4173

THERMAL PERFORMANCE OF NON-AIR-CONDITIONED OFFICES IN THE U.K.

D.K.Alexander and P.J.Jones
Welsh School of Architecture
University of Wales College of Cardiff
PO BOX 25, Cardiff,
U.K.
CF1 3XE.

ABSTRACT. The acceptability of summertime office environments, in the absence of air-conditioning systems, was investigated using a dynamic thermal building model. A realistic combination of solar shading, thermal mass, and night ventilation purging was found to allow reasonable conditions (average temperatures approximately 26°C), effectively dealing with internal gains of up to 40 W/sqm. Higher gain levels, of up to 60 W/sqm can also be controlled, but at the expense of higher mean temperatures. The options tested also lead to a significant reduction in cooling loads, had air-conditioning systems been supplied.

1. INTRODUCTION

Many office buildings in the U.K. are air-conditioned to produce what is considered to be an acceptable internal environment regardless of the outside conditions.
It has emerged that, far from producing a beneficial environment, such buildings can have a distinctly negative effect on the occupants. The causes of these effects can often be identified with the use of, or the mis-use of, air-conditioning plant. /1/
There is a movement towards the reduction of, and possible avoidance of, air conditioning systems in new office buildings. This has arisen from many concerns :
- the desire to reduce capital and maintenance costs,
- the desire to reduce energy usage and costs,
- the desire to reduce the usage of CFC's, and
- the desire to avoid the phenomena of "sick building syndrome".

Recent design endeavours have sought to alleviate such problems, for instance atria are provided for enhanced daylight and ventilation, and control over lighting and window opening is often returned to the occupants.
On the other hand, internal gains can be seen to be increasing (due to the spreading use of IT office electronics), as are fabric insulation levels.
Results of the monitoring of a naturally ventilated, thermally massive office building /2/ showed that at internal gain levels of approximately 30 W/sqm, overheating in summer was not a problem.
The question arises, to what level of internal gains, can active cooling be avoided through the use of architectural/engineering options?
This paper describes the use of a dynamic thermal model (HTB2) to investigate the reductions in cooling requirement, and the allied environmental consequences, caused by combinations of such design options as:
- the provision of controllable ventilation,
- the use of external solar shading devices,
- the use of high internal thermal mass to absorb internal heat gains, and
- the use night time purging to flush out those stored heat gains.

The investigation is based around an office design, and around internal heat gains, typical of modern practice.
The current study has evolved from a project option for third year architectural students, wherein they are encouraged to subject their own office designs to appraisal by simulation, and to explore the consequences of shading devices, glazing areas and types, ventilation options and varying incidental gains.

2. SUMMERTIME OVERHEATING AND COMFORT CRITERIA

There are in the U.K. guide-lines and procedures available to the designer wishing to provide an acceptable internal environment, such as those published by CIBSE /3/ and BRE /4/. These often lay out a set of criteria for acceptable conditions.
Six indicators of the summertime environmental performance of offices, and their recommended maxima, were selected as test criteria for this work. They are summarized in Table I.

Parameter	Criteria
Peak Air Temperature	< 26 °C
Peak Resultant Temperature	< 26 °C
MRT - Air Temperature Difference	< 4 °C
Average Temperature in Working Day	< 24 °C
Temperature Range in Working Day	< 4 °C
Psychometic limits	< 27 °C at 20%rh, < 23 °C at 80%rh

Table I. Comfort Criteria for Summertime Conditions in U.K. Offices.

Realistically, these criteria cannot be absolute maxima; it has been suggested that they not be exceeded more than 30 times in 10 years.

3. THERMAL MODELLING

The model used in this work was HTB2 /5/. HTB2 is capable of simulating, to fine time detail, the interactions of fabric, ventilation, plant and incidental energy systems, and the climate. This model was developed at the Welsh School of Architecture (R&D) as a general research and teaching tool for the investigation of energy and environmental performance of buildings.
HTB2 has been subject to external appraisal, and has been included in the recent inter-model comparisons of IEA Task VIII. It is in use in a number of higher education and commercial organisations in the U.K.

4. TEST CASE DESCRIPTIONS

4.1 Location and Time

The simulations were carried out for 30 days from mid-July through mid-August. The building was assumed to be on an unobstructed site near London. Kew 1967 meteorological data was used to provide data for external air temperature, humidity, and solar gains.

4.1 Layout

Although generic in nature, the office area and layout for the case study has been developed from a live (and fully air-conditioned) example. It contained a mixture of open plan and cellular accommodation as in Figure 1. The office areas under test were assumed to be situated on an intermediate floor of a multi-floor block. The gross floor area of the test offices was 900 sqm.

4.2 Structure

Two basic construction types for the office structure were considered, representing light-weight and heavy-weight structural options, as in Table II. The heavy-weight option included an exposed concrete ceiling; raised flooring was provided to allow provision for services. A third option further increased the thermal mass by assuming a waffled ceiling structure.
All opaque walls had U-values of 0.45 W/sqm/°C, and windows were double glazed.

Type -	Lightweight	Heavyweight
External Walls	40mm concrete 60mm insulation 200mm cavity 12mm plasterboard	105mm brick 55mm foamboard 105mm heavy block 12mm heavy plaster
Internal Partitions	12mm plasterboard 50mm stud/cavity 12mm plasterboard	12mm heavy plaster 105mm heavy block 12mm heavy plaster
Floor/ Ceiling	25mm flooring 65mm concrete 500mm cavity 12mm plasterboard	25mm flooring 500mm cavity 65mm concrete

Average Admittances (W/sqm):

	Light	Heavy	Very Heavy
Open Plan areas	6	9	13
Cellular Offices	6	12	17

Table II Construction Type Options and Equivalent Admittance Values (Very Heavy as Heavy with a waffled ceiling structure).

It was noted that the use of these structures did not achieve the admittance range suggested in the manuals, due to the relatively large open spaces in the test case.

4.3 Glazing areas and Shading

The amount of external glazing was fixed for all simulations and was based on 50% of the external elevation for all orientations (apart from the blank north elevation).
In cases where external shading was applied, the equivalent of a projecting horizontal awning of 2.5m depth was assumed on all facades.

4.4 Ventilation and Air Movement

A minimum ventilation rate of 1.5 air changes per hour during occupancy was chosen, based on the recommended fresh air supply for the assumed occupancy rates. Overnight infiltration was set to be 0.25 ac/h. Initially the ventilation rate was fixed under all conditions.
Ventilation options tested were the provision of boosted ventilation at 6 ac/h during high temperatures (>26 °C) in occupancy periods, and the provision of night-time purging at 6 and 12 ac/h. It was considered that the latter high rate could be achieved in practice as at night there would be no acoustic penalties. Mechanical ventilation was assumed in all cases.

The open plan areas were zoned to perimeter and deep areas, as in figure 1, and were connected thermally by the equivalent of a mixing air flow of 0.1 m/s.

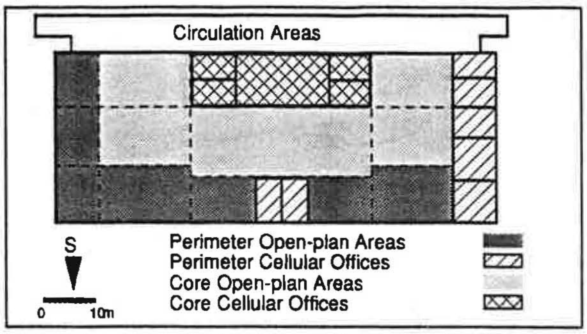

Figure 1. Test Office Floor Plan, Showing Zoning.

4.5 Internal Gains

Three levels of internal gains were tested, summarized in table II. These gain level do not necessarily reflect the total range found in U.K. offices, but were arrived at through reasonable assumptions on occupancy, lighting, and electronic equipment provision.
The office was assumed to be in use between the hours of 9:00 am and 5:00 pm; comfort criteria were assessed between those times. The internal gains, including lighting, were assumed to be on full over that entire period, and there were no weekend breaks in the building use.

4.5.1 Occupancy and small power gains

Two occupancy rates were assumed for the open plan areas; 15 and 10 sqm/person. Cellular offices were assumed to contain only one person. Each occupant was considered to contribute 100 W heat, and 40 g/h water-vapour to the space.
Small power gains were determined from the occupancy rates. Two scenarios of the provision of electronic office equipment were assumed. For the High and Medium gain cases, each "person" had a desktop computer (or electrical load equivalent) and each group of 5 people had a shared laser-printer. In the Low gain case, PCs' were assumed to be shared between staff, and there were no local printers.

4.5.2 Lighting

The lighting system installed load was taken to be 22 W/sqm for the High and Medium gain cases, and 17 W/sqm for the Low gain case.

Case -	LOW	MEDIUM	HIGH
Open Plan Office Areas	32W/sqm	44W/sqm	59W/sqm
Cellular Office Areas	30W/sqm	39W/sqm	42W/sqm
Mean Overall	33W/sqm	44W/sqm	53W/sqm

Table III Incidental Gains Cases, Breakdown By Office Type

5. RESULTS AND DISCUSSION

5.1 Tests

The test cases progressed incrementally from the lightweight, unshaded and minimally ventilated case, through the addition of design features; controllable ventilation boost, shading, high and very high internal mass. The two options of night purging, at 6 and 12 ac/h, were applied. The cases tested are summarised and coded in table IV.

Option -	Thermal Mass		
|	Light	Heavy	V.Heavy
Minimal vent. (1.5 ac/h)	"Base"	-	-
Boosted vent. (1.5-6 ac/h)	"V"	-	-
+ Shading (2.5m awning)	"VS"	"HVS"	"SVS"
+ Night Purge (6 ac/h)	"VSP"	"HVSP"	"SVSP"
+ High Night Purge (12 ac/h)	-	"HVSP2"	"SVSP2"

Table IV Test Case Matrix, repeated for each of Low, Medium, High Gains Cases.

Open plan and cellular offices were very different in their results, but there was little average difference between perimeter areas and deep areas. Perimeter areas had higher solar gains, and a higher afternoon temperature, whilst deep areas, with their lower fabric heat losses, had higher morning temperatures but lower increases over the day. Discussions on results will concentrate on perimeter areas only.

5.2 Environmental Criteria

Table V shows , for the open and cellular offices (in brackets), the ability of the various test cases to meet the comfort criteria listed in table I. The percentage of time exceeding the criteria are listed. Also listed are the mean daily, and mean peak, air and resultant temperatures, and the mean humidity in the spaces. All data is restricted to the working day.
In general those criteria based on environmental temperature were stricter than those based on air temperature. This was due to the extra radiant gains from solar and casual sources being included in the determination of MRT. The mean resultant temperature in the working day was the most severe criterion used in these tests.
In the open plan areas, the options tested had little effect on that particular criterion; for the best result >70% of working days averaged above 24°C, even for the low gain case.
The results for the criteria on peak temperatures fared better; by the best result <15% of working hours were below 26°C for the low gains case.
The results for the psychometric criteria were similar to those based on environmental temperature. Humidity levels were not a cause for concern, being in the range 40 - 60%rh for the best high gains case.
Due to the relatively higher thermal mass, and lower gain levels, in the cellular offices, conditions in the those spaces were often more satisfactory.

5.3 Environmental Conditions

Figures 2,3 indicate the average (and 1 standard deviation range) daily temperature variations for open plan and cellular offices, respectively. Mean and peak temperatures are listed in Table V.
The addition of shading reduced the overall temperatures, and also acted to reduce the difference between radiant and air temperatures.
The options of increased mass had little significant effect until night purging was introduced. Adding mass alone often increased problems, as heat gains built-up, increasing the average working day temperature. Night purging allowed some of that build-up to be removed. Test cases on night purging without added mass reduced the overall temperatures, but increased the temperature range through day.
The high gain cases could not achieve the comfort criteria laid out, and so this must mark an upper limit of feasibility. The environment produced was

Case	Percentage Time in working day Criteria not met (cf table I)						Resultant temperature		Humidity
							Mean Daily °C	Mean Peak °C	Mean RH %
	A	B	C	D	E	F			
HIGH GAINS									
"Base"	100(100)	100(100)	34(2)	100(100)	100(100)	65(66)	50.6(47.4)	53.5(50.4)	14(16)
"V"	100(99)	100(100)	85(41)	100(100)	100(100)	89(35)	36.4(32.7)	42.5(37.8)	32(36)
"VS"	100(90)	100(99)	1(0)	100(97)	100(100)	46(20)	31.5(28.8)	35.7(32.5)	36(41)
"VSP"	83(83)	77(69)	3(1)	73(66)	100(100)	74(41)	27.7(25.8)	31.6(29.2)	42(47)
"HVS"	100(93)	100(100)	0(0)	100(98)	100(100)	17(3)	31.1(28.7)	35.1(31.9)	37(41)
"HVSP"	75(22)	66(24)	2(0)	64(29)	100(75)	77(3)	27.0(24.7)	30.6(27.7)	43(50)
"HVSP2"	41(12)	51(19)	1(0)	41(20)	90(70)	20(2)	26.2(24.5)	29.4(27.3)	46(50)
"SVS"	100(93)	100(100)	0(0)	100(98)	100(100)	17(3)	30.7(28.5)	34.4(31.5)	37(41)
"SVSP"	65(17)	55(17)	1(0)	55(22)	98(71)	39(3)	26.3(24.4)	29.5(27.3)	45(51)
"SVSP2"	33(10)	39(13)	1(0)	41(20)	90(70)	20(2)	25.6(24.3)	28.6(27.0)	47(51)
MEDIUM GAINS									
"Base"	100(100)	100(100)	30(2)	100(100)	100(100)	82(67)	50.6(47.4)	53.5(50.4)	14(16)
"V"	99(99)	100(100)	88(39)	100(100)	100(100)	84(32)	36.4(32.7)	42.5(37.8)	32(36)
"VS"	94(84)	100(99)	2(0)	99(96)	100(100)	39(16)	31.5(28.8)	35.7(32.5)	36(41)
"VSP"	53(53)	63(49)	2(1)	62(48)	100(97)	47(17)	27.7(25.8)	31.6(29.2)	42(47)
"HVS"	94(87)	100(100)	1(0)	99(97)	100(100)	23(3)	31.1(28.7)	35.1(31.9)	37(41)
"HVSP"	46(15)	53(19)	1(0)	54(24)	89(70)	47(4)	27.0(24.7)	30.6(27;7)	43(50)
"HVSP2"	20(10)	44(16)	1(0)	47(23)	87(69)	35(4)	26.2(24.5)	29.4(27.3)	46(50)
"SVS"	95(87)	100(100)	0(0)	99(96)	100(100)	13(3)	30.7(28.5)	34.4(31.5)	37(41)
"SVSP"	36(12)	40(12)	1(0)	40(19)	80(63)	35(3)	26.3(24.4)	29.5(27.3)	45(51)
"SVSP2"	16(8)	23(11)	1(0)	33(18)	80(60)	30(2)	25.6(24.3)	28.6(27.0)	47(51)
LOW gains									
"Base"	100(100)	100(100)	21(1)	100(100)	100(100)	93(60)	49.3(45.7)	52.6(49.3)	15(18)
"V"	95(98)	100(100)	85(30)	100(100)	100(100)	80(27)	33.1(31.3)	38.8(36.1)	39(38)
"VS"	77(74)	99(96)	1(0)	95(90)	100(100)	27(9)	28.6(27.7)	32.1(30.9)	43(43)
"VSP"	33(33)	48(33)	1(0)	49(35)	85(81)	46(25)	25.7(24.9)	29.1(28.3)	48(50)
"HVS"	77(77)	99(98)	1(0)	95(90)	100(100)	18(3)	28.4(27.4)	31.6(30.2)	43(44)
"HVSP"	23(9)	36(10)	1(0)	39(18)	79(50)	48(4)	25.1(23.7)	28.4(26.9)	49(53)
"HVSP2"	11(7)	31(9)	1(0)	36(17)	79(48)	42(4)	24.9(23.7)	28.0(26.8)	50(53)
"SVS"	79(77)	97(97)	0(0)	90(.86)	100(100)	11(3)	28.0(27.4)	31.0(29.8)	43(44)
"SVSP"	15(6)	20(6)	0(0)	26(14)	73(37)	23(0)	24.4(23.4)	27.6(26.5)	51(54)
"SVSP2"	9(5)	16(6)	0(0)	23(14)	71(37)	22(0)	24.3(23.4)	27.3(26.4)	51(54)

Table V Criteria and Environmental Results for All Test Cases; Open Plan (and Cellular) offices.

however thought marginally acceptable. On average, the internal temperature of the open areas peak, at the end of the day, at 27°C. There may therefore be expected some loss of comfort, but note that with local air movement as might be produced by desk fans, the comfort temperature can exceed 30°C.
The cellular offices fared much better, peaking below 25°C on average.

5.4 Equivalent cooling loads

Air-conditioning is sometimes provided for reasons beyond environmental comfort, i.e. for prestige, competition, or increased rentability of speculative buildings.
Some of the high gain tests were repeated with an active cooling system in operation, so that the reduction in cooling requirement, due to these measures, could be assessed. A cooling set point of 23 °C was assumed.
The best case was the same as that for the non-cooled cases, that is with the provision of high mass, shading, and night purging.
The best reduction on average cooling requirement for the whole office area was some 50%, while the peak cooling loads were reduced by 33%. The results are summarized, for the total office area, in table VI.
It was noted that in the initial test cases, the air-conditioned environment fared little better in meeting some comfort criteria, than the non-air-conditioned cases. Though air temperature was completely controlled, the presence of radiant gains meant that other criteria failed.
The addition of shading, thermal mass, and purging options improved the internal environment considerably, in addition to reducing cooling energy demand.

Case	A/C Load Average W/sqm	A/C Load Peak W/sqm	Resultant Temperature Mean °C	Resultant Temperature Peak °C
"V"	59	74	26.3	27.3
"VS"	48	60	25.0	25.5
"HVS"	48	59	24.9	25.4
"HVSP"	32	51	23.3	24.5
"SVSP"	29	51	23.0	24.1

Table VI Cooling Loads and Temperatures for Air-Conditioned Test Cases.

CONCLUSIONS

The options investigated have been shown to offer potential for improved comfort and reduced energy costs in offices.
The use of external shading devices are seen to be effective in both reducing cooling loads, in reducing the radiant temperature levels in a space, thus increasing comfort levels.
Through a combination of responsive day time ventilation, night time purging, solar shading and thermal mass, a significant reduction in cooling requirement can be achieved. At moderate levels of internal gains (approximately 40 W/sqm), reasonable internal environments were predicted, without the recourse to active cooling. At higher gain levels (<60 W/sqm), active cooling could also be avoided, although some relaxation of expectation or provision of local air movement would be required.
Even though ventilation rates greater than 6 ac/h were not used during occupancy periods, the effect has been as if much higher rates had been applied throughout the day.
Even in the air-conditioned test cases, some comfort criteria were not always met. This in particular was due to the presence of radiant gains (from solar or internal sources) to the spaces, increasing the resultant temperature. The options could also significantly improve internal conditions, and reduce cooling loads, where air-conditioning had been provided.

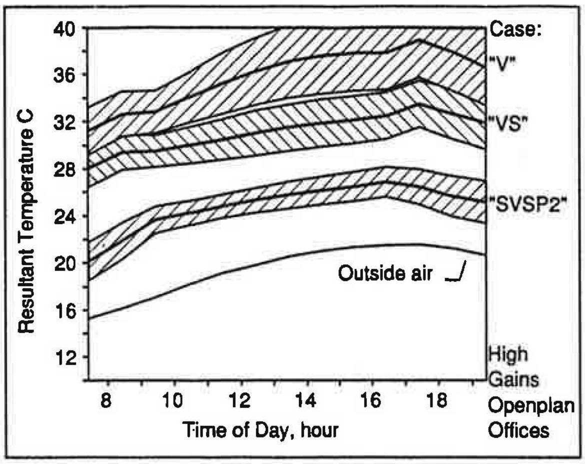

Figure 2. Reduction in Mean Daily Temperature Profiles In Open Plan Offices (shaded area indicates 1 s.d range).

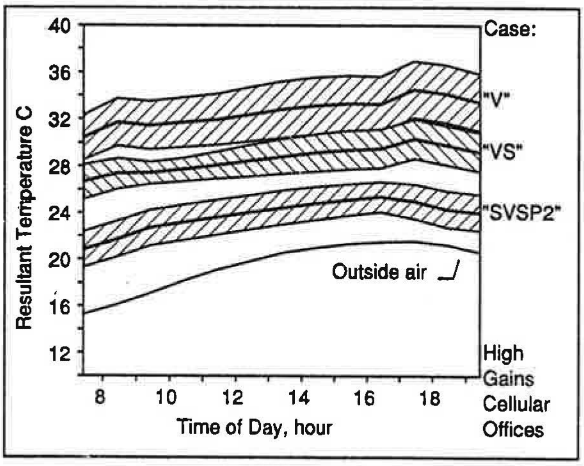

Figure 3. Reduction in Mean Daily Temperature Profiles In Cellular Offices (shaded area indicates 1 s.d range).

REFERENCES

1 Wilson,S., O'Sullivan,P., Jones,P., Hedge,A., "Sick Building Syndrome & Environmental Conditions: Case Studies of 9 Buildings", Building Use Studies Ltd, London, 1987.

2 Databuild Ltd., "South Staffordshire Water Corporation Headquarters: EPA Technical Report", ETSU, 1989 (draft).

3 CIBSE, "A8 - Summertime Temperatures in Buildings", CIBSE, London, 1980.

4 Petherbridge,P., et al, "Environmental Design Manual, Summer Conditions in Naturally Ventilated Office", Building Research Establishment, Garston, Watford, 1988.

5 Lewis,P.T., Alexander,D.K., "HTB2: A Flexible Model for Dynamic Building Simulation", accepted for publication in Building and Environment, 1990.