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Summer cooling
Using thermal capacity

IT heat loads are increasing the problems of summer overheating. BRE research indicates how a building's thermal capacity can reduce this risk while avoiding air-conditioning. **Barrie Evans** reports.

Using the thermal mass of a building to reduce mean temperatures and temperature fluctuations has obvious potential, clearly demonstrated in massive structures like cathedrals. But methods of effectively harnessing thermal mass are not well established. In part, this is because once one moves away from the massive simplicity of the cathedral, thermal mass becomes one factor difficult to disentangle from others — orientation, shading, ventilation, insulation, lighting and more. It is also because making thermal capacity readily available in modern offices requires changes to current design traditions.

Typically, any significant thermal mass is likely to be in the slabs (and, to a much lesser extent, in the external skin or in fixed partitions). The underside of slabs can be exposed to the room by missing out the suspended ceiling. This allows heat to be absorbed, reducing air and radiant temperatures. It also gives the opportunity for night-time, fresh-air ventilation through the space to be used to cool the slab, so increasing its daytime capacity. The top of the slab will usually be significantly insulated from heat exchange with the space by a carpet and/or raised floor. Even with no mass exposed, night-time cooling through open windows can be beneficial. And, with suspended ceilings and raised floors, night air can be mechanically driven through these voids to cool the slabs. In the daytime, ventilation air delivered through the voids can, in turn, be cooled by the slabs.

To shed light on this emerging area of expertise, BRE commissioned a study of recent offices which have attempted to avoid or minimise the use of air-conditioning, predominantly by the use of thermal mass to limit peak summertime temperatures.

Integrated design

The case studies show that the use of thermal mass and night-time cooling ventilation are likely to prove disappointing unless the building is also designed and managed to minimise heat gains. Integrated design must include an effective building fabric, solar control devices, efficient and well-controlled lighting and, where possible, avoid the siting of hot equipment in general office spaces. Localised equipment hot spots can be more easily cooled. Further design guidelines identified are as follows:

- measurements suggest that the most effective and lowest energy way of cooling a building at night is to leave the windows open. Weathertight, secure windows need to be developed for this purpose, and someone has to be responsible for opening and closing them under a combination of manual and automatic control. Window opening becomes a key part of the environmental system. Manual window opening alone may be unreliable by day and ineffective at night when windows may need opening or closing during the period. The difficulty of achieving this has been one stimulus for using mechanical ventilation
- significantly greater benefits of thermal mass are achieved by exposing some of it to the occupied space — typically this is by using the underside of the slab as the ceiling. This absorbs heat and keeps down radiant temperatures. Also, the slab underside, typically being higher than a suspended ceiling, increases air volume per person, and allows warm air to stratify more effectively with the hottest air above head height and near the ceiling. In addition, it allows more effective cross-ventilation and daylight penetration. However, if night cooling is not effective, temperature swings can be reduced but the mean radiant temperature of the exposed ceiling remains high, possibly higher than for a suspended ceiling
- with an exposed slab soffit as the ceiling, it is difficult to extract ventilation air at ceiling level. With floor extract instead, there can be greater heat build-up near the ceiling and greater warming of the ceiling mass than with heat extract through recessed light fittings in a suspended ceiling
- three of the buildings used the raised floor space as a plenum for inlet ventilation air. (One had ducted supply using the void as a return-air plenum. However, the slab would then tend to be nearer room temperature.) Night cooling of the slab was attempted in these three buildings by passing air through the void, so that ventilation air passing over the slab during the day would be cooled by it. In practice, and for several reasons, this was less effective than expected. For example, air flow in underfloor voids is fairly slow and so tends to be laminar, thus heat transfer between air and slab surface is not as high as in a room with free natural convection. In one case the system was attempting to force air across a 32m void; air distribution requires planning with supply ducting and outlet grilles at calculated intervals. Also, supply air to the void can be warmed by heat conducted downward from the room through the raised floor. The swirl diffusers used in three cases may not be the right floor outlet devices as

The research on offices was carried out as part of the DoE Construction Directorate's Energy Related Environmental Issues Research Strategy. This strategy is managed by the BRE and aims to reduce CO_2 emissions associated with the UK building stock.

mixing with room air occurs rapidly near the floor. This makes the system less effective at producing displacement ventilation — cooler air at low level with warmer air above head height. Some similar mixing, undesirable from the stratification point of view, is also produced by desk fans and natural ventilation of the space

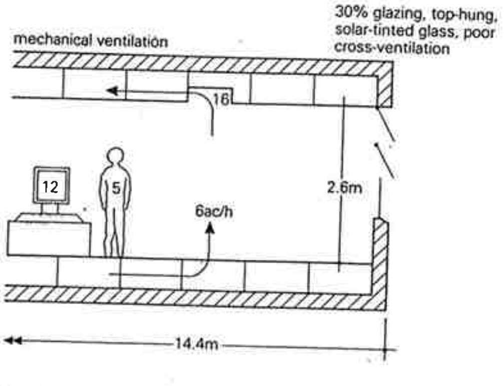
- supply air for cooling can be significantly warmer than outside air by the time it arrives in the space. The wasted cooling potential occurs, for example, because air intakes may be poorly positioned — in one case on a slate-coloured pitched roof, in another through louvres on a flat roof. Heat gains from fans and general plant can add 1-2°C (a vital, but apparently widely ignored, design aim is to keep fan energy consumption as low as possible)
- the design and implementation of mechanical night-time ventilation is not an exact science. For example, some systems did not respond much to changes in outdoor temperatures; in some buildings, fan power was even found to introduce a significant amount of heat. Generally, night-time cooling ventilation needs more careful designing than buildings usually get. Other research indicates that in some cases energy may not be saved at all by night cooling; energy saved on cooling was instead spent on fan power. It may be that Britain should follow some US recommendations and install a separate system for mechanical night ventilation
- where night ventilation systems existed, building managers did not always appreciate their role nor did they receive the right information to run the building. For example, in the daytime on hot days three of the buildings were over-ventilated, bringing in unnecessarily large quantities of warm fresh and recirculated air, and raising room temperatures; thus demonstrating that it is possible to over-ventilate. In temperate climes like the UK, our habit is to close up buildings at night and open them in the day; in warmer climes with cool nights people tend to do the opposite — open at night, closed in the day. Such climates may be a better model to bear in mind when thinking about overheating in UK buildings
- the intermittency of solar energy and natural ventilation are testing for building controls. To overcome this, electronic building management systems offer the potential to provide the technical resource to make decisions and to advise building managers when and where things are going wrong. Unfortunately, however, BRE is finding that, at present, this is seldom, if ever, done. Given the difficulty of getting buildings right first time, such information is needed for tuning the building in use. The services rule is keep it simple, and provide good information
- high on the list of major variables in integrated design is lighting energy. The installed lighting load for average new office buildings is 15-20 W/m^2. One case study building had a high-efficiency system rated at 11 W/m^2. Another had 25 W/m^2 in open offices, 32 W/m^2 in cellular offices. The difference, of 21 W/m^2, is equivalent to a reasonably high IT heat load. The energy rating is not, of course, the entire lighting story; there is also significant potential for energy saving in the controlled use of lighting. Unfortunately, once again, many installations studied did not even meet the simple criteria of the 1983 BRE Digest 272 on lighting. Making effective use of daylight in open-plan, VDU-populated environments is also proving difficult — especially where there are continuous strips of windows and where standardised arrangements make it nearly impossible to allow individual adjustments of furniture and VDU positions
- another key variable is solar shading. While external overhangs and louvres are more effective at keeping out summertime heat gains than internal blinds, internal blinds are often needed in addition for glare control, and once fitted, they often stay down with lights on.

Case studies

As a condition of the research, the buildings must remain anonymous. So the following six case descriptions cannot fully give a feel of form, fabric and services working together as a whole system. But, as rare examples of simply monitored buildings in operation, the studies do give a good sense of what actually goes right and wrong and thus offer insight in to the aspects of strategy and detail where the design team is likely to have to focus its attention.

Much of the BRE study covers detailed services design, control and commissioning, often poorly done, including design and control of windows. Here we restrict ourselves to points about servicing strategy, combined with points on fabric, lighting, solar shading, ventilation, mass and so on, as they affect summertime performance.

Building A



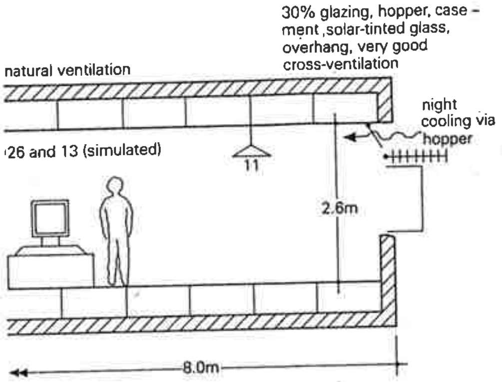
The diagram for each case study indicates the main energy-design factors. Heat gains for equipment, people and installed lighting are in W/m^2:

- heavy construction, thermal mass in slab, mass exposed to supply airflow in floor void; no night cooling
- 30 per cent south and north glazing
- solar-treated glass, no other solar protection
- open office (10 per cent cellular)
- internal depth 14.4m, no atrium
- floor-to-ceiling height 2.6m
- lighting 460 lux, 16 W/m^2, local and central manual switching, 75 per cent of lights on during monitoring
- equipment heat gains 12 W/m^2 by

day, 3 W/m² by night
- mechanical ventilation, air supply through swirl diffusers in floor, typically 6 ac/h
- no central building management system
- top-hung windows, cross-ventilation poor, window draughts problematic
- occupancy 20 m² per person (5 W/m²).

Among the study's conclusions: more sophisticated control procedures would be required to make the system work. In the daytime, intermediate floor slabs can be cooled by fresh-air supply from above, while being heated by exhaust air from below. If night cooling was introduced it should be passed over both sides of the slab. On hot days, mechanical ventilation rates were higher than needed for freshness and were introducing extra heat. Partial air recirculation in summer, heat from fans and other services malfunctions (such as disconnected dampers) contributed about 4°C to ventilation supply air temperature.

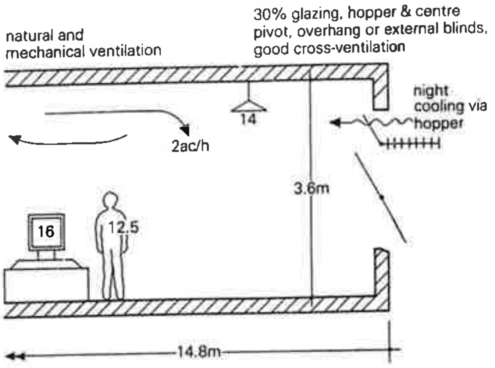
Building B



- Light construction, thermal mass in slab, no mass exposed, space night cooling via windows
- 30 per cent south glazing, solar-treated glass
- 1.5m external overhang for shading
- open office (20 per cent cellular)
- internal depth 8m, no atrium
- floor-to-ceiling height 2.6m
- lighting 420 lux, 11 W/m², local switching (7 per group), 100 per cent lights on for monitoring only
- equipment heat gains — varied during monitoring
- natural ventilation
- hopper and centre-pivot windows providing very good cross-ventilation with minimal window draughts.

Building was unoccupied at the time of the visit, so monitoring was completed using simulated people (light bulbs) and equipment heat gains. Even temperature distribution from edges to centre of space. Shading is important here but reduces daylight so lights (though efficient) are probably always on. Morning space temperatures were well controlled by leaving windows partially open at night, though temperatures do rise above external with average (37 W/m²) loads. It may be more robust to use low-energy lighting, good solar control and effective natural ventilation, as here, than to rely on mechanical ventilation, as in Building A, which requires very careful design, control and management. However, temperature swings are rapid for Building B and more exposed mass could have been beneficial. Building performance is very dependent on how occupants use the potential of window opening; cellularisation would hamper cross-ventilation for example.

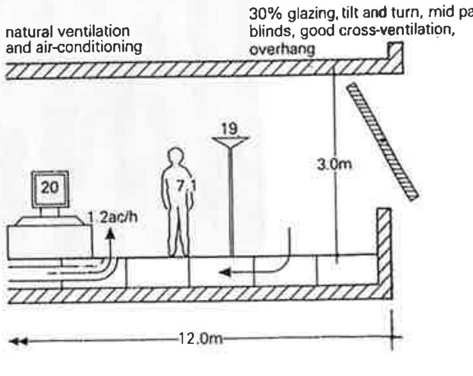
Building C



- Heavy construction, thermal mass in slab and walls, mass exposed as ceiling (and walls) and to extract airflow, night cooling of space via windows
- 30 per cent north and south glazing
- overhanging shading and internal Venetian blinds to south
- open office (15 per cent cellular)
- internal depth 14.8m to atrium
- floor-to-ceiling height 3.6m (3.1m to beam)
- lighting 350 lux, 14 W/m², local switching at 5 per bay and automatic switching
- equipment heat gains 16 W/m² by day, 3 W/m² by night
- mixed mechanical and natural ventilation, typically 2 ac/h mechanical with recirculation, some local air-conditioning
- central building management system
- hopper and centre-pivot windows, good cross-ventilation, minimal window draughts
- occupancy 8m² per person (12.5 W/m²).

No useful continuous monitoring data were obtained from this building (which is being measured again this summer). The strategy was to use orientation, solar protection, heavy concrete construction with external insulation high ceilings with exposed soffits, cross-ventilation, and high-speed ventilation for night cooling. In practice, mechanical night ventilation is not used because leaving the hopper windows open is felt to provide enough night cooling ventilation. Temperatures never rose above 27°C despit high external temperatures.

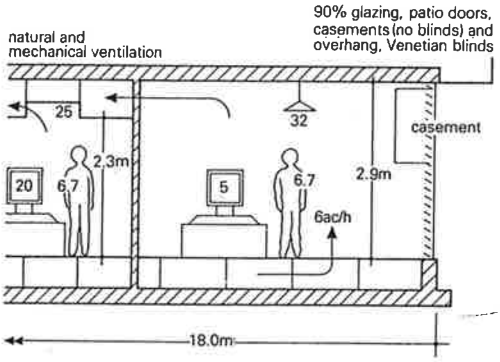
Building D



- Heavy construction, thermal mass in slab and walls, mass exposed in ceiling (and walls), and to floor-extract air flow
- 30 per cent glazing to east and west, 5 per cent north and south
- internal Venetian blinds to east, south, west
- open office (15 per cent cellular)
- internal depth 12.0m, no atrium
- floor-to-ceiling height 3.0m
- lighting 400 lux, 19 W/m², group switching, automatic, 25 per cent of lights on during monitoring
- equipment heat gains 20 W/m² by day, 3 W/m² by night
- natural ventilation and air-conditioning with recirculation, typically 1.2 ac/h
- central building management system
- tilt-and-turn windows, good cross-ventilation, draughts minimal in summer
- occupancy 14 m² per person (7 W/m²).

Designed as 'mixed mode' (mixing natural and mechanical air treatment) with exposed thermal mass, openable windows and minimum fresh air (rest recirculated). Intended to provide acceptable conditions without mechanical cooling most of the time, with fan coil cooling top-up if required. The exposed thermal mass of the ceiling is very effective in stabilising internal temperatures. There were difficulties in switching off the cooling when windows were opened, so management made cooling available all the time. The daytime summer space temperatures of 24-25°C are higher than normally acceptable; maybe the temperature stability and openable windows increase staff tolerance. Often these temperatures were higher than external air temperature, so plant could be run on full fresh air for cooling rather than mechanical cooling. Night cooling was not operated.

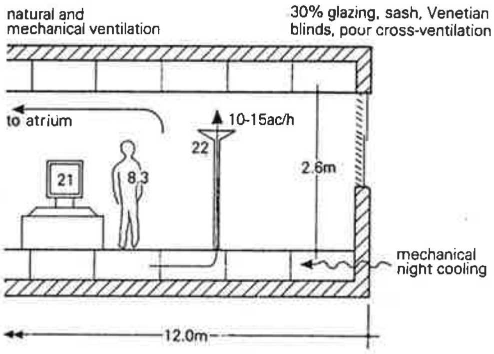
Building E



- Heavy construction, exposed mass in ceiling (and walls) and to supply airflow through floor void, mechanical night cooling of floor void
- 90 per cent north and south glazing
- external overhang and internal Venetian blinds to north and south
- 60 per cent cellular offices
- internal depth 18.0m, no atrium
- lighting 600 lux, 25 W/m² in open plan, 32 W/m² in cellular offices, group switching, 100 per cent lights on during monitoring
- equipment gains 20 W/m² by day, 4 W/m² by night in open plan
- mechanical and natural ventilation, 6.5 ac/h, air supply from floor through swirl diffusers
- central building management system
- patio doors and small casements, cross-ventilation to a central void, window draughts problematic, cross-ventilation of perimeter cellular offices via the ceiling plenum
- occupancy 15 m² per person (6.7 W/m²).

Thermal mass has a stabilising effect on space temperatures, and takes 0.5-1.5 °C off-peak air-supply temperature. But night cooling of the floor void reduced mean temperature by only around 2°C. Overall building performance was reduced by the high lighting load, and by the plant transferring heat to ventilation air, as for Buildings A and F, though less detrimental in total at around 2°C. When outside air is too cool at night, minimum fresh indoor air is recirculated. Staff complained at 24-25 °C internal temperature in core spaces, perhaps affected by feeling enclosed as in a sealed building. Night cooling would be more effective if air passed through the floor void to the outside rather than into the space; the energy cost of fans for night cooling is greater than the chiller energy cost/m² of Building D.

Building F



- Heavy construction, thermal mass in slab, mass exposed to supply airflow in floor void
- 30 per cent glazing to all four facades
- internal Venetian blinds to north and south, solar-treated glass
- open office (20 per cent cellular)
- internal depth 12.0m to atrium
- floor-to-ceiling height 2.6m
- lighting 470 lux, 22 W/m², local switching, 75 per cent of lights on during monitoring
- equipment heat gains 21 W/m² by day, 4 W/m² by night
- mechanical and natural ventilation, with circulation of supply air from floor through uplighters, typically 10-15 ac/h
- no central building management system
- sash windows, poor cross-ventilation
- occupancy 12 m² per person (8.3 W/m²).

Mechanical ventilation was run for 24 hours per day in summer to keep the vegetation in the atrium alive. This is expensive on fan energy and might have been used to improve night cooling of the building. The cooling capacity stored in the slab to cool supply air was dissipated by the high air-change rate (10-15 ac/h), by the airflow picking up heat from the plant, and by heat gains to this incoming air from the roof. The building would work more effectively with lower air-change rates, natural ventilation, high-level air outlets in the atrium to promote cross-ventilation, responsive lighting controls, avoiding supplying air through uplighters and more effective night cooling.□