STEEL solutions

in association with TATA STEEL BCSA

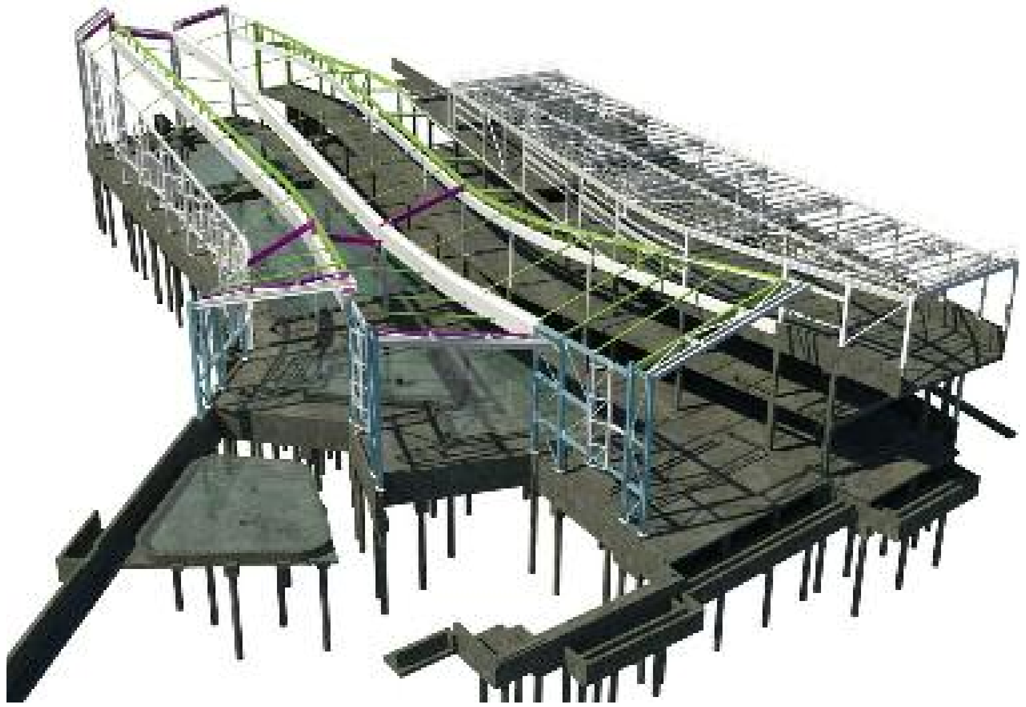
The first of our special features on steel construction, produced with Tata Steel and the British Constructional Steelwork Association, examines projects by Wilkinson Eyre and Arup Associates.

Wilkinson Eyre Splashpoint Leisure Centre Worthing

Splashpoint Leisure Centre by Wilkinson Eyre Architects and engineer AECOM forms the centrepiece of an ambitious seafront regeneration scheme in Worthing, West Sussex. Replacing the town's ageing Aquarena leisure centre, the £17m complex includes a six-lane 25-metre swimming pool, a combined learner/diving pool, indoor leisure pools, a health centre, cafe and creche. The accommodation takes the form of 'ribbons' that flow from north-to-south, maximising the available site and establishing a connection between the land and sea.

Evoking sand dunes, a sinuous roof profile reduces the visual mass of the building and mediates the change in scale from the terraced houses that line the coastal road to the open sea beyond.

Structural spans between the longitudinal ridges widen as the height of the structure increases towards the sea, terminating in a series of glazed facades overlooking the water. "The scheme occupies a prominent location on the seafront, but rather than dominating the site in the style of a grand seaside pavilion, it sits informally, even playfully, within its setting", explains Wilkinson Eyre director and project architect Sebastien Ricard.



Externally, copper and red cedar cladding provide a simple palette of self-finished materials that are intended to age gracefully and require minimal maintenance. Inside, exposed concrete, timber and ceramic tiles provide tactile hard-wearing surfaces.

Structural design

Forming the structural heart of the project is a curving, multi-pitched pool hall with a complex steel frame made by Severfield (UK). Supported by 305x305mm universal steel columns spaced at between 5- and 12-metre centres, the primary roof structure comprises a series of 1.3-metre-deep, asymmetric, double-curved steel plate box girders. The beams span 50 metres longitudinally, allowing uninterrupted views of the diving and competition pools from the spectator galleries above. They also support steel-framed clerestorey glazing that runs the length of the hall.

Lateral bracing between the beams is provided by slender 100mm square hollow sections at 3- to 8-metre centres. A spruce plywood deck is located between the primary beams, presenting a 'clean', uncluttered soffit to the pool and supporting the roof insulation above. An innovative stability system formed from steel struts and moment frames eliminates the need for conventional bracing, which would have visually interrupted the glazed facades. Artificial lighting is fixed to the column casings and walls. A subterranean plenum provides air distribution to the pool hall.

Steel specification

"The use of steel was fundamental to achieving the architectural concept", says structural engineer and AECOM regional director Matthew Palmer. 'Steel not only allowed us to achieve 50-metre clear spans, high-level clerestorey

Top *View from the beach, interior, and gable end (phs: Julian Abrams).*
Above *Site plan.*
Left *Steelwork moment frame model; software employed in the steelwork design included Nemetschek's Scia Engineer and Revit 3D (ph: AECOM).*
Right *Frame construction (ph: AECOM).*

glazing and transparent gables, it also gave a 'lightweight' appearance favoured by the design team. Another advantage is steel's ability to achieve tight construction tolerances. These were essential for the interfaces with the glazing, copper cladding, and timber roofing. The latter was machine-fabricated in Germany and required a 5mm installation tolerance. Last but not least, steel provided the benefits of a reduced on-site programme and the avoidance of wet trades."

Detail design

"The double-curved asymmetric beams are subject to biaxial bending, axial compression and torsion, as the complex geometry gives rise to a range of imbalanced wind and snow loads", explains Matthew Palmer. "Analysis involved first-principle checks, custom spreadsheets, and finally a full non-linear finite element investigation of the entire structure, to accurately predict the forces and movements."

Nemetschek's Scia Engineer software was used to explore and optimise cross-sectional properties, as well as calculate the precambered deflections. A detailed model of the beam constructed as a series of plates was also used to investigate distortional deformations. Movement joints were designed into the clerestorey structure to reduce axial loads posed by Vierendeel action.

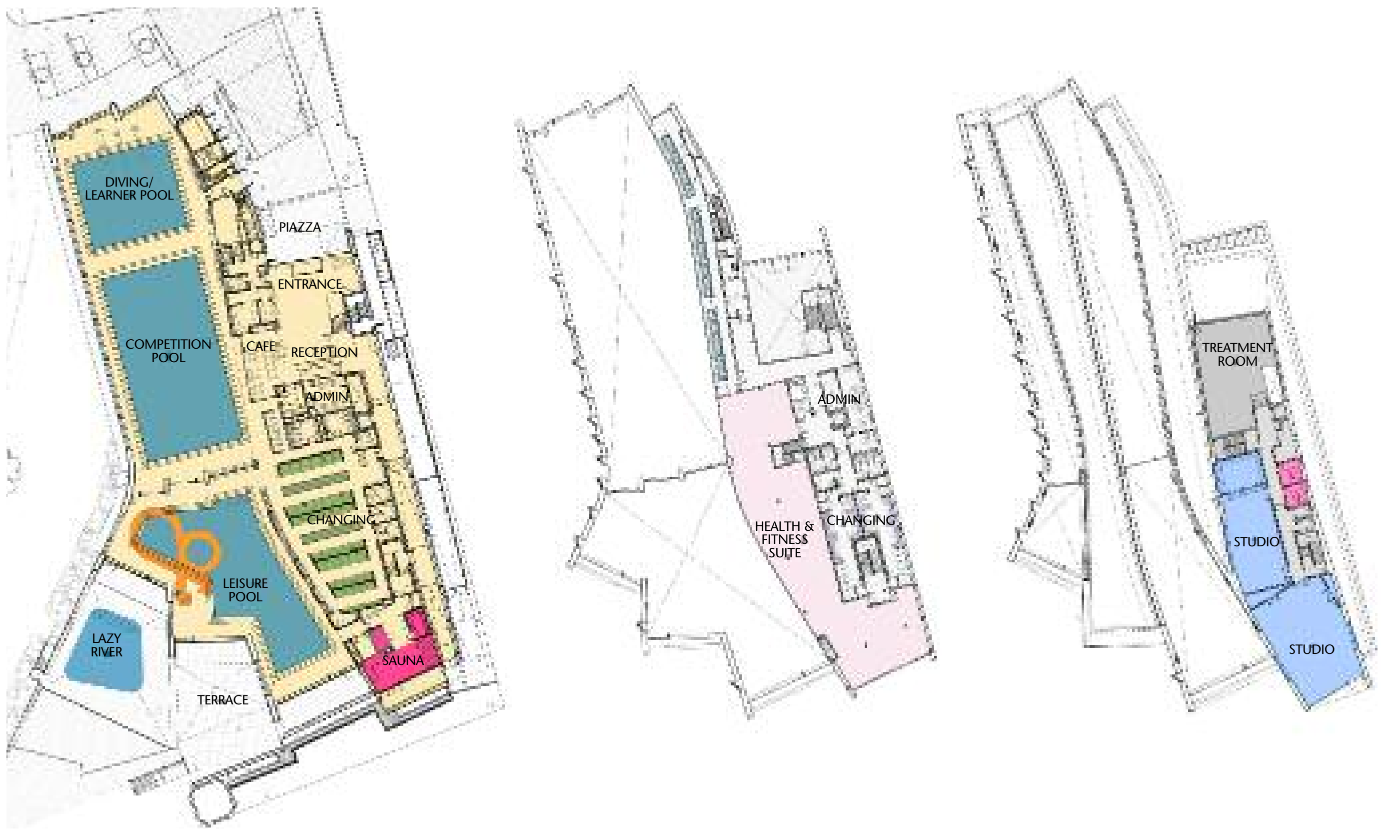
Coordination of the design was undertaken using 3D Revit CAD models, with the architectural, steelwork and timber fabrication models overlaid for early clash detection. This helped to reduce both the overall cost of the project and potential delays on site.

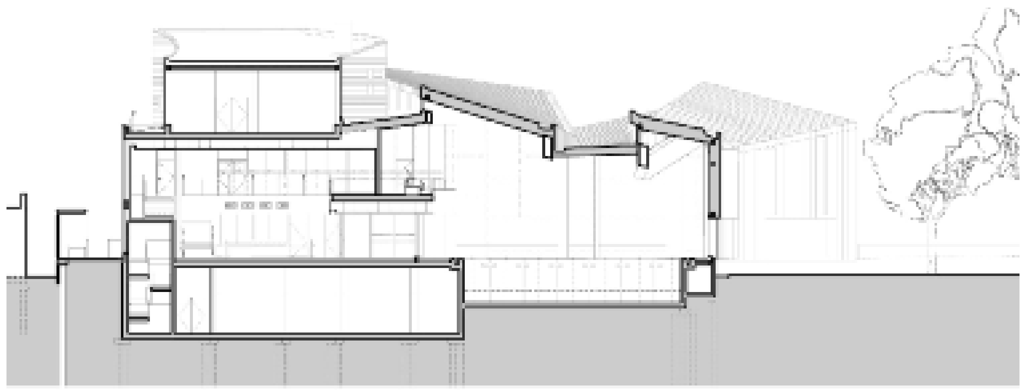
Fabrication

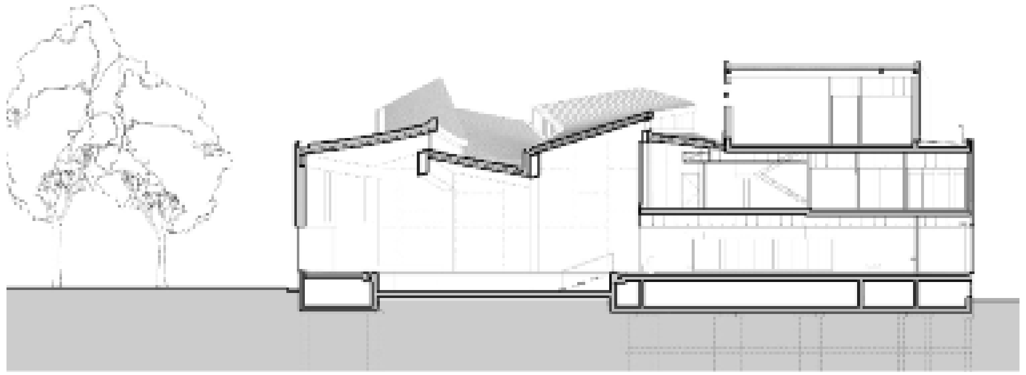
Samples of each of the main beams were fabricated to provide quality benchmarks. Flush-finished shop- and site-welds provide the exposed structure with clean, uninterrupted lines. Thorough geometric checks were made throughout the fabrication process to ensure that the complex geometry was adhered to. Exposed steelwork in the highly corrosive pool environment required a 275μm, three-layer paint system, which is guaranteed for a life-to-first-maintenance of 20 years. Fire protection was not required as the steelwork provides the roof and facade structure only.

Erection

The complex load-paths required a detailed plan for the erection sequence. An 800-tonne crane was used to lift the 50-tonne main spans into place, while a second lighter crane was used to connect the lateral and torsional retraints. Site welding was limited to the midspan of the two primary beams, with bolted splices used elsewhere. This reduced the installation time and improved site safety. High-grade stainless steel fixings were used to support the timber roofing panels. "The fabricated structure was derived directly from the coordinated 3D model and fitted together perfectly on site – an impressive achievement, considering the complexity of the ridges, curves and steps", comments Matthew Palmer.







Top *The steel frame during construction (ph: AECOM); exterior and interior views (phs: Julian Abrams).*
Left *Ground, first and second floor plans; cross sections.*

Project team
Architect: Wilkinson Eyre Architects; structural, civil, m&e engineer, fire, acoustics, transport, access, environmental: AECOM; steelwork contractor: Severfield (UK); main contractor: Morgan Sindall; client: Worthing Borough Council; photos: Julian Abrams.

Arup Associates Engineering & Computing Coventry University

Arup Associates' Engineering & Computing Building (ECB) at Coventry University is a landmark project combining education, industry and research facilities in a single, state-of-the-art building. Rated BREEAM Excellent, the 16,000-square-metre scheme includes an engineering centre with flight simulators and engine test cells, a wind tunnel, workshops, lecture theatres, classrooms, interactive communal spaces and offices.

Intended to represent the duality of science and nature, the plan consists of two interlocking L-shaped structures organised around a landscaped courtyard. The three-storey Nature block to the south employs a simple glass envelope with an extensive green roof. By contrast, the seven-storey Science block to the north has a highly engineered canted facade comprising a lightweight timber frame and aluminium composite cladding panels. Hexagonal windows shaded by projecting aluminium hoods allude to the architects' concept of a 'busy colony'.

Central to the environmental and spatial concept is the Interactive Zone. This is located behind the inclined 'shop window' facade and forms the public and educational heart of the building. Structured using an expressive steel frame, the triple-height space contains the main circulation and breakout spaces, while also providing controlled daylighting and natural ventilation. The flexible, open-plan layout is designed to foster collaborative learning and the cross-fertilisation of ideas.

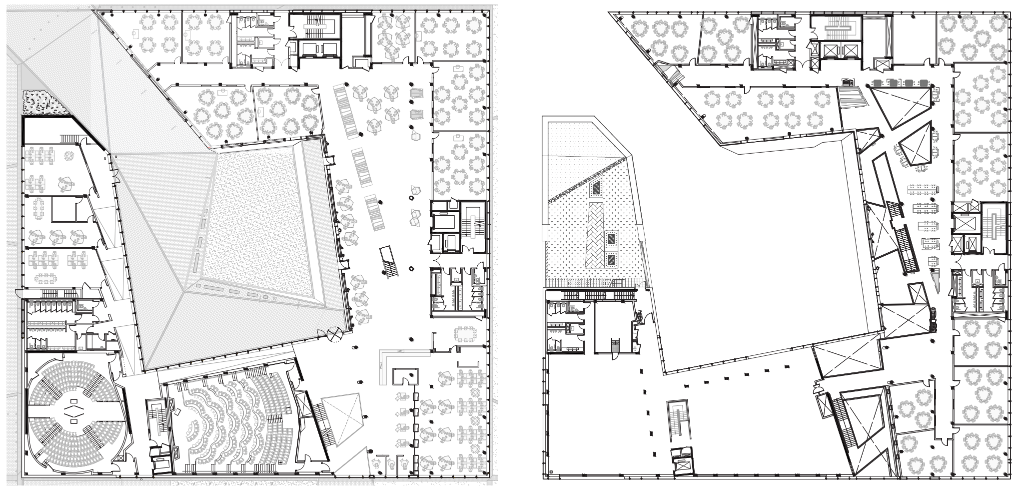
Structural design

Comprising a lattice of horizontal box beams and diagonal CHS struts, the steel structure not only supports a series of pod-like breakout spaces, but also provides lateral restraint for the atrium facade and additional compressive support for the transfer structure at third-floor level. "We chose steel because its inherent strength allowed us to create an aesthetically pleasing structure using relatively small sections", says structural engineer Robert Pugh of Arup.

Detail design

The apparently random grid of intersecting and non-intersecting diagonal steel struts is generated both by the desire to avoid running them past the hexagonal window openings, and by the locations within the atrium of the pods, which are of different sizes and have precisely defined geometrical relationships to each other.

Inclined in two directions and varying in diameter from 114mm to 244mm, the circular hollow sections are connected to each other and the horizontal box beams using continuous fillet welds. "We didn't want the struts to be of uniform size", says Pugh. "Instead, each one corresponds to the structural role it is performing. This is reinforced by printed labels attached to each section, which inform students of the forces acting on the members."



Above *Facade details (phs: Simon Kennedy).*
Left *Upper-ground and first-floor plans.*
Right *Interior view; air-flow diagram showing how thermal mass is employed to help moderate the internal environment.*

Spanning across the internal face of the inclined atrium facade and corresponding in position to the floor slabs are 450x250mm rectangular hollow sections. These are designed to balance the diagonal forces in the structure (emanating from the struts), and provide lateral bracing for the self-supporting atrium facade. They also serve as edge beams for the breakout pods.

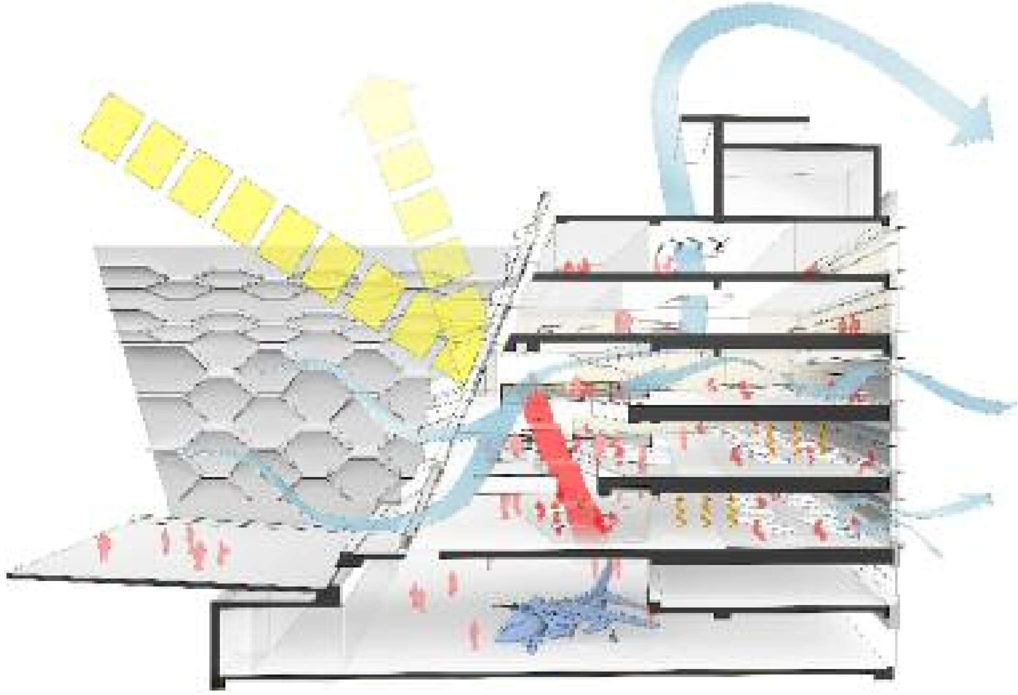
The steel structure of the Interactive Zone is bolted back to the rest of the building using steel base plates welded to the ends of the sections. "Some of the shear forces produced by the diagonal struts were reasonably large. This necessitated plates measuring typically 500 by 500mm to provide adequate spacing for up to six anchor bolts", explains Pugh. Projecting steel connection plates welded to the outer edge of the beams allow the inner face of the engineered timber facade frame to be bolted to the steel structure with articulation for vertical differential movement.

Autodesk's Revit Structure software, coupled with Oasys GSA, was used to model and analyse the design, which was then was transferred to Tekla software for steelwork contractor Traditional Structures to produce the fabrication model and shop drawings. "We even considered painting the steel sections the same colours as those expressing different axial loads in the General Structural Analysis software contour plot", recalls Pugh, "but the architect felt this would overcomplicate the atrium in visual terms."

Fabrication/erection

The steel sections, including a number of factory-welded components comprising several intersecting elements, were assembled on site using a small mobile crane. Erection took two weeks, after which the frame received an architectural-quality, silver-coloured, thin intumescent coating.

Project team
Architect, structural and service engineer: Arup Associates; steelwork contractor: Traditional Structures; main contractor: Vinci Construction; client: Coventry University; photos: Simon Kennedy.



Weighty matters

Thermal mass has the potential to lower energy consumption, but its use isn't limited to heavy construction methods.

Thermal mass or fabric energy storage – the capacity of a material to absorb, store and release energy – has the potential to reduce energy use in buildings by smoothing out fluctuations in conditions above or below comfortable ambient levels.

The ability of a material to absorb or release heat through thermal cycles is based on its thickness, thermal capacity and conductivity, surface resistance and density. Typically, concrete and masonry work well, absorbing heat from the air as the temperature rises and releasing it when it falls, and this can be harnessed in either a heating or cooling mode. The surface of the material must be sufficiently exposed to allow heat transfer, and the greater area exposed, the greater the benefits in terms of thermal mass. If the mass is to absorb heat, the interface is better on ceiling soffits and higher walls. Unsurprisingly, suspended ceilings and drylining can reduce heat transfer.

Typically in the UK, through a daily thermal cycle, only 100mm of a concrete floor slab is available to absorb and discharge heat energy. This potential for thermal mass is therefore already maximised in standard floor slabs, which will typically be 200-300mm thick for structural design purposes. Increasing the depth of the slab simply adds weight, which impacts on resource efficiency without increasing thermal mass performance.

In multi-storey buildings, the upper floors are the most important elements in terms of providing 'accessible' thermal mass. Whether a building is steel or concrete framed, the upper floors are generally either made of cast in-situ or precast concrete, and therefore the potential to use the thermal mass of the upper floors is not restricted by the choice of framing material.

Consultant AECOM's study 'Thermal Mass in Commercial Buildings' (2008, for Tata Steel) modelled the cooling potential of five different floor types with fully exposed soffits in a naturally-ventilated four-storey office building – Slimdek, composite floor slab, precast concrete, reinforced concrete and hollow-core precast concrete. The results demonstrated the effectiveness of the thermal mass – in all cases the peak temperatures remained below 28 deg C for at least 99 per cent of the occupied hours, suggesting mechanical cooling methods could be avoided, and implying that little additional benefit would be gained by providing additional thermal mass. Significantly, these results were consistent with other research showing that the optimum thermal mass gain can be achieved as long as 75-100mm depth of exposed concrete slab is available. However, the study also noted that the performance of glazing, in terms of cooling load, could be as significant as benefits from using thermal mass – ie using high performance solar control glazing rather than standard clear low-e glass (with 40 per cent glazing area).

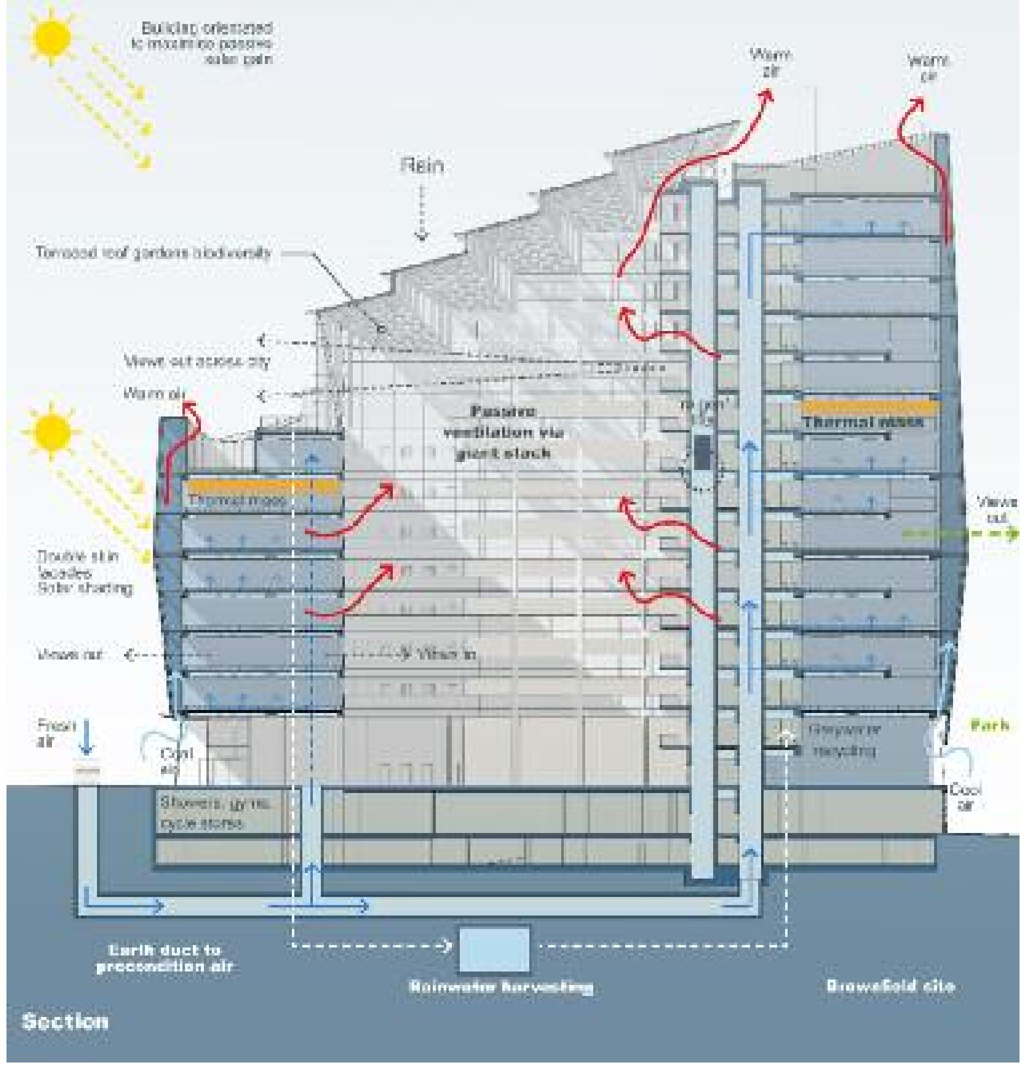
In designing buildings to exploit thermal mass, factors that may require consideration include: what conditions are needed in the particular building type; do heating or cooling loads (or both) require control; and how might the building fare in relation to climate change predictions? Moreover, conventional wisdom suggests that thermal mass is more suited to buildings with regular occupation, such as offices.

Thermal mass strategies can be hampered if natural ventilation is not viable for example, because of orientation, acoustics or air quality, or if areas are compartmentalised or air-conditioning is needed.

Above *The Woolwich Centre, by architect HLM, is designed to achieve 50 per cent carbon reductions. The steel frame comprises fabricated beams that support exposed, precast concrete vaults on their bottom flanges. The mixed-mode ventilation strategy utilises the glazed facade. When needed, extra convection cooling can be provided by passive chilled beams that hang within the vaults (phs: Diane Auckland/Fotohaus).*

Thermal mass key points:

- *The maximum thickness of concrete useful for thermal mass is 75-100mm*
- *Available thermal mass is already maximised in standard floor slabs as thicknesses greater than 100mm will be provided*
- *Upper floors in steel- and concrete-framed multi-storey buildings are typically concrete*
- *Effective thermal mass solutions are independent of structural frame material*
- *Exposing floor soffits for thermal mass can have constructional impacts and costs*



Left *3D Reid's Co-operative Group Headquarters, Manchester, features 16.5m steel beams supporting precast concrete coffer units. Three large earth tubes temper the air entering the building, which is distributed by a passive stack system.*

Further complications can arise because of diurnal and seasonal changes in external conditions. For instance, the building may sometimes be required to contain heat, sometimes capture it, and sometimes reject it.

Night-time cooling can be achieved in a number of ways. Natural ventilation is the most consistent with environmental savings, though often some mechanical control of shutters will be required. Employing natural ventilation to cool the thermal mass can also raise issues such as security of openings, ceiling finishes, acoustic needs and services distribution. Other cooling options include mechanical ventilation, ideally integrated with a building management system, and cooling of slabs from within using piped water or ducted air. Other, more complex design strategies that employ ground energy systems include thermal labyrinths, as at 3D Reid's Co-op Group headquarters in Manchester.

Further reading Tata Steel and the British Constructional Steelwork Association (BCSA) have recently published The Steel Construction Thermal Mass Supplement, which examines fabric energy storage and sustainable strategies (see www.steelconstruction.info).