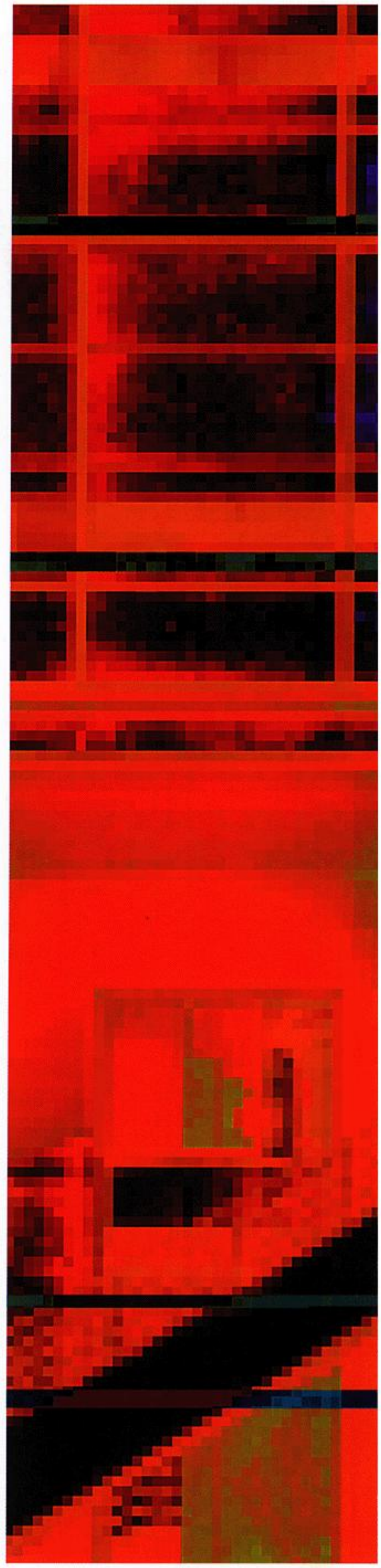
Environmental floor systems

A range of floor options for steel framed buildings which optimise thermal capacity



Summary

This document describes the background to the development of naturally ventilated or cooled buildings and the associated key design features.

Several possible systems for use with steel framed construction are outlined in principle. These systems are classified as 'passive', in which case the thermal capacity of the building fabric is simply exposed, or 'active', providing performance and control in maintaining ambient conditions.

All of the passive systems use forms of construction in current use. The active systems rely on air ducted across the surface of the floor slab, and a number of generic solutions are presented appropriate to different flooring systems.

Indicative measures of performance and cost are included, and related issues such as fire protection and lighting are addressed. Ways in which some of the ideas can be incorporated within refurbishment projects are also suggested.

Environmental floor systems

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The Steel Construction Institute

The Steel Construction Institute develops and promotes the effective use of steel in construction. It is an independent, membership based organisation.

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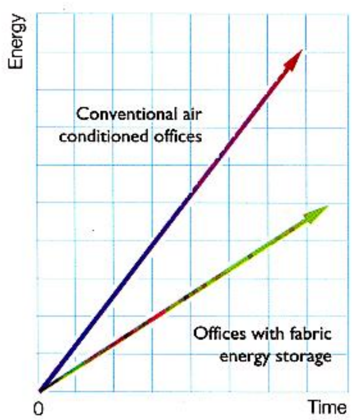
Introduction

Most buildings are designed to carefully controlled cost constraints. These have traditionally been based on initial cost, but there is an increasing recognition that cost in use should be considered and one very important element of this is energy consumption.

Coupled with concerns for environmental protection and the need to reduce CO_2 emissions in particular, energy use considerations are encouraging building designers to adopt more energy efficient solutions for their buildings, which, in the UK, account for approximately 50% of all energy consumption and CO_2 emissions. CO_2 is a significant factor in the so-called greenhouse effect, which the government is committed to addressing, and it therefore may not be very long before legislation follows encouraging reduction in man-made CO_2 emissions. Reducing electricity consumption is particularly important in this context, since unavoidable losses in generation reduce efficiency to about 30%.



BUILDINGS 'CONSUME' ENERGY IN A NUMBER OF WAYS

- in the production of the building materials and the construction process (the 'embodied' energy)
- in the lighting, heating, cooling, ventilation and operation of the building (operational energy)
- in the incidental energy or activities such as those incurred by occupants of the building in travelling to work

WAYS OF MINIMISING ENERGY USAGE

There are a number of ways concerned with minimising energy use, which include:

- reducing heat loss by adopting high insulation standards and a well sealed envelope (during the 'heating' season)
- maximising the use of natural lighting (but avoiding glare and excessive solar gain),
  and using low energy artificial lighting where necessary

and finally, the main concern of this document -

- reducing energy consumption and CO_2 emissions associated with heating, cooling and ventilating the building

This last area has received little attention with respect to modern commercial buildings, although recently a small number of designers have introduced the concept of 'fabric energy storage' (thermal capacity), reducing both capital and recurrent costs, energy consumption and CO_2 emissions.

This guide focuses on ways in which designers can use conventional methods of floor construction in conjunction with a steel frame to take full advantage of the thermal capacity of the building to reduce the demand on cooling, whilst achieving a visually acceptable ceiling. The suggestions are generic ideas rather than prescriptive remedies and the systems illustrated demonstrate principles rather than fully developed details. All are simple adaptations of existing construction methods. Although some may involve higher initial capital costs, it is important to recognise that there will be cost savings in reduced services and, more significantly, in lower recurrent energy costs.

The information contained in this guide is part of a continuing programme of research. More details can be obtained by consulting the technical references cited, or contacting the authors directly.

Interior of Ionica building, Cambridge, U.K.

Exterior of Ionica building, Cambridge, U.K.

The principles of fabric energy storage (FES)

Fabric energy storage is a way of reducing the need for air conditioning by using the thermal capacity of the building fabric - a measure of its ability to absorb and store heat - to even out the diurnal variations in temperature.

CONTROL OF AMBIENT HEAT GAINS WITHIN THE BUILDING BY MEANS OF FABRIC ENERGY STORAGE

In simple terms, the heat flow between a building and its environment is cyclical. During the day the heat flow is generally into the building. This may be due to increased outside temperatures, solar gain, and internal gains resulting from the heat emitted by occupants and equipment such as computers and photocopiers etc.

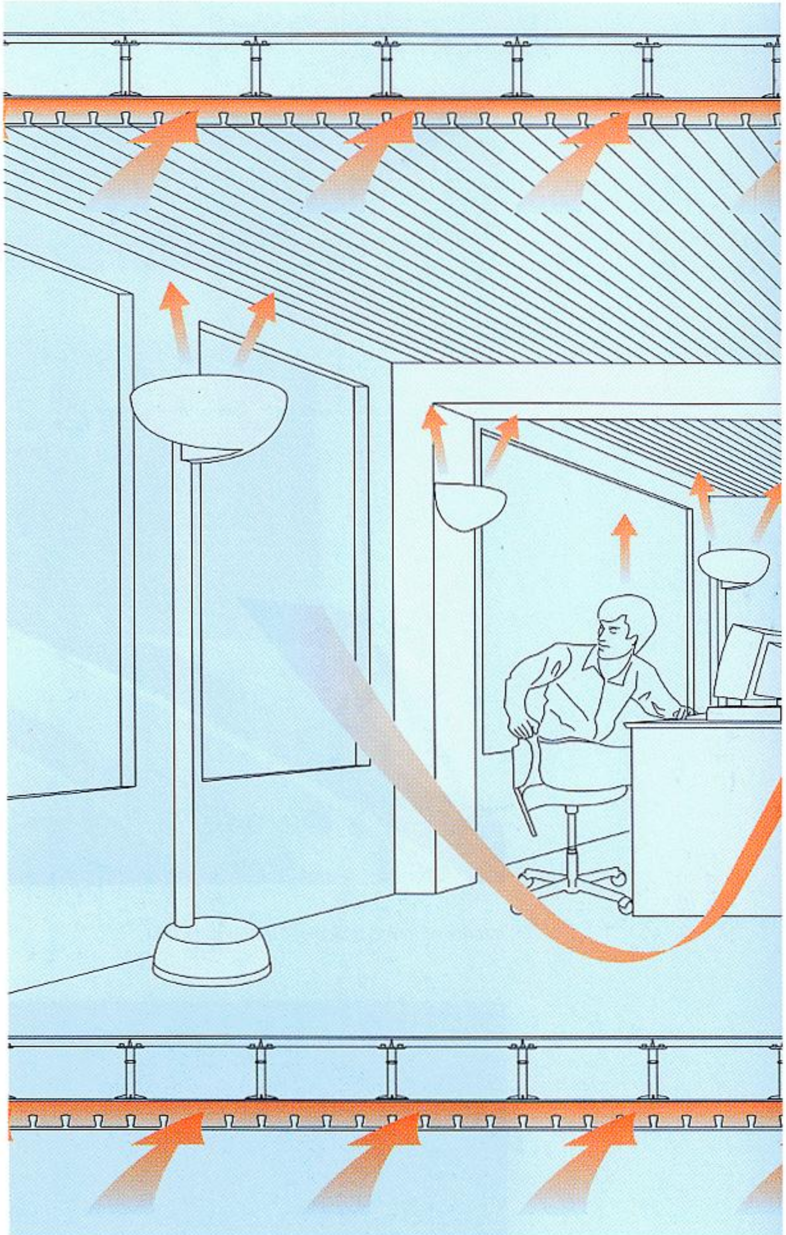
At night the external air temperature falls and internal gains are significantly reduced, so heat is lost from the building. In summer the daytime gains are typically dealt with by the use of air conditioning, whilst in winter the gains may be inadequate to maintain comfort and there is a need for heating.

If heat can be absorbed by the building fabric during the day, the maximum air temperature will be reduced. At night when the ambient temperature falls this stored heat can be released. This process can be assisted significantly if night ventilation of the fabric is possible. In this way a more even temperature regime can be achieved, and the need for air conditioning can be reduced or eliminated.

This process can reduce both capital and recurrent costs, and CO_2 emissions.

USING HEAT EXCHANGE TO MAXIMISE ENERGY STORAGE

The ability of heat to be absorbed within the building fabric is termed the 'thermal capacity' of the building and is determined by two key factors: heat exchange between or at surfaces and the ability of the building fabric to store the transferred heat. In practice, it is the first of these factors which is the most important. The mechanism for heat exchange between the room (occupants, contents, etc.) and the building fabric is a combination of convection and radiation. Although the relative significance of these two methods can vary quite widely depending on a range of factors, both are of comparable importance. Heat transfer by convection can be improved significantly by increased air flow (preferably 'turbulent') across the surface of the building fabric, whilst radiation is affected by the nature of the surface.



TYPICAL OFFICE SHOWING DIURNAL HEAT FLOW

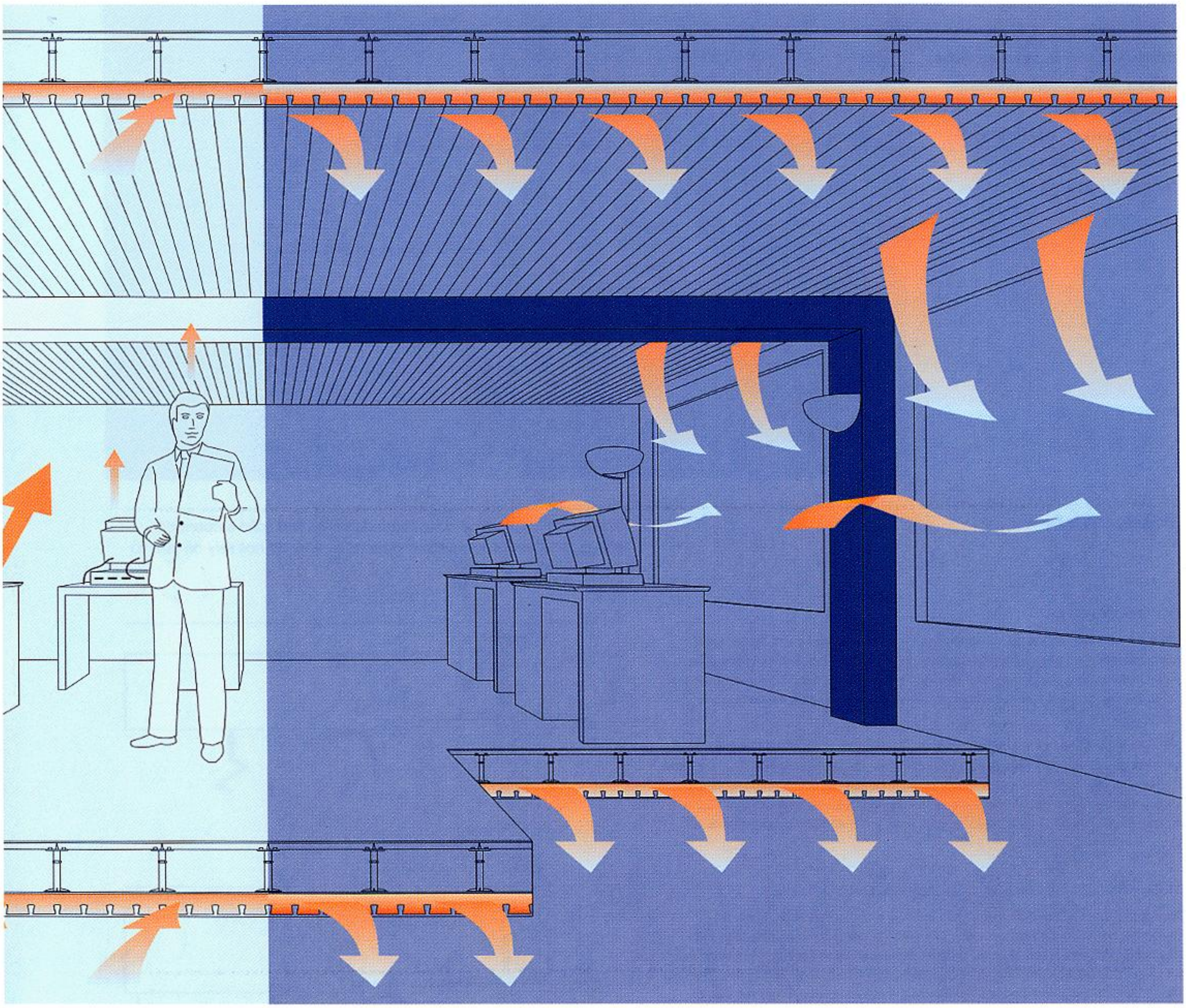
THERMAL IMAGE INDICATING SOURCES OF AMBIENT HEAT GAINS IN A TYPICAL OFFICE ENVIRONMENT

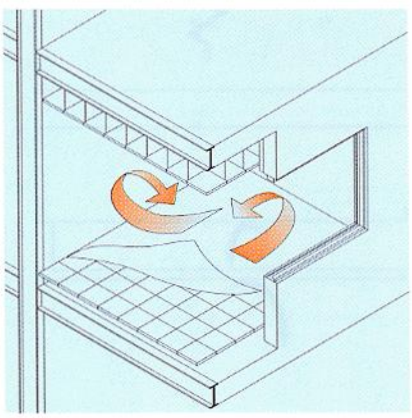
STORAGE OF ENERGY IN STEEL FRAME CONSTRUCTION

The thermal capacity of the building frame is not regarded as a significant means of controlling ambient heat gains.

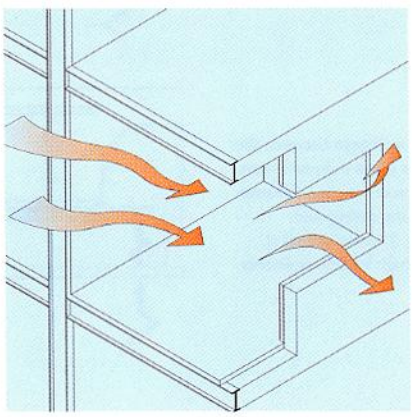
Floor slabs provide the most consistently available source of such thermal capacity, although some surface coverings such as carpets can effectively restrict efficient surface heat transfer. On a diurnal basis, a relatively thin depth of concrete slab (50-75 mm) is all that is needed to provide adequate fabric energy storage. Thus, when using composite slabs with metal decking, sufficient thickness is available. With precast concrete floors, which may be voided, there is generally adequate continuous thickness of concrete below the voids for fabric energy storage to be effective. Thicker slabs will afford negligible improvement, and the key issue is to encourage efficient heat transfer.

The need for raised floors in modern commercial buildings can mean that heat transfer from the top surface of the floor slab is restricted. Thus the only effective means of heat transfer, in this instance, is via the ceiling. However, effective heat transfer can be achieved if specific provision is made to route air so that it comes into contact with the slab surfaces, especially if the air flow is turbulent.

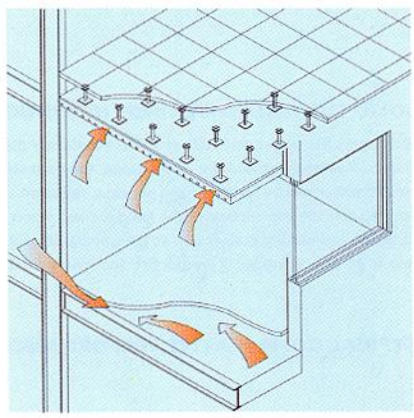




POOR THERMAL LINKAGE - POOR CONTACT WITH THERMAL MASS.



GOOD THERMAL LINKAGE - DIRECT CONTACT WITH THERMAL MASS.



ENHANCED THERMAL LINKAGE - IMPROVED CONTACT WITH THERMAL MASS BY MECHANICAL MEANS.

Range of fabric energy storage systems

The different options currently in use can be characterised in terms of the way in which heat accesses the floor slab.
The "passive" options are illustrated below and the "active" options opposite.

HEAT TRANSFER MECHANISMS

The primary heat transfer mechanisms are radiation and convection. Typical comparative performance indicators are given for each of the options. These assume normal weight concrete - performance will be reduced by 10 to 20% for light weight concrete. The indicators relate only to the element and thermal access route described. Other access routes and elements (e.g. walls) will add to give the overall performance of the space.

RADIATIVE HEAT TRANSFER

Heat transfer by electromagnetic waves between building surfaces and occupants. Efficient radiant heat transfer is reliant on the surfaces involved having relatively high surface emissivities (approx. 0.9) which is the case for most building materials and finishes. Paint or similar finishes can be applied to steel to enhance its surface emissivity, promoting good radiant heat exchange.

CONVECTIVE HEAT TRANSFER

Heat transfer by air movement to and from surfaces and occupants. For natural convection the air movement is driven by buoyancy. For forced convection the air movement to and from the surface is typically generated by fans. The rate of heat transfer achieved by forced convection where the air flow is highly turbulent can be many times that for natural convection.

RADIATIVE HEAT

NATURAL CONVECTION

FORCED CONVECTION

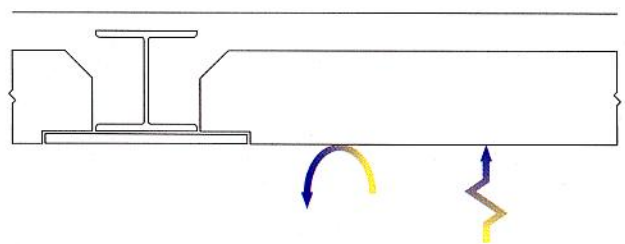
Passive Airflow

Exposed soffits, open grid suspended ceilings and solid suspended ceilings are identified as passive options as they do not rely on fans to create air movement.

EXPOSED SOFFITS

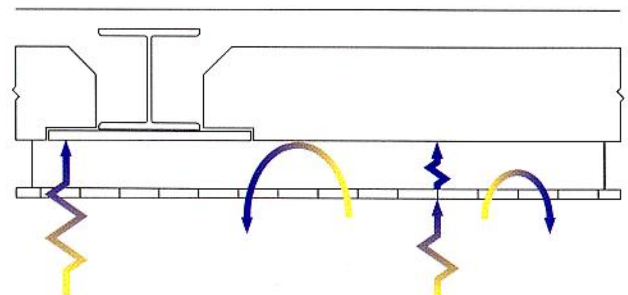
The most common and simplest option is to have an exposed soffit. Radiant and natural convective heat exchange take place between the slab and the space. The typical night cooling performance of an exposed flat slab in the UK is in the region of 20 W/m^2. For profiled surfaces with a greater exposed area this will increase to around 25 W/m^2.

Different finishes may be applied to the soffit. Ideally, the finish should be in good thermal contact with the slab, have a low resistance to conductive heat flow and have a high emissivity, but these will normally be weighed against other requirements. For example, a plasterboard finish will reduce performance by approximately 20% because of its resistance to conductive heat flow, but may offer improvements in terms of aesthetic appearance.



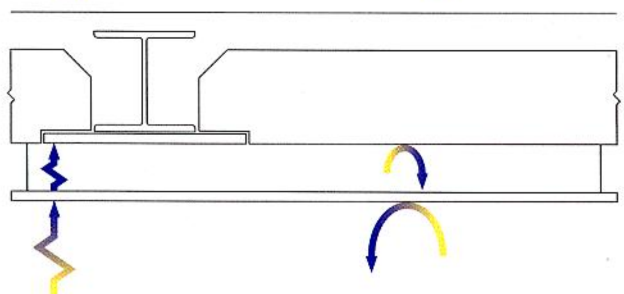
OPEN GRID SUSPENDED CEILINGS (CONDUCTIVE)

Open grid suspended ceilings give partial exposure of the slab soffit. Natural convection between the bottom surface of the slab and space can still occur, but direct radiation is reduced as some will be intercepted by the ceiling. However, this will be re-radiated or enter the space by natural convection from the ceiling. The nett effect of the ceiling is to convert a portion of the radiant cooling from the slab to convective air cooling. For conductive ceilings (which maximise the re-radiation heat transfer) preliminary studies indicate that the overall cooling performance should be similar to that of an exposed soffit.

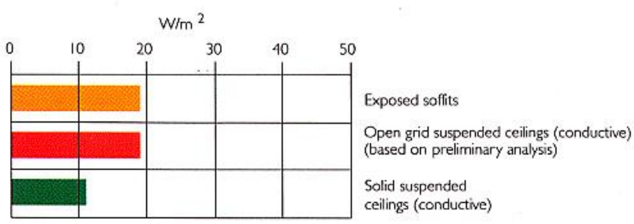


SOLID SUSPENDED CEILINGS (CONDUCTIVE)

Although solid suspended ceilings will preclude any direct heat exchange between the underside of the slab and the room space, they can still provide some thermal access. Heat transfer will be a three stage process; radiation and natural convection between the slab and the top surface of the ceiling, conduction through the ceiling, and radiation and natural convection at the underside of the ceiling. Thermal access is reliant on the ceiling being conductive and having a reasonably high surface emissivity.



TYPICAL COMPARATIVE PERFORMANCE



These are approximate values only

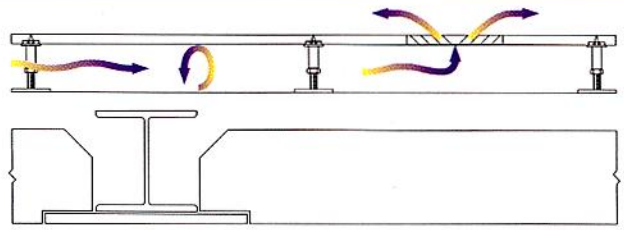
Active Airflow

Active options encourage air flow in contact with the structural floor slab to improve heat transfer. They generally rely on fans to create air movement. Although there is an energy penalty relative to the passive options, active options can offer better performance and/or control. This is particularly so for air cores and air ceilings.

RAISED FLOOR VOIDS

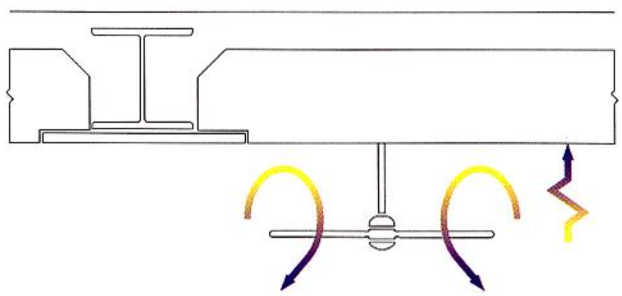
The most commonly used active option is the supply of air through a floor void. Convective heat exchange takes place in the floor void, cooling the supply air. The convection can either be natural or forced depending on the air flow velocity and void depth.

Heat transfer rates are normally fairly low, restricting the performance of these systems relative to the other active options. Modulating control over the system can also be achieved by means of a bypass, but in practice these are rarely provided.



SPACE FANS

Space fans can create forced convection cooling by blowing (or drawing) air over an exposed slab soffit. This provides enhanced forced convective cooling at the slab surface. Fan speed variation will give partial modulating control.

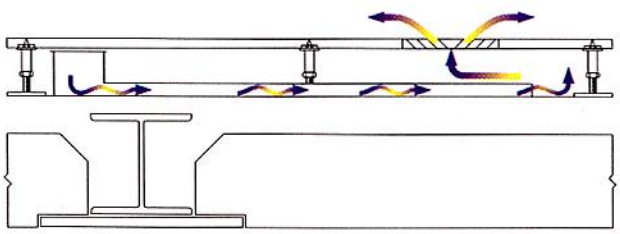


AIR CORES*

Air cores provide enhanced forced convective cooling of the supply air. This is achieved by creating high levels of air flow turbulence within the cores to bring the supply air into close thermal contact with the slab. Modulating control of heat transfer can be achieved by means of a bypass.

Air can be directed through ducts formed specially to improve heat exchange with the structural floor slab - this is the basis of the Termodeck system (see Glossary, page 29) - or by using the profiling of the steel decking, such as the Airdeck system, pages 8 and 9, and the Slimdek system, page 11.

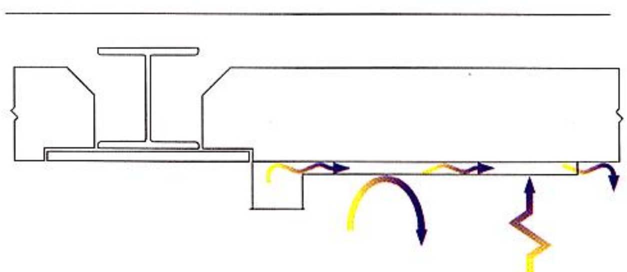
* Includes air deck (illustrated right), Slimdek air core and hollow core systems



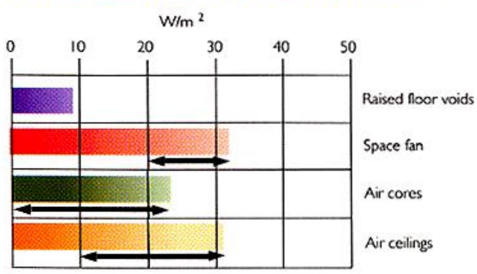
AIR CEILINGS

Air ceilings combine cooling of the supply air and surface cooling. Air ceilings provide enhanced forced convective cooling of the supply air similar to the air core solutions described above. However, in addition to being cooled itself, the supply air is used to transport cooling from the slab to the exposed surface and thence into the internal space by radiation and natural convection. Partial modulation of the output can be achieved by varying the air flow rate.

One example of an air ceiling construction using profiled steel sections is given on page 10.



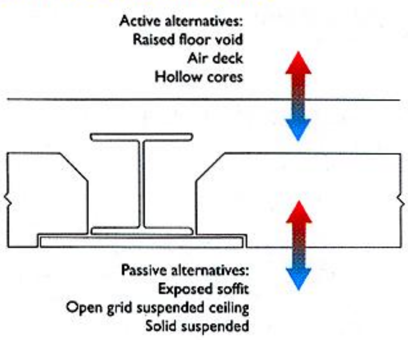
TYPICAL COMPARATIVE PERFORMANCE



The above values are approximate and are variable within the parameters of the mechanical ventilation system.
The effect of modulation control is shown by arrows.

SIMPLE PASSIVE AND ACTIVE COMBINATIONS

All the passive options are based on heat exchange at the bottom surface of the slab. These can be used in simple combinations with active options which use heat exchange at the top surface (raised floor voids and air deck) or inside hollow cores within the concrete slab. As a first approximation, the overall thermal performance of the combinations will be the sum of the passive and active options.



Active fabric energy storage systems - construction details

A variety of construction techniques, materials and alternative finishes can be used to provide improved performance specifications and control. Some of these are described in this Section.

INTRODUCTION

The typical performance indicators given for each of the options show both the cooling capacity and the degree to which this can be modulated; two key parameters which will govern the effectiveness of a system in practice. Although there is an energy penalty relative to the passive options (this will be small for well designed systems), the active options can offer better cooling capacity and/or control. These are achieved by enhancing heat transfer at the air/slab interface and variation of the air flow which comes into thermal contact with the slab.
The characteristics of systems which have limited performance and those which offer improved performance are compared in the box opposite.

UPGRADING AIR FLOW SYSTEMS TO HIGH PERFORMANCE

Limitations

The two most common passive air flow systems used in the UK are: false floor void supply systems (with no bypass facility) and exposed soffits.
These systems normally suffer from two limitations:

1. Low heat transfer rates

Gentle air movement at contact surfaces gives low convective heat transfer coefficients (2-3W/m^{2}K), resulting in a limited charging/discharging rate and therefore reduced performance. A longer time is required for night cooling, and consequently more energy is required for fans since they operate for longer periods.

2. Lack of control

Supply or internal air is permanently linked to the thermal store which means that charging /discharging takes place even when undesirable. This can result in:

- energy wastage e.g morning heat-up to offset unwanted cooling
- occupant discomfort
- conflict between central plant and the thermal store

Active systems with high capacity and control

Air deck, Slimdek air core, hollow core systems and air ceilings induce highly turbulent air flow at the contact surfaces and can provide a bypass capability. The systems offer:

High heat transfer rates

Turbulent air movement at contact surfaces gives high convective heat transfer coefficients (10 -15 W/m^{2}K upwards) resulting in a good charging/discharging rates and therefore performance. The efficient storage of cooling will minimise the night cooling period.

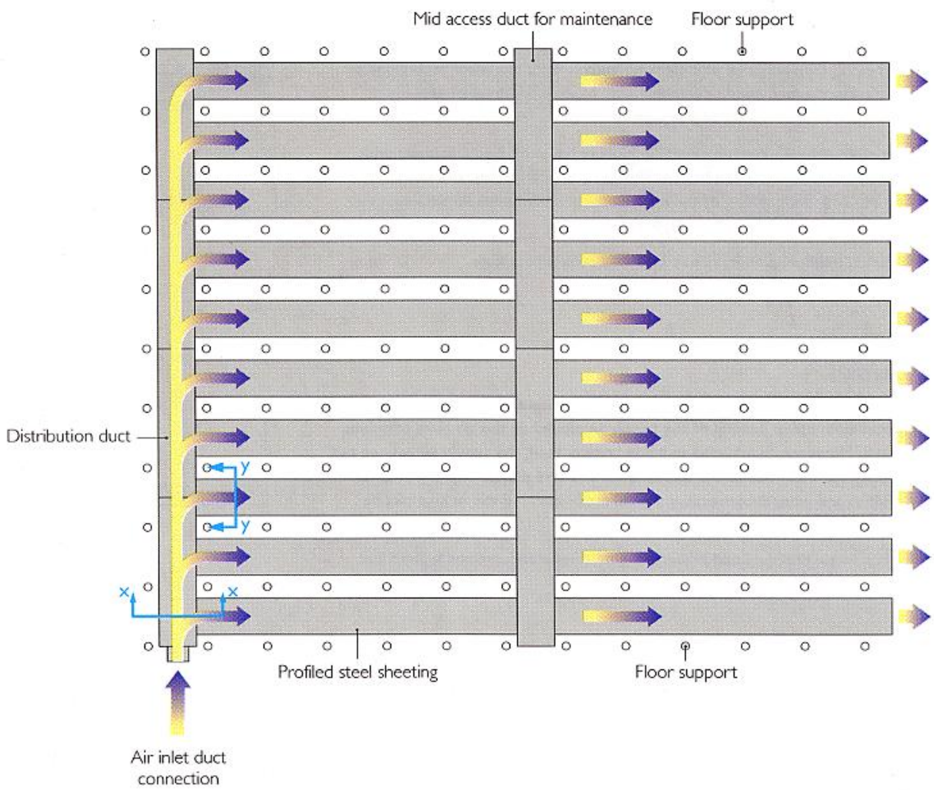
Modulating control

Provision of a thermally isolated bypass route with a diverting damper will give modulating control over the air flow and therefore the charging/discharging of the store. This will enable output to be matched to demand.

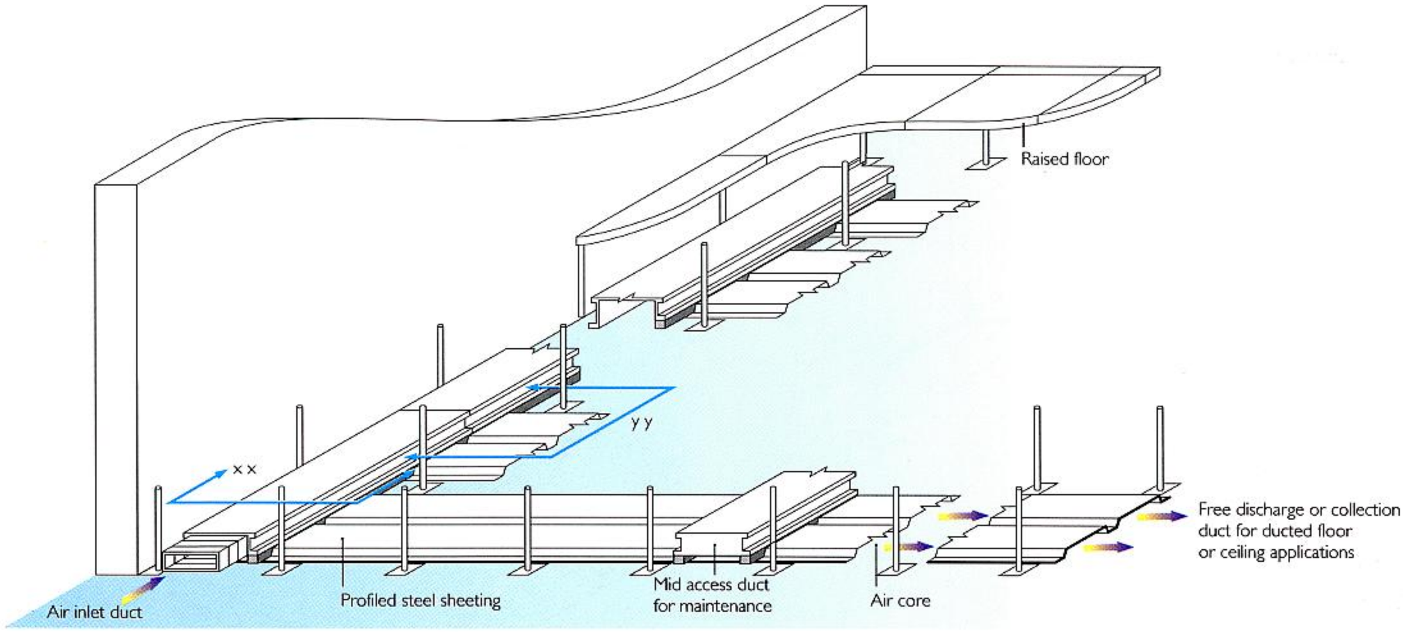
AIR DECK

This approach uses strips of profiled steel sheeting to form air cores between the sheeting and the slab. Key characteristics are:

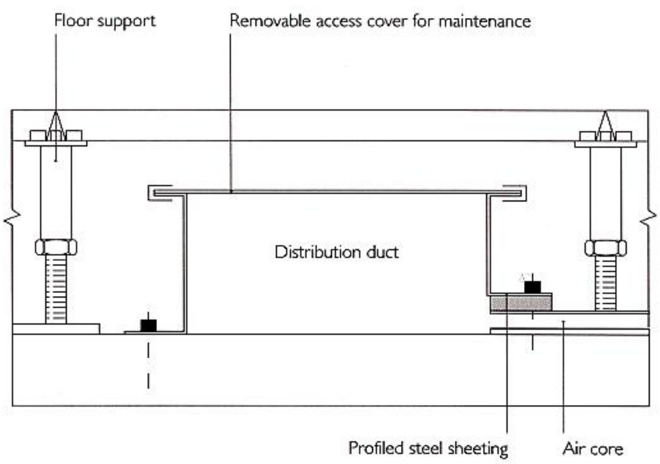
- High rate of heat transfer created between the air and the slab
- Supply air cooling
- Modulation can be achieved by using a damper arrangement on the inlet to divert air via the floor void or a bypass duct
- Suitable for new and retrofit applications
- Suitable for floor or ceiling applications
- Slim construction depth
- Maintenance via access covers to the ducts or can be fully demountable



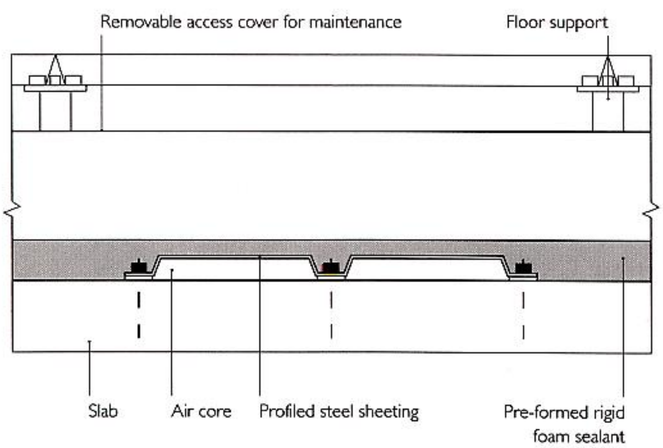
AIR DECK - PLAN VIEW



AIR DECK - GENERAL VIEW



AIR DECK - SECTION XX



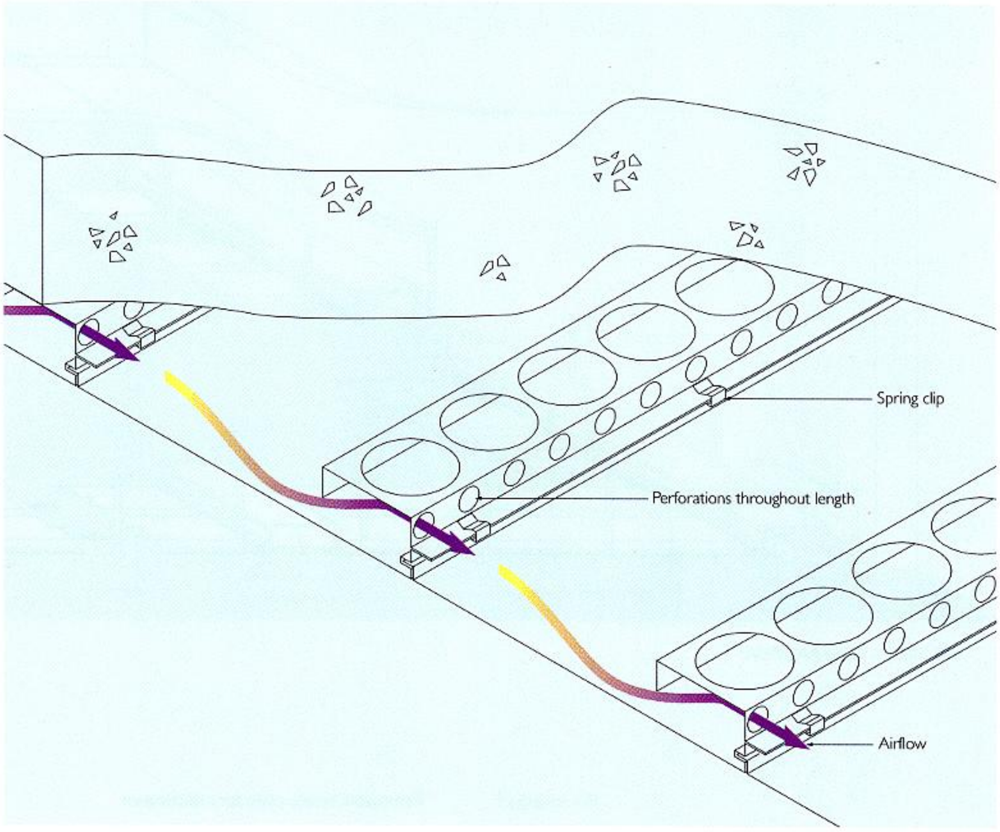
AIR DECK - SECTION YY

Active fabric energy storage systems - construction details continued

AIR CEILINGS

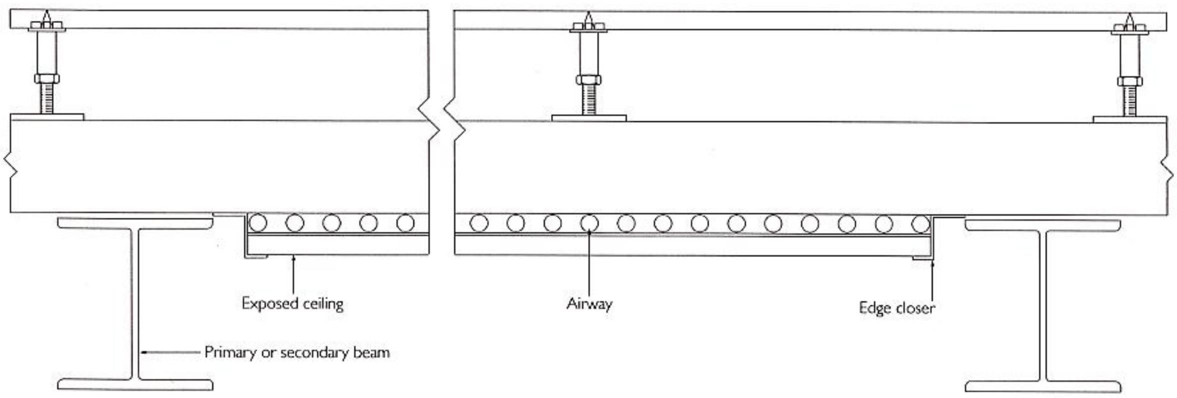
This approach uses profiled steel sheeting applied to the underside of a slab to form an air path between the sheeting and the slab. Key characteristics are:

- Cooling may be provided both by heat transfer through the ceiling panels and chilling of the supply air
- Partial modulation of output can be achieved by varying air flow rate
- Suitable for new and retrofit applications
- Shallow construction depth
- Ceiling is fully demountable for cleaning/maintenance

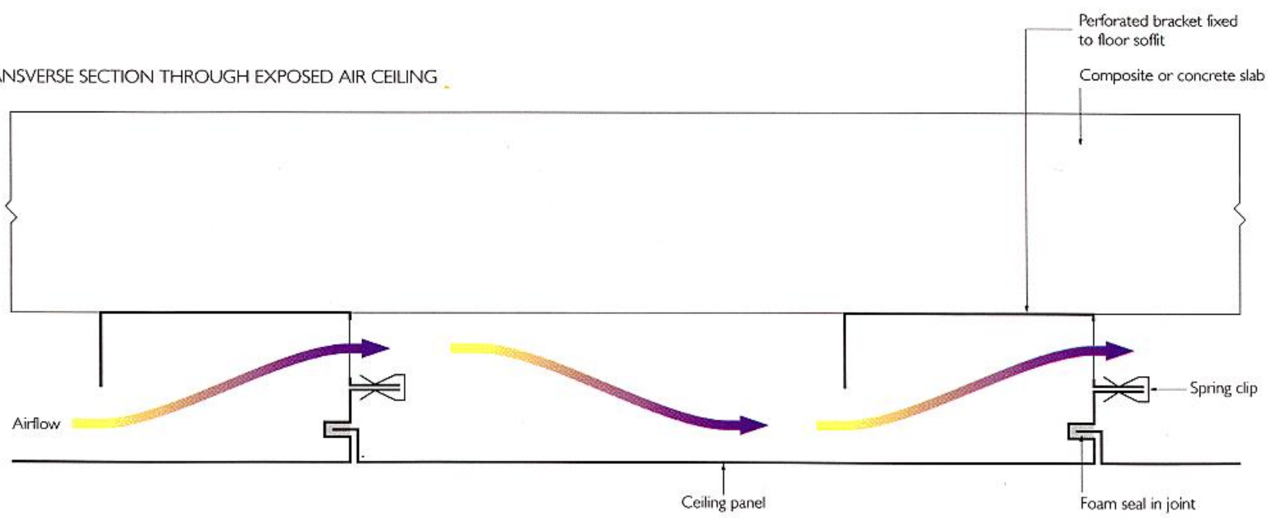


ISOMETRIC VIEW

DETAIL SECTION THROUGH EXPOSED CEILING



TRANSVERSE SECTION THROUGH EXPOSED AIR CEILING



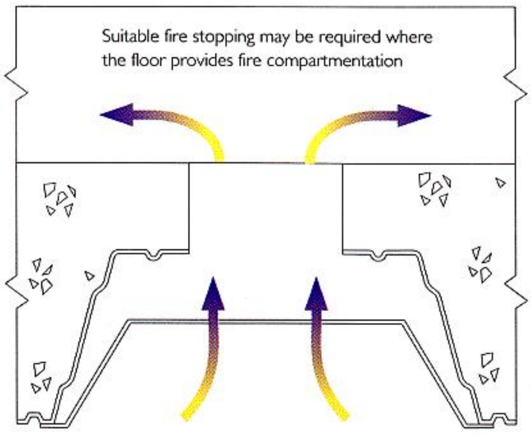
SLIMDEK®* AIR CORES

The approach uses a steel liner to form a narrow airway along ribs on the underside of Slimdek floor construction.

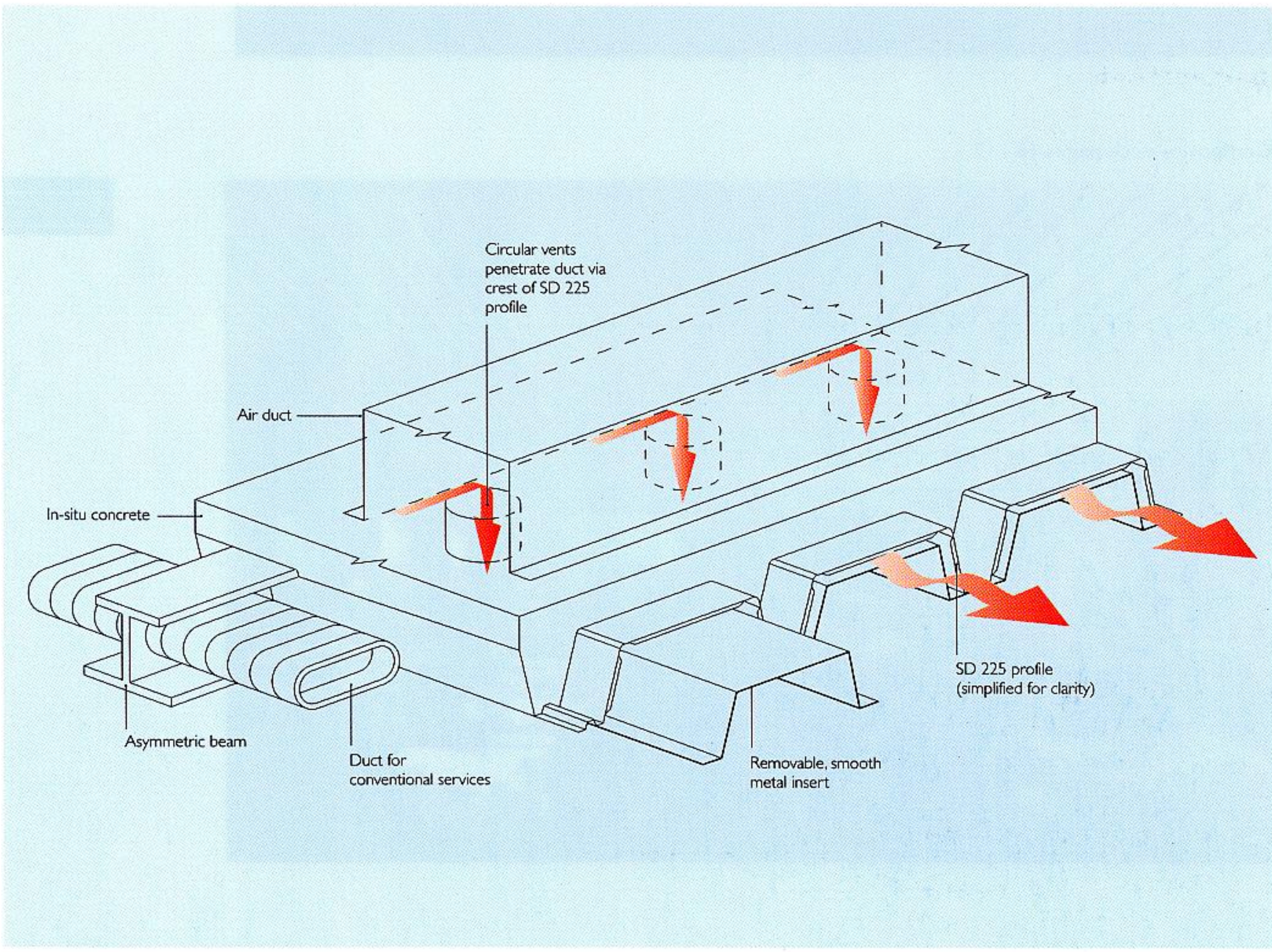
Supply and extract air may be channelled through distribution ducts either beneath or below the floor slab. Ducts positioned above the floor slab are connected to the ribs by sleeves cast in the floor slab. Where compartmentation is required, supply and extract ducts may require fire protection and specialist advice should be sought.

* Slimdek® is a registered trademark of British Steel and is covered by patent

- Supply and extract ducts may be contained within the raised floor void thus minimising high level ductwork
- A single damper arrangement may control the supply route on each floor
- The floor slab may be cooled during the night without cooling to internal spaces
- High rates of heat transfer can be achieved between the slab and the air supply ribs in the Slimdeck profile increase air turbulence
- Air path may be cleaned easily by removing steel liners



SECTIONAL DETAIL OF PENETRATION INTO DUCT THROUGH SLIMDEK PROFILE (SD225)

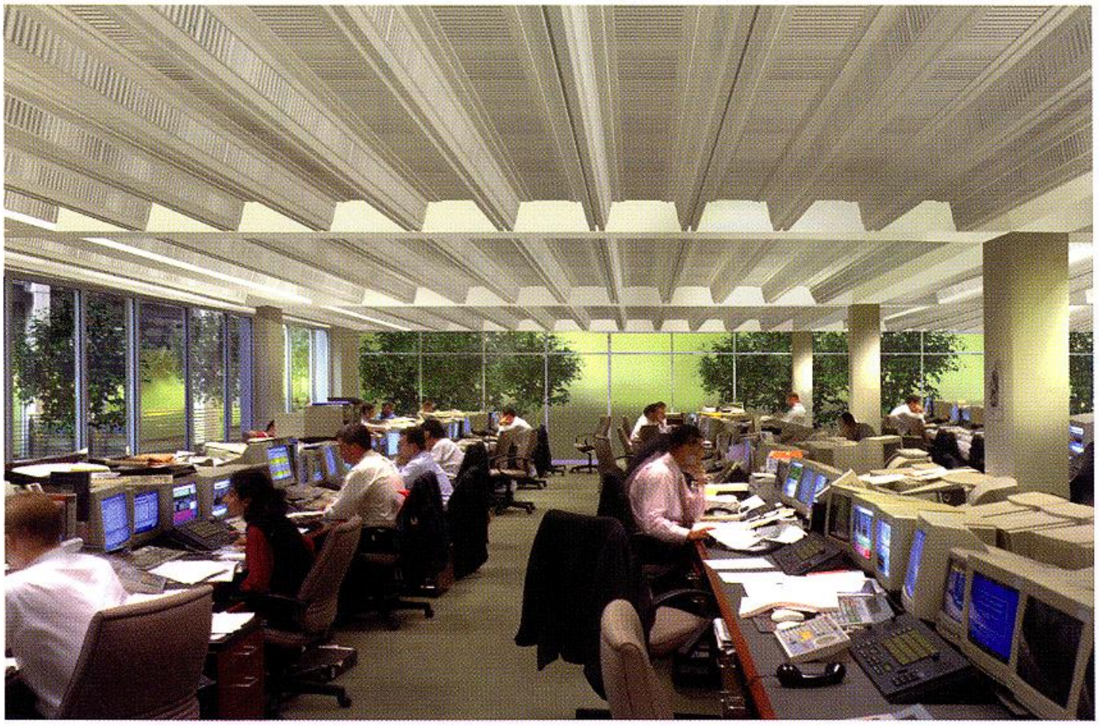


GENERAL VIEW OF PENETRATION INTO DUCT THROUGH SLIMDEK PROFILE

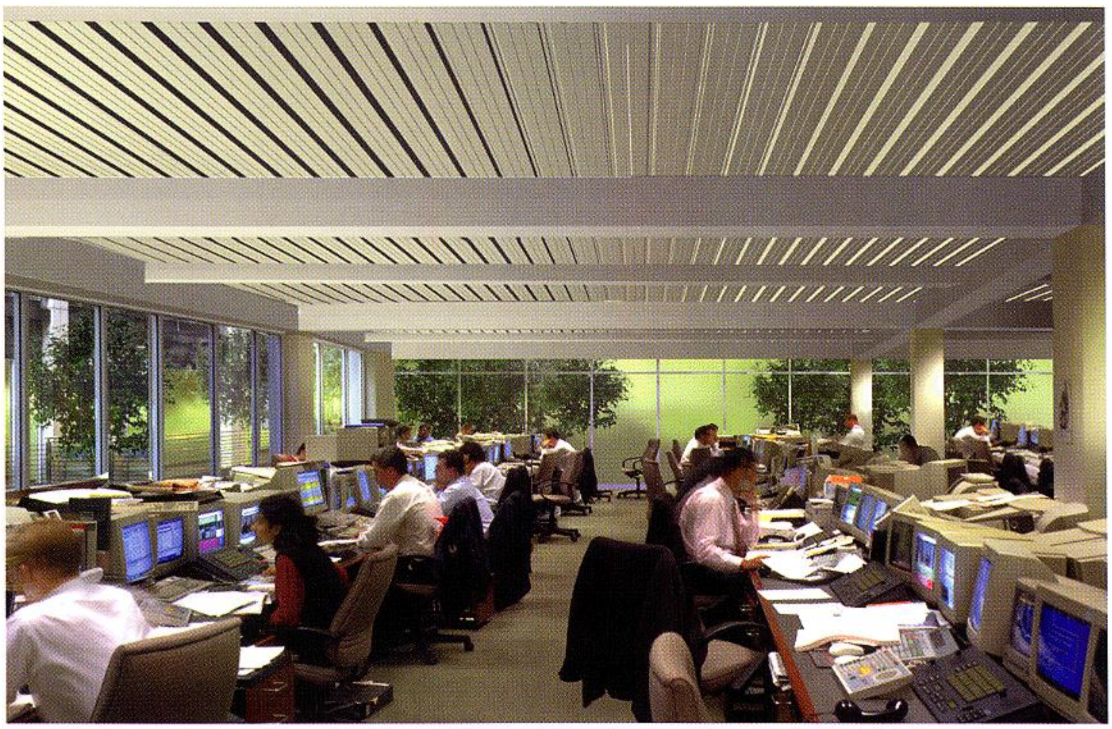
Five floor systems

**The following ten pages present a series of floor details which show designers ways of taking advantage of the thermal capacity of the building to reduce the need for cooling.
The illustrations on these pages (12 and 13) are indicative of the appearance of each of the systems with exposed soffits.**

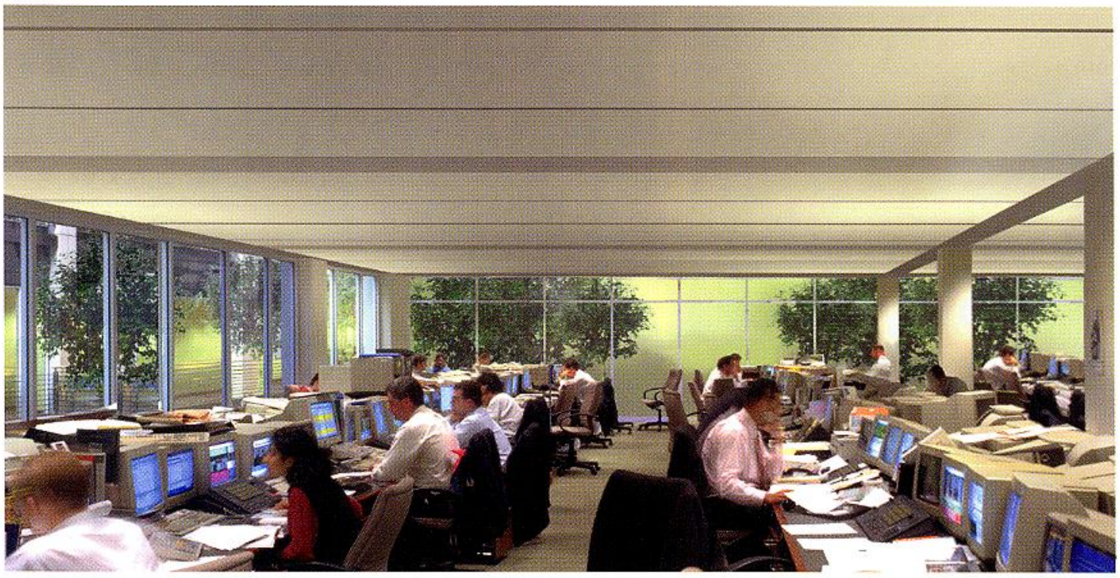
Slimdek® pages 14 - 15



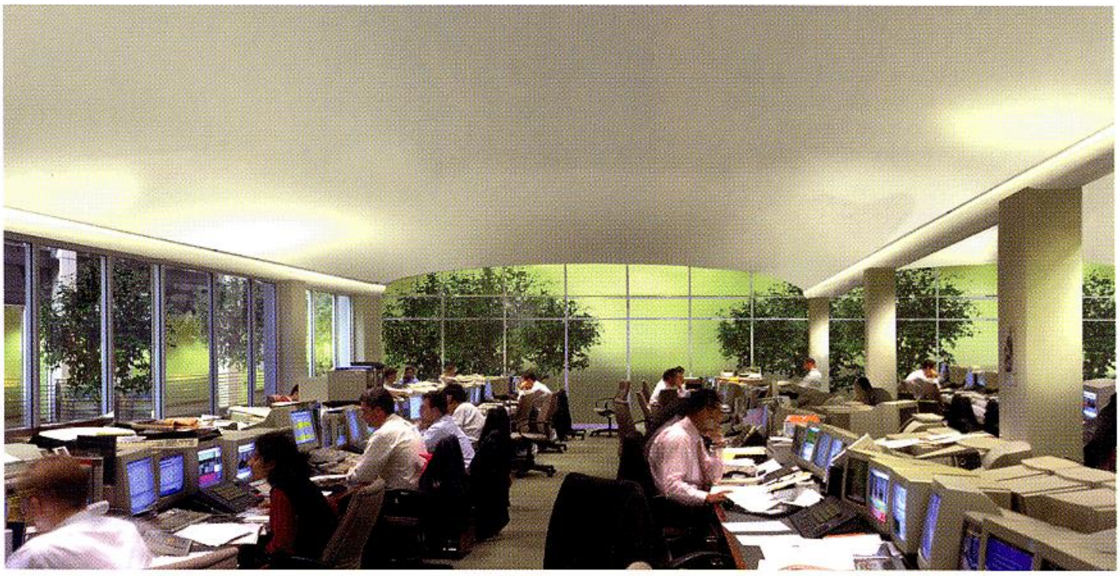
Composite deck pages 16 - 17



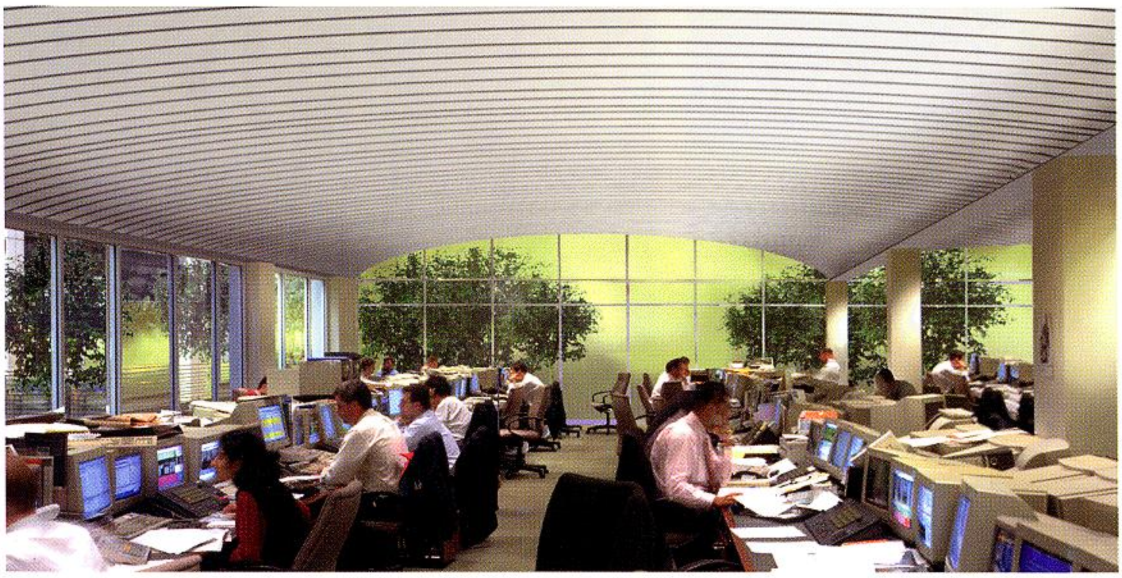
Steel frame and precast flat slab pages 18 - 19



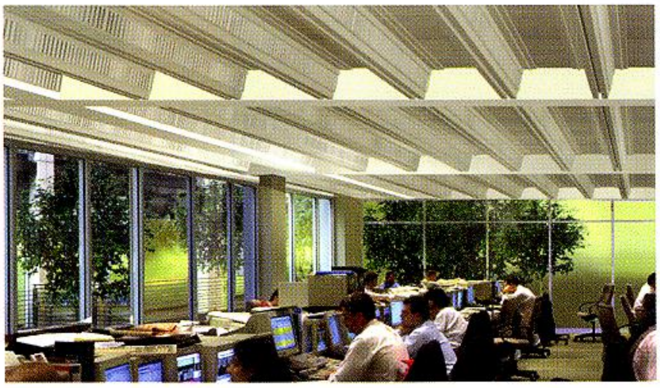
Steel frame and precast curved slab pages 20 - 21



Archdeck pages 22 - 23



Slimdek®* solutions



DESCRIPTION

This system has either a 210 mm deep deck profile (CF210 from PMF or RD 210 from Richard Lees), or the new 225 mm deep deck SD225 as part of the Slimdek system from British Steel. The beam sections for Slimdek are either the Asymmetric Slimflor Beam (ASB) or fabricated Slimflor Beams using Universal Column sections with a welded plate. Slimdek is covered by patent - further details of the system can be obtained from British Steel.

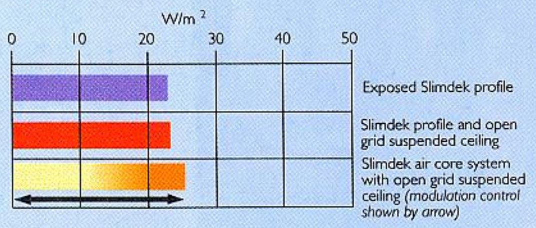
With the Slimdek system, floor depths of as little as 300 mm can be achieved with fire ratings for unprotected beams of up to 60 minutes and for the deck 120 minutes.

Deck spans are typically about 6 m unpropped and up to 8 m when propped during construction. Beam spans up to 9 m can be achieved. The system is engineered to give optimum performance in both composite action in normal conditions and in the fire state.

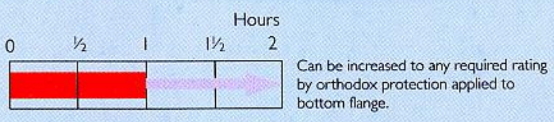
* Slimdek is a registered trademark of British Steel and is covered by patent

PERFORMANCE

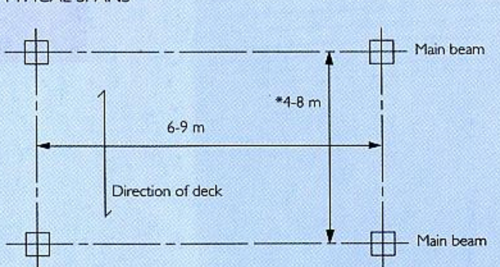
THERMAL



FIRE RESISTANCE

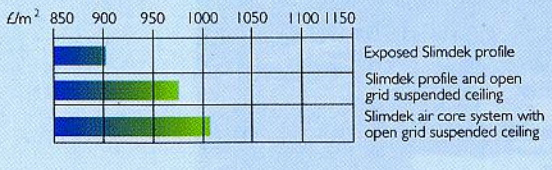


TYPICAL SPANS



*Above 6.5m, Slimdek decking units require temporary propping

INDICATIVE COSTS (as applied to whole of building, see also page 28)



FABRIC ENERGY STORAGE SYSTEMS

Passive air flow FES systems (natural ventilation)

Exposed profile with high emissivity finish

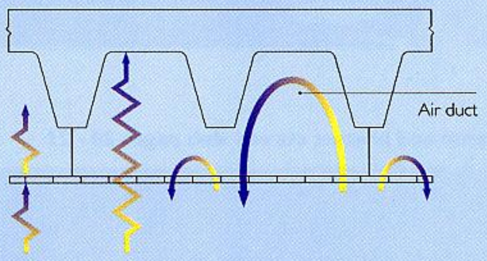
A high emissivity finish to ensures good radiative heat transfer. Thermal performance is 20% greater than exposed flat soffit, due to increased surface area.

Plasterboard or expanded metal lathing (EML) finish

Limited direct thermal contact between the finishes and the decking – performance reduced by 50% relative to an exposed flat soffit.

Open grid suspended ceiling with high emissivity finish on profile

Similar performance to exposed profiles. However, the ceiling will provide integration options with lighting and other services.
A particular benefit is the ability to close off individual profile voids to form natural ventilation air ducts to internal zones.



OPEN GRID SUSPENDED CEILING

Solid suspended ceiling

Limited indirect thermal access possible with suitable choice of ceiling materials.

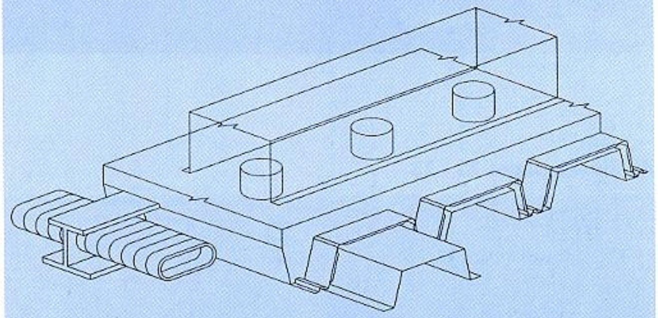
Active FES systems (mechanical ventilation)

These options can provide upgrade paths from the passive options to improve performance and/or control:

Deep deck air core system

Enhanced heat exchange between supply air and slab plus heat exchange at exposed air core surface.

Slimdek air core system (refer also to page 11)



SLIMDEK AIR CORE SYSTEM

Raised floor void

Heat exchange between air and slab.

Air deck at top surface

Enhanced heat exchange between supply air and slab.

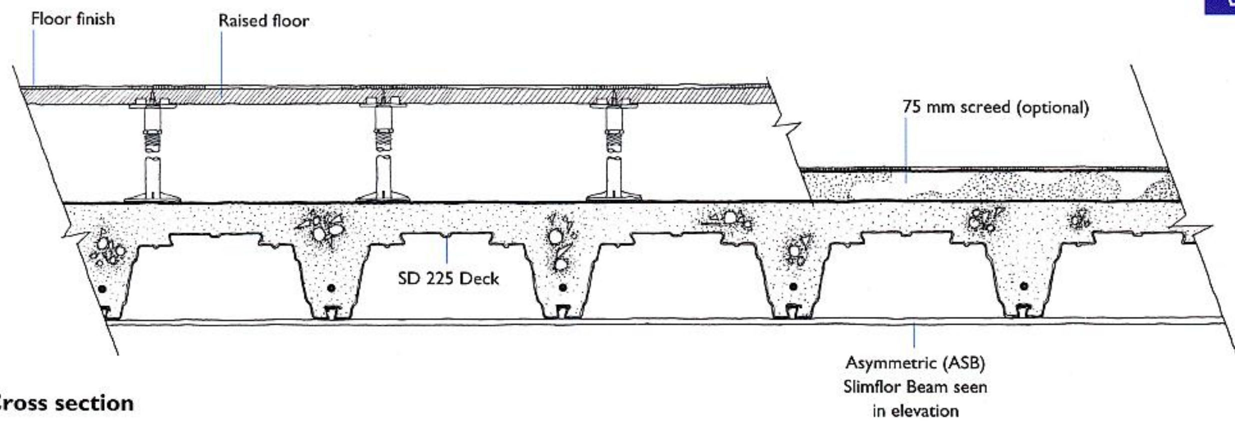
Space fan

Forced convective heat exchange at exposed slab surface.

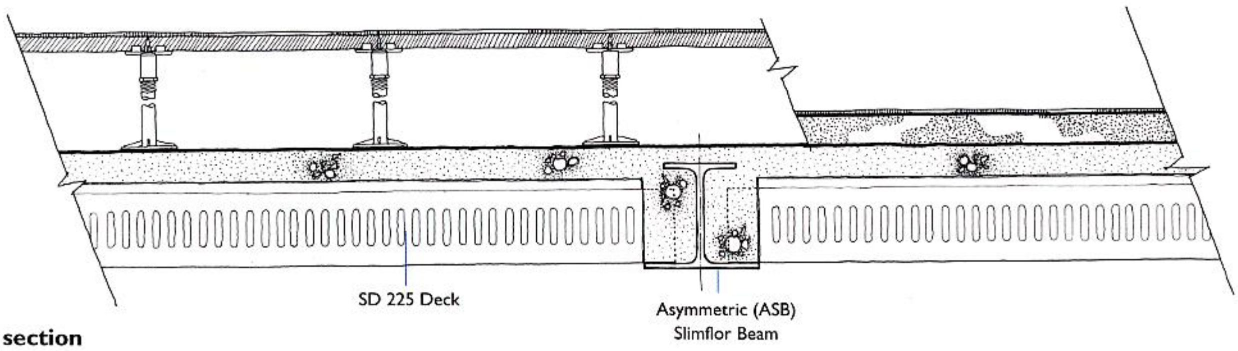
Air conditioning upgrade possibilities

Duct and pipework routes within voids

Location of chilled beams or other cooling elements within voids



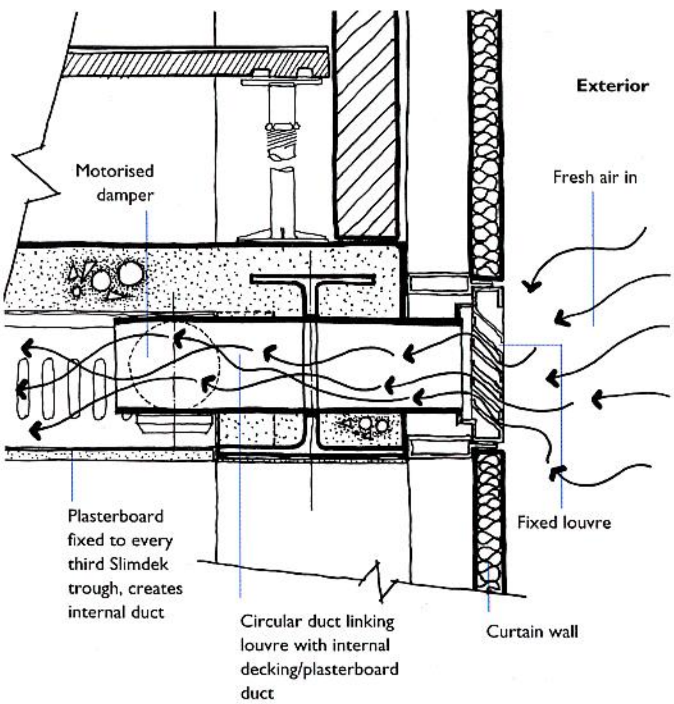
Cross section



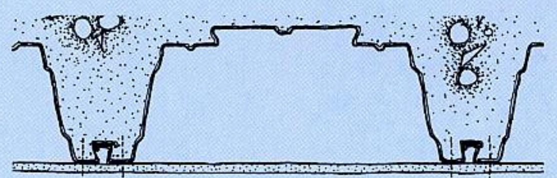
Long section

Section through floor and envelope intersection

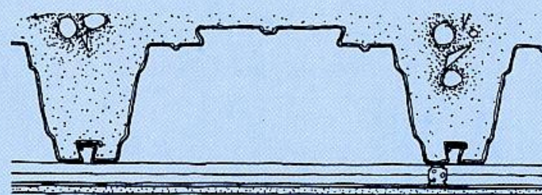
By fixing plasterboard to every third or fourth profile trough, a series of internal ducts are created which are linked to the exterior via louvres fixed into the curtain walling systems. Fresh air can therefore be introduced into deep plan interiors via these ducts.



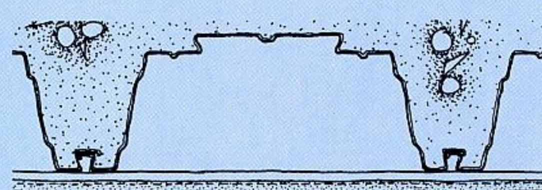
Flat ceiling finishes



15 mm plasterboard fixed direct to soffit at 230 mm centres

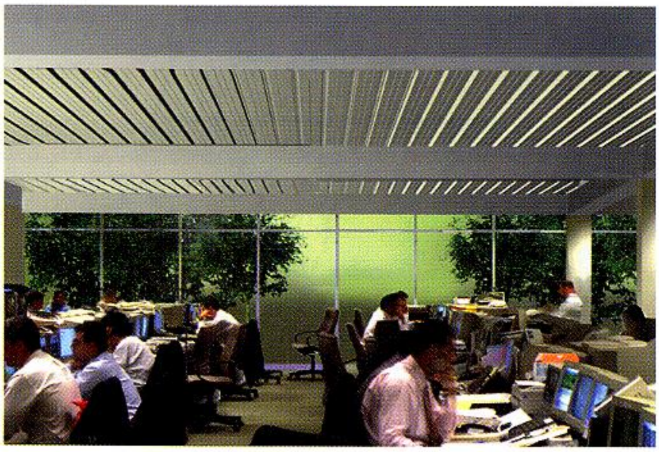


12.5 mm plasterboard ceiling using Gyproc 'Gypliner' system fixed at 1200 mm centres



EML (Expamet, Riblath or similar) and 13 mm, 2 coat plaster finish fixed at 600 mm centres

Composite systems

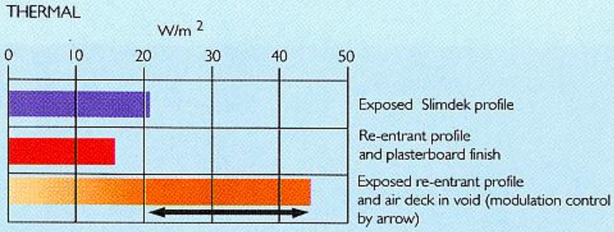


DESCRIPTION

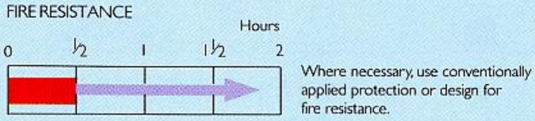
This system uses one of the range of composite shallow steel decks typically less than 100 mm deep of either the trapezoidal or re-entrant sectional form. The typical span of the deck is up to 3.5 m with an approximate slab depth of 130 mm overall. The supporting steel beam may be designed to act compositely with the slab by the inclusion of shear studs welded to the top flange of the beam.
Fire protection must be applied to the beam if a fire rating of over 30 minutes is required. This can be fire protection board, sprayed vermiculite, plaster or intumescent coatings. The last is available factory applied to beams. A screed is optional.

PERFORMANCE

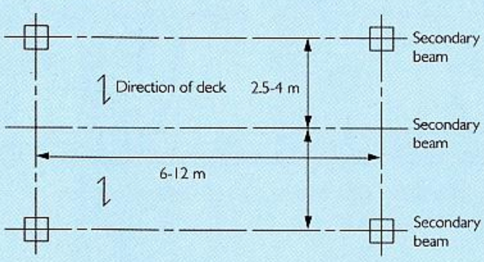
THERMAL



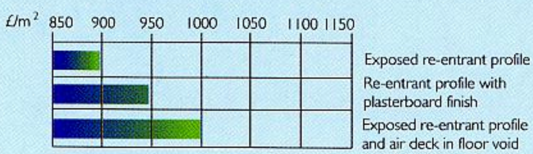
FIRE RESISTANCE



TYPICAL SPANS



INDICATIVE COSTS (AS APPLIED TO WHOLE OF BUILDING) see also page 28



FABRIC ENERGY STORAGE SYSTEMS

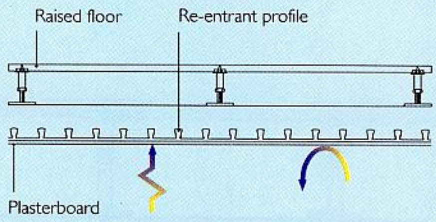
Passive air flow FES systems (natural ventilation)

Exposed profile with high emissivity finish

A high emissivity finish is desirable to ensure good radiative heat transfer. Thermal performance – 10% better than exposed flat soffit due to increased surface area.

Plasterboard finish

Thermal performance reduced by 30% for re-entrant profile due to insulating effect of plasterboard. Performance is reduced by 50% for trapezoidal profile which has a lower profile/plasterboard contact area.



RE-ENTRANT PROFILE WITH PLASTERBOARD

Open grid suspended ceiling with high emissivity finish on profiles

Similar performance to exposed profiles, however the ceiling will provide integration options with lighting and other services.

Solid suspended ceiling

Limited indirect thermal access possible with suitable choice of ceiling materials.

Active FES systems (mechanical ventilation)

These systems can provide upgrade paths from the passive options to improve performance and/or control (refer also to page 8-11):

Raised floor void

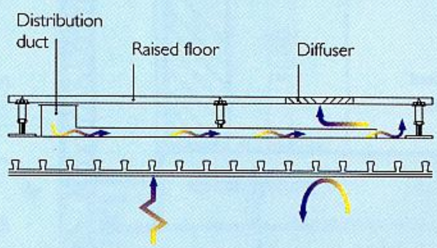
Heat exchange between supply air and slab.

Air deck at top surface

Enhanced heat exchange between supply air and slab.

Space fan

Forced convection heat exchange at exposed slab surface.

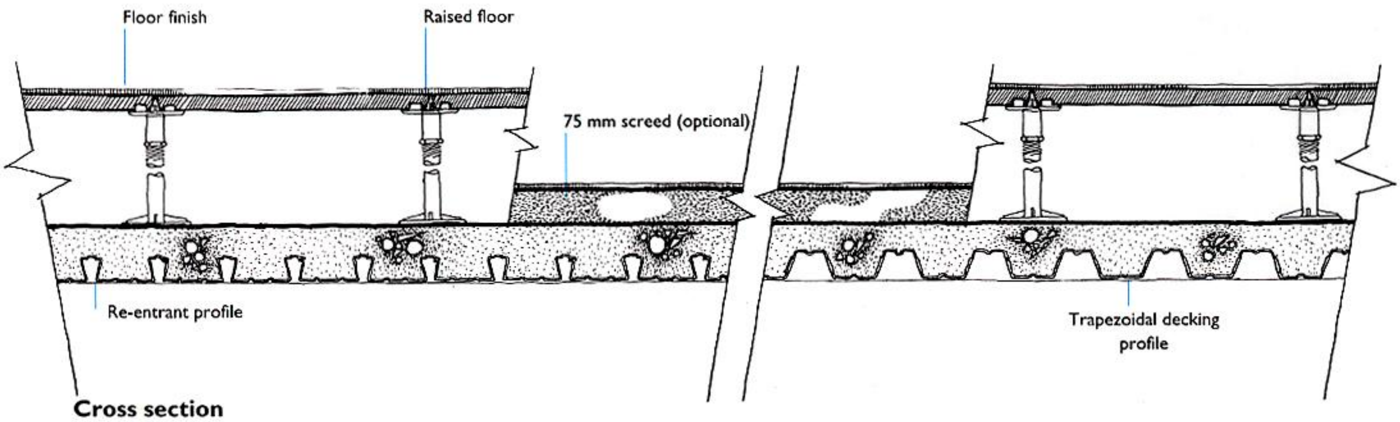


AIRDECK AND EXPOSED RE-ENTRANT PROFILE

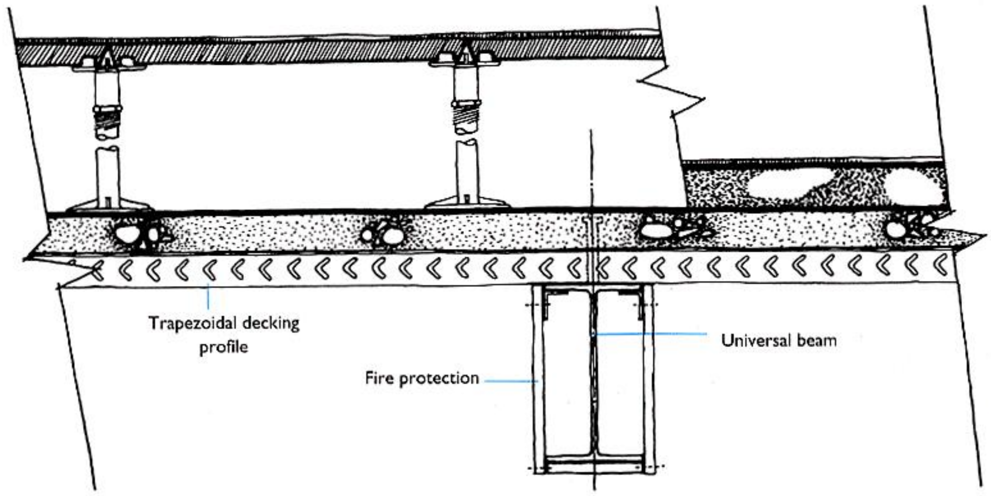
Air conditioning upgrade possibilities

Duct and pipework routes within beam casings

Location of chilled beams in beam casings

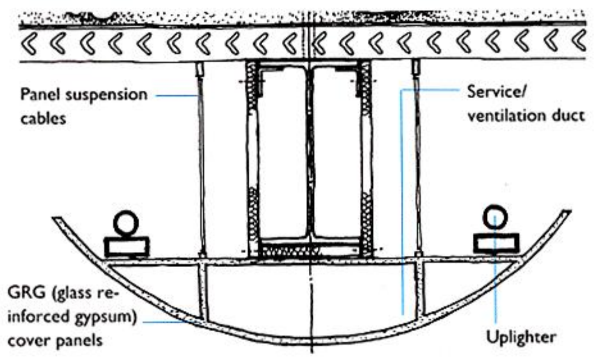


Cross section

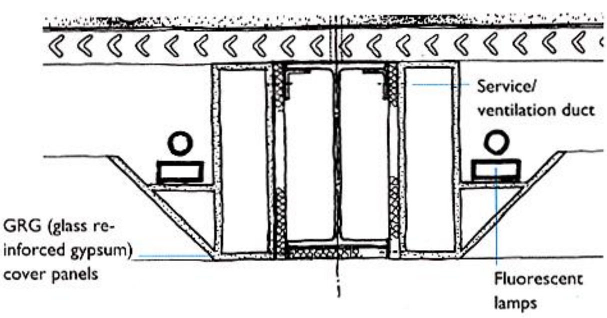


Long section

Beam casing options with indicative lighting solutions

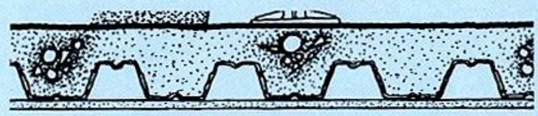


Option 1

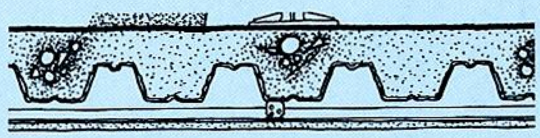


Option 2

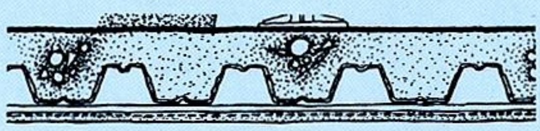
Flat ceiling finishes



15 mm plasterboard fixed direct to soffit at 230 mm centres



12.5 mm plasterboard ceiling using Gyproc 'Gypliner' system fixed at 1200 mm centres



EML (Expamet, Riblath or similar) and 13 mm, 2 coat plaster finish fixed at 600 mm centres

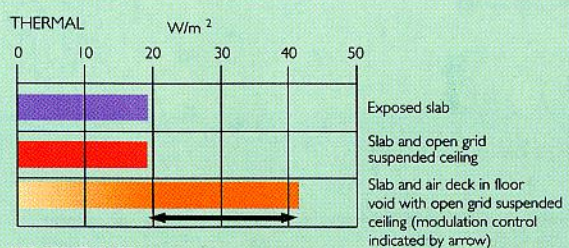
Steel frame and precast flat slab solutions

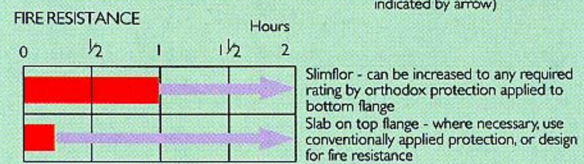
DESCRIPTION

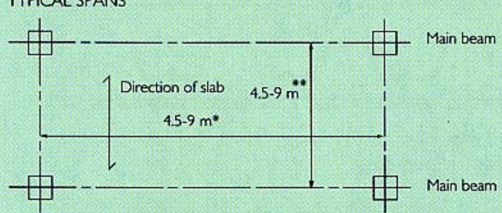
The flooring system uses precast planks typically spanning 4.5 - 9 m which can be up to 1.2 m wide. The depth of the units will vary depending upon span and reinforcement but typically range from 150 to 400 mm. Using the illustrated systems the smaller units in the range can be rapidly dropped into position within the steel frame. Two arrangements for supporting beams are shown, a Slimflor beam (top) and a standard Universal Beam (UB), right, centre. The Slimflor beam is fabricated by welding a plate to the bottom flange of a Universal Column (UC) section. The beam supports the precast units, and allows rapid placement. An in-situ, concrete structural infill around the beam and over the precast units provides stiffness and also prevents the passage of flame, smoke and gasses in the event of fire. Typically, up to 1 hour fire resistance is achieved by the unprotected Slimflor beam. The system using UB sections supports the precast units on the top flange. The minimum flange width that provides an adequate bearing for the precast units is 150 mm. Composite action can be achieved by welding shear studs to the top flange. These usually fit into pockets in the precast units. Fire protection to the beam is required and can be one of several types - board, sprayed vermiculite, plaster or intumescent coatings. The last is available factory applied to beams.

Slimflor® is a registered trademark of British Steel and is covered by patent.

PERFORMANCE

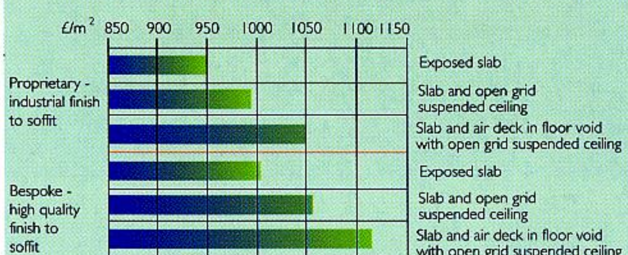




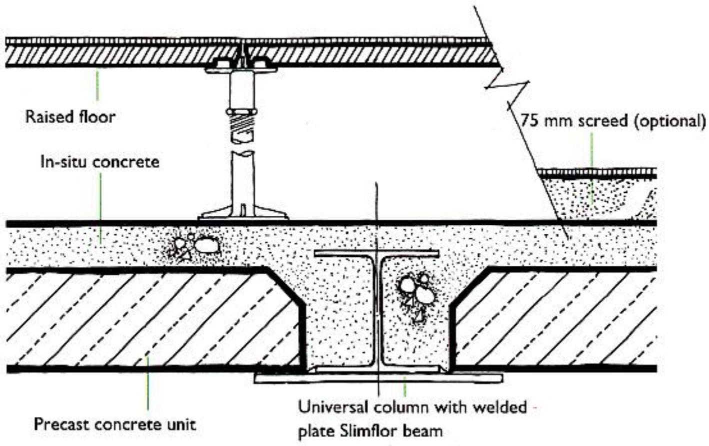


*For slim floor beam, but could be up to 12-15 m for downstand beam.
**If precast unit are pretensioned, they can span up to 12 m

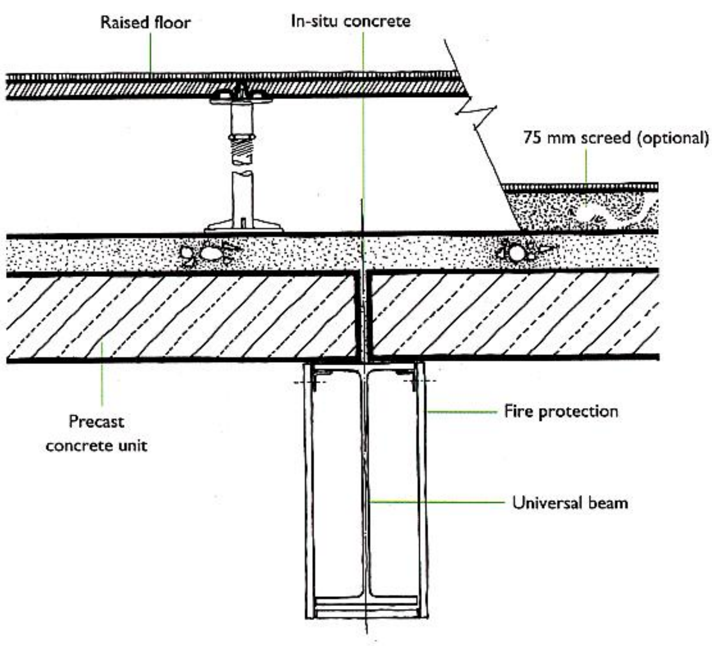
INDICATIVE COSTS (AS APPLIED TO WHOLE OF BUILDING) see also p 28.



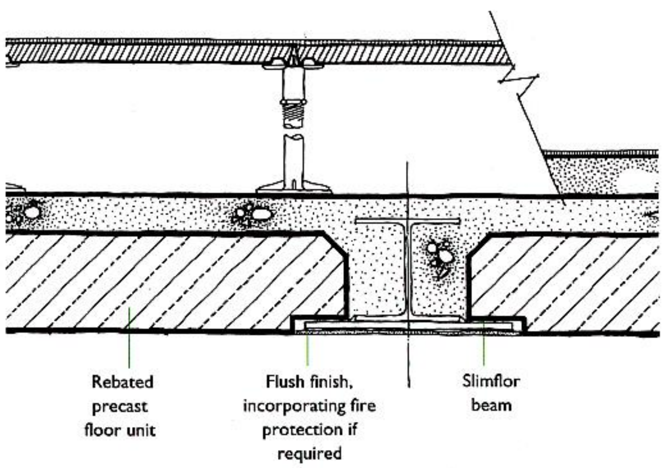
Slimflor beam and precast unit floor



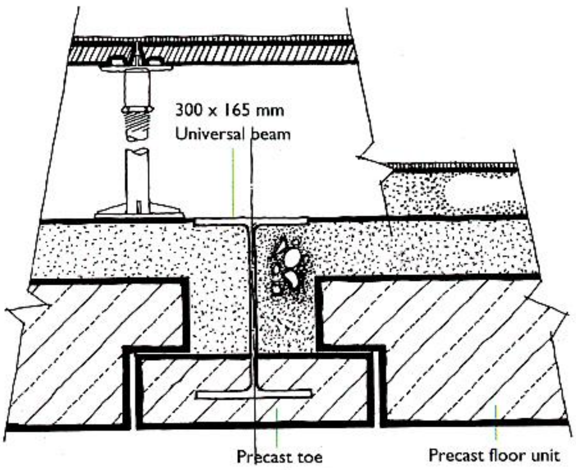
Steel universal beam precast plank floor



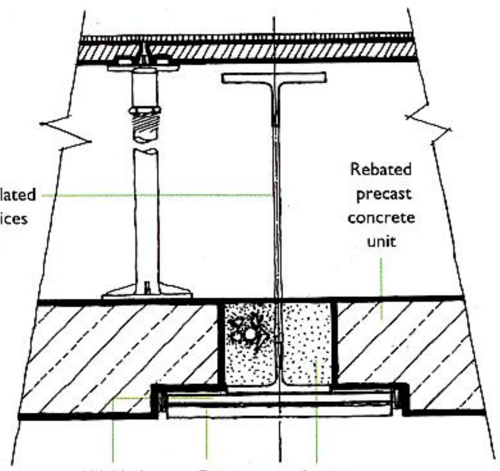
Slimflor beam and rebated precast unit with flush soffit



Universal beam and precast floor providing flush soffit

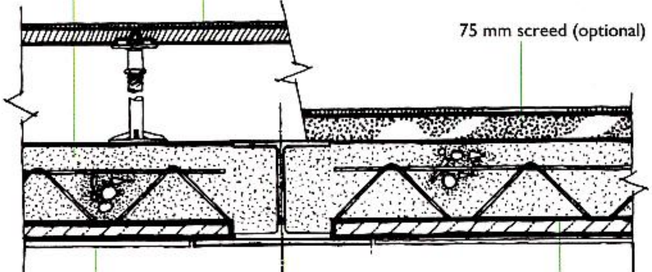


Cellform or castellated beam and rebated pre-cast units

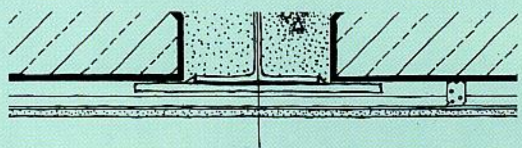


Omnia system

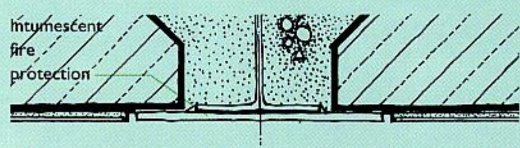
This system, which uses a thin precast reinforced concrete plate, is available as 'Omnidec' from Birchwood Omnia Ltd, to provide permanent formwork to in-situ topping. Support details can be similar to any of those for conventional precast units. The floor slab typically spans 6-8 m although spans greater than 10 m are possible. A variety of finishes to the soffit can be specified.



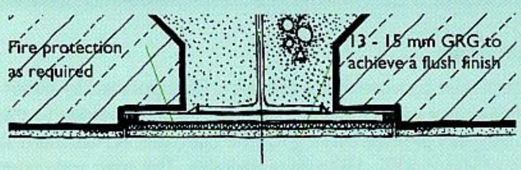
FLAT CEILING FINISHES



12.5 mm plasterboard ceiling using Gyproc 'Gypliner' system fixed at 1200 mm centres



15 mm plasterboard with optional skim coat fixed direct to soffit at 230 mm centres



13 mm, 2 coat plaster finish fixed at 1200 mm centres

FABRIC ENERGY STORAGE SYSTEMS

Passive air flow FES systems (natural ventilation)

Exposed soffits

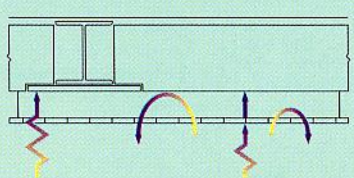
A high emissivity finish is desirable to ensure good radioactive heat transfer.

Plasterboard finish

The insulating effect of plasterboard will reduce performance to 20% less than an exposed flat soffit. However, the plasterboard will offer significant acoustic absorption.

Open grid suspended ceiling

Similar performance to exposed soffit, but the ceiling will provide integration options with lighting and other services.



Solid suspended ceiling

Limited indirect thermal access possible with suitable choice of ceiling materials.

Active FES systems (mechanical ventilation)

These systems can provide an upgrade path from the passive options to improve performance and/or control:

Raised floor void
Heat exchange between supply air and slab.

Air deck at top or bottom surface
Enhanced heat exchange between supply air and slab.

Hollow core system
Enhanced heat exchange

Air ceiling
Enhanced heat exchange between supply air and slab, plus heat exchange at exposed air ceiling surface.

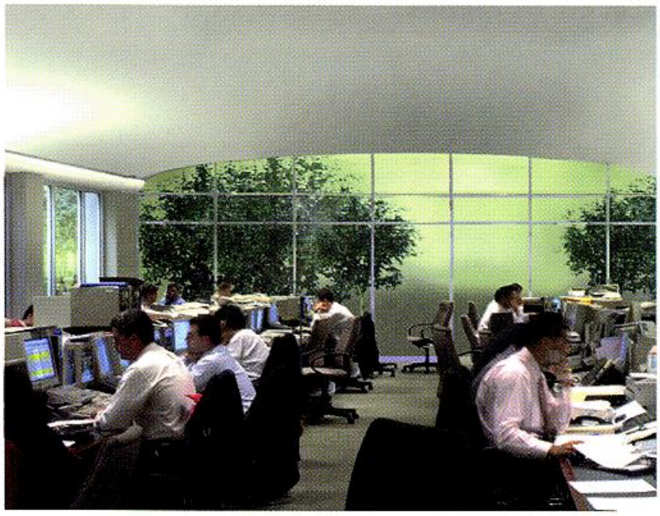
Space fan
Forced convective heat exchange at exposed slab surface.

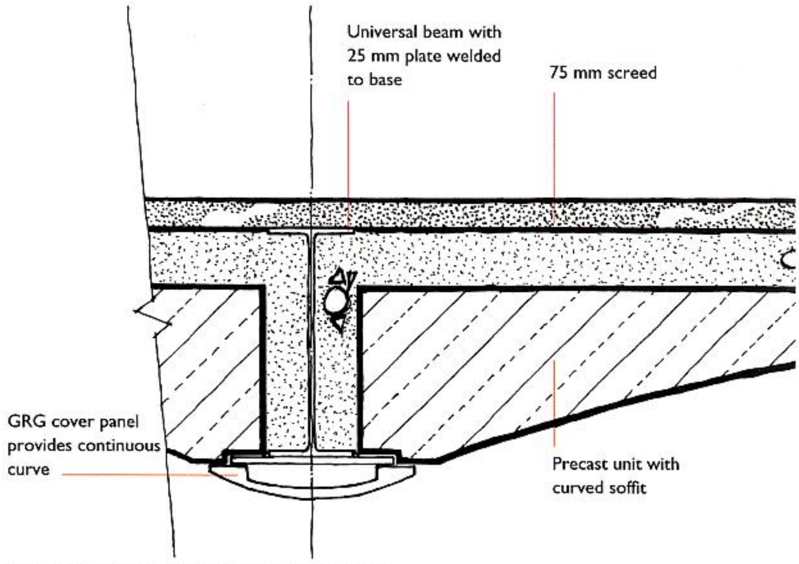
Air conditioning upgrade possibilities

Duct and pipework routes within beam casings

Location of chilled beams in beam casings

Steel frame and precast curved slab solutions





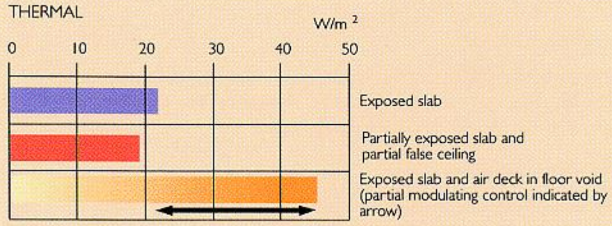
DESCRIPTION

This system uses purpose made precast units supported by either a Slimflor® Beam or by a Universal Beam with a plate welded to the bottom flange to provide bearing for the concrete. A maximum slab thickness of about 100 - 150 mm is advisable. The span and curvature of the slab then determines the depth of the supporting steel beam (approximately 450 - 600 mm). However, shallower beams can be used if spans and loading conditions permit.

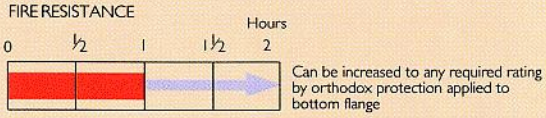
*Slimflor® is a registered trademark of British Steel and is covered by patent.

PERFORMANCE

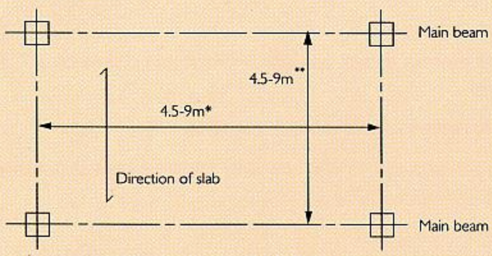
THERMAL



FIRE RESISTANCE

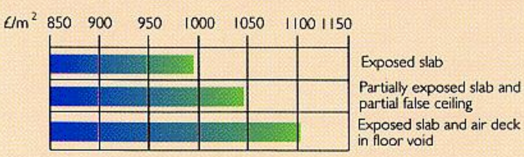


TYPICAL SPANS



*For Slimflor beam but could be up to 12-15 m for alternative beams
**If precast units are pretensioned, they can span up to 12 m

INDICATIVE COST (AS APPLIED TO WHOLE OF BUILDING) see also p 28



FABRIC ENERGY STORAGE SYSTEMS

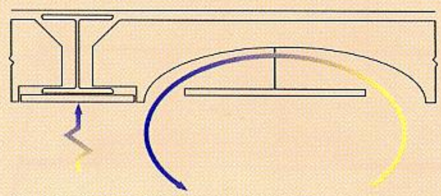
Passive air flow FES systems (natural ventilation)

Exposed soffits

A high emissivity finish is desirable to ensure good radiative heat transfer. Greater surface area will typically increase thermal performance relative to a flat soffit by 20%.

Partial suspended ceiling

This will normally be insulating, offsetting the increase in thermal performance due to the greater surface area. Overall performance will typically be similar to an exposed flat soffit. However, the ceiling offers integration options with lighting and other services and can provide significant acoustic absorption through suitable material selection.



PRECAST CURVED WITH PARTIAL SUSPENDED CEILING

Active FES systems (mechanical ventilation)

These systems can provide an upgrade path from the passive options to improve performance and/or control:

Raised floor void

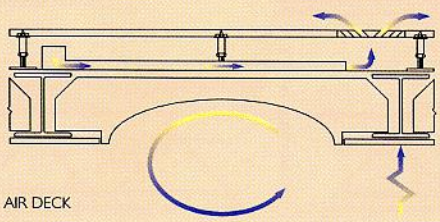
Heat exchange between supply and air and slab.

Air deck at top surface

Enhanced heat exchange between supply air and slab.

Space fan

Forced convective heat exchange at exposed slab surface.

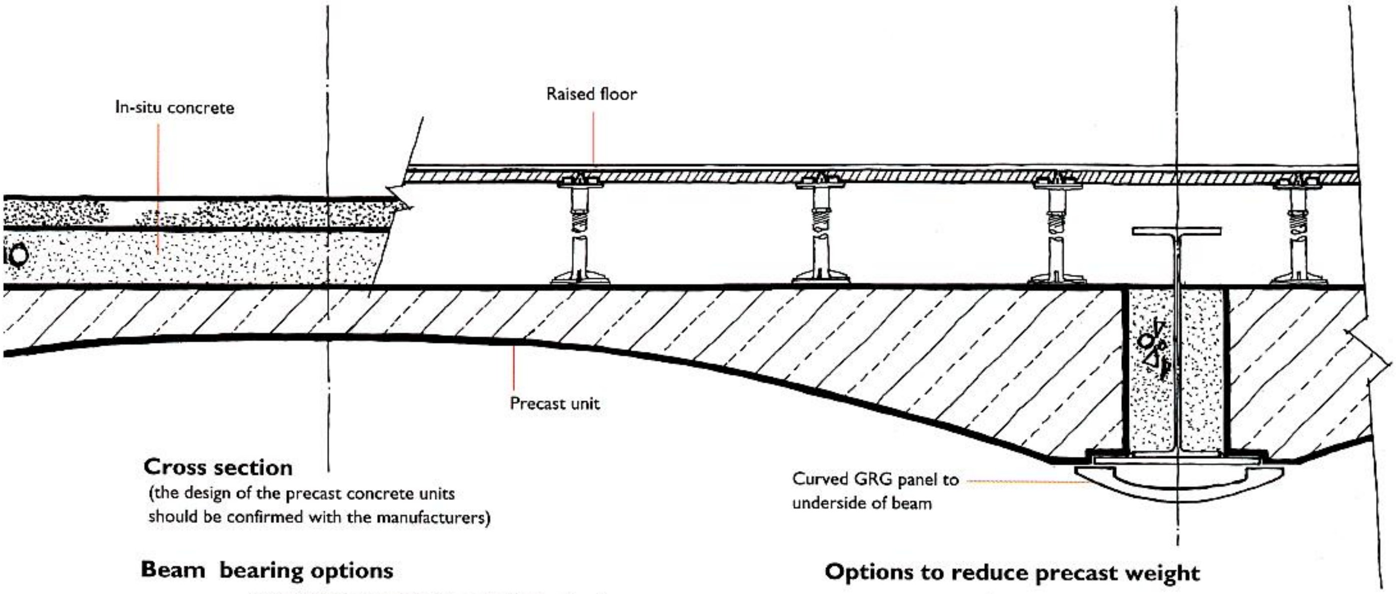


AIR DECK

Air conditioning upgrade possibilities

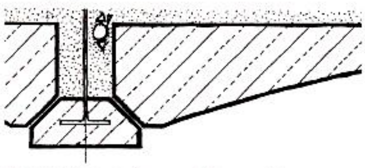
Duct and pipework routes above partial false ceiling

Location of chilled or other cooling elements above partial false ceiling

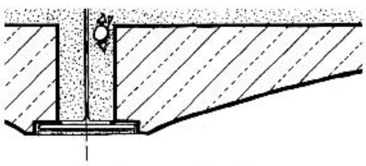


Cross section
(the design of the precast concrete units should be confirmed with the manufacturers)

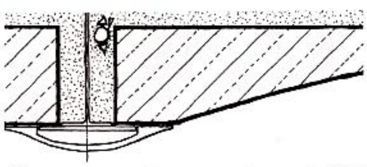
Beam bearing options



Precast toe and curved floor unit

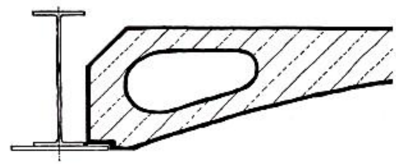


Rebated precast floor unit with flush finish at beam

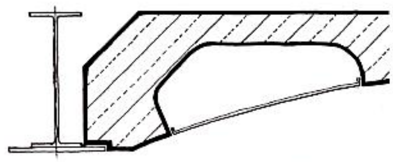


Flat precast unit bearing with curved GRG panel

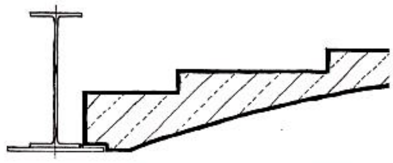
Options to reduce precast weight



Precast unit cast with void

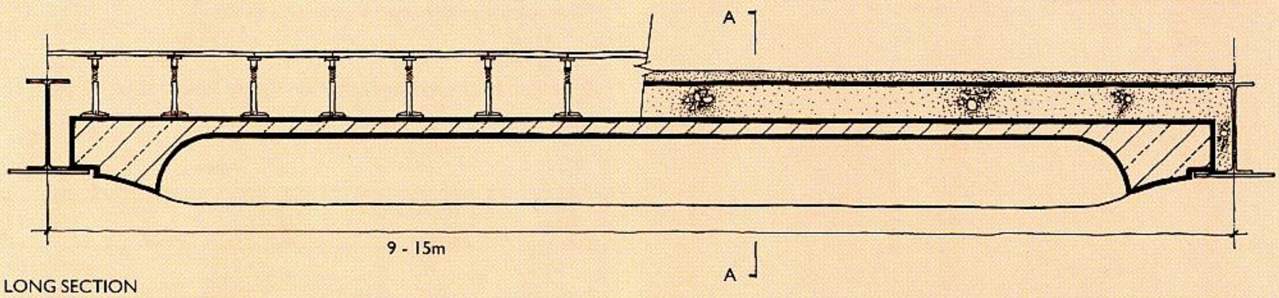


Precast unit cast with services void and curved GRG panel

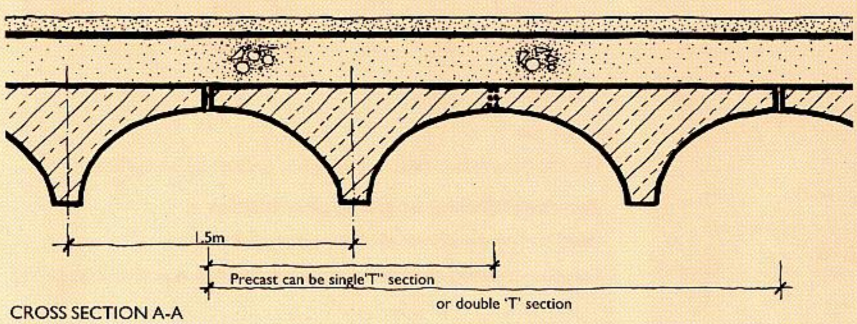


Step cast precast unit - used with adjustable raised floor system

Long span solutions



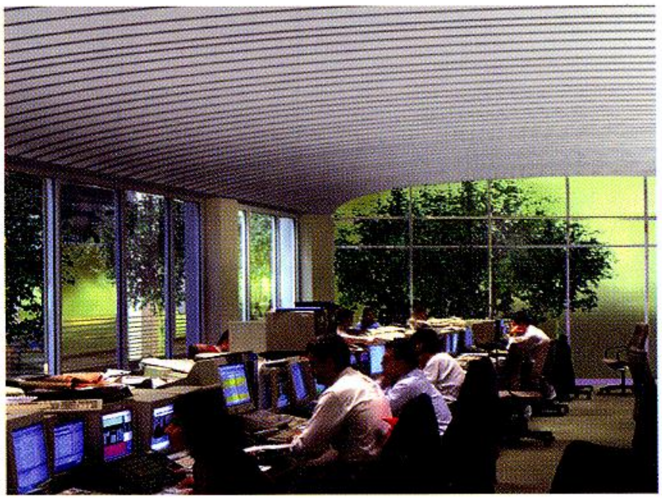
LONG SECTION

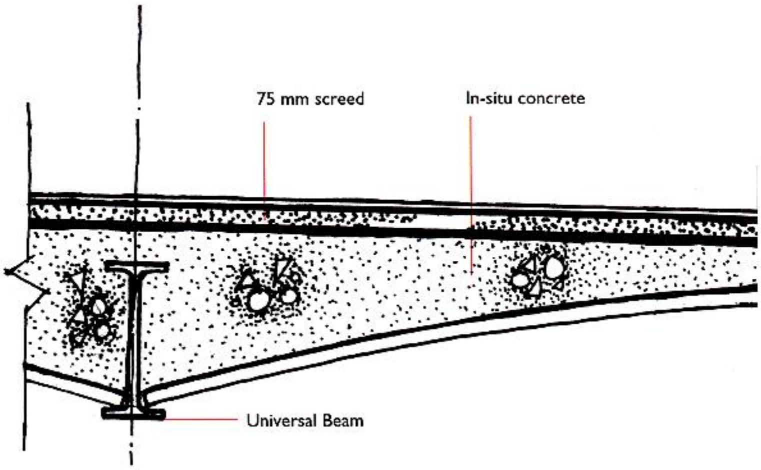


CROSS SECTION A-A

As an alternative to spanning in the short direction between the supporting steel beams, curved precast concrete floor units could be designed to span in the longitudinal direction, taking advantage of the increasing structural depth where the slab is thickest. The ends of such units can be supported on conventional steel framing, but the edges may be unsupported. However, it will be necessary to ensure lateral stability both during construction and in service and adequate tying should also be provided. This can be achieved by steel beams located within the depth of the floor construction.

Archdeck systems



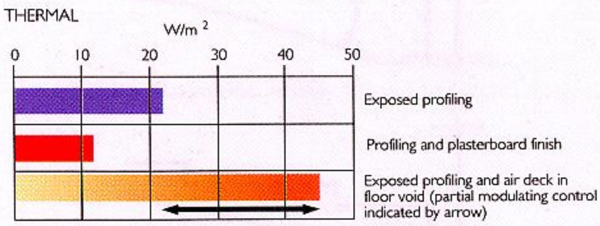


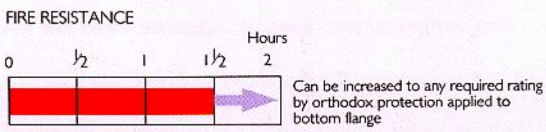
Arch deck section
(note, the design of the Archdeck system should be confirmed with the manufacturers)

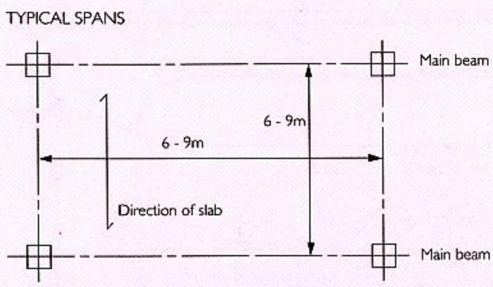
DESCRIPTION

This system uses special curved profiled steel decking available from Ward Building Components, supported on the bottom flange of conventional Universal Beams. The Archdeck typically spans 6-9 m, as does the supporting beam. The depth of concrete at the crown of the arch is generally about 100 mm. At the supporting beam, the concrete effectively provides fire protection and no additional applied protection is necessary for fire resistance periods up to 90 minutes.

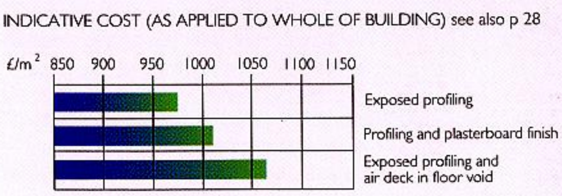
PERFORMANCE







*For Slimflor beam but could be up to 12-15 m for alternative beams



FABRIC ENERGY STORAGE SYSTEMS

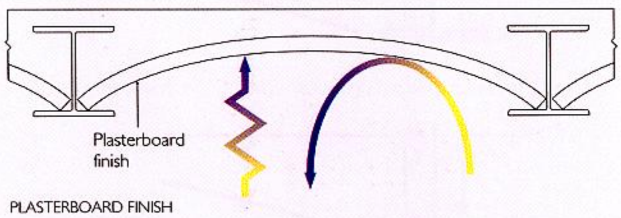
A Passive FES system (natural ventilation)

Exposed profiles with high emissivity finish

A high emissivity finish is desirable to ensure good radiative heat transfer. Thermal performance 10% better than exposed flat soffit due to increased surface area.

Plasterboard finish

Thermal performance reduced by 50% due to insulating effect of plasterboard.



Active FES systems (mechanical ventilation)

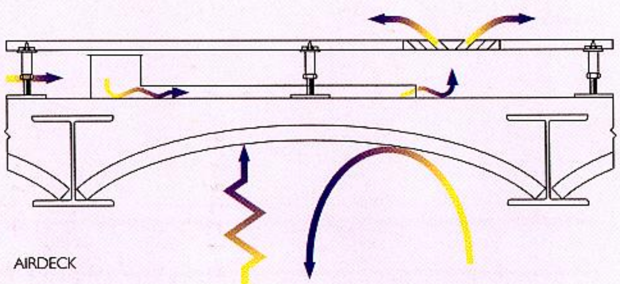
These options can provide an upgrade path from the passive options to improve performance and/or control:

Raised floor void

Heat exchange between supply air and slab.

Air deck at top surface

Enhanced heat exchange between supply air and slab.



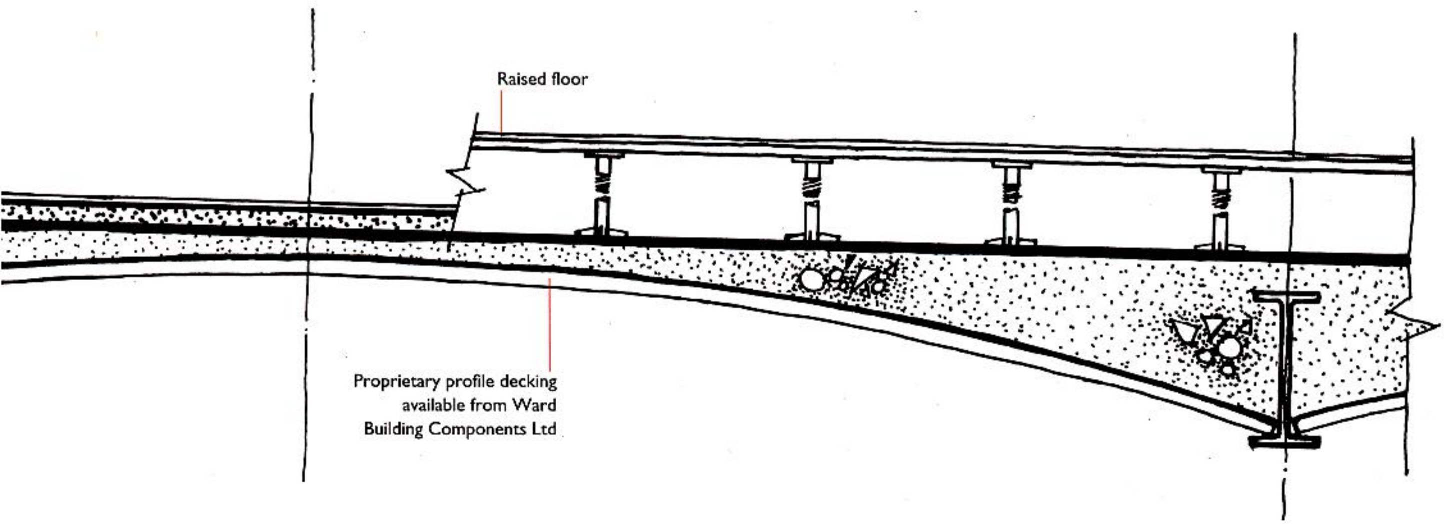
Space fan

Forced convective heat exchange at exposed slab surface.

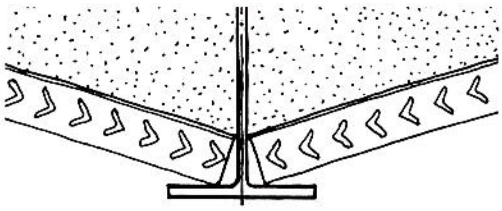
Air conditioning upgrade possibilities

Duct and pipework routes above partial false ceiling

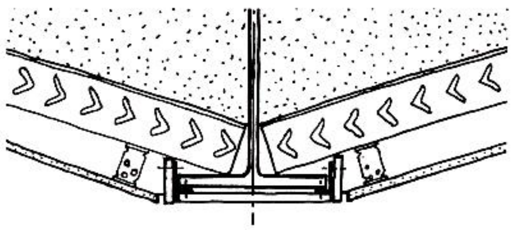
Location of chilled or other cooling elements above partial false ceiling



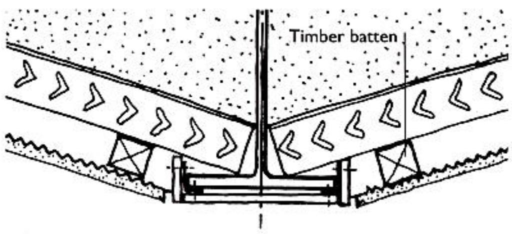
Beam bearing options



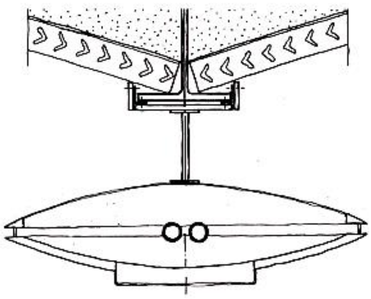
Beam to archdeck - exposed



Beam to archdeck - with fire protection and gyproc plasterboard system

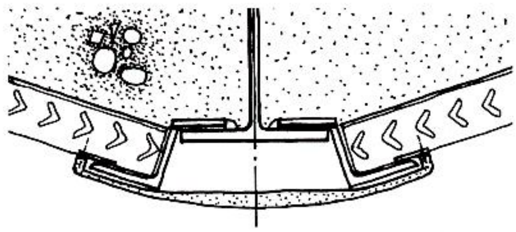


Beam to archdeck - with fire protection and EML and plaster finish

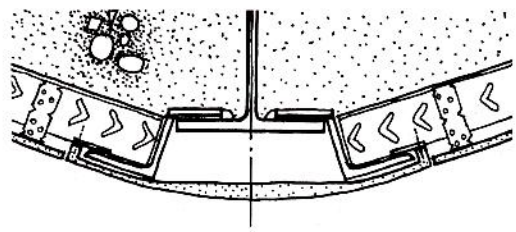


Beam to archdeck - with fire protection and lighting system

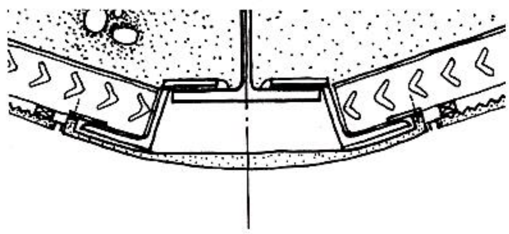
Dropped angle bearing options



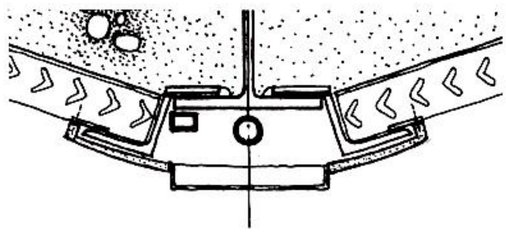
Archdeck with angle supports and glass re-inforced gypsum (GRG) cover



Archdeck with angle supports and GRG cover strip



Archdeck with angle supports, GRG cover strip and EML and plaster finish



Archdeck exposed with angle supports and lighting system

Lighting systems and fabric energy storage

As the largest consumer of electricity in office buildings and a substantial generator of ambient heat, lighting can have a dramatic effect on construction techniques and the efficacy of fabric energy storage systems.

The advent of fluorescent lighting has allowed the creation of the deep plan office, often with the window wall functioning only as a vision slit, providing minimal daylight contribution. The energy efficient office, making maximum use of daylight is likely to be of much shallower plan. The function of the window wall has now become more complex, allowing view, accepting daylight and attenuating glare. In order to allow daylight to penetrate deeply into the office, floor to ceiling heights will need to be increased. An example of this would be by allowing the window line to follow a waveform ceiling's shape and using the greater floor to ceiling height at the top of the arch. Soffits and downstand beams may be angled upwards at the window/wall to reduce obstruction and effectively increase window height.
The fundamental lighting criteria listed below should be considered when designing any office environment:

THE HUMANE OFFICE

Offices contain people, often using information technology, their skills and imagination to not just complete the day's tasks, but to ensure the future wealth of the organisation. The biggest cost in an office is not its electricity bill, but its wages bill. The successfully designed office lighting system should not be just energy efficient and compliant with regulations, but provides a visual environment that boosts productivity and reduces absenteeism.

ILLUMINANCE LEVELS

Most offices require 300-500 lux to provide adequate, workable illuminance.

CREATING INTEREST

Good lighting helps people work more efficiently by creating an interesting and comfortable environment. To this end, the view beyond the work station of the far wall, ceiling and colleagues should be lit in a balanced and interesting fashion.

LAYOUT

Layout and function often change in the working environment. Light levels and positioning of luminaires should, to some degree, be able to cope with these changes.

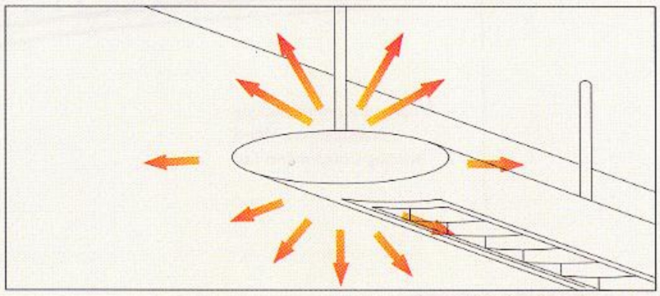
INFORMATION TECHNOLOGY

Information technology is now a standard feature, therefore lighting techniques, levels and balances of illuminance across all room surfaces, and the control of glare must take into account the use of display screens.

The following pages illustrate, in general terms, types of lighting that may be used in a variety of fabric energy storage constructions. It must be stressed that, due to the scope and versatility of lighting technology, appropriate aesthetic and performance criteria can almost always be met whatever the type of construction.

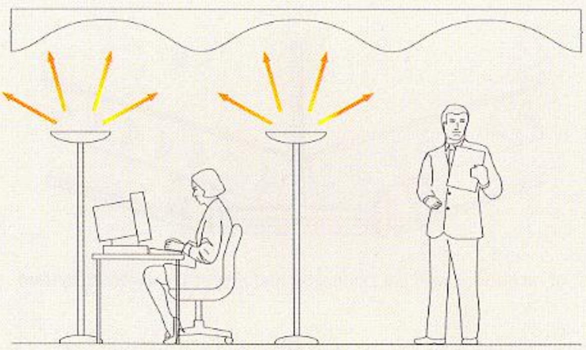
TYPES OF LIGHTING

DIRECT AND INDIRECT LIGHTING



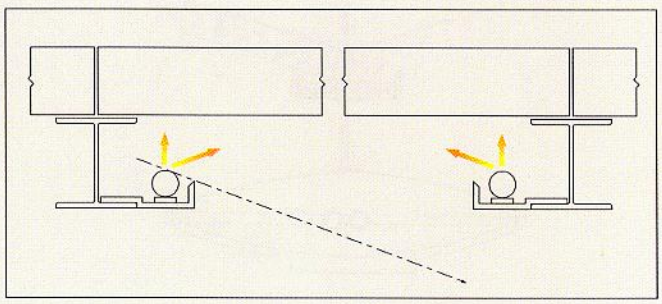
Light is received on the working plane both directly from the luminaire and indirectly by reflectance off the ceiling - often with the two components separately switchable. Where daylight linking or occupancy sensing results in only some parts of the ceiling surface being lit, the visual result may be patchy and not harmonious. Well designed systems ensure that the luminaire body itself is gently diffusing and thus is not visible as a dark silhouette against the ceiling.

UPLIGHTING



Uplighting creates a bright space, but the 'flat' light may make modelling a little soft. Energy consumption of 4-7 W/m^2/100 lux is greater than direct lighting due to the inherent losses in reflection and longer light path. Ceiling heights must be adequate to ensure a gradual transition of brightness across the ceiling, with no 'hot spots' directly above luminaires. Where floor or furniture mounted uplights are used, consideration should be given to cable management and switching.

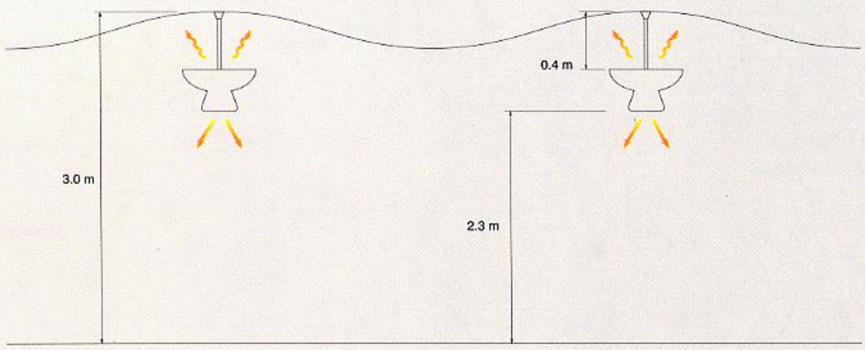
CORNICE SYSTEMS



These may be incorporated into the edge of vaulting, as an architrave, or integrated with the downstand beam. They may either provide indirect, or direct-indirect lighting. Where the luminaire forms part of the extract or air supply path, excess cooling or heating of the lamp's surface can reduce light output.

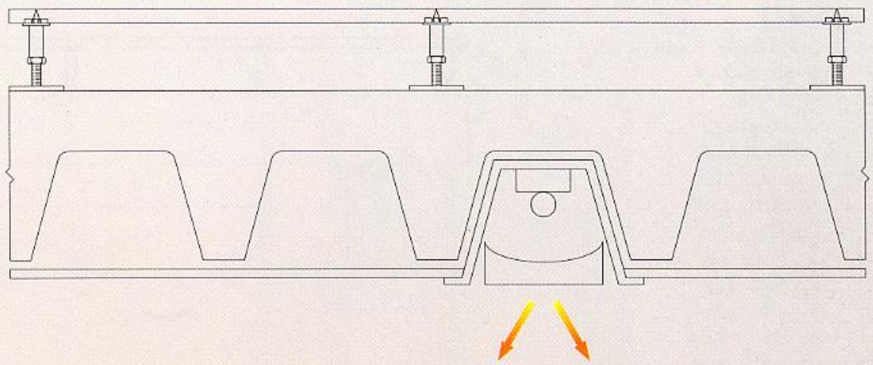
PROFILED CEILING

These constructions have been frequently lit using pendant, floor or furniture mounted uplights or direct/indirect lighting, as shown in illustration, (right). This technique uses the soffit as a large area reflector, which, to be efficient, must have reflectance of at least 70-80%. A gloss factor of no more than 10% is required, otherwise lamp images will be visible. Uplighting techniques are particularly useful where the soffit is not serviced, or where its sculptured form may be successfully accented.



STEEL DEEP OR SHALLOW DECKS

Single lamp luminaries may be recessed into the flat soffit providing direct lighting, with the body housed in the troughs of the steel Slimdek®. If the soffit is uplit, care should taken to achieve a surface reflectance of 70-80% across the ceiling plane and a gloss factor of less than 10%.



ARCHED AND FLAT SLABS

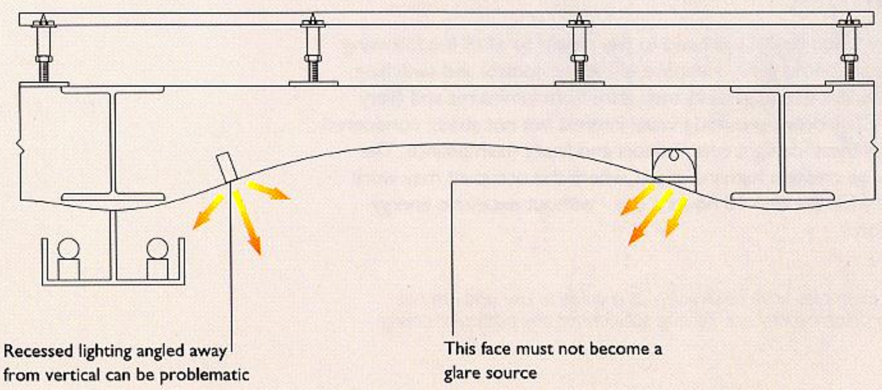
Where downlight luminaires are recessed into the angled soffit of precast slabs, two aspects must be addressed.

(1) If flush with the soffit, the luminaire will be tilted away from the downward vertical such that glare may be created.

(2) If a casting box is used, so that the luminaire sits horizontally up within the slab, the lower protruding edge must not 'catch' the light so that it becomes a glare source.

Three simple rules of geometry apply in vault lighting; the horizontal distance of the lamp from the wall should be half of the vault's vertical height, the full face of the lamp must 'see' two thirds of the vault; and the lamp must be shielded from the view of a standing observer on the other side of the room.

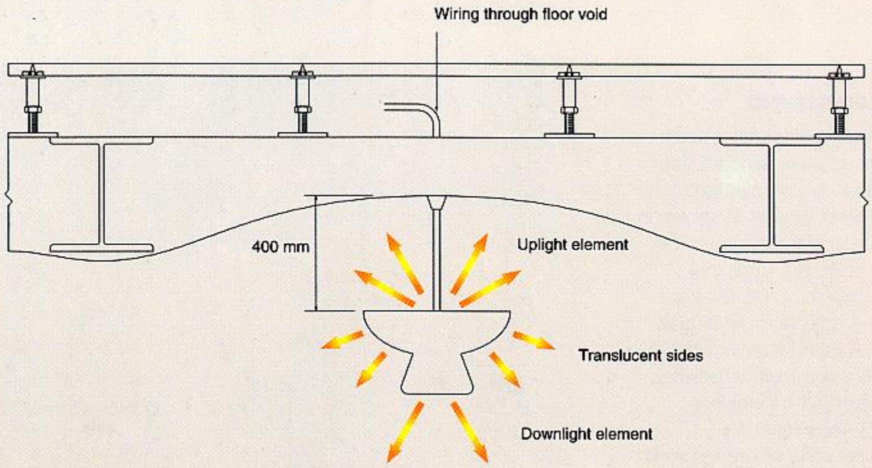
Note that 'cast-in' luminaire positions must be determined at an early design stage and they cannot be moved to reflect changes in office use.



Lighting systems (cont.)

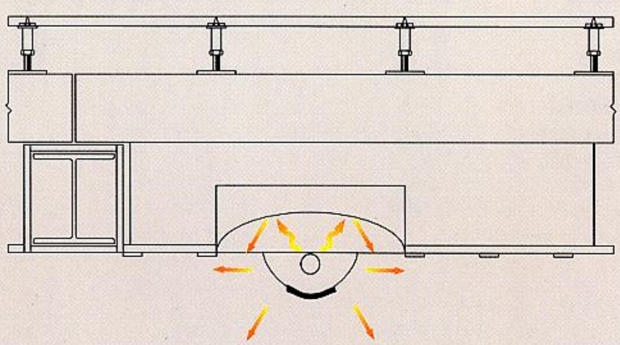
WAVEFORM & VAULTED CEILINGS

These constructions may become integrated with direct/indirect lighting systems and combine the advantages of direct systems, i.e. modelling and efficiency with those of indirect systems, giving a brighter space with better balanced brightness. Pendant systems, often mounted as continuous booms, may be co-ordinated with acoustic treatments.



SUSPENDED CEILINGS

Either full or partial. Commonly lit by the easily integrated, recessed, modular, louvered, low brightness downlights, these are energy efficient, 2-3 $W/m^2/100$ lux. However the lit result is often characterised by dark tops of walls and a dark ceiling, which can be oppressive. Recessed direct/indirect luminaires (as shown right) are available, where part of the diffuser can 'see' the ceiling, then the ceiling plane will be brightened.



SUMMARY

In summary, good design will need to pay regard to all of the following: lamp efficacy; control gear; luminaire efficiency; control and switching; surface reflectances and gloss factors; glare from luminaires and (very importantly) windows; providing visual interest but not stress; considered surface brightness; daylight contribution; and finally maintenance. The objective is to create a humane space, where the occupant may work productively for the 8 to 10 hours a day - without excessive energy consumption.

N.B.

The above examples have been given as a guide to use and are not intended to prescribe any one lighting solution for any particular ceiling system.

Making use of fabric energy storage in retrofit situations

Utilising the thermal capacity present in existing buildings can help to upgrade their performance. This can be achieved at relatively low cost as part of a major refurbishment; in response to changes of use; or increasing internal heat loads. It can lead to significant savings in the running costs of cooling plant, or in some cases, the elimination of the need for mechanical cooling. Maximum benefit is likely to be gained when exposure of the thermal capacity mass is used in conjunction with the introduction of cooler air into the building during the night time to absorb and remove heat stored.

IMPROVING THERMAL LINKAGE

In most commercial buildings, floor slabs are, by far, the most significant element in terms of fabric thermal storage. Thus, most benefit is likely to be gained by exposing the top and bottom surfaces of the floor slab. It may also be possible to utilise the hollow cores of slabs, if such a slab has been installed.

EXPOSING THE SOFFIT

Clearly, an exposed soffit provides direct exposure of the slab. Where a false ceiling is installed, two main options exist for directly linking the air within the room space to the slab:

REMOVAL OF THE CEILING

Aesthetically pleasing solutions may be achieved along the lines of the illustrations provided in the early Sections of this document. However, costs and problems associated with relocating or replacing services such as lighting and partitions that are integral with the false ceiling, may limit this approach to cases of major refurbishment, or to open plan offices.

REPLACEMENT WITH AN OPEN GRID CEILING

This option allows the services that may be present in the ceiling void to remain concealed by providing a ceiling that enables heat exchange between the air and the underside of the floor slab. In many cases, such a solution may be more feasible than exposing the soffit as it will often be possible to co-ordinate with existing services resulting in less disturbance to the building (although the slab surface and the services may need to be painted black to achieve this).

Fans can be used to increase air movement across the lower surface of slab, thus improving heat transfer (as well as improving air circulation within the space). They provide a controllable means of boosting the output of the system and can be located either in the occupied space or in the ceiling void above.

Air ceilings are highly suited to retrofit applications, particularly in combination with fresh air fan coil units located within the office space. They provide a medium-cost, high-performance solution with modulating control. The penalty in terms of lost floor-to-ceiling height is minimal, at approximately 50 mm, and high quality ceiling finishes are possible, incorporating lighting and achieving a variety of acoustic effects.

EXPOSING THE TOP SURFACE OF THE FLOOR SLAB

Where a false floor exists in a building, the simplest approach is to use the void beneath as a supply air plenum. Air decks can be used, as described earlier, to improve performance and control, and thermally to isolate the supply air from the slab. As with air ceilings, a particularly attractive option for retrofit would be to use air decks in conjunction with local fresh air fan coil units on a modular basis. The loss in void height from the use of air decks will be about 50 mm. Consideration will also need to be given to integration of the air deck with the existing flooring system supports.

Where no false floor exits, difficulties associated with altering floor heights (changing doors, etc.) may discount the use of the air deck floor system in retrofit applications. In such buildings the floor finish is important and avoiding the use of insulating floor finishes will help increase heat transfer between the floor slab and the air within a space.

INTRODUCING AIR INTO THE BUILDING AT NIGHT

The cooling effect achieved when exposing thermal mass in an existing building can be increased by introducing cooler night-time air to pass over the slab. This can be achieved by the use of either natural or mechanical ventilation.

NATURAL VENTILATION

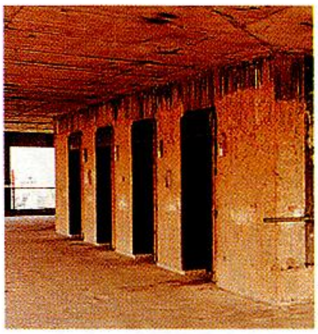
For a typically naturally ventilated building, automating existing windows or other openings, or providing new ones for automated night ventilation may prove problematic at a reasonable cost, except when glazing systems or whole curtain walling system are being replaced as part of major refurbishment. Security issues must also be addressed. In many cases, therefore, mechanical ventilation option may be more suitable.

MECHANICAL VENTILATION

Where a mechanical ventilation system is already installed for daytime use, it will generally be most cost-effective to use this also for night ventilation (except where the fan pressure drop is very high, reducing cooling potential and requiring high fan energy consumption).

Fitting a new centralised mechanical ventilation system with a ductwork distribution system in an existing, non-mechanically ventilated building is unlikely to be practical in most cases due to space restrictions on service routes. A modular system using local, fresh air fan coil units is likely to be the most feasible approach.

OFFICE REFURBISHMENT



The refurbishment of outdated 60s and 70s office buildings, which are characterised by high operational energy consumption and poor thermal efficiency, is an increasing trend. This process is typified by the refurbishment of New London House in the City of London where the existing building was stripped down to the structural frame and a complete refurbishment carried out, including new envelope and services providing much greater energy efficiency. This was completed in the early 90s by Allies Morrison architects.

EXAMPLE OF ENERGY EFFICIENT RETROFIT

The new cladding at Regency House includes fixed glazing, trickle ventilators operated by pull cords at the top, and ventilation hoppers at the bottom (Photography courtesy of Montresor Partnership)

Regency House, a four-storey office building constructed in 1957 in Weston-Super-Mare, was refurbished by Montresor Partnership Architects in 1995 (AJ 13-6-96). To avoid the use of air conditioning, the curtain walling was replaced to allow controllable ventilation for night-time purging of the heat stored in the exposed thermal mass. The new wall cladding provides fixed glazing for natural light and views, controlled by internal louvre blinds; trickle ventilators at the top of the glazing for background ventilation; and bottom hung ventilators (as illustrated above) installed around the perimeter, protected by wire mesh screen and louvres on the outside (for security and weather protection). During the day, occupants control the amount of ventilation by opening the hoppers or pulling the pull cord operating the trickle ventilators. At night, in the summer, it has been found that leaving the hoppers open allows cross ventilation cooling the exposed mass and significantly reducing internal temperatures the following day.

Cost analysis

The indicative costs included within the performance box of each generic floor system and as detailed in the table below, have been provided by Davis Langdon & Everest (DLE). The costs are at January '97 price levels, assuming an outer London location and have been compiled by reference to DLE's own database together with discussion with specialist suppliers/manufacturers. The costs for each generic floor system do not include structural columns, floor finishes, different possible lighting solutions and the effect each particular floor system would have on storey height and the integration of services.

The difference between the comparable cost of each system must be considered in relation to the overall construction cost of the building. Reference to the '*Offices of the Future Cost Model*' by DLE (published in the Procurement Supplement to Building magazine, September '96), suggests that an appropriate total construction cost, in this instance is approximately £1050 m².

The cost model is based on a specification level equivalent to the precast flat (proprietary finish) enhanced floor system. The indicative costs shown in the performance box of each generic floor system have been calculated by reference to this specific cost.

Explanation of terms (for table below)

Basic systems: Exposed soffit with suitable decorative finish. Manually openable windows for natural ventilation during the day. Automatic vents for night cooling. Perimeter heating.

Basic systems with ceiling/soffit treatment: As 'basic option', but with the addition of either plasterboard/plaster or eml to the soffit if suitable. If unsuitable, the inclusion of an open grid suspended ceiling.

Active systems: These systems are enhanced and include mechanical ventilation systems for daytime ventilation and night cooling. Perimeter heating.

ELEMENT	Structural steelwork	Steel fire protection	Composite decking & reinforced concrete topping	Temporary propping	Proprietary flat precast planks and reinforced concrete topping	Bespoke curved precast rebated planks and concrete infill	Raised floor	Decorations to soffit	Exposed grid suspended ceiling	Plasterboard ceiling	Plasterboard suspended ceiling	Inlet grilles, dampers & thermal controls	Air core system	Air deck system	Central plant & controls	Sub totals	Preliminaries (8%)	Contingencies (5%)	**Totals**
Basic systems (£/m²)																			
Slimdek	25		26				39	5				32				127	10	7	144
Composite deck	29	5	14				39	5				32				124	10	7	141
Precast flat (P)	43				41		39			14		32				169	14	9	192
Precast flat (B)	43				99		39	3				32				216	17	12	245
Precast curved	29					100	39	7				32				207	17	11	235
Arch deck	35		77	4			39	5				32				192	15	10	217
Basic systems (£/m²) with soffit treatment																			
Slimdek	25		26				39		18			32				140	11	8	159
Composite deck	29	5	14				39			14		32				133	11	7	151
Precast flat (P)	43				41		39		18			32				173	14	9	196
Precast flat (B)	43				99		39		18			32				231	18	12	261
Precast curved	29					100	39	7			17	32				224	18	12	254
Arch deck	35		77	4			39	5	18			32				210	17	11	238
Enhanced systems (£/m²)																			
Slimdek	25		26				39		18				20		60	188	15	10	213
Composite deck	29	5	14				39	5						20	60	172	14	9	195
Precast flat (P)	43				41		39		18					25	60	226	18	12	256
Precast flat (B)	43				99		39		18					25	60	284	23	15	322
Precast curved	29					100	39	7			17			20	60	272	22	15	309
Arch deck	35		77	4			39	5						20	60	240	19	13	272

Notes:

Precast flat (P) = Precast flat proprietary system

Precast flat (B) = Precast flat bespoke system with fair face soffit finish

Glossary

Building fabric
The physical fabric of the walls, floors, etc. of the building

Charging rate
The rate at which thermal mass can absorb heat

Conduction
A form of heat transfer caused by the vibration of molecules, principally occurring in solids, (lattice vibration and transport of free electrons)

Convection
A form of heat transfer occurring mainly in fluids (air). Convection is the bulk movement of air to and from a surface. This can be by natural forces, or forced by mechanical means

CO_2
Carbon dioxide - the principal gas implicated in global warming

Embodied energy
The energy used to find, mine and convert raw materials into construction components and then transport and build them into structures

Emissivity
A measure of the efficiency of a surface in absorbing and radiating electromagnetic radiation.

Discharging rate
The rate at which thermal mass can release heat

Fabric energy storage
Heat stored within the materials forming the mass of the building

Forced convection
Air movement and heat transfer resulting from some form of mechanical propulsion

GJ
Giga Joule = 1 Joule x 10^9

Greenhouse effect
The natural mechanism that is responsible for global warming

Heat exchange (transfer)
The passing of heat from one medium to another, e.g. from air to the surrounding walls, floor and ceiling. In buildings the mechanism of heat exchange within a room is by convection and radiation

Internal gains
Heat gains to internal spaces from people, office machines and other electrical appliances, lights and solar gains.

Joule
Joule - a measure of energy
KW Kilo watt = 1 Watt x 10^3
KWh Kilowatt hour = 3.6 x 10^6 Joules or 3.6 Mega Joules (MJ).

Modulating control
The ability to increase or decrease one variable (e.g. heat transfer) by changing a second variable which can normally be directly regulated (e.g. air flow)

Natural convection
Air movement (and heat transfer) resulting from natural bouyancy forces, i.e. pressure differences caused by wind or the stack effect.

PJ
Peta Joule = 1 Joule x 10^{15}

Radiation
A form of heat transfer from one surface to another by electromagnetic waves

Surface heat transfer coefficients
The rate (in W/m^2K) at which heat is transferred from one material to another (e.g. air to concrete) at a temperature difference of $1K/m^2$

Temperature gradient
The temperature difference across a material or surface

Thermal capacity (mass)
The ability of the building fabric to store/discharge thermal energy. This is determined by two key factors:
i) Thermal linkage/access
ii) Thermal mass

Thermal exchange
The exchange of heat between materials (e.g. from air to concrete)

Thermal linkage/access
These factors are ostensibly the same. They are important factors in determining the heat transfer between the internal air and the building/structural fabric

Turbulent air movement
Non-laminar flow characteristics by increased air movement (eddies and vortices) at the surface

W
Watt - a measure of power
(1W = 1 Joule/second)

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