GUIDELINES ON COST EFFECTIVE NATURAL AND LOW ENERGY VENTILATION STRATEGIES FOR RETROFITTING TO UK OFFICES

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ABSTRACT

Work carried out in the UK, on behalf of, and fully funded by the Department Transport and Regions, has produced guidelines for the cost effective refurbishment of offices for natural and low energy ventilation. The aim of the work is to counteract the current trend towards the installation of air conditioning when other low energy strategies will provide suitable comfort conditions. This paper shows ways in which comfort conditions can be achieved with zero or minimal energy use in a range of office types, using natural ventilation or simple mechanical low energy systems.

1 INTRODUCTION

Many existing offices either overheat in the summer or use excessive amounts of energy to maintain acceptable temperatures. The reasons are increasing internal heat gains from office IT equipment, poor efficiency lighting systems, density of staff and original poor building design causing excessive solar gains. The trend is for problem offices to have air conditioning systems replaced - at the end of the life of the existing services - or installed in previously naturally ventilated offices when refurbishment occurs. Introducing or replacing air conditioning is an energy intensive solution and is unnecessary for most office buildings in the UK climate. The trend needs reversing; natural and low energy ventilation strategies work and can be incorporated during refurbishment.

There is much recent advice on using natural and low energy ventilation in *new* non-domestic buildings [1,2]. Existing buildings being refurbished can also benefit from many of the strategies to displace, avoid or reduce the use of air conditioning (AC) and the associated energy consumption. This UK Government funded study concentrates on the refurbishment case.

The retrofitting of natural and low energy ventilation systems in existing UK office buildings during refurbishment can maintain comfortable indoor conditions and result in significant energy and CO_2 savings compared to the common solution of just installing AC.

Where natural and low energy ventilation strategies do not eliminate the need for air conditioning altogether, they can improve the situation by one or more of the effects below:

(i) reducing the AC load (by reducing internal gains and using the thermal mass of the fabric with night cooling)
(ii) reducing the area of the office where AC is needed (spatial mixed mode)
(iii) reducing the proportion of the year when AC is needed (temporal mixed mode).

2 NATURAL AND LOW ENERGY VENTILATION SYSTEMS

A retrofit natural or low energy ventilation strategy comprises measures which act to reduce the internal gains as far as possible, absorb heat in the fabric of the structure and promote the flow of cooler outside air through the building. The measures are listed in Table 1.

Removal of suspended ceilings acts to expose the thermal mass of the floor slab and increase floor to ceiling heights. Increased height of the office space increases the efficiency of natural ventilation at the occupied level by providing a larger air flow path across the office space and improving thermal comfort by allowing air to stratify. Night cooling by ventilating with cool night air and storing the "coolth" in the exposed heavy floor slab reduces peak temperatures the following day.

The introduction of an atrium in a deep plan building to reduce the depth of the floor plan improves daylight penetration to the centre of building and promotes stack ventilation to draw air through the adjacent office space from windows or vents on the façade.

3 REFURBISHMENT LEVELS

It can be seen from the list of measures in Table 1 which might make up a natural ventilation or low energy ventilation strategy, that they involve varying levels of disruption to the building. BSRIA have put forward four likely levels of office refurbishment, together with the opportunities for natural and low energy ventilation measures to be introduced for each level of refurbishment [3]. This information is incorporated into Table 1.

Level 1 is a *minor* refurbishment and involves the introduction of opening windows, reduced window area, modern internal blinds, low energy IT option on replacement, re-painted interior and re-designed office layout to maximise access to available daylight.

Level 2 is an *intermediate* refurbishment, as level 1 but with mid-pane blinds for solar control, a new, more energy efficient lighting and control system, removal of false ceiling to expose thermal mass and raise ceiling height, providing the possibility of occupant controlled night cooling.

Level 3 is a *major* refurbishment, as level 2 but with external solar control, possible use of stair cores as ventilation stacks, BMS controlled night cooling with motorised window/vent opening.

Level 4 is a *complete* refurbishment, options as level 3 and with radical changes to air flow paths, for example by addition of a central atrium, or use of a double facade to drive stack ventilation.

Table 1 Natural and low energy ventilation measures to be incorporated at the of four levels of refurbishment

Refurbishment measures: options at each level	Refurbishment level 1. Minor	Refurbishment level 2. Intermediate	Refurbishment level 3. Major	Refurbishment level 4. Complete
• Repaint interior with cool, light colours	x	x	x	x
• Layout of work stations and office equipment near extract	x	x	x	x
• Choice of low energy office equipment on replacement	x	x	x	x
• Replacement opening windows with multiple openings	x	x	x	x
• Reduced window area	x	x	x	x
• Good daylighting from positioning of windows	x	x	x	x
• Some solar control by glazing choice and internal blinds	x	x	x	x
• Reduction of unwanted infiltration	x	x	x	x
• Efficient electric lighting systems and controls		x	x	x
• Removal of suspended ceiling		x	x	x
• Night cooling by leaving windows open - manual control		x	x	x
• Added solar control by use of mid-pane blinds		x	x	x
• Controllable windows or vents, perhaps by the BMS			x	x
• Use of stair wells or service shafts for stack ventilation			x	x
• Added solar control by use of external blinds			x	x
• Use of a double facade or solar chimney to act as a ventilation stack				x
• Introduction of an atrium in a deep plan building				x

We have added a level of refurbishment, *AC Upgrade* which involves just the replacement or introduction of a typical fan coil AC system and allows comparison with the low energy ventilation approach. The new or replacement AC system is assumed to be a fan coil AC system, with a COP of 3, set point of 22°C, typical low velocity fans and 100% air re-circulation, giving 5 air changes per hour. It is assumed to operate when the building is occupied.

Simple low energy mechanical ventilation (Hybvent) can be used in conjunction with the measures and strategies described above for each level of refurbishment where the result of their being retrofitted does not quite eliminate the need for AC. A simple low energy mechanical ventilation solution should use high efficiency fans with a minimum of ducting and only be used when and where the natural ventilation driving forces need to be supplemented. The system investigated

here, in conjunction with cases where the natural ventilation refurbishment *just* fails to meet the summer comfort criteria, is a simple mechanical extract using best practice low energy fans, operating only in the peak summer months, in the areas of the office building where it is required.

4 ASSESSMENT METHOD

The benefits of retrofitting natural ventilation and low energy ventilation solutions to existing office buildings during refurbishment have been assessed using the BRE design tool NITECOOL. NITECOOL predicts hourly temperatures, number of hours over a certain temperature and cooling season energy use (if mechanical ventilation or AC is specified) for a variety of design options such as glazing area and type, orientation, solar control, air change rate, window or vent opening area, building thermal mass, night ventilation, and internal heat gains.

The program predicts dry resultant temperatures, (DRT - based on a weighting of 50% air temperature and 50% radiant temperature) and so are the most closely linked to a human thermal comfort (no allowance is made for air movement). Therefore, the maximum internal temperature during the occupied hours of the hot period is used to assess the overheating risk and success or failure of the natural ventilation strategies incorporated at each level of refurbishment.

The acceptability criteria used to assess the success of the low energy ventilation refurbishment strategies in this study are:

- an internal maximum dry resultant temperature for the July hot week of 28°C (this is 1°C above the maximum outside air temperature used in the simulation)
- a maximum of 15% of occupied hours over 27°C in the July hot design week (with an overall yearly maximum hours over 27°C of 2% of occupied hours).

4.1 Weather data for modelling

NITECOOL works with a week of CIBSE Kew weather data for each of the cooling season months, May-September. Maximum and minimum air temperature data (correlated with solar radiation and wind speed) is contained in the NITECOOL programme. The programme assumes a sinusoidal profile between daily maxima and minima. The work described here uses two different temperature profiles as used for predicting either comfort or energy use:

(i) **peak temperature assessment**; hot design period data (a warm five days with maximum temperature of 23.3°C and minimum of 15°C, followed by two very hot days with max 27°C and minimum of 16°C), and

(ii) **summertime cooling energy use**; average weather data for May-September.

4.2 Office types

In order to make realistic comparisons in typical office buildings, four common office types [4] have been used in this analysis to assess the benefits of natural ventilation and low energy ventilation for refurbished offices. Each office type has been simulated with NITECOOL for each level of refurbishment. Results from a South facing office (high solar gain), and results averaged for North, East, South and West orientations are presented.

5 SIMULATION RESULTS FOR DIFFERENT OFFICE TYPES

5.1 Type 1 Naturally ventilated, cellular

It is estimated that 68% of England and Wales office stock (71.7km^2 gross floor area) is Type 1.

Characteristics:

- Simple shallow plan buildings
- often small and in converted residential accommodation
- naturally ventilated
- predominantly cellular
- typical building depth 10-20m, typical office

- depth, 4-10m
- individual windows
- lower illuminance levels than other types
- local light switches and heating controls
- occupied 2500h/y (equivalent to 10h/d, 5d/wk, assuming that the office is open for work 50 weeks of the year).

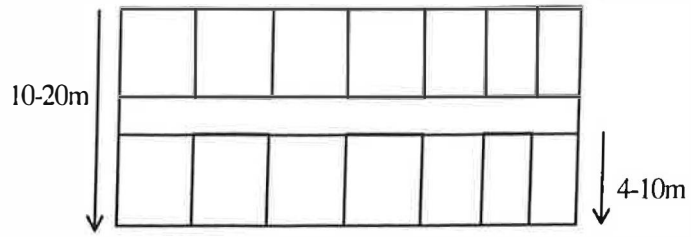


Figure 1 Type 1 typical office plan

Internal gains:
- typical- 30W/m^2
- good practice - 20W/m^2

Table 2. Type 1 office: base case and refurbishment levels - performance of South facing office

Case	Features	Max temp °C	% hours over 27°C in July hot week	Cooling energy/y (average temps) kWh/m^2/y
base case	• internal gains - 30W/m2 • 7 ach single sided ventilation (daytime) • occupation -10h/d (08-18:00) • 60% glazing ratio • single glazed • internal blinds with solar trans=70% • suspended ceiling (indicating lightweight construction with respect to accessible thermal mass).	38.1°C	85%	0
ac upgrade	• base case + fan coil AC system	22.0°C	0%	47.0
Refurb level 1	• base case + 25W/m^2 internal gains, reduced glazing ratio (40%), double glazing, 10ach daytime, new office layout and repainting with light colours	32.6°C	63%	0
Refurb level 2	• level 1 + internal gains 20W/m^2, mid-pane blinds (solar transmission of 40%), removal of suspended ceiling (increased thermal mass), 10ach day and for night cooling	27.0°C	0%	0
Refurb level 3	• as level 2 + external louvres (solar transmission of 20%), use of stair cores as stacks , BMS controlled motorised vents/windows, day time 10ach, night ventilation 13 ach	26.3°C	0%	0
Refurb level 4	• as level 3 + option of using double façade to get around site problems of noisy/polluted façade (same ach)	26.3°C	0%	0

Key: the shaded block indicates where natural or low energy ventilation strategies provide acceptable temperatures

5.2 Type 2: naturally ventilated, open plan

It is estimated that 9% of E&W office stock (9.3 km^2 gfa) is of this type.

Characteristics:

- purpose built, sometimes converted industrial space
- typical size 500m^2 - 4000m^2,
- largely open plan with some cellular offices and special areas
- typical depth 10-15m
- light levels, internal gains and hours of use are usually higher than type 1 cellular,
- occupied 3000h/y (=12h/d, 5d/wk, 50wk/yr)
- Internal gains: typical - 35W/m^2, good practice - 25W/m^2

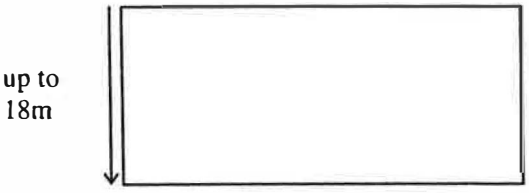


Figure 2 Type 2 office typical plan

Table 3. Type 2 office: base case and refurbished levels - performance of South facing office

Case	Features	Max temp °C	% hours over 27°C in July hot design week	Cooling energy/y (average temps) kWh/m^2/y
Base case	• internal gains - 35W/m2 • 10ach cross ventilation (daytime) • occupation -12h/d (07-19:00) • 60% glazing ratio • single glazed • internal blinds with solar trans=70% • suspended ceiling (indicating lightweight construction with respect to accessible thermal mass).	36.9°C	81%	0
AC Upgrade	• base case + fan coil AC system	22.0°C	0%	54.9
Refurb level 1	• base case + 30W/m^2 internal gains, reduced glazing ratio (40%), double glazing, 10ach daytime, new office layout and repainting with light colours	33.1°C	61%	0
Refurb level 2	• level 1 + internal gains 25W/m^2, mid-pane blinds (solar transmission of 40%), removal of suspended ceiling (increased thermal mass), 10ach day and night (night cooling)	27.5°C	8%	0
Refurb level 3	• as level 2 + external louvres (solar transmission of 20%), use of stair cores as stacks , BMS controlled motorised vents/windows, day time 10ach, night ventilation 13 ach	26.7°C	0%	0
Refurbishment level 4	• as level 3 + option of using double façade to get around site problems of noisy/polluted façade (same ach assumed)	26.7°C	0%	0

Key: the shaded block indicates where natural ventilation strategies provide acceptable temperatures

5.3 Type 3: air conditioned, standard

It is estimated that 14% of E&W office stock (15.7km^2 gfa) is of this type.

Characteristics

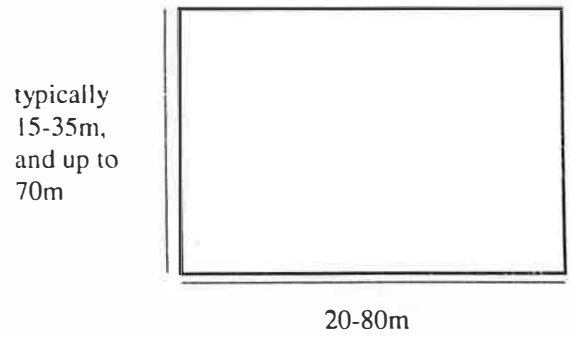
- Similar in occupancy & planning to Type 2
- usually deeper floor plan (up to 70m, typically 35m),
- tinted or shaded windows,
- occupied 3200h/y (=13h/d, 5d/wk, 50wk/y)

Internal gains:

- typical - 40W/m^2
- good practice -25W/m^2 perimeter zone

Modelled example:

- 35mx35m=1225m^2,
- passive zone (6m perimeter band)=696m^2
- service zone (central) - 10% of gfa (from Econ 19) = 11.1mx11.1m=123m^2
- core zone is 6m deep band within the perimeter band = 406m^2.



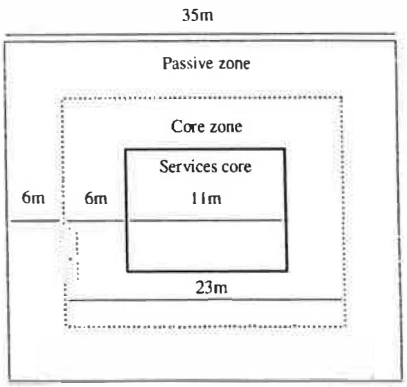


Figure 3 Type 3 office floor plan

Table 4. Type 3 office: base case and refurbishment levels - performance of South facing office

Case	Features	Max temp. °C	% hrs over 27°C in July hot week	Cooling energy/y (average temps) kWh/m^2/y
Base case	• internal gains - 40W/m2 • 5ach (daytime) • occupation -13h/d (07-20:00) • 80% glazing ratio • single glazed • internal blinds with solar trans=70% • suspended ceiling (indicating lightweight construction with respect to accessible thermal mass).	45.0°C	96%	91 (type 3 typical use)
AC Upgrade	• base case + fan coil AC system	22.0°C	0%	66.9
Refurb level 1	• base case + 35W/m^2 internal gains, reduced glazing ratio (40%), double glazing, 10ach daytime, new office layout and repainting with light colours	36.6°C	82%	0
Refurb level 2	(a) natural ventilation: level 1 + internal gains 25W/m^2, mid-pane blinds (solar transmission of 40%), removal of suspended ceiling (increased thermal mass), 10ach day and night (night cooling)	28.4°C	21%	0
HYBVENT	(b) low energy mechanical ventilation: level 2(a) + simple extract fans to assist natural driving forces, to give 10ach day and night (and 15ach for hottest July periods)	27.9°C	12%	3.1
Refurb level 3	• as level 2 + external louvres (solar transmission of 20%), use of stair cores as stacks, BMS controlled motorised vents/windows giving 7ach day and night ventilation	26.9°C	0%	0
Refurb level 4	• as level 3 + central atrium replacing service core giving 10ach day and night ventilation	26.7°C	0%	0

Key: the shaded block indicates where natural or low energy ventilation strategies provide acceptable temperatures

5.4 Type 4 air conditioned prestige

An estimated 9% of England and Wales office stock (9.9km^2 gfa) is of this type.

Characteristics

- usually deep plan (up to 70m, typically 50m)
- purpose built or refurbished to high standard
- occupied 3500h/y (=14h/d).

Internal gains:

- typical - 45W/m^2,
- good practice - 30W/m^2 (perimeter zone with good daylighting + controls, 35W/m^2 core zone)

Modelled example:

- 50mx50m=2500m^2
- passive zone (6m perimeter band)=1056m^2
- service zone (central) - 15% of gfa (from Econ 19) = 19.4mx19.4m=376m^2
- core zone = 9.3m deep band within the perimeter band = 1063m^2.

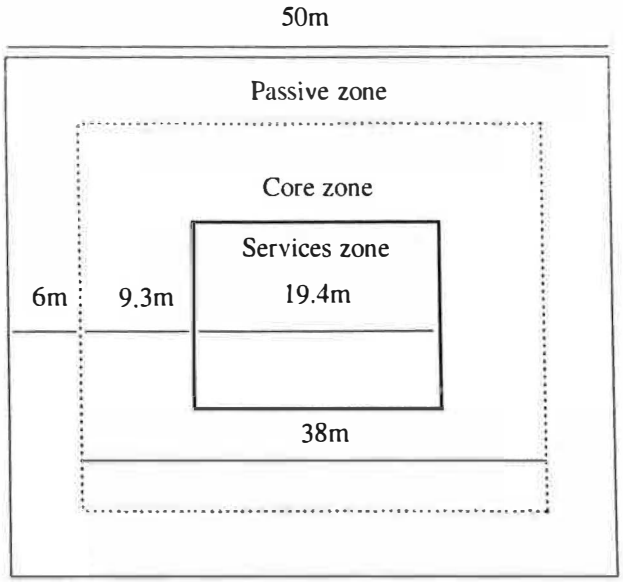


Figure 4 Type 4 office floor plan

Table 5. Type 4 office: base case and refurbishment levels - performance of South facing office

Case	Features	Max temp. °C	% hrs over 27°C in July hot week	Cooling energy/y (average temps) kWh/m²/y
Base case	• internal gains - 45W/m2 • 5ach (daytime) • occupation -14h/d • 80% glazing ratio • single glazed • internal blinds with solar trans=70% • suspended ceiling (indicating lightweight construction with respect to accessible thermal mass).	45.8°C	97%	108 (type 4 typical use)
AC Upgrade	• base case + fan coil AC system	22°C	0%	73.4
Refurb level 1	• base case + 40W/m² internal gains, reduced glazing ratio (40%), double glazing, 10ach daytime, new office layout and repainting with light colours	37.5°C	85%	0
Refurb level 2	(a) natural ventilation: level 1 + internal gains 30W/m², mid-pane blinds (solar transmission of 40%), removal of suspended ceiling (increased thermal mass), 10ach day and night (night cooling)	29.2°C	26%	0
HYBVENT	(b) low energy mechanical ventilation: level 2(a) + simple extract fans to assist natural driving forces, to give 10ach day and night	28.0°C	14%	6.6
Refurb level 3	• as level 2 + external louvres (solar transmission of 20%), use of stair cores as stacks, BMS controlled motorised vents/windows giving 7ach day and night ventilation	27.5°C	7%	0
Refurb level 4	• as level 3 + central atrium replacing service core giving 10ach day and night ventilation	27.2°C	5%	0

Key: the shaded block indicates where natural or low energy ventilation strategies provide acceptable temperatures

6 RESULTS

The shaded areas of Table 6 highlight where a low energy ventilation refurbishment level has succeeded in eliminating the need for AC. All refurbishment levels from 2 upwards, where thermal mass of the floor slab is exposed and night cooling made possible, are successful with all four of the typical offices modelled in this study. For office types 3 and 4, level 2 refurbishment has to be supplemented by a simple low energy mechanical system (Hybvent) to provide acceptable summer temperatures without AC.

Table 6 shows a summary of the modelling results. The mode of servicing required to provide acceptable summer temperatures is recorded for each refurbishment level. The table also shows the summertime energy use (kWh/m²y) for providing acceptable temperatures in the example office buildings, averaged over East, West, South and North facing offices (core zone not included), for the different levels of refurbishment of the four offices types.

Table 6 Natural and low energy ventilation to provide acceptable internal summer temperatures: mode of servicing and energy use (kWh/m²y)

Refurbishment level	Type 1	Type 2	Type 3	Type 4
AC Upgrade	**AC** - 43.4	**AC** - 51.7	**AC** - 61.2	**AC** - 69.3
level 1	**AC** - 33.9	**AC** - 41.6	**AC** - 51.0	**AC** - 54.3
level 2 (with night cooling)	**NV** - 0	**NV** - 0	**Hybvent** - 3.4	**Hybvent** - 5.4
level 3 (with night cooling)	**NV** - 0	**NV** - 0	**NV** - 0	**NV** - 0
level 4 (with night cooling)	**NV** - 0	**NV** - 0	**NV** - 0	**NV** - 0

Key: AC= air conditioning required for acceptable temperatures Hybvent = simple low energy mechanical ventilation required for acceptable temperatures **NV** = natural ventilation provides acceptable temperatures

As a check on the methodology used, the NITECOOL predicted energy use for the AC Upgrade of office types 3 and 4 (i.e. installation of new, efficient AC system into an unmodified and poorly specified offices) has been compared with the ECON 19 *typical* practice data (without humidification). The predictions consistent with ECON 19 figures shown in tables 4, 5.

Level 1 refurbishment It can be seen from Table 6 that for all office types, the measures introduced at the level 1 refurbishment - though not enough to allow natural and low energy ventilation to provide summer comfort - result in a reduction in AC energy consumption of about 20% from the *AC Upgrade* option.

Level 2 refurbishment Two approaches to low energy ventilation provision are proposed for this level of refurbishment: natural and low energy mechanical (Hybvent).

Natural ventilation For shallow plan office types 1 and 2, the level 2 refurbishment allows natural ventilation to provide acceptable summer temperatures, with no electrical energy consumption. Level 2 refurbishment measures are as for level 1 but with mid-pane blinds (about 40% solar transmission), new efficient lighting system and controls (reduces heat gains from electric lights) and removal of suspended ceiling. Removing the suspended ceiling has several beneficial effects:

- it increases head height which allows more effective cross ventilation and gives a larger reservoir for warm stale air to accumulate without affecting occupants
- it allows access to thermal mass in the floor slab and, with manually operated night cooling (cool night air coming through open windows and vents) can be used to build up a store of "coolth" to reduce the peak temperatures of the next day.

Low energy mechanical ventilation For the deeper plan office types 3 and 4, the level 2 refurbishment does not satisfy the summer comfort criteria. However, it is only just outside the band of acceptability for a couple of months in the middle of the summer and the effect of introducing simple low energy mechanical ventilation was investigated. A simple extract system with low energy fans was modelled to provide a higher air change rate (10ach) and this was found to bring acceptable summer temperatures to both office types with minimal energy consumption (less than 8% of the AC Upgrade energy consumption).

Level 3 refurbishment provides acceptable summer temperatures for all office types using natural ventilation. For office types 1 and 2 which were bought into the comfort zone by refurbishment level 2, then the extra measures which can be incorporated in level 3 provide more flexibility and ventilation effectiveness where, due to site factors (for example polluted, noisy environment to one facade of a building), the strategies possible at level 2 are not able to be fully implemented.

Level 4 refurbishment is mainly applicable to deeper plan type 3 and 4 offices. As level 3 refurbishments of all office types provide acceptable summer conditions in the July hot design week, the extra measures which can be incorporated in level 4 provide more design options for effective ventilation where site or building restrictions prohibit the use of the strategies possible at level 3.

7 COST ANALYSIS

Plant capital and maintenance costs A typical air conditioning system has been estimated to cost £200/m^2 with maintenance costs of £15/m^2.

A simple low energy mechanical ventilation solution would be an extract system using fans with best practice performance (0.75W/l/s). The cost of installation and maintenance of such a system is estimated to be: £20/m^2 for installation, £0.90/m^2/y for maintenance.

The installation and maintenance costs have been added on to level 2 refurbishment costs for office types 3 and 4.

Low energy ventilation on-cost bands when refurbishing an office anyway
Level 1 on-cost for low energy ventilation refurbishment (if it is assumed that redecoration and minimal repairs would happen at the same time anyway) of £100-£250/m^2.

Level 2 on-cost for low energy ventilation refurbishment (if it is assumed that modernization and improvement of space would happen at the same time anyway) of £50-£300/m^2.

Level 3 on-cost for low energy ventilation refurbishment (if it is assumed that modernization and improvement of space would happen at the same time anyway) of £300-£500/m^2.

For *level 4*, there are two possibilities, for estimating on-costs: relative to a standard refurbishment package of space modernization and improvement, or relative to a major structural alteration (involving changes to cladding, core, all finishes):

> Level 4 on-cost for low energy ventilation refurbishment (if it is assumed that modernization and improvement of space would happen at the same time anyway) of £500-£700/m^2.
>
> Level 4 on-cost for low energy ventilation refurbishment (if it is assumed that a major structural alteration - involving changes to cladding, core, all finishes - would happen at the same time anyway) of £0-£200/m^2.

Maintenance costs for natural ventilation are shown with those for air conditioning for comparison in Table 7.

Refurbishment level 3 and 4 maintenance costs, though still those associated with natural ventilation are much higher than those for levels 1and 2 as it is assumed that the higher levels will include BMS control of automated windows and vents.

Table 7 Maintenance costs, £/m^2 y

Office type	1	2	3	4
Refurbishment level 0, with fan coil AC	15	15	15	15
Refurbishment level 1	1.1	1.1	1.1	1.1
Refurbishment level 2	1.1	1.1	1.1	1.1
Refurbishment level 3	4	4	4	4
Refurbishment level 4	N/A	N/A	4	4

NB. Maintenance costs for refurbishment level 1-4 assume AC is avoided, else level 0 costs apply

The above estimated costs – together with other estimates of typical office refurbishment costs [3,4] - have been used to assess the simple payback figures and lifecycle costs. This information is shown in Tables 8 and 9.

Table 8 Simple Payback Periods

Simple payback, years	Type 1	Type 2	Type 3	Type 4
level 0 (full ac)				
level 1				
level 2 (with night cooling)	0-5.2y	0-5.1y	0-6.1y	0-6.4y
level 3 (with night cooling)	6.1-18.4	6.1-18.2y	5.9-17.8y	5.9-17.8y
level 4 (with night cooling) – relative to space modernization /improvement refurb (£300/m^2)	n/a	n/a	17.8-29.6y	17.8-29.7y
level 4 (with night cooling) – relative to structural upgrade refurb (£800/m^2)	n/a	n/a	0y	0y

The light shaded area indicates where the refurbishment level avoids the need for installation or replacement of AC.
The dark shaded area indicates where the refurbishment level *with simple fan assistance* (Hybvent) avoids the need for installation or replacement of AC.

Table 9 Lifecycle costs relative to air conditioning over 25 years

lifecycle costs relative to level 0: -ve is a saving, +ve is an extra cost (£/m^2 over 25y)	BRECSU type 1	BRECSU type 2	BRECSU type 3	BRECSU type 4
level 0 (full ac)	0	0	0	0
level 1				
level 2 (with night cooling)	-£381 to -£631	-£385 to -£635	-£308 to -£608	-£345 to -£595
level 3 (with night cooling)	-£109 to -£309	-£113 to -£313	-£123 to -£323	-£122 to -£322
level 4 (with night cooling) – relative to space modernization /improvement refurb (£300/m^2)	n/a	n/a	+£123 to -£77	+£122 to -£78
level 4 (with night cooling) – relative to structural upgrade refurb (£800/m^2)	n/a	n/a	- £27 to - £227	-£28 to -£228

The light shaded area indicates where the refurbishment level avoids the need for installation or replacement of AC.
The dark shaded area indicates where the refurbishment level *with simple fan assistance* (Hybvent) avoids the need for installation or replacement of AC.

These financial parameters are based on modelling estimates of savings in cooling, ventilation, lighting and heating energy resulting from the refurbishment measures which result in the avoidance of air conditioning.

8 CONCLUSIONS

All office types, on refurbishment involving retrofit of low energy ventilation strategies, show significant energy savings from the avoidance and reduction of air conditioning, whilst providing comfortable internal temperatures.

For deeper plan types 3 and 4, more minor levels of refurbishment with natural ventilation strategies were not sufficient to provide acceptable internal temperatures. However, when the ventilation was supplemented by low energy mechanical systems, they were found to provide the required comfort levels with minimal energy use.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the UK Government funding of this project through the DETR.

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