OCCUPANT SATISFACTION WITH ENVIRONMENTAL CONDITIONS IN NATURALLY VENTILATED AND AIR-CONDITIONED OFFICES

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During the past three years, BRE has conducted winter and summer occupant surveys on satisfaction with environmental conditions in 23 buildings. These were a mixture of naturally ventilated and air conditioned buildings. The results presented in this paper are based on a secondary analysis of 5136 completed questionnaires. The aim of the analysis was to determine the effect of ventilation type and season on occupant satisfaction with key environmental parameters: thermal sensation, thermal comfort, humidity, air movement, stuffiness, air quality, lighting and noise. Although 3% more occupants were satisfied with the environment in air conditioned offices than in naturally ventilated ones, this difference does not justify the 60% extra energy consumption and the additional installation and maintenance costs associated with the air-conditioned offices.

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INTRODUCTION

The type of ventilation system installed in offices affects a variety of important parameters such as indoor environmental conditions, occupant satisfaction, energy efficiency and energy consumption, space utilisation, and capital and running costs. This report focuses on the relationship between the occupants' satisfaction with indoor environmental conditions and the type of ventilation in the building, taking into account the building's energy consumption.

In some circumstances the design of a ventilation system may provide satisfaction with one environmental factor whilst producing dissatisfaction with another factor. For example, opening a window in a naturally ventilated (NV) city-centre office in summer may provide cooling whilst increasing air and noise pollution with little effect on energy. In contrast, increasing the ventilation rate in an air conditioned (AC) office may improve air quality and thermal comfort but increase noise and energy costs. A compromise solution is therefore produced by weighing the pros and cons of the ventilation systems against the effect on occupant satisfaction and energy costs.

During the past three years the Healthy Building Centre at BRE has conducted post-occupancy evaluations in 23 office buildings. More detailed method and results from 14 of these buildings can be found elsewhere[1,2,3]. Occupant ratings of a range of comfort factors were collated from 5136 returned questionnaires. This data set allows further analysis to be conducted to determine any differences in the overall satisfaction of NV in comparison with AC offices and to identify any conflicts in satisfaction between the individual environmental parameters.

METHOD

The data were collected as part of three separately funded projects. These projects included questionnaire surveys of occupant satisfaction with indoor environments, environmental monitoring and collection of energy data. A brief summary of the buildings investigated is shown in Table 1. Buildings A to I were surveyed in the winter and summer of 1995, J to Q in 1996, and R to W in the winter of 1994.

Table 1 also shows the annual energy consumption of the buildings, as supplied by the energy or facilities manager. The difference is shown between the actual energy consumption and that typical of a building with a similar layout and ventilation system, based on a database[4]. Comparison of these two figures was used as an indicator of how energy efficient the building was.

The occupants were administered one of three different self-completion questionnaires during the surveys. The nine questions shown in Figure 1 were common to all three questionnaires were used for the current analysis. Questionnaire responses were subjected to transformations changing them from rating scales to binary satisfaction scores. For example, on a seven point unipolar scale, where 1 is the ideal value, responses of 1-3 were coded as satisfied, and responses of 4-7 were coded as dissatisfied. On a seven point bipolar scale, where 4 is the ideal value, responses of 3-5 were coded as satisfied, and responses of 1, 2, 6 and 7 were coded as dissatisfied. This means that scales with different numbers of points/categories and polarity can be compared.

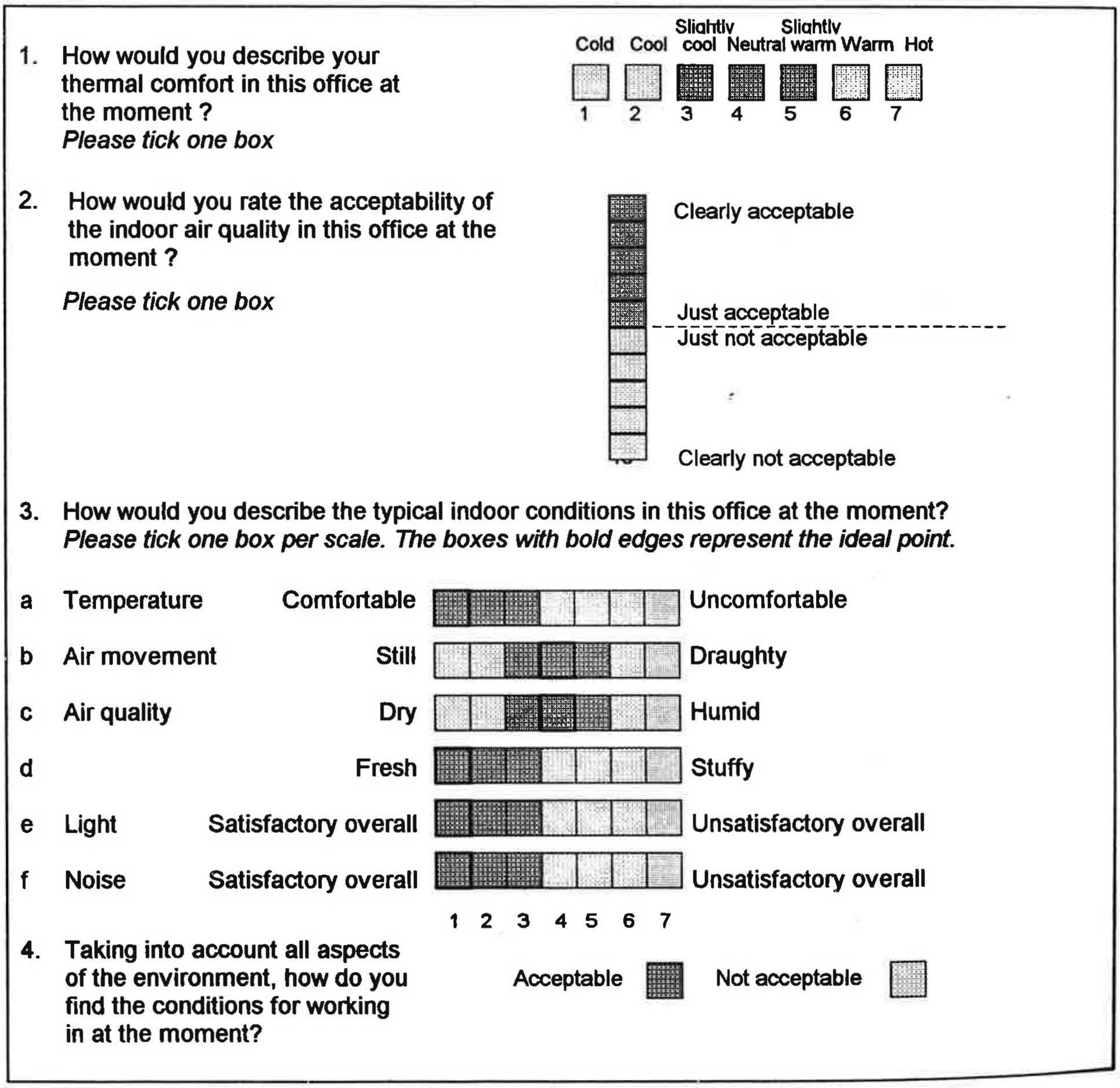

Figure 1 Nine common questions (darker shading represents satisfied)

RESULTS

Response rate

Response rates varied between buildings, ranging from 40% to 95%. The variation in response rate depended greatly on whether the occupants remained at their desk for most of the day or were more mobile, and on whether the questionnaires were given out and collected on the same day or collected at a later date.

ID	Site	Vent	Plan	*N* per season		Annual energy (MJ/m^2)	% change from typical
				Winter	Summer		
A	R	NV	CO	69	61	1085	+22
B	U	AC	OP	159	59	2079	+36
C	R	AC	OP	119	106	1099	-28
D	U	AC	OP	249	191	1659	+9
E	U	NV	CO	163	145	738	-18
F	U	NV	CO	127	91	1199	+34
G	U	AC	OP	332	231	1037	-55
H	U	NV	OP	164	150	811	-17
I	U	AC	OP		119	n/a	n/a
J	U	AC	OP	136	107	n/a	n/a
K	U	NV	OP	100	99	708	-21
L	U	AC	OP	128	138	1177	-48
M	U	NV	OP	91	112	1235	26
N	U	NV	OP	127	86	702	-28
O	U	AC	OP	134	111	1500	-34
P	U	AC	OP	112	86	n/a	n/a
Q	R	NV	OP	75	87	468	-52
R	U	AC	OP	149		1700	+11
S	U	AC	OP	149		n/a	n/a
T	U	AC	OP	168		1800	+18
U	U	NV	CO	151		1300	+45
V	U	AC	OP	147		1900	-17
W	U	AC	OP	108		1200	-21
Type of site: R = rural, U = urban, Type of layout: CO = Cellular, OP = Open plan *N* = Number of returned questionnaires , n/a = not available							

Table 1 Summary of the buildings selected for the office environment surveys

Table 1 also shows that only three of the 23 buildings surveyed were on green-field sites and only four were of a cellular office design. Because of these low numbers, site and office plan were not used as independent variables in the analysis. Approximately 43% of the offices were deep plan.

Percentage satisfied

Percentage satisfied with individual environmental parameters

Table 2 shows the percentage of occupants satisfied with each of the nine main environmental parameters between ventilation type and season. Two-way Analyses of Variance were carried out to compare the difference in the satisfaction scores between ventilation types and seasons. The significant main effects and interaction, between ventilation and season, are also shown in Table 2.

Environmental parameter	Ventilation		Season		Two-way interaction
	NV	AC	Winter	Summer	
Thermal sensation	65***	74***	72*	67*	***
Thermal comfort	56***	63***	59	58	***
Air quality	69*	72*	72	69	**
Air movement	47***	53***	50	52	
Humidity	57**	62**	60	60	*
Stuffiness	29***	38***	34	34	***
Lighting	68	64	64**	69**	
Noise	62	59	59	62	*
Overall satisfaction	67*	70*	67	71	***
Satisfied with all eight	11*	13*	12	13	
Significant effect: * $p< 0.05$, ** $p<0.01$, *** $p< 0.001$					

Table 2 Percentage of occupants satisfied by ventilation type and season

Table 2 shows that significantly more (9%) occupants were satisfied with their thermal sensation in AC offices and significantly fewer (5%) were satisfied in summer. Figure 2 shows that there was no major difference in occupant satisfaction with thermal sensation during the winter but during the summer significantly (13%) fewer occupants were satisfied in NV offices. The figure highlights the interaction between season and ventilation and shows that the main effect of ventilation type is only evident in the summer.

As expected, satisfaction with thermal comfort produced a similar direction of effect to satisfaction with thermal sensation (see Figure 3). However, Table 2 shows that the percentage difference between seasons (1%) and ventilation type (7%) was much lower. The satisfaction with thermal comfort is 15% lower in NV offices in summer compared to AC ones, but is similar in AC offices between seasons.

Table 2 and Figure 4 show that occupant satisfaction with the air quality displayed a similar pattern of effect to thermal comfort and thermal sensation. Occupants were equally satisfied in winter, albeit NV offices were slightly better, but in summer NV offices produced less satisfied occupants.

Table 2 shows that significantly more (6%) occupants were satisfied with the air movement in AC compared to NV offices but there was no significant difference between seasons. Figure 5 also shows that slightly more occupants were satisfied with the air movement in the AC offices in both seasons, and no interaction was found.

As with air quality, Table 2 shows that the humidity was considered satisfactory by slightly more (5%) occupants in the AC offices, but no differences were found between seasons. Figure 6 shows that the difference between ventilation types is only evident in the summer, when10% fewer occupants in NV offices were satisfied.

Table 2 shows that significantly more (9%) occupants were satisfied with the air quality in terms of freshness/stuffiness in AC offices compared with NV ones. Again there were no significant differences between seasons. Figure 7 shows that the satisfaction with freshness/stuffiness follows a similar pattern to the other parameters, i.e. 18% fewer occupants were satisfied in NV offices in summer. However, the figure also shows that the percentage satisfied with freshness/stuffiness is much lower than for the other environmental parameters.

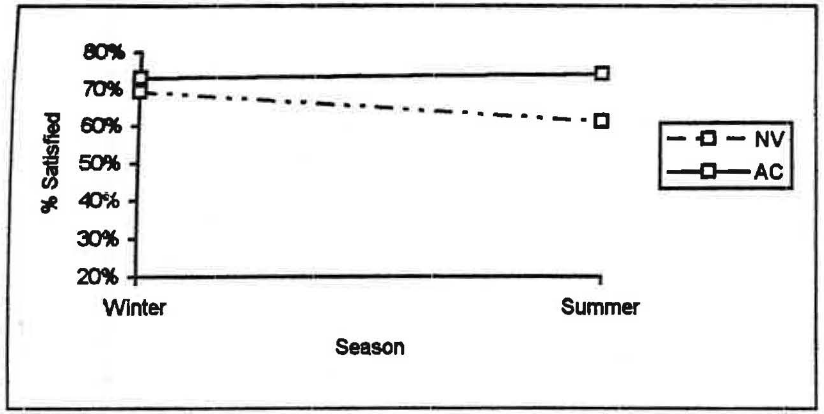

Figure 2 Percentage satisfied with thermal sensation

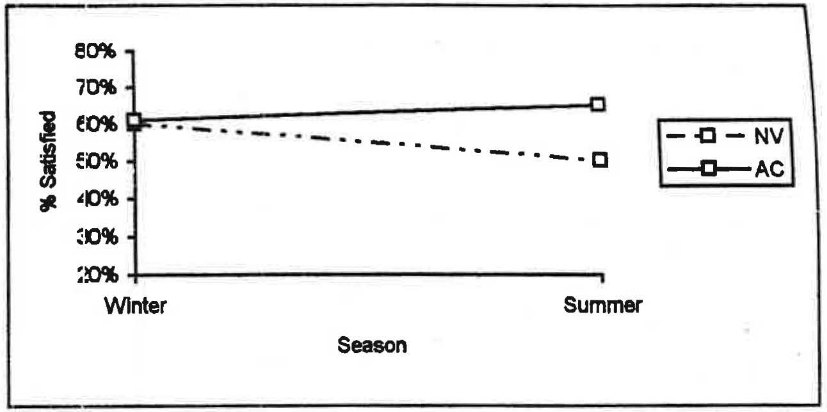

Figure 3 Percentage satisfied with thermal comfort

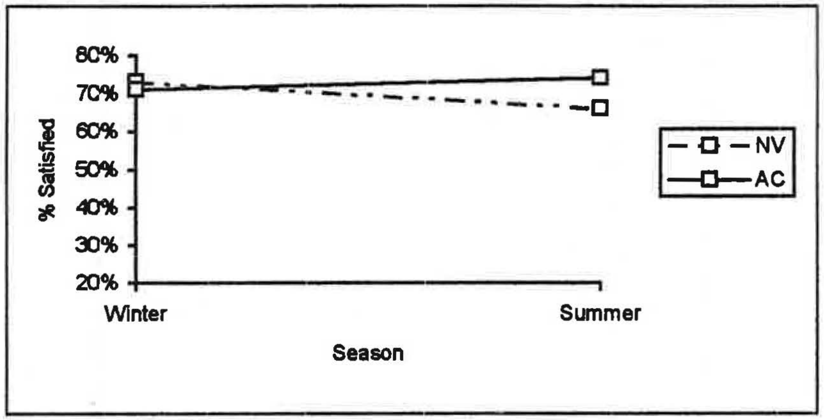

Figure 4 Percentage satisfied with air quality

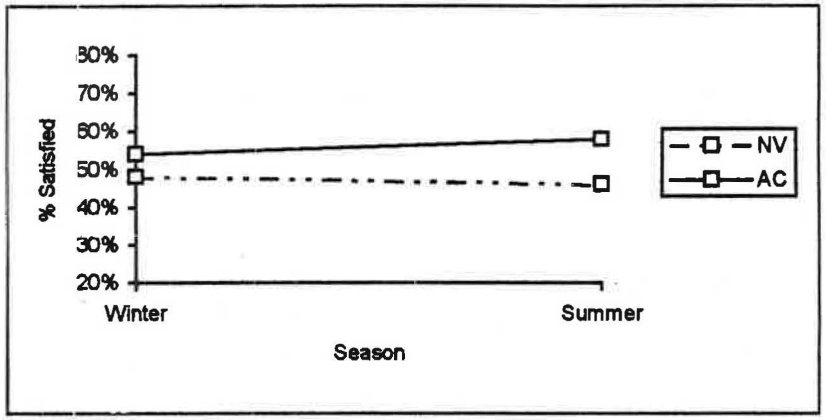

Figure 5 Percentage satisfied with air movement

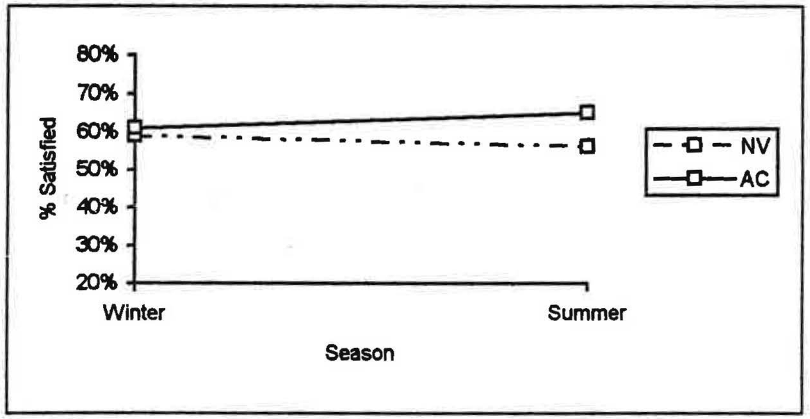

Figure 6 Percentage satisfied with humidity

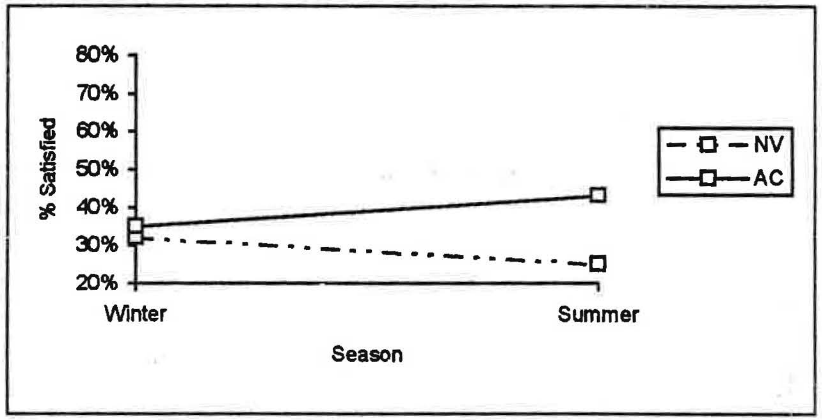

Figure 7 Percentage satisfied with freshness/stuffiness

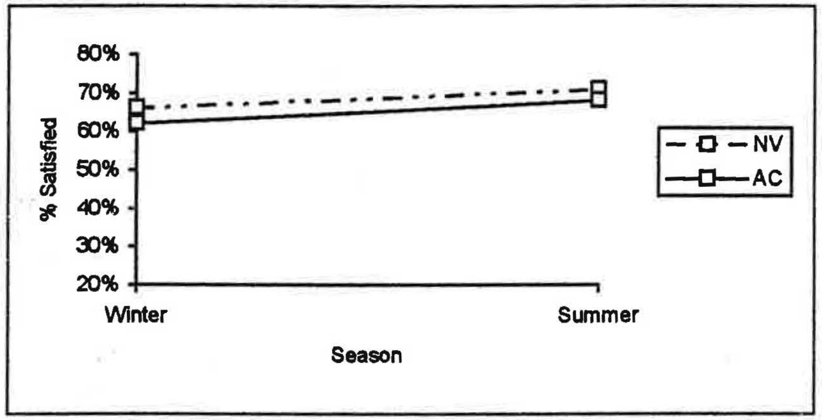

Figure 8 Percentage satisfied with light

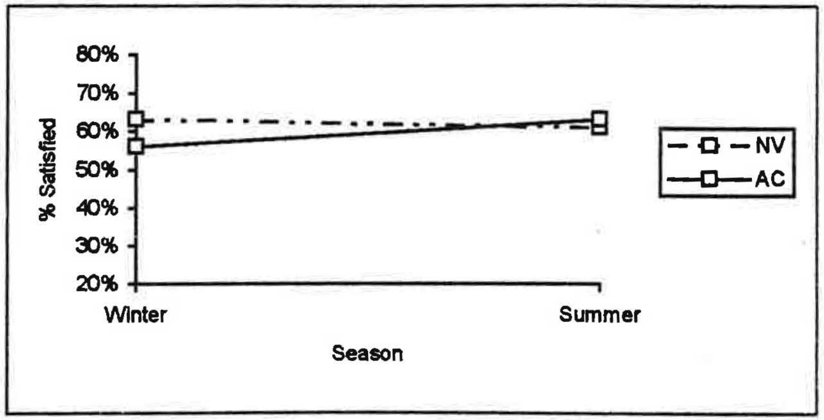

Figure 9 Percentage satisfied with noise

Table 2 shows that 5% more occupants were satisfied with the lighting in summer compared to winter and 4% more occupants were satisfied with the lighting in NV offices compared to AC ones, but the difference was not significant. Figure 8 confirms the slightly higher satisfaction with light in NV offices in both seasons and the slightly higher satisfaction in summer for both office types.

Table 2 shows there were no significant differences in satisfaction with noise between seasons or ventilation types, but slightly more (3%) occupants were satisfied in NV offices and in summer. Figure 9 shows that fewer occupants were satisfied with the noise in AC offices in winter, but this was not a significant effect.

Satisfaction overall

Figure 10 shows the percentage of occupants satisfied with the overall environmental conditions, computed from the two-point acceptability scale, broken down by season and ventilation type. The figure shows that AC offices in winter (66.2%) and NV offices in summer (65.8%) produce the least number of satisfied occupants whereas AC offices in summer (75.5%) and NV offices in winter (68.5%) resulted in higher numbers of satisfied occupants.

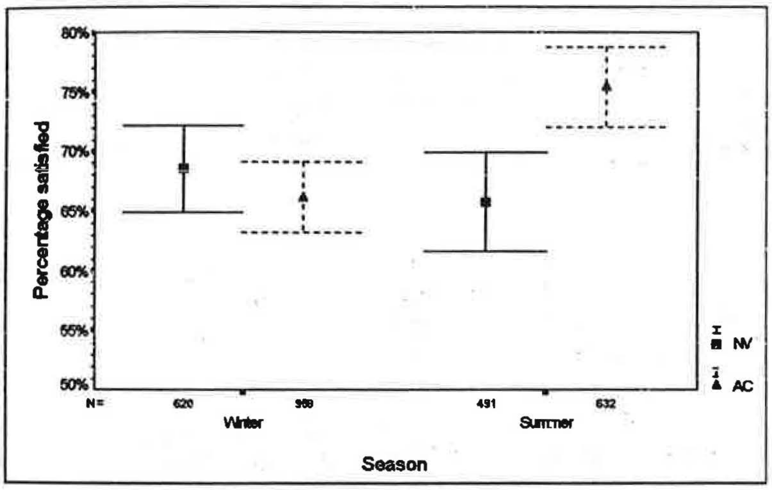

Figure 10 Percentage satisfied with overall environmental conditions

Energy and satisfaction

The ratio between the actual energy consumption and the typical energy consumption was calculated for NV and AC, as a proxy for energy efficiency. The average energy consumption for the AC buildings was found to be 4% less than the typical values, and the average energy consumption of the NV buildings was 18% less than typical values. Table 3 compares the mean energy consumption and energy efficiency of the building with the percentage of occupants satisfied with the overall environmental conditions. The table shows that overall 3% more occupants were satisfied in AC offices but at a cost of a 60% increase in energy consumption.

Ventilation type	Percentage satisfied	Mean Energy (MJ/m^2)	Efficiency (%)
AC	70	1447	4%
NV	67	894	18%

Table 3 Mean energy and percentage satisfied

SUMMARY OF RESULTS AND DISCUSSION

Simple comparisons indicate that slightly more occupants are satisfied with the eight individual environmental parameters in AC offices than in NV ones and fewer occupants are satisfied in summer than in winter. However, two-way breakdowns of satisfaction by season and ventilation type show significant interactions and reveal that the main effects are mostly due to there being slightly fewer satisfied occupants in NV offices in summer, with a few exceptions. In summary, AC offices result in slightly higher numbers of satisfied occupants in summer but there is little advantage of operating in AC mode in winter. The results indicate that one compromise design solution is mixed mode ventilation systems.

The percentage satisfied with the overall conditions in AC offices was marginally higher than in NV offices by 3% over the whole year and 10% during in summer. The higher satisfaction in AC offices was mostly due to an 13% increase in satisfaction with the thermal environment in summer. However, on average the AC offices used 60% more energy than the NV offices so the fundamental question is whether the improved satisfaction warrants such a high increase in energy consumption.

Lorsch and Abdou[5] reviewed examinations of building and staff costs which indicate that a 1 to 2% increase in productivity is likely to offset the total energy costs of the building but up to 5% productivity gain is required to offset the AC running costs (energy, operation and maintenance) and a further 3% increase is required to cover the AC installation. There is no definitive method of predicting productivity from general satisfaction. However, Berglund, Gonzalez and Gagge[6] produced a model to predict thermal discomfort (on the DISC scale) and performance decrement with temperature change. Their model is based on a limited laboratory experiment which examined the performance of Morse code operators. Therefore the model may not be considered directly relevant to general office work, but nevertheless is a useful indicator for the current analysis. Their model was improved to predict productivity directly from the percentage dissatisfied.

The new non-linear model indicates that the 13% higher thermal satisfaction in AC offices in summer is equivalent to a 3% change in productivity which offsets the costs of the increased energy consumption but not the AC running or installation costs. If it is assumed that the model is appropriate for overall satisfaction rather than just thermal comfort then the 3% higher general satisfaction is equivalent to a 1% change in productivity which again only offsets the extra energy costs but not the AC running costs. An alternative method to air-conditioning for providing comfort cooling, but at lower initial and running costs, is the use of passive low energy design features[7] such as stacks, high thermal mass and night-cooling[8].

Furthermore, studies of sick building syndrome (SBS) show that the occupants in AC offices are likely to report more SBS symptoms than the occupants of NV offices, see Raw[9] for a full review. A clear relationship between SBS symptoms and productivity was also found by Raw, Roys and Leaman[10]. It is therefore recommended that, when practical, air-conditioning should be avoided and passive cooling techniques employed.

CONCLUSIONS

Slightly fewer (10%) occupants in naturally ventilated offices were satisfied with their overall environmental conditions in summer compared to air-conditioned offices. Combining data from summer and winter revealed that on average only 3% fewer occupants were satisfied in naturally ventilated offices. Air-conditioned offices consumed on average one and a half times as much energy (550 MJ/m^2 per annum) as naturally ventilated ones. Furthermore, more occupants were satisfied with the light and noise in the naturally ventilated offices, probably due to the fact that these offices mostly had cellular layout rather than open plan thus allowing more control over light and noise. It may therefore be considered that the extra energy consumption, and higher installation and maintenance costs, in air-conditioned offices do not warrant the small increase in satisfaction.

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