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THE ENERGY EFFECTS OF CONTROLLING SOLAR SHADING

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Summary

This paper has examined the energy and thermal comfort implications of installing solar shading, including automatically controlled shading. Two buildings, an air conditioned office and naturally ventilated hospital block, were simulated using a sophisticated environmental modelling program (DOE-2), for a range of shading and control systems. These comprised manually controlled internal blinds, a fixed external overhang, and internal or external blinds under automatic control and manual override.

Results for the office suggest that in England shading can result in significant reductions in carbon dioxide emissions and energy cost, where buildings are air conditioned. Additional CO_2 savings were obtained with automatic control of shading, of around 3% compared to simple manually controlled or fixed systems. Overall, an automatically controlled shading system gave building CO_2 savings of 9% (with internal blinds) and 8% (with external blinds) in the London area compared to the no shading case.

The benefits of shading are latitude dependent; in Scotland, installation of external shading gave an energy penalty of between 3% and 9%. Moveable external shading gave the highest energy penalty because occupants would use the external blinds to control glare, reducing solar gains on cloudy days. Automatic control of internal shading was more successful here, reducing CO_2 emissions by around 2% compared to no shading or manually controlled internal shading.

In the naturally ventilated hospital, the installation of shading resulted in an energy penalty of between 2% (for internal blinds either manually or automatically controlled) and 11-13% for automatically controlled external shading. However the external shading resulted in significant reductions in summertime internal temperatures, which could avoid the need to install cooling in some areas.

Introduction

The need to control overheating and glare is increasingly important in all types of buildings. Solar shading (refs 1,2) can benefit occupant comfort, by reducing internal temperatures on hot days and controlling glare.

A few studies have examined the general energy benefits of providing shading. A BRE case study (ref 3) estimated that installing a/c in a typical 1960s open plan office would require an extra 55kWh/m^2/year, resulting in overall a/c running costs of £15/m^2/year. The same study showed that comfort could be achieved at zero cooling energy consumption, with a combination of solar shading (either mid-pane or external) and night ventilation. The extra cost of such measures will usually be substantially less than that of installing cooling. Even in a building where cooling had already been installed, the shading could pay for itself in under five years.

A literature review by Dubois (ref 4) quoted studies giving savings of between 23 and 89% in cooling energy use from installing shading. Dubois also investigated the effect of having an awning on a south facing office window. This study showed that large energy savings (around 12 kWh/m^{2}yr) could be obtained by using a simple seasonal awning but that this was almost completely offset by extra heating and lighting use if the awning was fixed and remained in place year-round.

This indicates that moveable shading (ref 5) is especially appropriate. Under cloudy conditions, or in winter, it can be withdrawn to allow daylight and useful solar gains to enter the building, reducing its dependence on electric lighting and its heating requirement. This strategy requires that the shading be appropriately controlled. Otherwise, if the shading is withdrawn by mistake, unwanted solar gain may enter the building in heat wave conditions, causing overheating. Conversely, the shading may be in place at times when it is performing no useful function; this can lead to excessive use of electric lighting and reduction in useful solar heat gain in winter.

This paper sets out to quantify the benefits of shading control. It describes environmental modelling of two example buildings with an automatic shading control system, and comparison with the same buildings with no shading, with fixed shading, and with manual control of blinds.

The Buildings

The modelling was carried out for two example buildings: an office and a simplified hospital block. The office is illustrated in Figures 1 and 2. It is mainly open plan but includes some cellular spaces. It is assumed to have full air conditioning including cooling. The HVAC system considered in the analysis uses fans in both heating and cooling mode.

The hospital building is shown in figures 3 and 4. This consists of wards on floors 1 and 2, with ancillary accommodation on these floors and the whole of the ground floor. All the rooms are naturally ventilated.

Each building has the default U values and services provision given in the limits to design flexibility in the 2006 England and Wales Building Regulations Approved Document L2A (ref 6). The windows are standard low emissivity double glazed units (total solar transmittance or g value 0.68, U value 2.0 W/m²/K). Photoelectric dimming of electric lighting is provided. The natural ventilation strategy used in the hospital building is assumed to provide the minimum fresh air flow required for occupants.

The Modelling procedure

The buildings were modelled using the sophisticated dynamic thermal model DOE 2, with Equest interface (ref 7). Each building was modelled assuming it was located in each of London, Manchester, and Edinburgh. The standard CIBSE Test Reference Year for each location was used to provide weather data. The duration of each simulation was one complete year in order to take account of seasonal weather variations.

Each building was modelled with five different types of shading:

a) Internal shading (roller blinds), manually controlled. The roller blinds were of a White/Pearl fabric, with the white side facing outwards (ie against the glazing). Its properties are T_{solar} 9%, R_{solar} 54%, A_{solar} 37%, T_{vis} 8%.

b) Internal shading as above, automatically controlled with manual override.

c) External shading, fixed (a simple overhang). The overhang was 1 metre deep on all faces. No radiation was assumed to be reflected from the underneath of the overhang.

d) External shading, moveable, automatically controlled with manual override. The moveable external shading is modelled as venetian blinds, mid coloured with slat reflectance R_{solar} 0.35. The blind is assumed to have thin curved slats of width 100mm and vertical spacing 80mm. The slats are assumed to be closed when lowered.

e) No shading (base case).

Algorithms for manual and automatic control

Manual control

To assess the way people use blinds, BRE carried out five surveys of office buildings (ref 5):

- a pilot study in two office buildings at BRE's own site in Garston
- a multi storey office block in Croydon
  BRE building 4, an office / laboratory building
- a large open plan, multi storey office block in Bootle
- a large office block in Westminster

In the two earlier studies the office tasks were mainly paper based, while in the later studies there was a range of modern office equipment including computer screens. Contrary to popular belief, people do not always keep their blinds down. Typically 30% of a south facing façade might be covered by blinds. However this proportion varies a lot between buildings and with time of year, as Table 1 shows.

Table 1.
Occlusion values (percentage of window area on façade covered by blinds) for each building.

Building	Period of stydy	Façade orientation	Occlusion value %		
			Mininum	Maximum	Average
BRE B3	Feb-May 79	South	18%	46%	27%
BRE B9	Feb-May 79	South	50%	70%	60%
Croydon	Jan-Jul 83	South-east			9%
		South-west			9%
BRE B4	May-Sep 89	South	70%	95%	84%
Bootle	Jan-Jun 90	South-west	15%	75%	27%
	Aug-Nov 90	South	9%	85%	39%

It was fairly common for people to alter their blinds (once every three days on average). Sunshine is the main factor affecting lowering of blinds. Blind changes were only weakly related to temperature, however, implying that the visual rather than the thermal impacts of sunlight were the dominant factor. People are more likely to raise their blinds at the beginning or end of the day.

Further analysis of the Westminster data indicated that blind use could be modelled using the following equations. In these equations the occlusion factor F is the fraction of blinds down over an entire façade. F depends on sunshine probability σ over the whole hour. σ is the actual sunshine probability if the sun can reach the façade. If the solar altitude was less than 5°, or the solar azimuth was more than 80° from the azimuth of the normal to the façade, σ was taken as zero.

At any time if space is not occupied, F= Fprevious

where = $F_{previous}$ is the occlusion factor for the previous hour.

During the day, if the space is occupied

$F = F_{previous} - 0.056\ F_{previous} + (0.025 + 0.065\ \sigma)\ (1 - F_{previous})$

At the end of occupancy

$F = F_{previous} - 0.122\ F_{previous} + (0.025 + 0.065\ \sigma)\ (1 - F_{previous})$

At the start of occupancy

$F = F_{previous} - 0.142\ F_{previous} + (0.025 + 0.065\ \sigma)\ (1 - F_{previous})$

However if there has been an automatic reset, the occupants have a 60% probability of putting their blinds back to their preferred position (data by Rubin et al (ref 8)).

$F = 0.6 \times (0.25 + 0.35*\sigma)$ if the blinds have been reset up

$F = 1 - 0.6 \times (1 - 0.25 - 0.35*\sigma)$ if the blinds have been reset down.

In hospital wards, blinds are assumed to be shut at the end of the day (F=1) then opened at the start of the day unless it is sunny $F = (0.1 + 0.26\ \sigma)$. Offices and consulting rooms in hospitals are assumed to have the same blind use patterns as office buildings.

The results for manual control, and automatic control with manual override, need to be interpreted with care because of the number of assumptions made:

1. The way people use blinds in the office, and, except at the start and end of the day, in the hospital, is assumed to be the same as in the actual Westminster office studied.
2. The Westminster building had internal venetian blinds. The analysis assumes that people use internal roller blinds, and external venetian blinds, in the same way as internal venetian blinds.
3. The analysis has assumed that blind operations are spread evenly over the entire façade. In practice blind operation may be clustered, with some people or groups of people using their blinds a lot and others rarely raising or lowering them. This is unlikely to affect solar gain appreciably but may have an impact on predicted lighting use (it may underestimate the actual impact of blinds on lighting use).
4. In Rubin et al's study on blind reset (ref 8), they manually set a proportion of the blinds in a large building upwards overnight, without telling the occupants. No data are available on how occupants would react to a regular resetting of blind positions when they would be aware it was part of the building management strategy.

Automatic control (with manual override)

Because of the way people use blinds, energy use and comfort may be adversely affected for a number of reasons:

1. On hot days, occupants may only lower the shading after the space has already started to overheat. And if the occupants are absent from part of the building, the shading may not be functioning all day, causing heat build up in these areas which may spread to other occupied zones.
2. People may keep their blinds down longer than required, resulting in extra lighting use and loss of useful solar gain in winter.
3. During the night there may be a reduction in heat loss from the building if blinds are kept down. Occupants are unlikely to shut their blinds at night deliberately (except in spaces used for sleeping such as hospital wards).

For these reasons an automatic control was investigated. The control was assumed to work in the following ways.

Room unoccupied

If a room is unoccupied (either during or outside working hours) blinds are always down, except that blinds are up to warm the building if it is a cold day (external temperature less than 16ºC at any time over the last 24 hours) and there is some sun on the façade.

The criterion of 16 degree external temperature over the last 24 hours is intended to stop solar preheating on summer mornings when the external temperature may start low but become high later.

Blinds are up to help cool the building at night if the outdoor temperature at any time in the last 24 hours was above 20 degrees and the outdoor temperature is currently less than 16 degrees.

Room occupied

If a room is occupied, then the automatic system sends the blinds up just before the start of occupation, except in summer (June, July, August), when the system sends the blinds down if there is sun on the façade, to prevent possible overheating.

In spaces like offices and hospital wards occupants value having control over their environment. They may also want to alter blind position so that they can have a view out or to control glare or provide privacy. Accordingly, in the analysis users were taken to be able to override the blind position at any time. They are assumed to do this using the manual control algorithms above. The system resets the blind position to its initial value at 1030, 1330 and 1630, though

(a) It only does this if the sunshine level is appropriate. So in summer, it only sends them down if there is sun on the façade. For the rest of the year, it only sends them up if there is no sun on the façade.

(b) Users can put them back again, see above.

In hospital wards occupied at night, users are assumed to close the blinds.

Results

Office building

Tables 2-4 give, respectively, calculated delivered energy, carbon dioxide emissions, and energy cost for the following five cases (see also figure 5):

A. Internal shading (roller blinds), manually controlled.

B. Internal shading, automatically controlled using SOMFY algorithms.

C. External shading, fixed (a simple overhang).

D. External shading, moveable, automatically controlled using SOMFY algorithms.

E. No shading (base case).

Table 2.
Delivered energy (kWh/m²) in the office building.

Case	Location	Space Heating	Space Cooling	Lighting	Vent Fans	TOTAL	% of base
A	LON	74,3	11.6	51.4	24.1	161.5	97.1%
B	LON	71.6	9.8	51.9	22.1	155.3	93.4%
C	LON	76.5	11.5	51.4	24.6	164.0	98.7%
B	LON	85.6	5.4	53.4	19.8	164.1	98.7%
E	LON	70.8	15.8	51.0	28.6	166.3	100.0%
A	MAN	93.5	5.9	51.4	22.4	173.2	98.5%
B	MAN	90.2	4.8	51.7	20.5	167.2	95.0%
C	MAN	96.3	5.8	51.3	23.0	176.4	100.3%
B	MAN	107.4	2.1	53.1	18.8	181.5	103.2%
E	MAN	89.0	9.0	50.9	27.1	175.9	100.0%
A	EDI	110.6	3.1	51.6	21.7	187.0	102.3%
B	EDI	106.1	2.3	51.9	20.8	181.1	99.1%
C	EDI	114.0	2.9	51.5	22.1	190.6	104.3%
B	EDI	124.9	0.8	53.2	25.9	204.7	112.0%
E	EDI	106.2	5.2	51.0	20.3	182.8	112.0%

The CO_2 emissions factors used were taken from the 2006 England and Wales Building Regulations Approved Document ADL2a (ref 6):

Natural Gas (for heating): 0.194 $kgCO_2/kWh$

Grid Supplied Electricity: 0.422 $kgCO_2/kWh$

Table 3.
Carbon dioxide emission (kgCO2/m²) in the office building.

Case	Location	Space Heating	Space Cooling	Lighting	Vent Fans	TOTAL	% of base
A	LON	14.42	4.90	21.71	10.17	51.20	94.8%
B	LON	13.89	4.13	21.88	9.31	49.21	91.1%
C	LON	14.84	4.87	21.68	10.38	51.77	95.8%
B	LON	16.60	2.29	22.52	8.35	49.76	92.1%
E	LON	13.74	6.68	21.51	12.09	54.02	100%
A	MAN	18.14	2.50	21.67	9.45	51.76	96.0%
B	MAN	17.49	2.01	21.83	8.66	49.99	92.7%
C	MAN	18.69	2.44	21.63	9.69	52.46	97.3%
B	MAN	20.83	0.89	22.42	7.95	52.09	96.6%
E	MAN	17.27	3.78	21.46	11.44	53.94	100%
A	EDI	21.46	1.30	21.75	9.16	53.68	101.5%
B	EDI	20.59	0.95	21.89	8.79	52.22	98.7%
C	EDI	22.12	1.24	21.71	9.34	54.42	102.8%
B	EDI	24.23	0.32	22.44	10.91	57.91	109.4%
E	EDI	20.61	2.21	21.53	8.56	52.91	100%

The CO2 emissions factors used were taken from the 2006 England and Wales Building Regulations Approved Document ADL2a (ref 6):

Natural Gas: 0.194 $kgCO_2/kWh$

Grid Supplied Electricity: 0.422 $kgCO_2/kWh$

Table 4.
Energy cost (p/m²) in the office building.

Case	Location	Space Heating	Space Cooling	Lighting	Vent Fans	TOTAL	% of base
A	LON	148.6	75.5	334.4	156.7	715.2	93.8%
B	LON	143.2	63.6	337.1	143.3	687.2	90.2%
C	LON	153.0	75.0	334.0	159.9	721.9	94.7%
B	LON	171.1	35.2	346.9	128.6	681.9	89.5%
E	LON	141.6	103.0	331.3	186.2	762.1	100%
A	MAN	187.0	38.5	333.8	145.5	704.9	94.9%
B	MAN	180.3	31.1	336.2	133.3	680.8	91.7%
C	MAN	192.7	37.7	333.2	149.2	712.8	96.0%
B	MAN	214.8	13.7	345.3	122.5	696.2	93.7%
E	MAN	178.0	58.2	330.5	176.2	742.9	100%
A	EDI	221.3	20.1	335.1	141.1	717.5	101.1%
B	EDI	212.3	14.6	337.2	135.4	699.5	98.5%
C	EDI	228.0	19.1	334.4	143.9	725.5	102.2%
B	EDI	249.8	4.9	345.7	168.1	768.5	108.2%
E	EDI	212.5	34.0	331.7	131.8	710.0	100%

Costs were assumed to be

Natural Gas: 2 p/kWh

Grid Supplied Electricity: 6.5 p/kWh

These are approximate costs and will depend on tariff and supplier, so should be taken as indicative only.

Hospital building

For the hospital building, tables 5-7 give, respectively, calculated delivered energy, carbon dioxide emissions, and energy cost for the same five cases (see also figure 6):

A. Internal shading (roller blinds), manually controlled.

B. Internal shading, automatically controlled using SOMFY algorithms.

C. External shading, fixed (a simple overhang).

D. External shading, moveable, automatically controlled using SOMFY algorithms.

E. No shading (base case).

No cooling energy is used as the hospital is assumed to be naturally ventilated. Table 5 and Figure 7 also give overheating data in terms of the number of hours key temperatures are exceeded. Columns 6 and 7 give the data for the worst affected zone in the building; columns 8 and 9 give the average data for all the zones in the building.

Table 5.
Delivered energy (kWh/m²) in the hospital building, plus numbers of hours given temperatures were exceeded.

Case	Location	Space Heating	Lighting	TOTAL	Max n° of h above		Ave n° of h above	
					24°C	29°C	24°C	29°C
A	LON	40.4	36.1	76.6	1992	1345	1212	617
B	LON	41.5	35.9	77.5	1891	1248	1074	515
C	LON	49.1	35.7	84.8	1580	850	936	348
B	LON	48.8	37.3	86.1	1277	476	627	153
E	LON	42.0	34.6	76.6	2062	1481	1342	785
A	MAN	51.9	35.9	87.8	1541	657	708	275
B	MAN	53.4	35.7	89.1	1343	564	556	211
C	MAN	62.6	35.3	97.9	1034	355	477	144
B	MAN	62.9	37.2	100.1	706	169	287	50
E	MAN	53.5	34.2	87.7	1639	848	843	379
A	EDI	63.8	36.3	100.1	1220	382	421	91
B	EDI	64.4	36.0	100.4	818	228	276	51
C	EDI	76.0	35.5	111.5	662	116	248	29
B	EDI	75.0	37.4	112.4	364	24	118	5
E	EDI	65.5	34.4	99.9	1341	587	553	180

Table 6.
Carbon dioxide emissions (kgCO2/m²) in the hospital building.
The same CO2 emissions factors were used as for the office building.

Case	Location	Space Heating	Lighting	TOTAL	% of base
A	LON	7.85	15.24	23.09	101.6%
B	LON	8.06	15.16	23.22	102.1%
C	LON	9.52	15.08	24.60	108.2%
B	LON	9.46	15.74	25.21	110.9%
E	LON	8.15	14.58	22.73	100%
A	MAN	10.07	15.17	25.23	101.8%
B	MAN	10.35	15.08	25.43	102.6%
C	MAN	12.15	14.89	27.04	109.1%
B	MAN	12.20	15.69	27.89	112.5%
E	MAN	10.38	14.42	24.80	100%
A	EDI	12.38	15.31	27.69	101.7%
B	EDI	12.50	15.20	27.69	101.7%
C	EDI	14.75	14.99	27.69	109.2%
B	EDI	14.54	15.79	30.33	111.4%
E	EDI	12.70	14.52	27.22	100%

Table 7.
Energy costs (p/m²) in the hospital building. The same energy prices were used as for the office building.

Case	Location	Space Heating	Lighting	TOTAL	% of base
A	LON	80.9	234.8	315.7	102%
B	LON	83.1	233.5	316.5	103%
C	LON	98.2	232.3	330.4	107%
B	LON	97.5	242.5	340.1	110%
E	LON	84.0	224.6	308.6	100%
A	MAN	103.8	233.6	337.4	103%
B	MAN	106.7	232.3	339.0	103%
C	MAN	125.3	229.4	354.7	108%
B	MAN	125.8	241.6	367.4	112%
E	MAN	107.0	222.0	329.1	100%
A	EDI	127.7	235.8	363.5	103%
B	EDI	128.8	234.1	362.9	102%
C	EDI	152.0	230.8	382.9	108%
B	EDI	149.9	243.2	393.1	111%
E	EDI	130.9	223.7	354.6	100%

Discussion

In the analysis, the addition of shading always produces a reduction of cooling demand and an increase in artificial lighting and, nearly always, heating. The only exception is in the hospital where adding internal blinds slightly reduces the heating load. This is because of reduced heat loss through windows during cold nights, by reducing the conductivity of the window system when the blinds are lowered.

Air conditioned office

The results for the office building show that substantial cooling savings are possible. External automatic shading control (option D) achieves the biggest savings in cooling. Compared to the no shading case (option E) it gives a 66% reduction in London, 77% in Manchester and 85% in Edinburgh. This shows the potential of this strategy to reduce cooling requirements in air conditioned buildings (or even avoid the need to install cooling in some locations). Cooling savings are best achieved with external devices that prevent additional solar gains.

However, cooling savings need to be balanced against the increases in heating and lighting energy use. When analysed using delivered energy, internal automatic shading (b) produces the best results in all locations with a total delivered energy reduction (table 2) of up to 6.6% in London. However delivered energy is not the best metric to use when assessing the impact on the environment (for which CO_2 emissions (table 3) are more suitable) or building occupier (who will be more interested in energy cost (table 4)). If either of these metrics are chosen, the provision of shading gives greater savings compared to the no shading case (up to 10% in energy cost in London if an automatically controlled system is used). For London, there is very little difference between the performance of internal and external shading systems in predicted energy cost or CO_2 emissions.

However, latitude is a critical factor for shading systems. At high northern latitudes additional shading does not generally achieve energy savings, although it may increase user comfort by reducing glare.

For internal blinds, the introduction of the automatic control components (option B) always gives a saving of around 3% in total energy use compared with manual control (option A), for all latitudes. Both heating and cooling energy are reduced, but lighting energy use increases marginally, because the blinds are lowered more in summer.

Comparison of the automatically controlled external shading (option D) with the simple fixed overhang (option C) shows that the controlled shading gives a 5% reduction in energy cost in London and 2% reduction in Manchester. However in Edinburgh there is a 6% increase in energy cost. This is due to the increase in space heating costs in winter, because the modelling takes account of the occupants using the moveable external shading like blinds to reduce glare. The fixed overhang does not control glare from low angle sun in winter, so would be unlikely to be acceptable on its own as a shading device.

A combination of automatically controllable internal shading (winter) and external shading (summer) could result in the best strategy for energy savings and comfort levels in an air conditioned building.

Naturally ventilated hospital

As the hospital does not have cooling installed, adding any form of shading will increase the energy use (tables 5-7). Depending which metric is used, internal shading results in an energy penalty of 1-3%, and external shading a penalty of 7-12%, compared to the no shading case.

With internal shading, automatic control (option B) gives similar energy use to manual control (option A). For external shading, the moveable automatically controlled system (option C) gives energy use 1-4% higher than the simple fixed overhang (option D).

However energy use is not the only important issue here. Thermal comfort is critically important too. Table 5 gives the temperature data for the building. A typical thermal comfort criterion for naturally ventilated buildings is a temperature of 25ºC over less than 5% of occupied hours (ref 9). For a hospital occupied 24 hours a day, this is 438 hours over the year. Temperatures over 28ºC are very uncomfortable and should be avoided.

Table 5 shows that the hospital design is particularly prone to overheating, especially in Southern England. Taking the hospital as a whole, a very high temperature of 29ºC is exceeded 9% of the year with no shading. Internal shading reduces the temperatures slightly. Fixed external shading gives a further reduction, but the most effective system uses the moveable automatically controlled shading. Even with this system there is a tendency for the building to overheat, so it would need to be applied as part of a package of measures, for example improved ventilation and maybe cooling of the hottest zones.

Further north the overheating is not so marked if suitable shading is installed. With the moveable automatically controlled solar shading, overheating is limited to a few 'hot spots' in the building. There is a substantial difference in thermal comfort between the different shading options.

Moveable shading also helps to provide privacy, which is important in hospital buildings. Options C (fixed overhang on its own) and E (no shading) would not be acceptable in most areas in hospitals for this reason.

Conclusions

This paper has examined the energy and thermal comfort implications of installing solar shading, including automatically controlled shading. The addition of shading reduces cooling demand but increases the need for artificial lighting and, nearly always, heating. Consequently energy savings are generally possible only in buildings which have cooling installed, or where cooling would have to be installed if the shading were not present.

Analysis of an air conditioned office suggests that in England shading can result in significant reductions in carbon dioxide emissions and energy cost. In the London area, compared to a building without shading, overall CO_2 savings of 5% were predicted for manually controlled blinds and 4% for a simple external overhang. In Manchester the corresponding savings were 4% and 3% respectively.

Additional savings can be obtained by installing automatic control of shading. This happens if the system can lower blinds on hot days, especially in unoccupied spaces; if it can raise the blinds to admit daylight on dull days when shading is not required to control glare; and if it can lower blinds on cold nights to reduce heat loss. In offices manual override is still recommended to allow occupant control, especially of glare. The analysis in this paper has shown that such automatically controlled shading will typically give extra CO_2 savings of around 3% compared to simple manually controlled or fixed systems. Overall, an automatically controlled shading system gave building CO_2 savings of 9% (with internal blinds) and 8% (with external blinds) in the London area compared to the no shading case.

The benefits of shading are latitude dependent; in Scotland, installation of external shading gave an energy penalty of between 3% and 9%. Moveable external shading gave the highest energy penalty because occupants would use the external blinds to control glare, reducing solar gains on cloudy days. Automatic control of internal shading was more successful here, reducing CO_2 emissions by around 2% compared to no shading or manually controlled internal shading.

In a naturally ventilated hospital, the installation of shading resulted in an energy penalty of between 2% (for internal blinds either manually or automatically controlled) and 11-13% for automatically controlled external shading. However, the external shading resulted in significant reductions in summertime external temperatures, which could avoid the need to install cooling in some areas.

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Figure 1. 3d view of the office building.

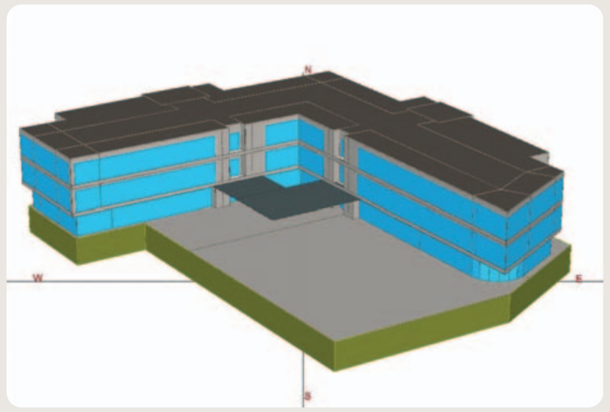


Figure 2. Typical floor layout for the office building showing zoning.

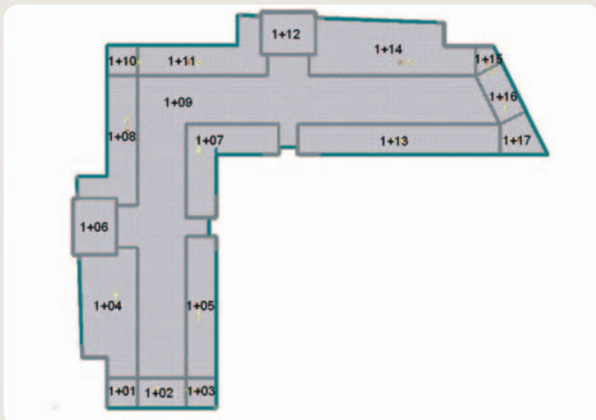


Figure 3. Three dimensional view of the hospital building.

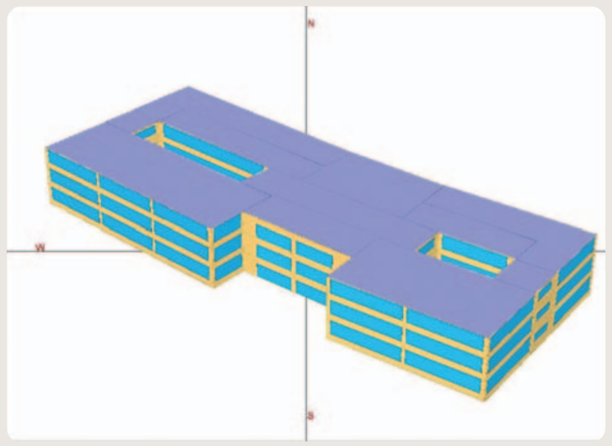
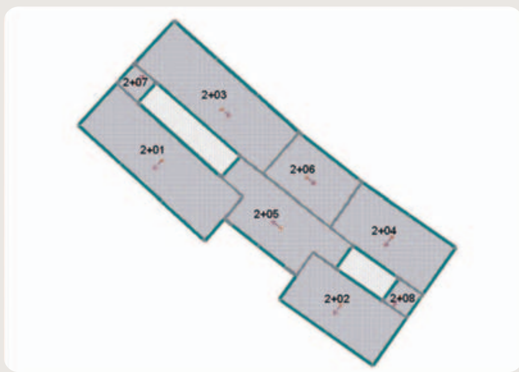


Figure 4. Typical floor plan for the hospital building. Zones 2+01, 2+02 and 2+03 are wards and 2+07 and 2+08 are stairwells. The remaining rooms are ancillary areas.



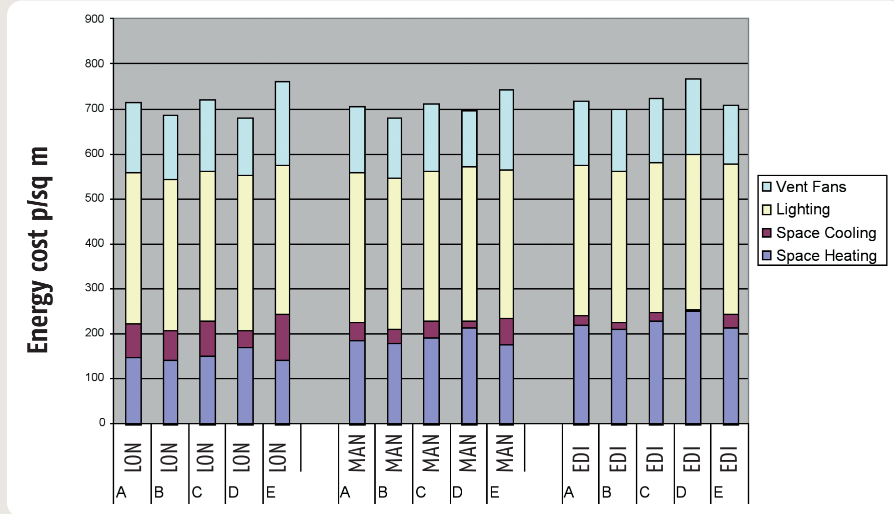


Figure 5. Energy cost (pence per square metre) for the office building for the five cases: A: Manually controlled internal blinds; B: Automatically controlled internal blinds; C: Overhang; D: Automatically controlled external shading; E: No shading.

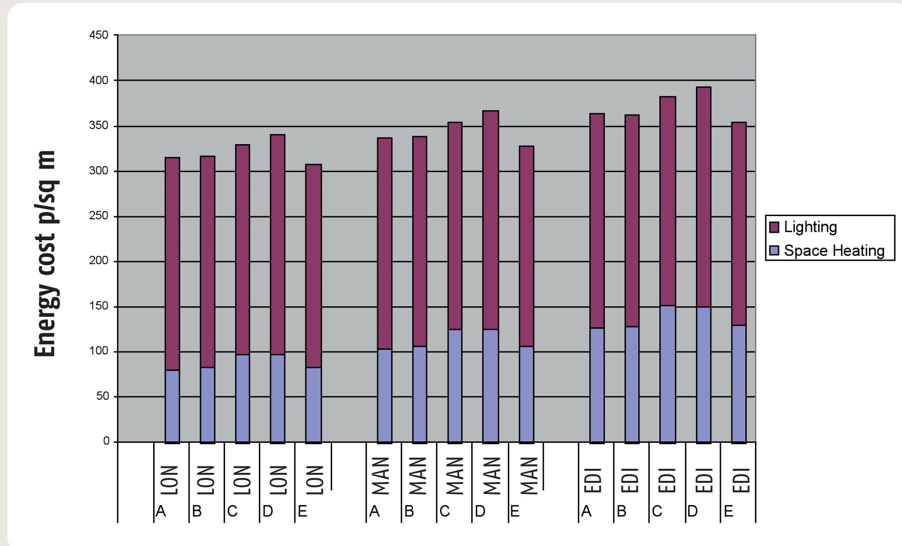


Figure 6. Energy cost (pence per square metre) for the hospital building for the five cases: A: Manually controlled internal blinds; B: Automatically controlled internal blinds; C: Overhang; D: Automatically controlled external shading; E: No shading.

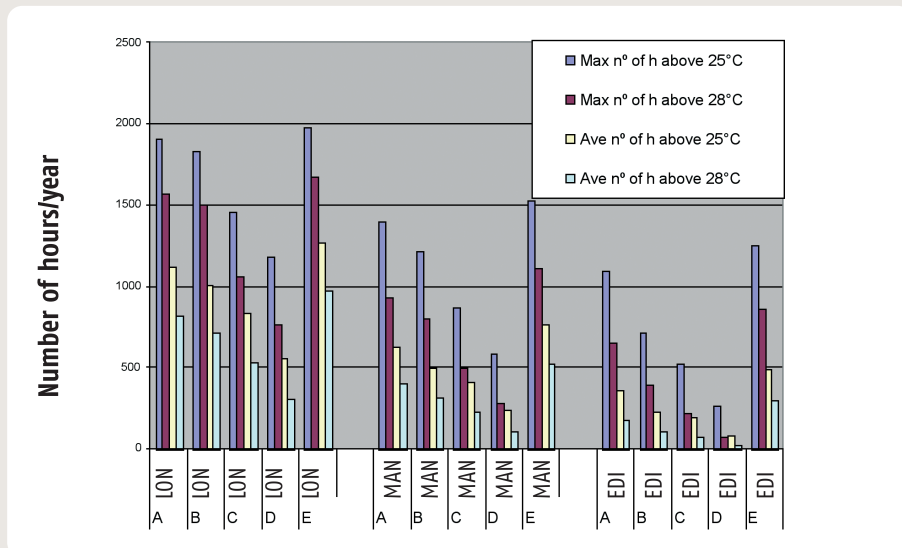


Figure 7. Hours of overheating for the five cases: A: Manually controlled internal blinds; B: Automatically controlled internal blinds; C: Overhang; D: Automatically controlled external shading; E: No shading.