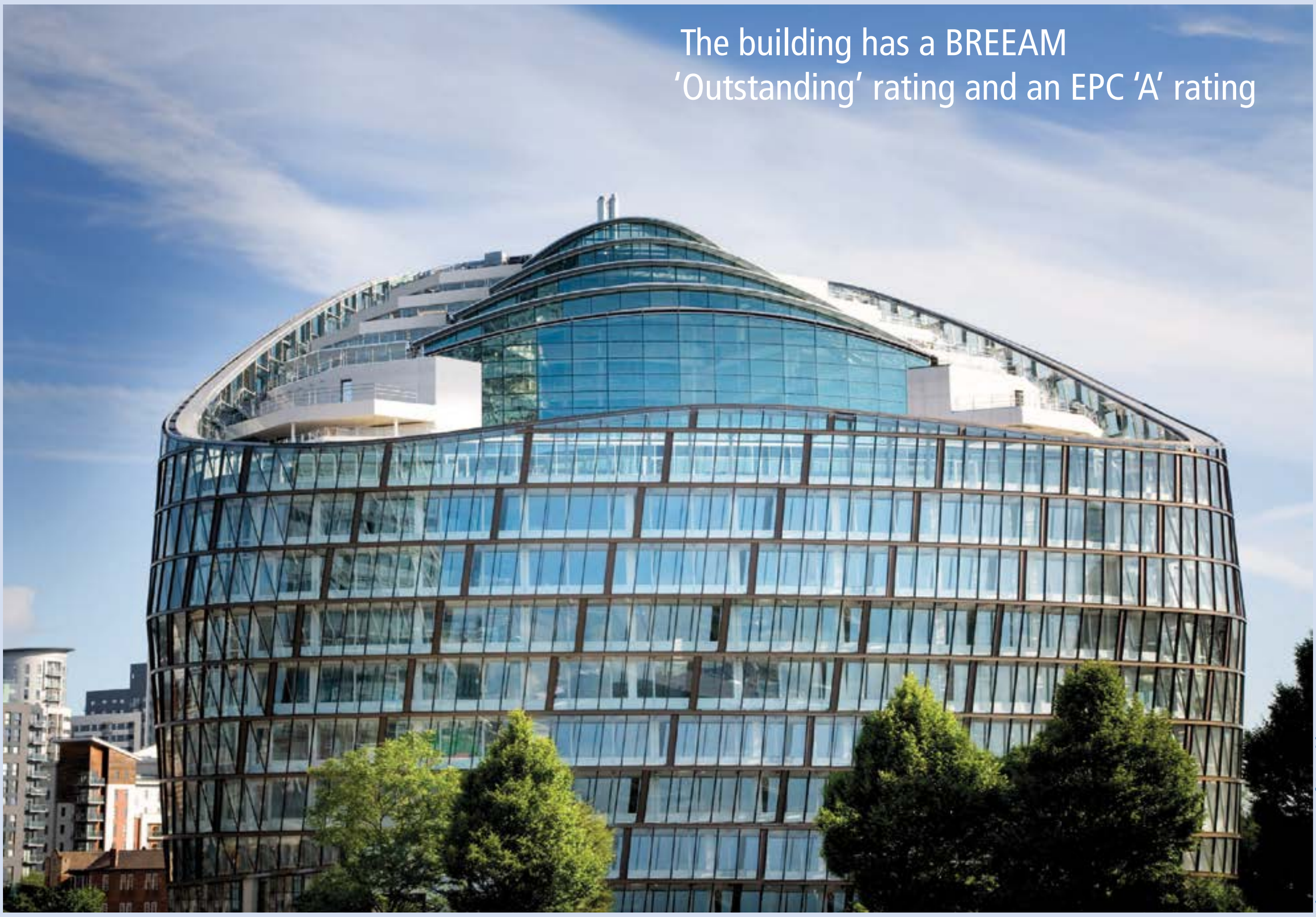
Triangular in plan, this 16-storey, deep plan building is centred around a soaring atrium which extends from the ground floor to roof level. The building has a glazed double-skin façade.

16.5m long fabricated steel beams provide large, column-free, flexible floor plates. The beams support exposed precast concrete coffer units that are notched to sit on the bottom flanges of the beams.

A natural ventilation system draws fresh air into the building through three large earth tubes which act as earth-to-air heat exchangers. A passive stack system then distributes the air through the building via displacement vents.

The concrete soffits have been left exposed maximising the thermal mass and a night cooling strategy reduces supplementary cooling alongside both annual and peak demand.





Photos courtesy of 3DReid

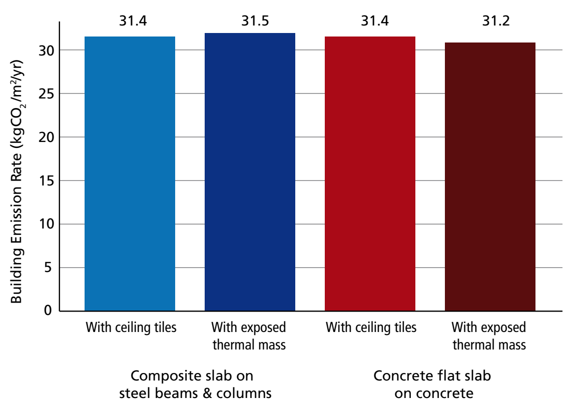
When and where to use Thermal Mass

A thermal mass strategy is no panacea and is not suitable for all building types and forms, or in all locations. In particular, factors that preclude a natural or mixed-mode ventilation strategy can be important in the decision to choose a FES strategy.

In many commercial buildings, air conditioning will be a requirement of the developer, building owner or tenant. Where this is the case, a thermal mass solution will have negligible impact on overall energy consumption.

Under the Target Zero programme, the operational carbon performance of One Kingdom Street, a 10-storey office building in central London, was modelled by AECOM. Equivalent lightweight (steel) and heavyweight (concrete) structures were modelled both with and without suspended ceilings. Despite the heavyweight structure being more than twice as heavy as the lightweight structure, dynamic thermal modelling showed less than a 1% variation in the predicted annual operational carbon emissions, see Figure 5.

Figure 5: Building emission rates (BER) for lightweight (steel) and heavy weight (concrete) structural options.



This confirms the findings from other studies that show that operational carbon emissions for buildings are independent of the framing material and dispels the myth that heavyweight buildings provide superior thermal mass performance.

The modelling results showed that when the ceiling tiles were removed to expose the floor soffits, the additional thermal mass benefit was negated by the increased internal volume that required additional heating and cooling.

When considering a FES strategy important factors to consider include:

Location – air quality, external noise and security issues, particularly in city centres, often preclude a natural ventilation strategy.

Occupancy – thermal mass strategies are best suited to buildings with intermittent occupancy patterns such as offices and schools, which enable night cooling to take place outside normal working hours. Buildings which are permanently occupied, such as hospitals, are less suitable.

Building form – natural cross-ventilation is only effective in narrow plan buildings. In deeper plan buildings atria can be used to provide natural ventilation. Ventilating highly compartmented buildings naturally is difficult and this can preclude effective thermal mass strategies in buildings such as hospitals, hotels and some schools.

Thermal mass should not be considered as a 'stand alone' solution; simply exposing the upper floor soffits in a
building is unlikely to be effective. To work well, thermal mass needs to be integrated into an holistic building design which considers:

- Orientation of the building to optimise natural ventilation, day lighting and solar gains
- Fenestration – both in terms of location and area of glazing and its material properties
- Shading (both internal and external) to control and limit solar gains
- Limiting internal heat gains
- Servicing strategy – particularly the ventilation strategy.

Each building is bespoke and therefore a detailed assessment is required to establish the suitability of using and optimising a FES strategy.

Birmingham City Council, Woodcock Street Offices

Birmingham City Council's award winning office development provides a flexible working environment for 3,000 employees over five floors. Open-plan office floor plates are provided in three four-storey wings of accommodation focused around four atria with interconnecting office floor space bridges between the wings.

A steel-framed solution was the only option able to achieve the challenging programme set for the project. The structure comprises predominantly cellular steel beams supporting 200mm thick hollow core concrete planks.

The building is naturally ventilated and has an adaptive cooling system using the thermal mass of the structure to moderate temperatures without mechanical cooling.

The building has a BREEAM 'Excellent' rating

Photo (right) courtesy of Associated Architects. Copyright Martine Hamilton Knight

Isaac Newton Academy, Ilford

The Isaac Newton Academy in Ilford, east London, is a 1,250 pupil school specialising in maths and music.

The Academy comprises two major elements, the main four-storey school building and the sports facility that projects 56m out of the school building and over the car park. As on many educational projects, a primary steel structure was chosen for speed, long spans and structural continuity within the main building.

In the main school building, the steel frame comprises asymmetric beams which support exposed, precast, 200mm thick concrete floor slabs that sit on the wider bottom flange of the beam within the 300mm slab depth.

By ‘floating’ the sports facility over the car park, it was possible to provide courtyards, roof gardens and light wells in the main building to promote the penetration of natural lighting into teaching spaces and to facilitate and enhance natural ventilation.

Photos courtesy of Fielden Clegg Bradley Studios. Copyright Timothy Soar

One Trinity Green, South Shields

One Trinity Green is a managed workspace building in South Shields, offering 2,700m^2 of flexible office, workshop and hybrid units. The building is conceived as three contemporary Victorian warehouses each with a distinctive character.

Each 'warehouse' benefits from exposed structure (for passive cooling), opening windows and a central winter garden (to aid cross ventilation).

Using dynamic thermal modelling, the design team recognised that by using a steel frame and combining it with 300mm hollow concrete floor slabs, they could achieve an optimum FES solution while taking advantage of the flexibility, time and cost advantages that come with using steel.

The exposed soffits are able to absorb heat from the room at times of peak temperature; this is then removed by the introduction of cool night air; reducing the need for mechanical heating and cooling.

The use of thermal mass, in addition to other sustainability features including photovoltaic panels and solar water heating, enabled the project to achieve a BREEAM 'Outstanding' rating and an EPC 'A' rating.

Photos courtesy of +3 Architecture

Other design issues

A well designed FES system has the potential to save carbon and operational costs over the lifetime of the building.

Nevertheless, as most FES systems involve exposing the upper floor soffits, there are other consequential factors that should be considered early in the design process. These include:

- The quality of the soffit finish
- The routing, co-ordination and integration of services
- The acoustic properties of the occupied space - to avoid reverberation and echo, sound-absorbing baffles suspended from the slab may be required.

These factors should be costed and weighed against the likely operational cost savings from implementing a FES strategy.

Achieving an aesthetically pleasing finish to an exposed in-situ concrete floor soffit requires significant care and extra cost. Formwork must be new and complete sections between designated construction joints must be capable of being concreted in a single operation. In addition, formwork must be adequately supported to prevent differential movement and high standards of dimensional tolerance in casting the slabs are required. Also the exposed surfaces must be protected after preparation to retain the specified surface finish. Painting will overcome colour variations in the concrete but will not mask physical imperfections in the surface. It is much easier to achieve a good finish using precast concrete.

Exposing floor soffits for thermal mass has construction impacts that need to be considered

The finished surface of a composite steel deck can be left bare or can be painted. If a coated surface is required, a range of coloured polyester coatings is available which, in addition to improving the appearance, also improves the heat transfer and light reflection properties of the exposed ceiling.

An exposed coated composite steel deck (ComFlor® with Colorcoat FD™25).

Sussex Coast College, Hastings

Photo courtesy of Julian Guffogg

This six-storey steel-framed college building is situated adjacent to the town's railway station and provides 20,000m^2 of new learning space for sixth form students.

Shallow steel beams are used to minimise the depth of the floor void and hollowcore concrete units are supported on plates welded to the bottom flanges of the beams to produce a flat soffit.

Fans blow air through the hollowcore slabs to warm or cool fresh air before it is distributed into room spaces of the building. Controlled by the building's management system, a supply of air passes through holes in the slab very slowly, giving plenty of time for passive heat exchange between the air and the slabs. The entire building wraps around an inner atrium which is glazed at roof level.

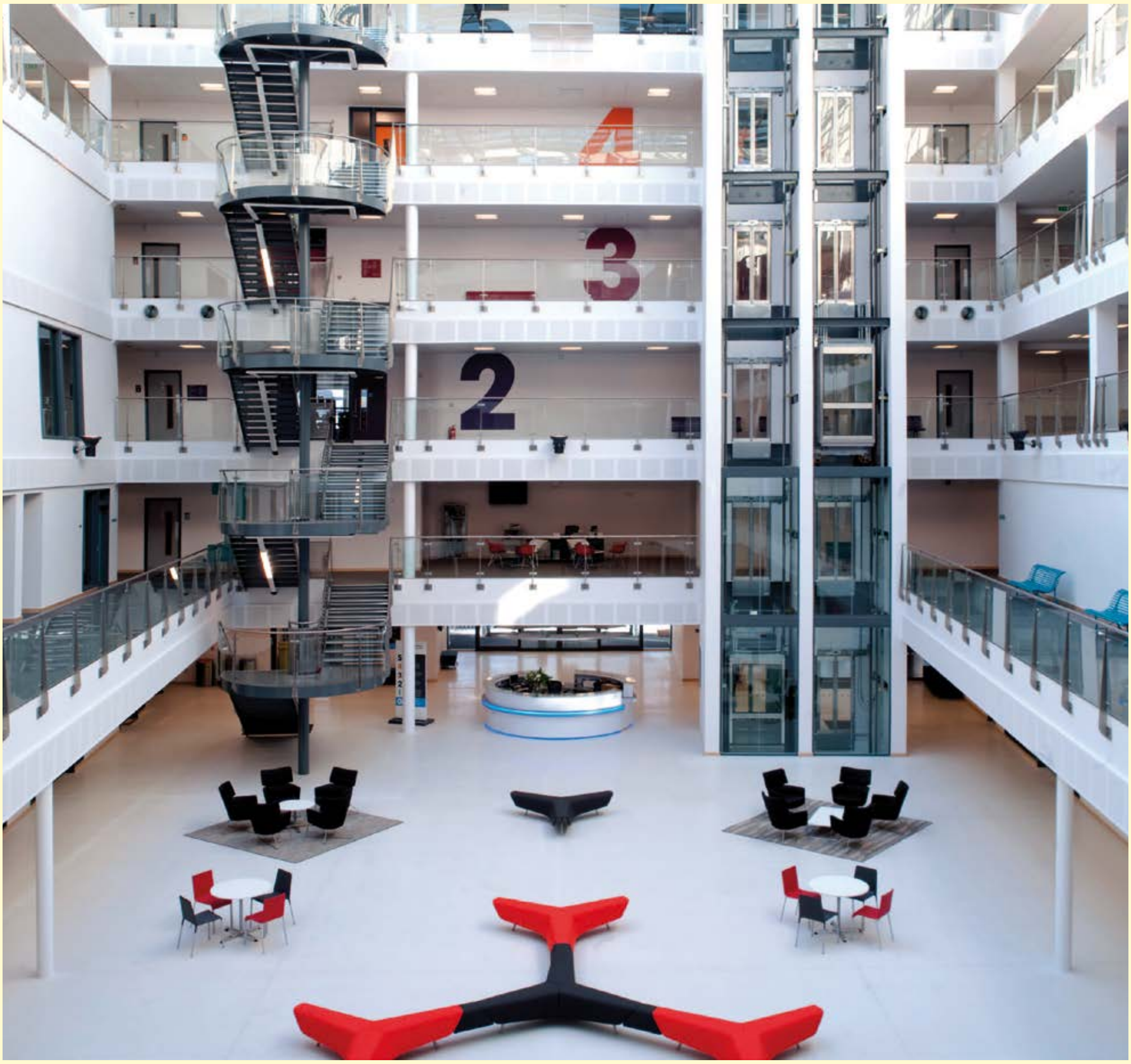


Photo courtesy of Sussex Coast College

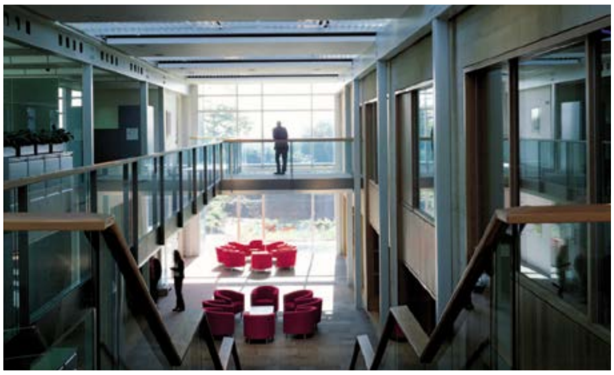
Photo courtesy of Sussex Coast College

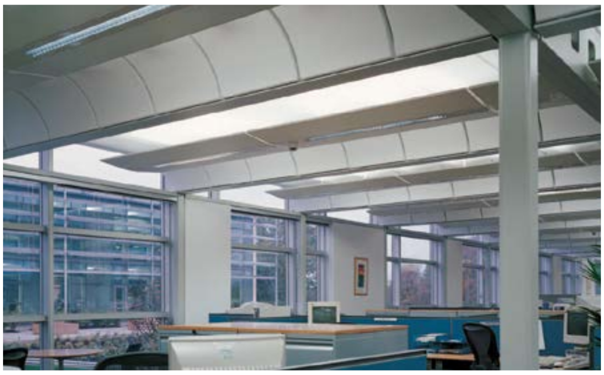
Wessex Water Operations Centre, Bath

Wessex Water is an early example of a steel-framed building specifically designed to be lightweight and resource efficient but also to reduce operational carbon emissions by using a FES strategy.

The steel structure supports slender, curved, precast concrete confers on the bottom flanges of the beams. An in-situ concrete topping ties the units together. This structural solution only uses around half of the concrete of an equivalent in-situ concrete framing solution yet provides the same FES performance.

The 15m wide office wings are naturally (cross) ventilated via high-level windows which are used to provide night-time cooling. To promote heat exchange with the floor soffits, downstand edge beams were eliminated from the design and spine beams were perforated to allow good air movement across the floorplates.





Wessex Water was one of the first office buildings to achieve a BREEAM ‘Excellent’ rating www.steelconstruction.info

Article of interest:

• THERMAL MASS

Many recent steel-framed buildings have benefited from using thermal mass. The following case studies are just some examples of this…


Met Office Headquarters, Exeter


Hauser Forum, University of Cambridge


Bridge Academy Hackney


St Alphege Learning and Teaching Building, University of Winchester


Outwood Academy, Adwick


Failsworth School, Manchester


Devonshire Building, Newcastle University


Houghton Health Centre, Houghton-le-Spring


South Cambridgeshire District Council, Cambourne


Barnsley College


The Business Academy Bexley


Photo courtesy of Capital City Academy

Capital City Academy, London


Arup Campus, Blythe Valley Park, Solihull


Vulcan House, Sheffield


ARK All Saints Academy, London


Oxtalls Campus, University of Gloucestershire

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