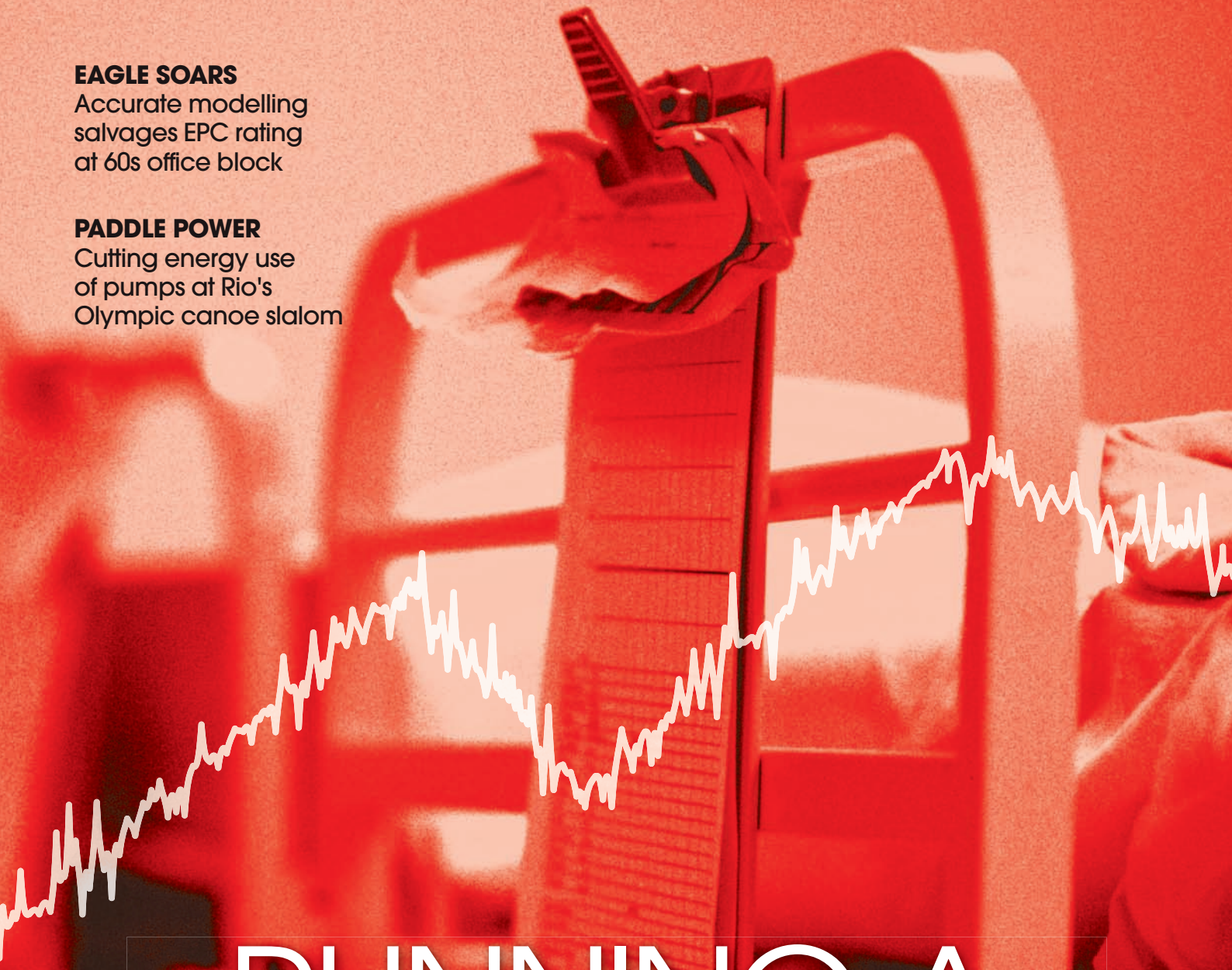
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August 2016

EAGLE SOARS
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RUNNING A TEMPERATURE

Study reveals extent of overheating in a Cambridge maternity hospital

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Mothers, babies and staff at the Rosie maternity unit in Cambridge can endure summer temperatures of over 30°C. **Alan Short**, **Renganathan Giridharan**, and **Kevin Lomas** look at what can be done to improve resilience at the 1983 facility at Addenbrooke's Hospital



HEAT STRESS



CARTER BRONZE MEDAL AWARD WINNER

This article is an edited version of the paper: *A medium-rise 1970s maternity hospital in the east of England: Resilience and adaptation to climate change* , which appeared in CIBSE's technical journal *BSERT*. The paper won the 2016 Carter Bronze medal for most highly rated paper relating to application and development. The paper was written by Alan Short, Giridharan Renganathan and Kevin Lomas (University of Cambridge/University of Kent/University of Loughborough). CIBSE members can access *BSERT* free at **www.cibse.org/knowledge**

The heatwave of 2003 – which peaked at 38.5°C in the UK – will be a normal summer by the 2040s, leading to related deaths more than tripling, according to the Committee on Climate Change (CCC) report published last month.

Currently no policies exist to ensure homes, schools and offices remain tolerable in high heat, and critical facilities – such as hospitals and care homes – are particularly at risk.

The paper *Design and delivery of robust hospital environments in a changing climate* – funded by the UK Engineering and Physical Sciences Research Council (EPSRC) – investigated the incidence of summer overheating in five hospital building types in the National Health Service's (NHS's) acute estate.[1] Here, we focus on the 1983 Rosie maternity hospital, part of Addenbrooke's in Cambridge, during the summers of 2010 and 2011, when it experienced elevated internal temperatures – increasingly an issue for the NHS.[2]

From analysis of its real and simulated performance – now and through the coming century – alternative corrective interventions were devised, with a focus on summer overheating. The full paper reports the relative costs and 'value for money' of four options.

The Rosie is a courtyard type of building: steel and concrete-framed, three storeys, with double-loaded racetrack corridors and brick-clad. Research identified 117 medium-rise courtyard examples in England, covering approximately 3 million m^2.

In 2010, the – since refurbished – building was mechanically ventilated throughout the year, with a set point of 24°C. Air, which was maintained below 22°C all year, was supplied through corridors, and exhausted in wards, WCs and dirty utility rooms. Warm air heating was supplemented by perimeter hot water (HW) heating elements without local thermostatic control and with no zone control. The building provided chilled water to an air handling unit (AHU), but only delivered comfort cooling to intensive care units (ITUs) and operating theatres. Orientated east-west, the building's main entrance, and many of the multi-bed wards – occupying the second and third levels – face south.

The researchers' data loggers were placed on the second floor in June 2010. Figure 1 records factors that were observed to contribute to overheating, including: uninsulated steam pipes; internal heat gains from lighting and equipment; liberal glazing, largely fixed with a limited row of lights opening to only 100mm, exposed to direct solar radiation. Thermal comfort was marginal, even on mild days, in south- and south-westerly facing wards.

Project definitions of thermal comfort included the simple static guidelines and criteria described by CIBSE and the adaptive thermal comfort thresholds in BS EN15251. The appropriateness of these approaches and their relative credibility is discussed by Lomas and Giridharan, and considered in the recent redrafting of the health technical memorandum (HTM) 07-02.[3,4]

The existing building enjoyed relatively low energy and low carbon performance



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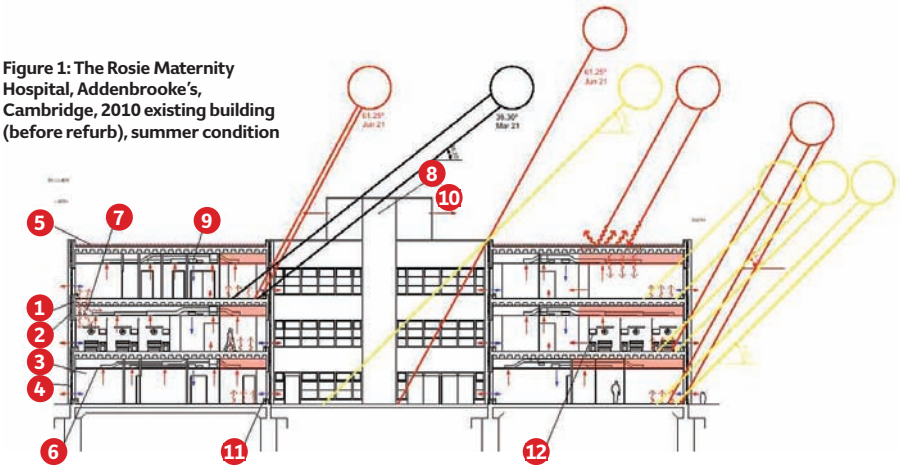


Figure 1: The Rosie Maternity Hospital, Addenbrooke's, Cambridge, 2010 existing building (before refurb), summer condition

1 From inner leaf to external cavity wall above glazing spanning full structural bay
2 External leaf of 100mm brick, 50mm polyurethane insulation in cavity, inner leaf 140mm concrete blockwork. Occasionally steel stud and two layers of plasterboard
3 Non-structural internal partitions vary: plasterboard on 100mm softwood studwork or 140mm concrete blockwork plastered both sides
4 External windows double-glazed in hardwood frames, mullions and transoms (75x100mm), opening lights restricted to 100mm since late 1990s
5 Roof: 150mm RC slab, waffle 300mm deep, 50mm roof deck of pre-screeded slabs with reinforced edges, asphalt, 50mm extruded polystyrene 'Roofmate' held down by 50mm of washed gravel
6 Lightweight suspended gypsum ceiling tile grid
7 HW pipes suspended within ceiling void, original insulation, some missing, water circulated at 55°C or 60°C continuously to avoid bacterial growth
8 Service riser to east and to west sides. Each connects to a plantroom on the ground floor (level 1), three AHU units in east, fresh air supply drawn down riser ducts from roof level
9 Supply air, two AHUs heating, one AHU cooling per plantroom. Unconditioned air supplied when external temperature below 22°C. Conditioned air delivered at 21°C through variable speed fan
10 Exhaust air vented mechanically. No heat recovery
11 Perimeter heating: thermostatic radiator valves recently installed (2011) supplied by HW at min 65°C. Target temperatures 24-25°C in all rooms/wards
12 Internal gains: TV 2.2w/m²; bed lamp 2.8w/m²; general ceiling mounted lighting 3.3 w/m² as calculated for multi-bed ward

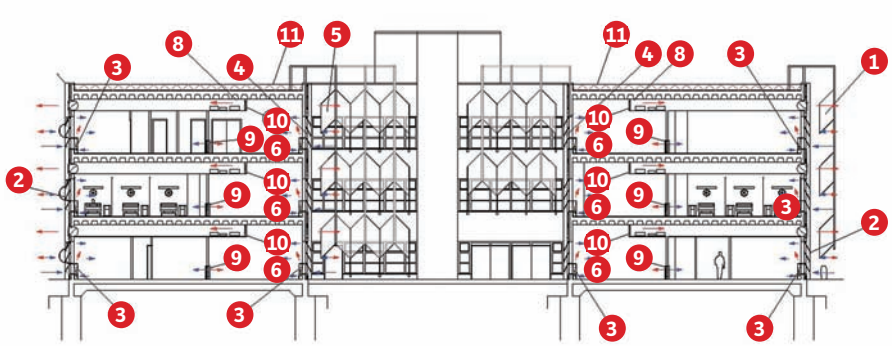


Figure 2: Natural cross-ventilation perimeter heating (option 2)

1 External sunshading applied to south, south-east, south-west elevations. Wing geometry of shade designed to maximise view to upper sky, in translucent coloured material
2 Existing timber window units, currently four upper panels open, restricted to 100mm. All eight glazed panels made openable to 45° with window guards to fulfill NHS safety regulations. Lower opaque elements to open, to admit air across perimeter heating units
3 Perimeter heating below glazing
4 Courtyard glazing units: all glazed panels opening to 45° protected by window guards
5 Sunshading as (1) applied to south-west and south-east elevations
6 Cellular rooms at centre of each elevation to courtyards removed to open circulation areas directly to courtyard fresh air supply; these become patient day areas
7 Service risers maintained
8 Suspended lightweight ceiling removed to expose concrete waffle slab
9 Transfer grilles enable fresh air from courtyards to cross-sections
10 Transfer ducts within suspended ceiling exhaust opened courtyard patient areas
11 Additional 100mm extruded polystyrene added to roof

against the Department of Health (DH) guidance benchmarks – but at the cost of comfort, unable to shed heat in relatively mild external conditions.

Hobo U2 temperature loggers monitored 26 spaces on three levels at hourly intervals from July 2010 to October 2011. The second level emerges as the hottest floor, where logger AR2-SB202 recorded the hottest space at 30.7°C. Maximum ambient temperatures during the summers of 2010 and 2011 were 29.6°C and 31.2°C respectively.

The year 2010 was relatively cool. Night temperatures were consistently uncomfortable – 23.4°C to 26.1°C – and one bedroom recorded 1,992 hours above 25°C, 888 of which occurred at night. Simple threshold criteria miss this. In the 2030 Design Summer Year (DSY), the existing building has a mean night temperature in excess of 25°C. The mechanical ventilation rate is too low – in most bedrooms it does not reach a minimum value of 10 l/s/p.

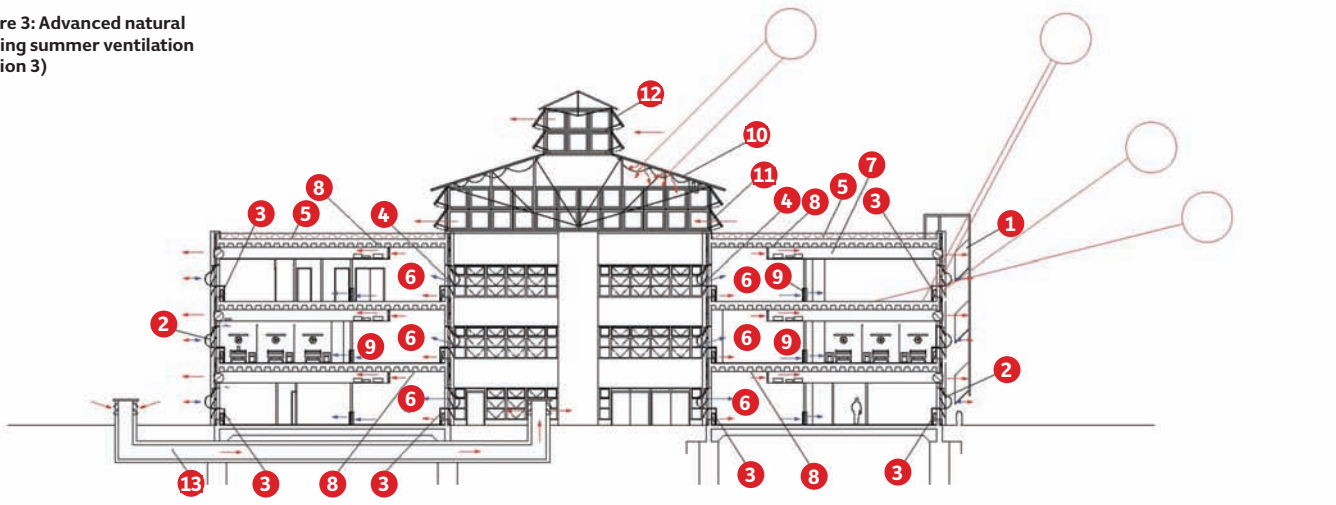
To predict the annual frequency of overheating of the wards, and the energy demands and CO_2 emissions in the current climate, the dynamic thermal model IES was used.[5] The full paper records reasonable agreement between IES predictions and measured values.

Current and future weather files were created by the Prometheus research team at Exeter University, and the future probabilistic weather files were derived using UKCP09 data. A detailed account of this process has been presented elsewhere.[6] Schemes intended to deliver greater resilience to hot summers were devised, starting with what appears to have become the enlightened – but questionable – industry standard Passivhaus-derived model.

Option 1: Sealed mechanical ventilation heating and cooling (SMVHC)

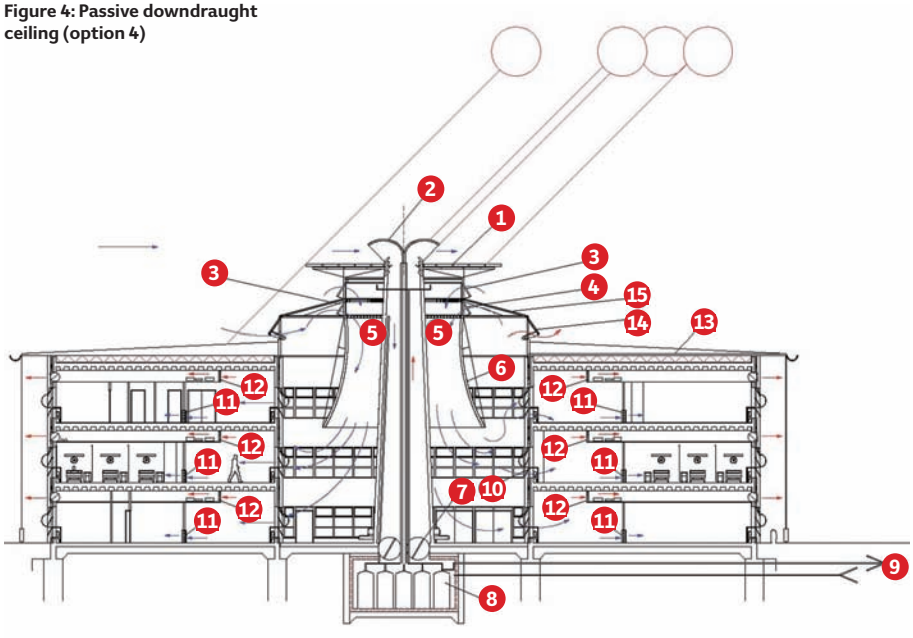
In this option glazing is sealed, airtightness

Figure 3: Advanced natural cooling summer ventilation (option 3)



1 External sunshading applied to south, south-east, south-west elevations. Geometry of shade designed to maximise view to upper sky, in translucent coloured material
2 Existing window units, currently four upper panels open, restricted to 100mm. All eight glazed panels made openable to 45° with window guards to fulfill NHS safety regulations. Lower opaque elements to open to admit air across perimeter heating units
3 Perimeter heating below glazing
4 Courtyard glazing units: all glazed panels opening to 45° protected by window guards
5 Additional 100mm extruded polystyrene insulation added to roof
6 Cellular rooms at centre of each elevation to courtyards removed to open circulation areas directly to courtyard fresh air supply, become patient day areas
7 Transfer ducts exhaust inboard spaces (6) to exterior
8 Suspended lightweight ceiling removed to expose concrete waffle slab
9 Transfer grills admit supply air from enclosed courtyard to wards
10 Lightweight steel-framed double-glazed roof across internal courtyards with actuated fabric awnings to exclude direct sunlight in overheating season
11 Low-level actuated vents cross-vent 'atrium', perform as smoke vents
12 High-level lantern vents summer heat gains from upper part of atrium
13 Low-level supply to atrium formed in spun concrete pipework

Figure 4: Passive downdraught ceiling (option 4)



1 Solar water heating panels supply 'winter' tanks below courtyard
2 Wind catchers flush thermal storage chambers as required
3 Opening glazed vents to exterior supply cooling batteries (5)
4 Internal opening glazed vents allow recirculation
5 PDC cooling batteries
6 Cone of acoustic absorbent material on light frame to direct PDC air flow
7 Vent connects cooled water tanks chamber to external environment as required
8 Cooled and warmed water tank enclosures formed below courtyard
9 Flow and return to geothermal array via horizontal pipe to field or borehole
10 Air admitted through opening vents in each bay of elevation
11 Transfer ducts through outer corridor partitions
12 Exhaust ducts connect courtyard-facing spaces to outer envelope
13 Lightweight insulation on roof
14 High-level vents to flush upper part of courtyard when PDC not engaged
15 Glazed roof with retractable shading

improved, and 100mm of insulation added to the roof and external walls. Mechanical ventilation is operated to achieve the then DH recommendation of 6ach, with 60% heat recovery. DSY peak temperatures will oscillate around 28°C, so additional cooling capacity will be required and will become increasingly necessary. Does the building have the capacity to accommodate it? Predicted energy demand is high (Figure 5) and associated CO_2 emissions very high – 130kgCO_2/m^2 (Figure 6). Almost two-thirds of this will result from its electrical demand, which will, of course, rise as cooling capacity is increased.

Option 2: Natural cross ventilation retaining perimeter heating (NCVPH)

This reintroduces natural ventilation as the primary ventilation strategy (Figure 2): roof insulation is increased; all glazing to south – southwesterly and southeasterly elevations – is shaded externally, to a geometry that preserves bedhead-level views out; all glazed panels open to 45° (safeguarded with grillage); opening, opaque panels are added; and the whole recipe is repeated on the glazed courtyard elevations.

Spaces adjacent to the courtyards are opened, to enable distributed cross-ventilation by the removal of some cellular rooms to form larger, open, patient day-spaces. Suspended ceilings are removed in these areas to reveal concrete soffits that capture 'coolth' from cross-ventilation. Ducts connect these inboard spaces directly to the perimeter.

Peak DSY temperatures hover between 33.5°C and 34.9°C. Additional cooling will be required, but night ventilation cooling is wholly excluded by current set-point policy. A peak of 31°C is predicted in Test Reference Year (TRY) summer conditions. More research is required into clinically safe night conditions in maternity wards. Option 2 has the lowest energy penalty (Figure 5) and markedly lower CO_2 emissions (Figure 6) than option 1.

Option 3: Advanced natural cooling summer ventilation (ANCSVPH)

Courtyards are unheated, glazed atria with a liberal opening area above to dissipate summer solar gains (Figure 3). Air is supplied via concrete ducts below the ground slab, offering a measure of ground cooling. All glazing to the atria becomes operable to 45° and perimeter heating is retained. In winter mode, air is admitted through damper-controlled perimeter heating units. Transfer ducts exhaust air from zones adjacent to the atria and, as in option 2, suspended ceilings are cut back to expose thermal mass. All vulnerable glazing is shielded from direct summer solar gains. Option 3 offers similar DSY peak conditions as option 2, but TRY peaks within current guidance. Predicted energy demand and CO_2 emissions are only marginally higher than option 2 (Figures 5 and 6).

Option 4: Natural ventilation incorporating Passive downdraught cooling and perimeter heating (NVPDCPH)

This option (Figure 4) also proposes enclosing the courtyards, but developing the low energy cooling strategy of the authors' UCL School of Slavonic and East European Studies in London. Cooled water batteries at high-level openings induce a downward flow of pre-cooled air, contained by a lightweight, acoustically absorbent, fabric shroud. The cooled air is then drawn across surrounding occupied spaces.

The diagram proposes ground-sourced cooling to supplement the action of the Passive downdraught ceiling (PDC) by using seasonal thermal storage, readily available water tanks, so that heat gained from summer hot spells is dissipated in winter, and winter coolth used in summer. Banks of passive solar water heaters on the roof of each PDC rooflight supplement warming of winter supply tanks. Recovered heat from all sources is gathered in winter to supplement the supply to the perimeter heating system. Option 4 offers lower TRY and DSY peaks than options 2 and 3. Energy input is higher, but the CO_2 penalty is in line with options 2 and 3 (Figures 5 and 6). This is a complex option to model.

During extreme years, DSYs, option 1 (not illustrated) projected the best performance, while the 2010 building exhibited the worst performance. For the current DSY extreme conditions, all four options broadly met the HTM 03 1%/28°C, while – for the 2030s – option 2, 3 and 4 exceeded the criteria. But improved performance is achieved at a cost. Although the 2010 building, unaltered, had the worst thermal performance, it had the lowest energy consumption (Figure 5).

The DH Energy Efficiency Fund Scheme of 2013-14, which Alan Short administered in part, would not have funded any of the options; the Treasury requires a return on investment of 2.4 within five years of implementation. This is potentially a major barrier to achieving the adaptation of the public, non-domestic building stock – which is unfortunate given that the NHS Retained Estate seems a particularly promising place to implement a public sector adaptation scheme.

Acknowledgements

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● This article was written by Alan Short, University of Cambridge; Renganathan Giridharan, University of Kent; and Kevin Lomas, University of Loughborough

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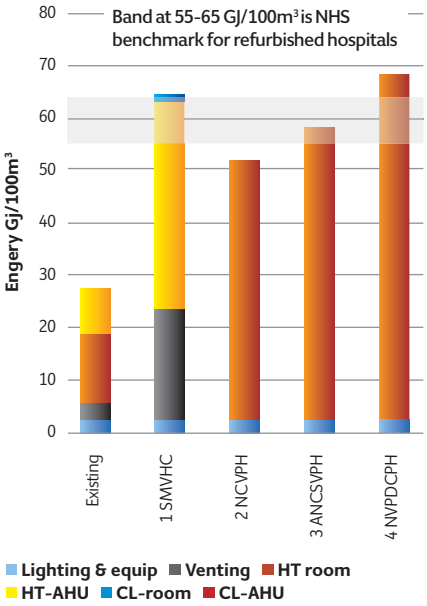


Figure 5: Predicted energy demand for existing and refurbishment options for the year 2010, Cambridge (Bedford weather file). The energy values are the average of monitored and modelled spaces AR1-EX, AR2-MB2 and AR3-DR

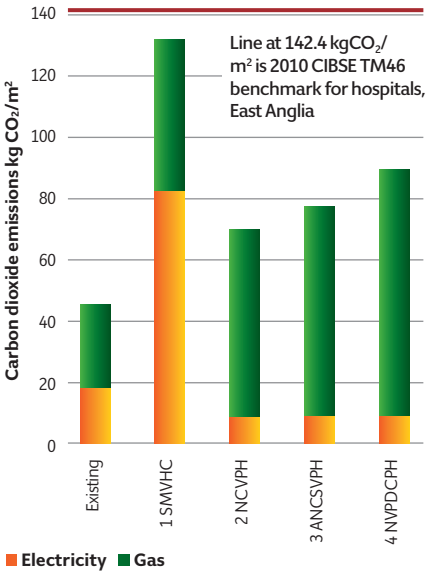


Figure 6: Predicted CO_2 emissions for existing and refurbishment options for year 2010, Cambridge (Bedford weather file). The CO_2 values are the average of monitored and modelled spaces AR1-EX, AR2-MB2, and AR3-DR