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MODERN VENTILATION TECHNIQUES - THE INDOOR ENVIRONMENT AND OCCUPANT PERCEPTION

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In recent years there has been a gradual re-emergence of the use of passive or 'low energy' ventilation and cooling techniques including mixed mode application. It is apparent that many clients, developers and agents are reluctant to make a commitment to such 'low energy' buildings due to concerns, albeit unsubstantiated by hard evidence, that such buildings will provide acceptable comfort levels for occupants.

The project included the measured assessment of three buildings which utilise these modern 'low energy' ventilation techniques, evaluating the internal environment performance with particular reference to occupant comfort and perception.

The monitoring was carried out in both the winter and summer seasons on a zonal basis using both long and short term logging techniques. BRE / RSH style questionnaires [1] were also used in both seasons with the personal well-being questions asked only during the winter monitoring.

The results of the three larger buildings are given relating the measured environmental parameters to the occupants' perception of their environment.

INTRODUCTION

Typically, modern passive 'low energy' buildings are characterised by the use of natural ventilation and night cooling either to fully, or partially, satisfy comfort conditions. Where the latter is the case, use is made of mixed mode techniques which incorporate various forms of mechanical cooling to meet peak loads.

The three buildings described in this paper are office buildings using mixed mode ventilation. Each of these buildings is structured around a central atrium and uses large exposed floor slabs to stabilise internal temperatures. The designs are described in more detail below and are summarised in Tables A1, A2 and A3 in Appendix A.

Parameters seen to be directly relevant to the ventilation, and thermal, techniques under consideration include internal and external dry bulb temperature and humidity together with internal black globe temperature, CO_2 concentration, respirable mass concentrations of airborne particles (nominally 0.3 to 10 μm), room air movement and building air change rate. An investigation of buildings incorporating these modern ventilation and mixed mode techniques also must include assessment of indirectly linked parameters such as internal light and noise levels. The occupant perception and the levels of these latter two parameters are affected by the types of building design implicit in the use of modern ventilation techniques such as large, open plan, internal spaces and opening windows.

The building monitoring was therefore designed to take a holistic approach to the assessment of these mixed mode, office buildings. In this way it was possible to assess the overall effects on occupant perception..

BUILDING DESCRIPTIONS

In Building 1 occupants are allowed to open the windows when required. No mechanical cooling has been installed for the open plan areas and so natural cooling is used to maintain comfort temperatures within the building if necessary. Night pre-cooling is used to cool the thermally massive floor slabs so a proportion of the internal heat gains can be absorbed during the day. Night cooling is achieved by opening the roof vents and automatic windows in order to maintain the slab temperature at a predetermined set-point. If required, mechanical ventilation is used to increase this cooling effect.

In Building 2 the four mechanical supply and extract systems operate constantly, during the occupied period, at low speed (1.5 air changes per hour). If required, at high speed, the fans can provide three air changes per hour. Air is supplied to the occupied space through floor diffusers. Three rows of openable windows are provided for natural ventilation. The building occupants control the bottom two rows. The top row of windows, however, is controlled by the BMS. If the internal air temperature rises above 23°C in a zone, the opposite BMS atrium vents are opened to encourage cross ventilation. Night cooling is also used to minimise day-time cooling load. Each zone is controlled separately to maintain the internal temperature set-point for night cooling. Partial mechanical cooling can be provided when required.

Building 3 is divided into four zones for ventilation. The mechanical system is by displacement ventilation. Air is supplied to the office space through the floor void and floor diffusers and then is extracted through an extract system situated at ceiling level and at the top of the atrium. For natural ventilation, the automatic windows are controlled by the occupants during the day and by the BMS for pre-cooling at night, if required. The building also incorporates six wind towers which draw the exhaust air through the atrium to outside. To achieve comfort cooling, evaporative cooling is used in co-ordination with a thermal wheel. The heat pumps can also be enabled for cooling if required. During the monitoring period night cooling had been suspended due to complaints of cold draughts from employees who occupy the building at night.

METHODOLOGY

For each building, floor plans and available information concerning building operation and management were obtained during site visits. Estimated occupancy levels were also acquired during the preparation periods.

Representative monitoring zones within the open plan office space were selected to ensure geographical spread throughout the building. Zones consisted of between 6 and 18 desk positions which were all individually numbered. Monitoring in each of these buildings was undertaken over a two week period in the winter and again in the summer. This monitoring is outlined briefly below.

Time Based Environmental Data

Data loggers were installed in each zone to monitor the dry bulb temperature every 12 minutes over the whole period. A number of relative humidity loggers were also installed alongside some of the temperature loggers. A few further loggers with carbon dioxide, illuminance, dry bulb temperature, relative humidity and globe temperature sensors were set up with readings taken at 5 minute intervals. CO_2, CO and total organic compounds (TOC's) were monitored using a gas analyser in various zones in each building for periods of up to a few days in each position. Air sampling to monitor CO_2 and CO in the fresh, supply and return air at plantroom level was also undertaken. External temperature and humidity were monitored at roof level for comparison with weather data from the meteorological office (wind speed and direction, dry bulb temperature and relative humidity and global radiation (summer only))

Gridded / Spot Data

Thermal comfort measurements were made, following the procedure laid out in ISO 7730:1995 [2], at desk positions in the monitored zones. In Buildings 1 and 2, a short form questionnaire was administered to the displaced people to gather instantaneous clothing levels and thermal comfort vote. Light and respirable mass concentrations were carried out in all the desk positions used for the thermal comfort measurements.

The room air movement (RAM) surveys were carried out over a grid using an array of six omni-directional anemometers. Between 15 and 25 grid points were visited in each zone during the allocated survey time period.

Zonal noise levels were determined during the day and outside the occupancy period to assess background noise. Further measurements were made to investigate external noise and the increase in internal sound levels found through opening windows.

The occupant questionnaire, based on the BRE/RSH model, included demographic data, questions concerning personal well-being, and some questions relating to the occupants' perception of the environment. Additional sections were added relating to the usage of opening windows, blinds and light shelves.

Questionnaires

Questionnaires were used in winter and summer to monitor the environmental perception of the occupants. The questionnaires covered demographic data, environmental perception, perceived control levels and personal symptom recording. All building occupants were included in the questionnaire administration irrespective of whether environmentally monitored zones covered their workstation. Each questionnaire was coded to give a geographical location within the building.

Questionnaire Response

The questionnaire response is presented in Table 1below. The overall response rate was about 60% and was consistent in all buildings winter and summer. The response of those occupants in the zone target regions is very similar to that of the building target population as a whole. This indicates that the comparison between the subjective questionnaire data and the measured environmental data is unlikely to be confounded by response rate.

Table 1 : Building And Selected Target Populations With Response Rates

Building and Season	Total Population	Total Response	Zonal Population	Zonal Response
Building 1 Winter	395	230 (58%)	167	93 (56%)
Building 1 Summer	371	203 (55%)	163	78 (57%)
Building 2 Winter	551	352 (64%)	226	153 (68%)
Building 2 Summer	562	338 (60%)	236	139 (59%)
Building 3 Winter	211	136 (64%)	211	136 (64%)
Building 3 Summer	202	123 (61%)	202	123 (61%)

BEHAVIOURAL MONITORING

In buildings incorporating natural ventilation through opening windows, together with manually operated blinds and adjustable light shelves, the proactive role occupants play in helping to control the indoor environment is essential. Such activity allows the building to be adapted to prevailing external conditions or the wishes of its occupants on a zone by zone basis. In the case of these buildings occupant manipulation of the windows and blinds aids in adaptation of the temperature and air movement within the space in addition to the effects on the light environment such action might make.

Behavioural monitoring was therefore carried out alongside the other environmental measurements and questionnaire administration to investigate the way in which the occupants take on their proactive role in the day to day environmental control of the building. Additionally 'in use' occupancy levels were recorded for comparison with design levels. Table 2 and Table 3 give the results of this procedure.

Table 2 : Summary of winter behavioural monitoring

	Building 1	Building 2	Building 3
Month	December	March	February
Average number of people	192	330	130
General window status	Inner windows open Outer windows closed	All windows closed	All windows closed
General blind status	Blinds open and light-shelves down	Blinds half-drawn	Upper blinds drawn, louvres vertical, lower blinds drawn, louvres horizontal

Table 3 : Summary of summer behavioural monitoring

	Building 1	Building 2	Building 3
Month	June	June	July
Average number of people	204	346	138
General window status	Upper windows open Lower windows closed	Ribbon windows open Mon, Tue, Thurs p.m., plus some other windows open	Generally windows are closed
General blind status	Blinds open and light-shelves down	25% of blinds drawn / half drawn	All blinds drawn / half drawn

Occupancy Levels

Reduced numbers of people were recorded (in comparison to design occupancy) for each building. Employees may have been working away from the building or involved in meetings in separate rooms. Generally, population numbers were found to peak at mid-morning and again at mid-afternoon.

Proactive Occupant Environmental Control

From the data given above it can be seen that in both seasons, window and blind positions were generally observed to be static. Variations were noticed however, on hot days in summer when more windows were found to be open. The reasons for usage, or non-usage, of the opening windows and blinds given by the building occupants through the questionnaire responses are outlined below.

Window Usage

Though the BMS controlled windows in Buildings 1 and 2 were observed operate automatically (over-ridden in Building 3), occupants supplied reasons for opening or closing the manual windows. A choice of answers was given in each case. The results are shown below in
Figure 1 and Figure 2.

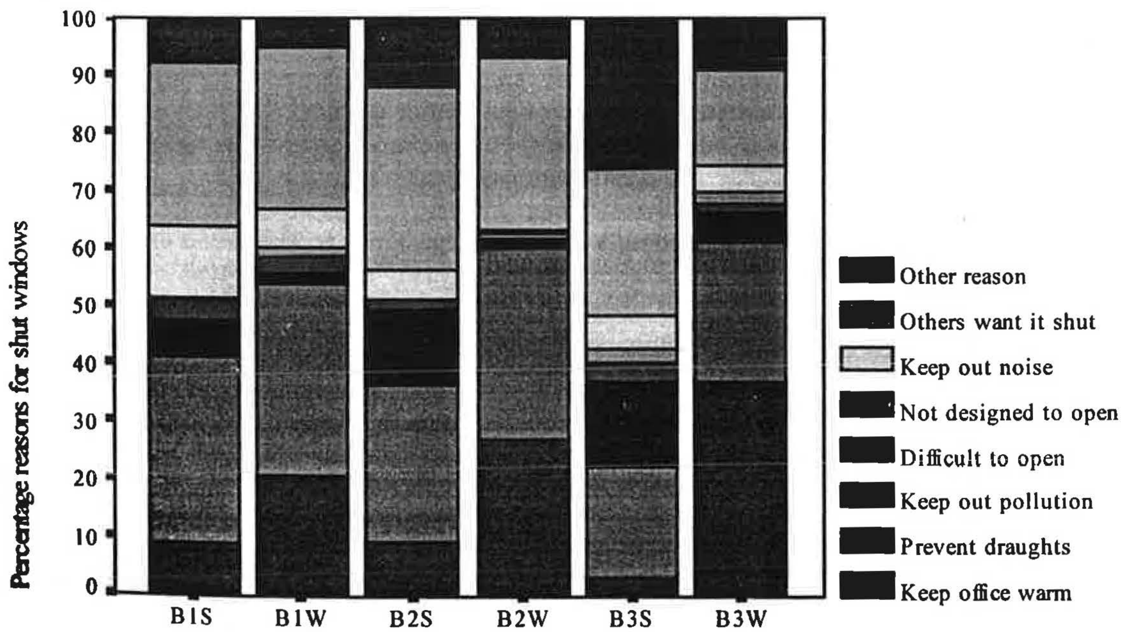

Figure 1 : Reasons Why Windows Are Not Opened

The most popular reasons for closed windows were similar in each building : 'others want them shut', 'to prevent draughts', 'to keep the office warm' (winter only), and 'to keep out pollution' (mainly summer).

During certain periods of the year, some building operators have requested that windows should remain closed to aid satisfactory building operation. The occupants were led to believe that the building would not perform properly if windows were used which may explain the limited opening behaviour.

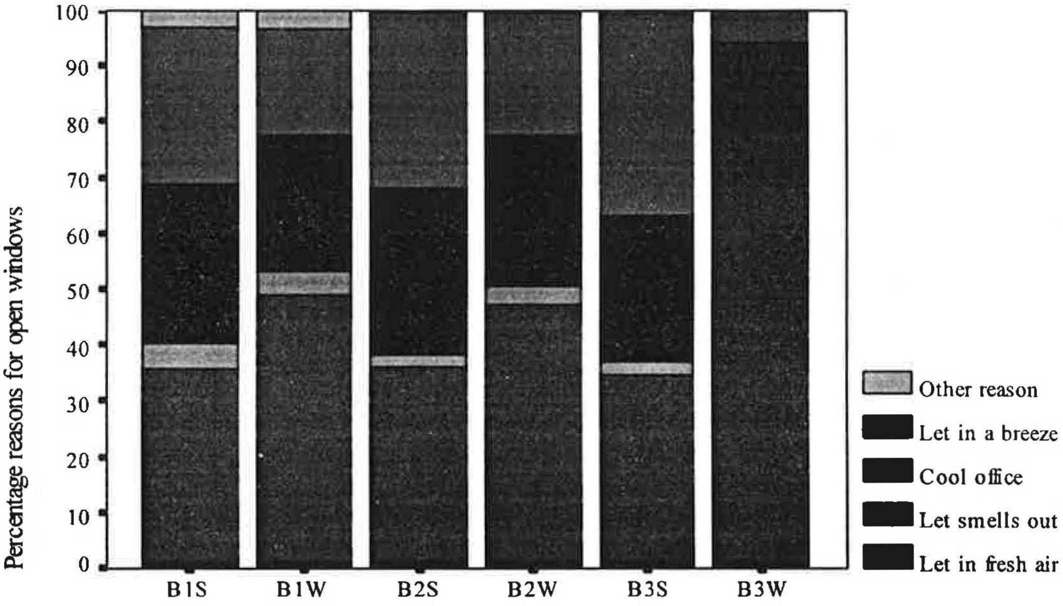

Figure 2 : Reasons Why Windows Are Opened

The most popular reason for open windows is 'to let in fresh air', closely followed by 'to cool office' and 'to let in breeze'. Table 5 shows that the buildings were perceived to be quite 'stuffy'. This may be the reason for these responses to window opening.

Blind and Light Shelf Usage

The buildings each indicate different blind usage.

- The blinds are generally open (and light-shelves down) throughout the year for Building 1.
- The blinds in Building 2 are used where appropriate - about 25% of all blinds are drawn or half drawn during the summer.
- The blinds for Building 3 are extensively used all year round.

Again the questionnaire collected data on reasons for occupant usage of blinds. This data is displayed in Figure 3 and Figure 4.

The reasons are similar for each building and are, 'reduce glare on VDUs' and 'stop sunlight'. From Figure 1it is seen that a large percentage of people, throughout all three buildings, try 'to please others' by not adjusting blinds. This would seem to be a direct result of the areas being open plan.

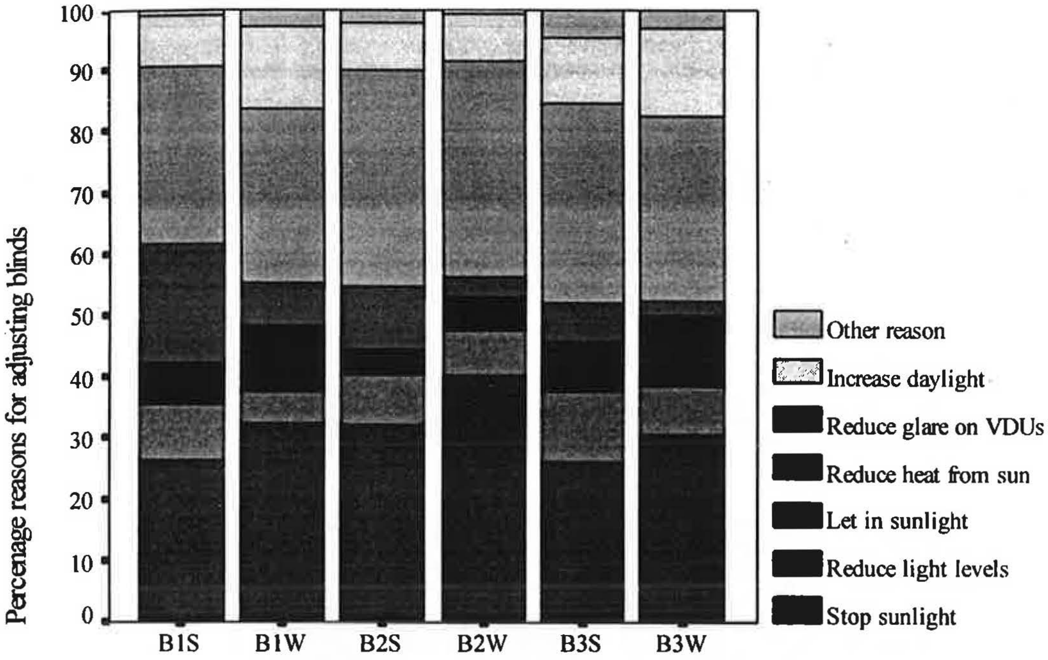

Figure 3 : Reasons Why Blinds Are Adjusted

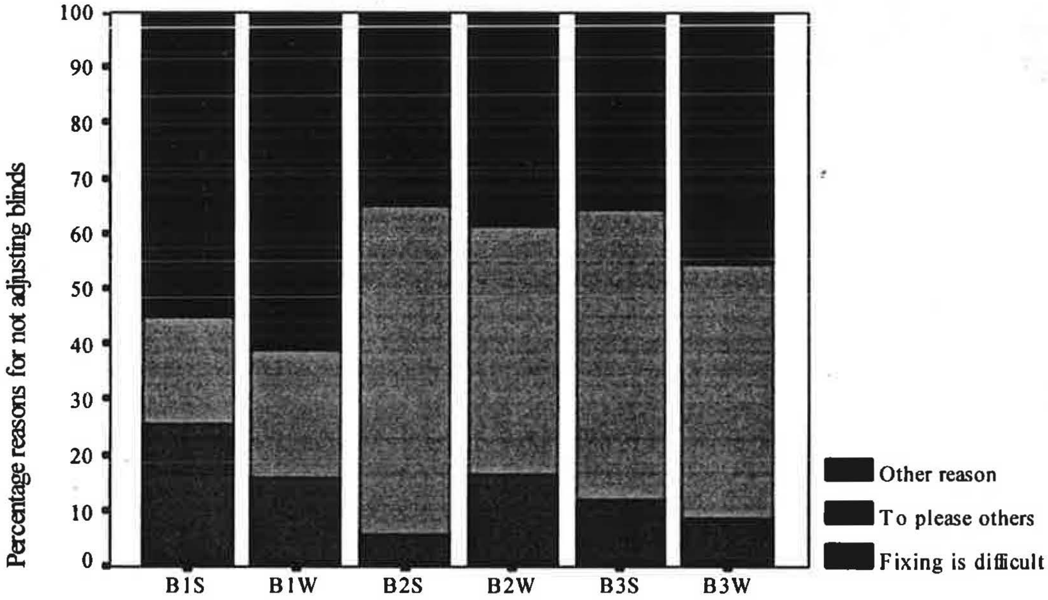

Figure 4 : Reasons Why Blinds Are Not Adjusted

Perceived Control

The levels of occupant perceived control is of particular interest in relation to the methods occupants have at their disposal for adaptation of the environment and their own comfort. The methods described above account for some of the actions which may be taken but also the occupants of these buildings have access to switching techniques, either directly or through a dial up system, for the electric lighting.

The questionnaire coding scheme for perceived control runs from 'no control' (1) to 'full control' (7). Therefore the smaller the average value, the less control the occupants perceive themselves to have. The average levels of perceived control over each environmental aspect are given in Figure 5 below for each building and season.

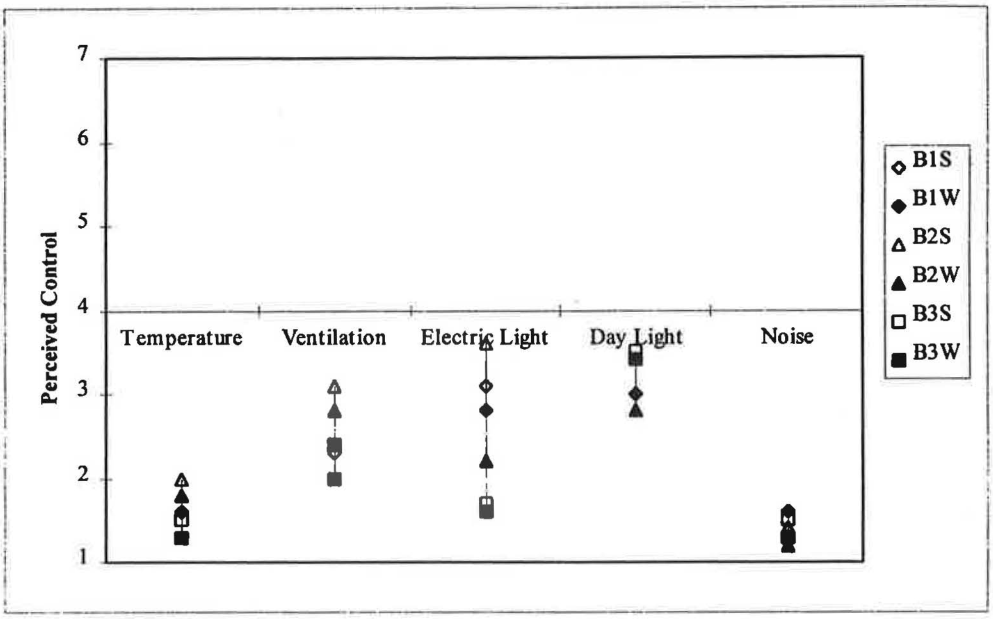

Figure 5 : Mean Perceived Control Levels

The maximum average level of control expressed in any aspect is less than the centre score of 4. This indicates low levels of environmental perceived control expressed by occupants in all the buildings and in each season. As perceived control is very subjective, the strong degree of correlation between control of one aspect and control of the others, found in this study and elsewhere, can be expected. This indicates that perceived control is more of a measure of overall control.

The generally low level of perceived control over the environment is somewhat surprising in buildings which encompass design features such as openable windows, manually operated blinds and user driven electric lighting. It would be anticipated that greater control over the thermal environment and ventilation would be expressed, due to usage of the openable windows, and greater control of the lighting would be felt due to user controlled blinds and light switching techniques than in air-conditioned buildings. Control of the noise environment, which scores lowest on average of these environmental aspects, might be expected to be low due to the open plan working conditions imposed by the ventilation techniques featured in the buildings.

The lack of perceived control may be in part due to poor occupant understanding of the role they must play in the building's overall control and therefore performance. It must also be mentioned that in Building 3 in particular there was evidence that the control strategy of the BMS was subject to well intentioned but counter productive manual intervention by the building operator. In such circumstances the efforts of occupants may be less effective where the background environmental support, offered by a well understood and run building, is lacking.

The relationships between environmental perception and level of perceived control indicate that higher environmental satisfaction levels tend to occur when perceived control is high. However, these links are not necessarily causal and such findings are not confined to modern ventilation technique buildings [3].

OCCUPANT PERCEPTION AND WELL-BEING

The success of otherwise of any building must include the perception and well-being of its occupants. Energy issues and productivity are, of course, important but are outside the scope of this study.

The sections below describe the occupant view of the environment in each building and where possible make a comparison with appropriate measured environmental data collected during the monitoring periods.

Occupant well-being levels

Occupant well-being is notoriously difficult to attribute to particular environmental levels although guidance is given in a number of documents regarding appropriate design and maintenance conditions for good indoor environments.

[4,5] For this reason it is not attempted to attribute particular symptom occurrences to particular aspects of the prevailing indoor environment. However, an assessment of the personal well-being of the occupants was felt useful to indicate any generally prevailing trend.

The BRE methodology was used to calculate the building sickness index (BSI_5). This indicates the average level of symptoms attributable to the building environment which may be suffered by its occupants.

Figure 6 gives the BSI_5 scores for the building populations. The study buildings show one in each category though it should be said that two are borderline cases and the amount of concern felt about BSI_5 scores should be a smoother, sliding scale. The BSI_5 scores given should therefore be interpreted with reference to the actual levels and not simply the descriptive band into which they fall.

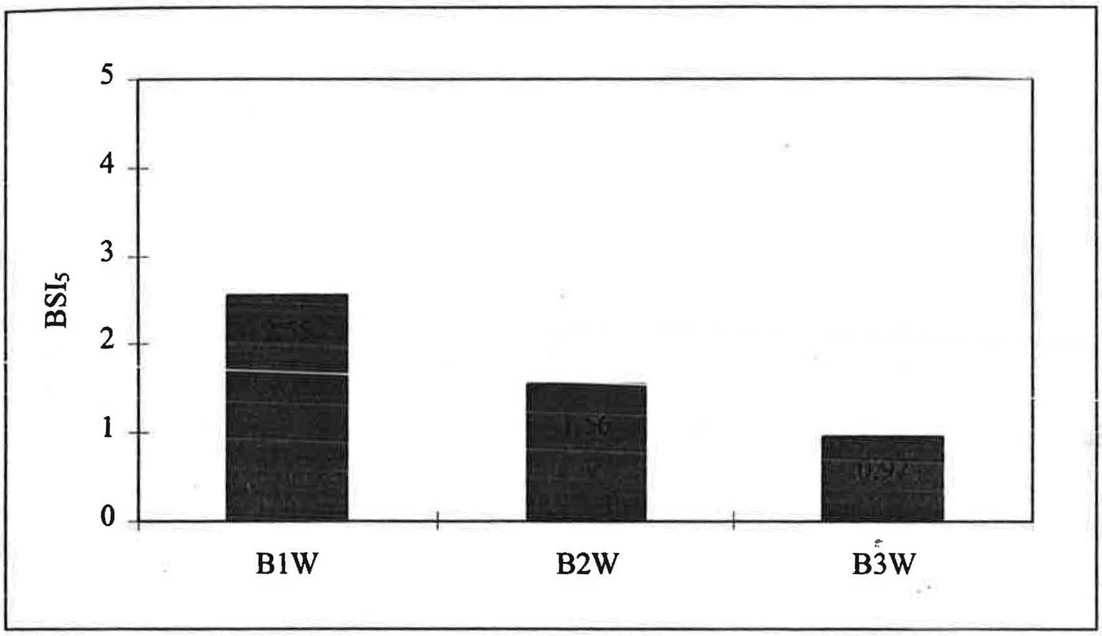

Figure 6 : Occupant Well-Being (BSI_5) Scores In Each Building

Looking in more depth at the reasons for the varying figures shown in Figure 6 above, it is useful to examine the occurrence of particular numbers of symptoms for the occupants of each building. Figure 7 indicates the percentage of occupants of each building recording particular numbers of symptoms. The higher levels of zero or five symptoms in Buildings 1 and 3 respectively, provide the background to the BSI_5 scores given above, with Building 2 being a more moderate case.

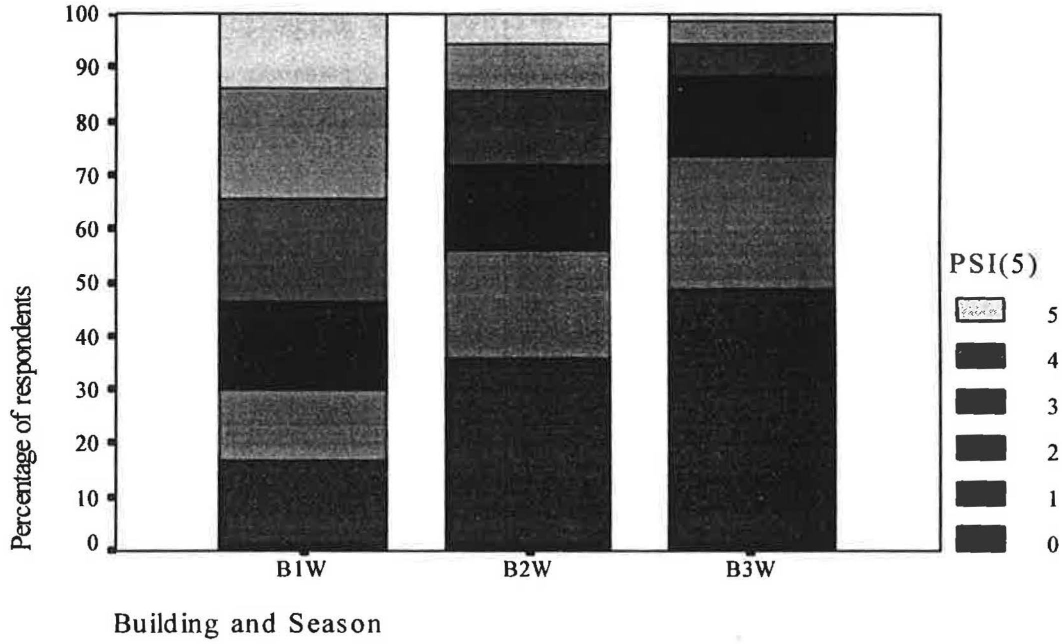

Figure 7 : Personal Symptom Index for Buildings and Gender Groups.

The particular symptoms suffered in each building are shown in Figure 8 below. This shows the preponderance of headache and lethargy symptoms though no symptom occurs minimally in relation to the others.

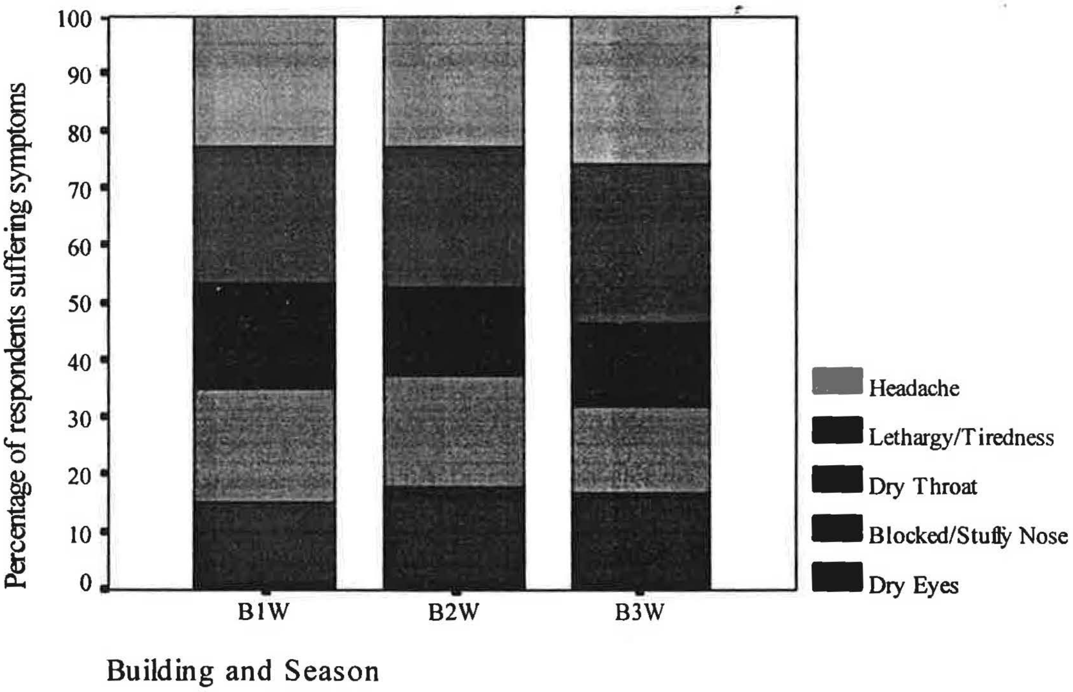

Figure 8 : Symptoms Suffered (by Building and Gender Groups).

With reference to the data presented above, occupant well-being levels appear to be unrelated to this type of mixed-mode modern 'low energy' building type with both low and high levels of symptoms being found in the case study buildings. Additionally, there appears to be no simple link between any particular symptom and these buildings. The higher levels of headache and lethargy may be due to other factors such as continued off-gassing from the relatively new fittings or psychological effects due to the work going on in the buildings.

Occupant Assessment of Environment

As mentioned above, occupant perception of the environment is a useful indicator of the success or failure of a building and for this research was of over-riding importance. The perception levels from the questionnaire study are shown in Table 5. The first column gives the questions followed by the optimum response. A large deviation from this optimum indicates discomfort on the part of the building occupants. The shading levels based on this deviation are described in Table 4 below.

Table 4 : Shading descriptions for Table 5

Shading and Descriptor	Bi-polar Scale	Unipolar Scale (1 = Ideal)	Unipolar Scale (7 = Ideal)
Ideal	4	1	7
Satisfactory	3 & 5	2 & 3	6 & 5
Further Investigation Indicated	2 & 6	4 & 5	4 & 3
Cause For Concern	1 & 7	6 & 7	2 & 1

From Table 5, it is possible to see that comparing the responses of each building indicates a level of general agreement about these buildings. There are however, slight variations between buildings. It must be noted however that Table 5 gives data averages (rounded to the nearest integer) and an 'ideal' value may be recorded on a bi-polar scale where there is simply positive and negative scatter about the midpoint.

Table 5 : Environmental Conditions And Acceptability

	Building and Season					
Question	B1S	B1W	B2S	B2W	B3S	B3W
Temperature (Too hot / Too cold) (4)	3	3	3	4	3	5
Temperature (Stable / Varies) (1)	5	4	4	4	4	4
Temperature (Comfortable / Uncomfortable) (1)	5	4	4	4	4	4
Air (Too still / Too draughty) (4)	3	3	3	4	3	4
Air (Dry / Humid) (4)	3	3	4	3	4	4
Air (Odourless / Smelly (1)	3	3	3	3	4	3
Air (Fresh / Stuffy) (1)	5	6	4	4	4	4
Air (Satisfactory / Unsatisfactory) (1)	5	5	4	4	4	3
Light (Too dark / Too bright) (4)	4	4	4	4	4	4
Light (Uneven / Uniform) (7)	4	4	4	4	4	4
Light (Satisfactory/ Unsatisfactory) (1)	4	4	3	3	3	3
Noise (Too noisy / Too quiet) (4)	4	3	3	3	3	3
Noise (Intrusive / Not noticeable) (7)	4	4	3	3	4	4
Noise (Satisfactory / Unsatisfactory) (1)	4	4	4	4	4	4
Vibration (Satisfactory / Unsatisfactory) (1)	3	3	3	3	3	3

The single case which stands out from all the other aspects is the perception of stuffiness recorded for Building 1 in the winter. This level of concern happens in no other aspect and in no other building or season. There may be some relationship in this case between stuffiness and the high percentage (25%) of occupants in the Building 1 winter survey suffering four or more symptoms (see Figure 7). The dark grey shading indicates the next most troublesome band. These are namely the variation and lack of comfort in the temperature, the stuffiness and lack of satisfaction expressed with the air, the uneven nature of the light, and the intrusive and unsatisfactory levels of noise. The most acceptable aspect is the perception of light level. Aspects falling in between the 'ideal' and 'cause for concern' bands are the humidity, movement and odour level of the air, satisfaction with lighting, noise level, and satisfaction with vibration.

Each of these factors is described in further detail below with reference to the effect of the use of mixed mode or other modern ventilation techniques as incorporated into these buildings.

ENVIRONMENTAL MONITORING

Temperature And Humidity

External Conditions

Table 6 shows the average external temperature and relative humidity, during occupancy for each building. The external conditions in both the winter and the summer were comparable across the buildings. This indicates that the internal temperatures found in each building can be assessed with little reference to any differences in external conditions.

Table 6 : Daytime average external conditions

Season	Building 1	Building 2	Building 3
Winter	3.3°C 83% RH	4.1°C 70% RH	1.5°C 79% RH
Summer	19.6°C 63% RH	20.7°C 64% RH	21.7°C 70% RH

Internal Temperature and Humidity

Figure 9 and Figure 10 show the minimum, average and maximum internal daytime conditions for the occupancy period.

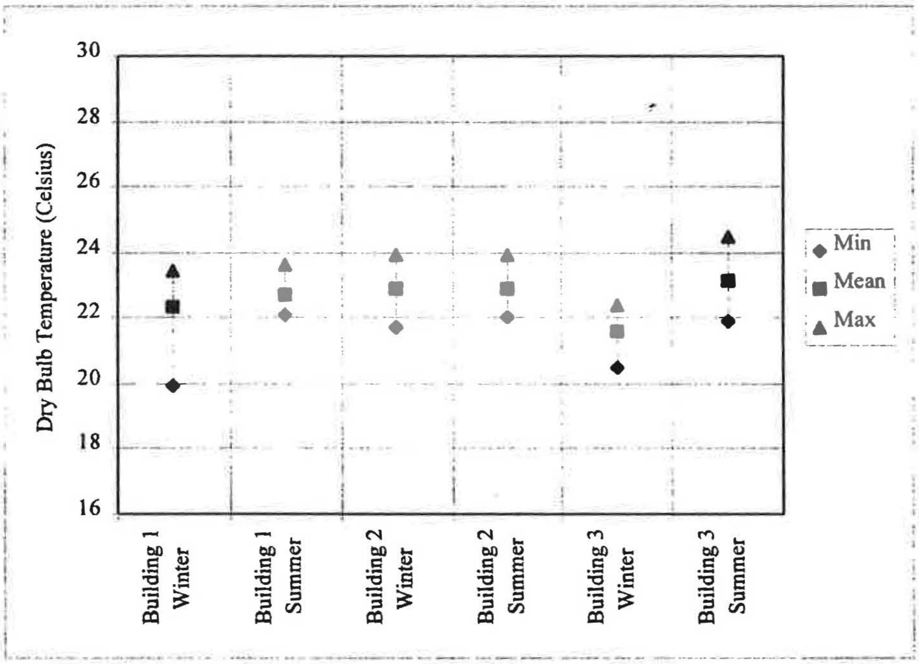

Figure 9 : Minimum, Average And Maximum Internal Temperature

During winter the temperatures maintained in most of the zones for Buildings 1 to 3 are satisfactory. The summertime mean internal temperatures are generally higher than those for the winter though values around 22.5 to 23 °C are common in both seasons.

Internal temperature was found to increase with external temperature. For each building, internal temperatures peak during the afternoon and also rise during a spell of hot weather.

Internal temperature did not increase with height within the buildings. High temperatures were evenly distributed between the floors of each building. This is either a product of good control or results from other influences. Peripheral areas, with high expected solar gain, were not generally hotter than core areas. The hottest zone is not always a south or west facing peripheral area.

Night cooling was used in Buildings 1 and 2. It is apparent that the combination of night cooling and natural ventilation operates satisfactorily in these buildings. The slightly higher temperatures in Building 3 might be reduced if the night cooling facility was used in the summer.

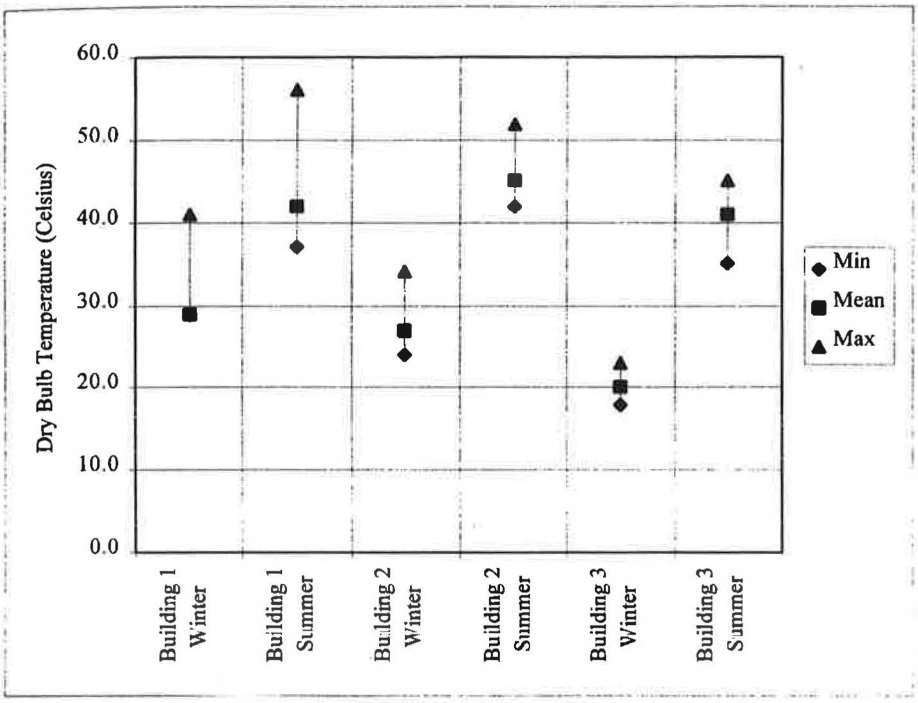

Figure 10 : Minimum, Average And Maximum Internal Relative Humidity

There is no humidity control in these buildings and the low winter levels were typical of conditions in naturally ventilated offices.

Occupant Perception

The average occupant perception of temperature and humidity are shown in Figure 11. In general the occupants feel the temperature to be slightly warm except for Building 3 in the winter where the temperatures become cool. However, the levels could still be said to be acceptable. In combination with the relative instability of the temperature, the occupants report a discomfort due to the temperature which may be worth further investigation. The humidity is perceived to be on the dry side of neutral but not at levels which would indicate severe discomfort.

The variation in temperature is the most relevant feature of these mixed mode buildings where natural ventilation plays a large part and the actual temperatures recorded are not unacceptable. Increased opening of windows might beneficially affect the environment to lower air temperatures and in turn occupant perception of the temperature. However, the instability of temperature may decrease perceived comfort if the occupants are not educated concerning the type of environment to expect in a naturally ventilated office. Another feature of these buildings is the incorporation of blinds in the design. Occupants who are encouraged during peak solar gain seasons to close the blinds, at appropriate times, in order to reduce the gains to the office space may reap the benefits and to a certain extent minimise the variability in temperature.

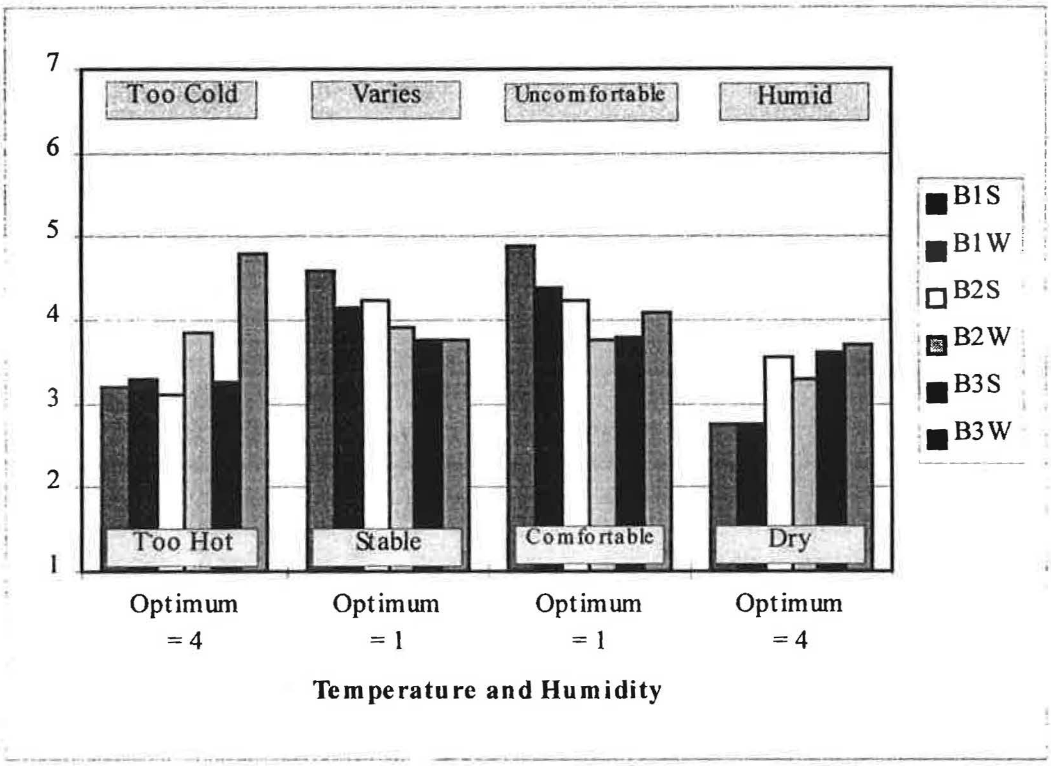

Figure 11 : Occupant Perception Of Temperature And Humidity

Predicted Mean Vote and Predicted Percentage Dissatisfied

The pattern of PMV and PPD thermal comfort values gathered using the Thermal Comfort Analyser, as expected, mirrors the internal temperatures. All the PMV's appear to be within the comfort band of ± 0.5. This is backed up by the average PPD values which are all under 10%.

Real clothing ensembles and actual mean votes (AMV) were collected from occupants. These were compared with standard office dress and activity PMV values. From Table 7 (TCA data), neither the standard nor the real clothing case predicts well the instantaneously gathered AMV figures which suggest that occupants are considerably cooler than might have been predicted.

Table 7 : Average Actual Mean Vote Compared With Predicted Mean Vote Based On Standard Clothing Levels And Real Occupant Clothing Ensembles

Building	AMVreal	PMV(Standard)	PMV(SFQ)
B1W	-1.222	-0.191	-0.518
B1S	-0.509	-0.315	-1.003
B2W	-0.976	-0.173	-0.371
B2S	-0.545	0.021	-0.384

In order to maximise thermal comfort occupants should be encouraged to take a proactive role in the control of both their environment and their personal clothing levels. A basic understanding of the importance of such a role may increase perceived comfort levels and the feeling of thermal comfort.

Room Air Movement

Room Air Movement surveys were conducted in the selected monitoring zones in each building. Table 8 gives the average RAM data for air speed, dry bulb temperature, predicted mean vote and predicted percentage dissatisfied.

Table 8 : Averages for the Spot / Gridded Data

Building and Season	VMEAN	TMEAN	PMVMEAN	PPDMEAN
B1W	0.09	23.3	-0.132	6
B1S	0.11	22.6	-0.263	9
B2W	0.08	23.5	-0.043	6
B2S	0.11	23.5	-0.048	0
B3W	0.07	22.9	-0.200	7
B3S	0.10	24.6	0.246	8

Comparing the measured mean air speeds with a common design value for an air-conditioned space of 0.15 $m.s^{-1}$ the measurements taken appear to be relatively low. However, these buildings are not air-conditioned and it may be felt to be an inappropriately high yardstick value to apply to the modern ventilation techniques in use in these buildings. The measured velocities were however, not untypical of those found in occupied mechanically ventilated buildings.

Though some of the winter velocities are low the summer averages are all greater than 0.10 $m.s^{-1}$. The lack of open windows, particularly in the winter, may be contributing in part to the low average air speeds measured in these buildings.

Respirable Mass Concentrations

The average respirable mass concentrations are given in Figure 12 below. The levels seen in both Buildings 2 and 3 in the winter are significantly higher than for the other cases but none give rise to serious concern.

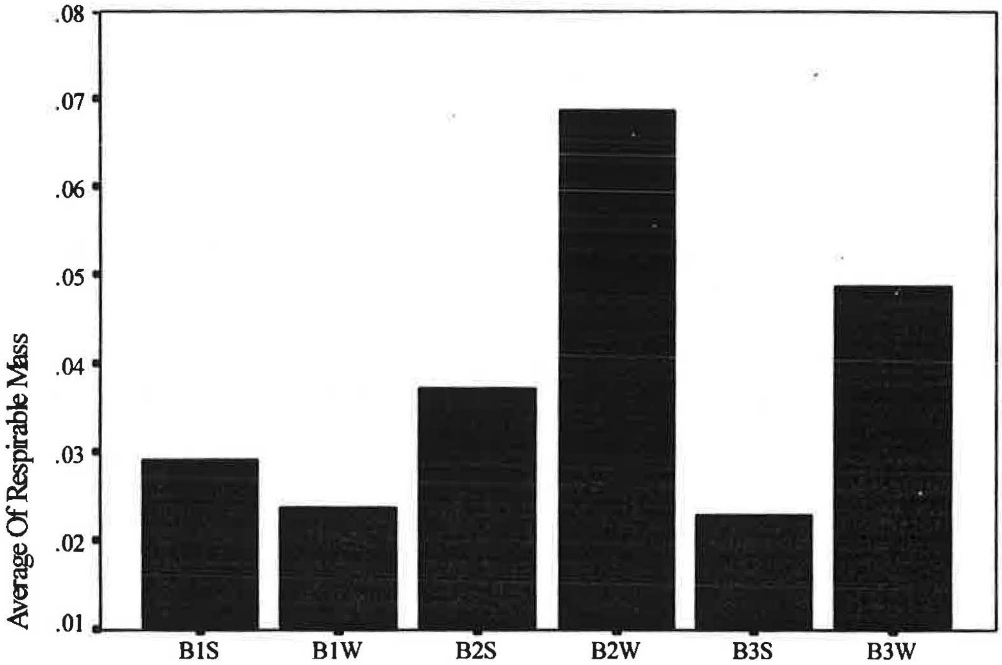

Figure 12 : Average Respirable Masses For Each Building and Season

Air contaminants

The carbon dioxide concentrations (used as an indicator of people based air contaminants), carbon monoxide and TOC concentrations are low in all the buildings monitored.

Occupant Perception Of Air Quality And Movement

The average occupant perception of the air quality and movement are shown in Figure 13. The air movement and odour perceptions indicate acceptability but the environment is still perceived as stuffy to a level where further investigation may be required. Building 1 gives a particularly high stuffiness score. The judgement of satisfaction with the air quality appears to be based on a perception of stuffiness as can be seen from the shape of the bars in Figure 13. Again increased window opening may decrease the levels of stuffiness but may also have an adverse effect on the perception of air movement. Occupants appear to prefer the environment to be still, possibly due to th effects on paperwork, or cold draughts, of having open windows, but then reap the consequences in terms of an environment which feels stuffy.

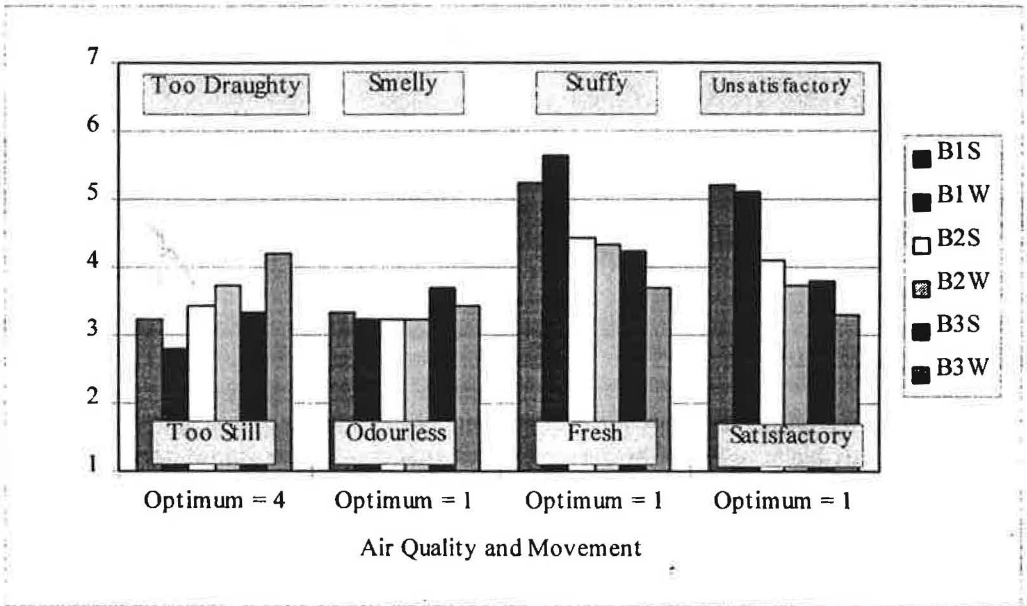

Figure 13 : Occupant Perception Of Air Quality And Movement

Light

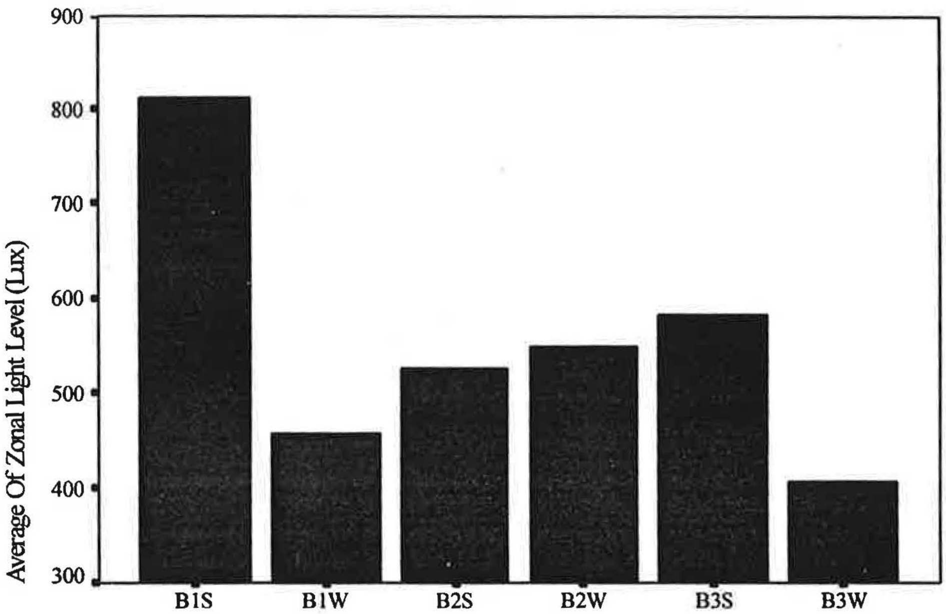

Figure 14 : Average Desk Light Levels For Each Building and Season

The average desk height light levels are given in Figure 14 above for each building. This emphasises the high light levels found in Building 1 in the summer as might be expected due to similar summer and winter time blind positions (see Table 3).

Except Building 1 in the summer (with most readings in the 600 - 900 lux range), the building readings are mostly in the 300 - 600 lux range which would be usual office design values.

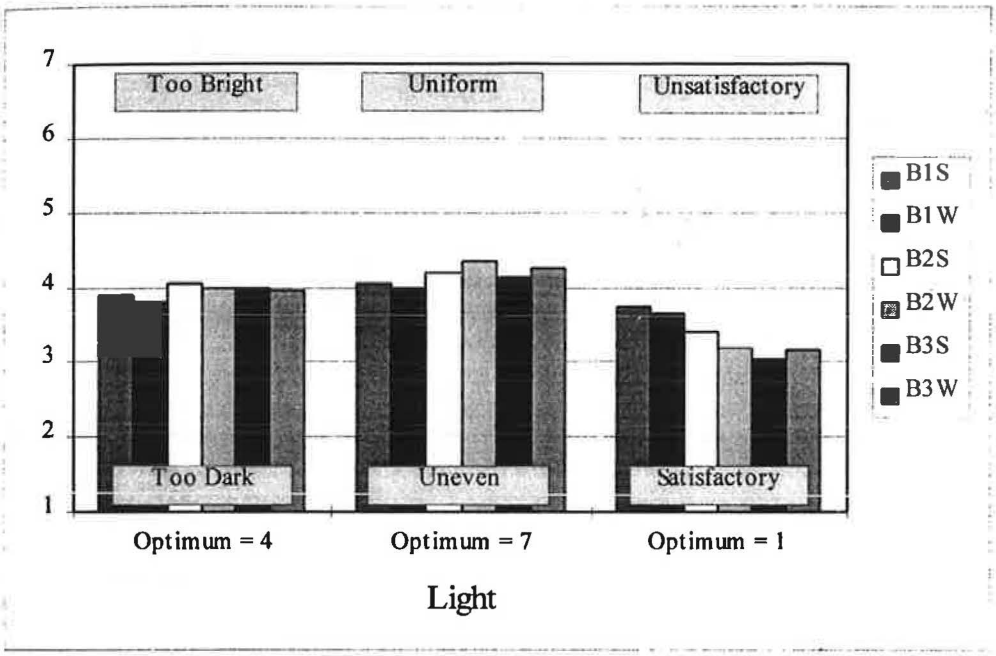

Figure 15 : Occupant Perception Of Light

Figure 15 shows the occupant perception of the light environment. In all the buildings the level of the light is reported on average as ideal, neither too bright nor too dark. However, the light is described as being relatively 'uneven' indicating the possible requirement for further investigation. The overall satisfaction level is good in Buildings 2 and 3 but the Building 1 occupants are less happy though their perception of brightness and uniformity is not significantly different from their counterparts in the other buildings.

Assessing these results, in relation to the perceived opportunities for occupant control of the light environment, the slightly higher dissatisfaction shown in Building 1 is not explicable purely by a lower level of perceived control than the other buildings. Building 3 expresses less perceived control over day light than Building 1 and the Building 2 levels are lower than Building 1 for electric light. It must be reiterated though, that the general occupant perception of control is low in all these buildings despite the opportunities available through adjustment of the blinds and switching of the electrical lighting.

One explanation of the lower satisfaction levels expressed in Building 1 for the lighting may be the significant change in average light levels between the winter and the summer. This change could be less pronounced if the blinds were drawn more in the summer.

Noise

Zonal noise measurements were taken to characterise sound levels and frequencies experienced both inside (daytime) and out of the occupancy period (evening) in Buildings 1, 2 and 3.

Table 9 : Noise Level Ranges In Each building And Season

		Winter Range		Summer Range	
	LEQ NR	LEQ middle NR rating	LEQ NR	LEQ middle NR rating	LEQ NR
BUILDING	Evening	Day	Occupancy Difference	Day	Occupancy Difference
1	25-38	38-53	7-25	45-56	10-27
2	36-45	45-53	0-12	45-51	0-15
3	23-39	43-56	4-29	43-52	7-20

Table 9 gives the evening and daytime levels for each season. The evening levels are also subtracted from the daytime figures to give a difference due to occupancy.

The background (evening) range for Building 2 is considerably higher than that found in Buildings 1 or 3. However this elevated level does not appear to increase daytime levels significantly with all three buildings giving similar ranges. The difference in noise levels due to occupancy can be quite significant with up to a 29 dB difference being recorded.

External noise levels were also measured for each building to characterise the noise environment in which each building is situated. The internal effects of open or closed windows during the unoccupied period were also measured to estimate the possible impact of external noise. It was demonstrated that a reduction of approximately 13 dB is possible in this regard.

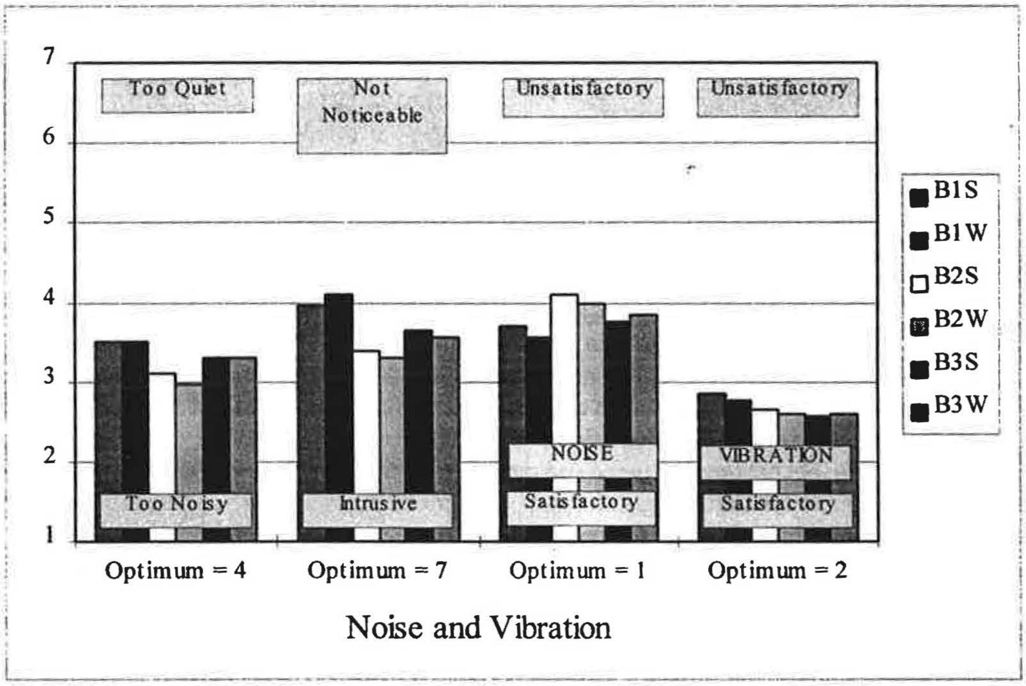

Figure 16 : Occupant Perception Of Noise And Vibration

With reference to the data given in Table 5 and displayed in graphical format in Figure 16 above, general comments can be made concerning the occupant perception of noise in all three buildings and both seasons. The noise level itself is judged to be acceptable but is intrusive to a point where further investigation may be required. It is this factor which seems to cause the dissatisfaction with noise rather than the loudness. There does not appear to be a problem with the acceptability of vibration within the building.

The intrusive nature of the noise is in part due to the types of activity going on in the buildings. Telephones ringing, the sound of equipment such as printers and faxes, and the verbal effects of both planned and impromptu meetings are intensified by the open plan office spaces involved in the building design. Additionally, openable windows allow external noise to easily enter the building and variable sounds, such as the passing of trains, add to the overall intrusive quality of the indoor noise environment.

CONCLUSIONS

Perceived And Proactive Environmental Control

- The data gathered in these buildings suggests that higher environmental satisfaction levels tend to occur when perceived control is high. However, these links are not necessarily causal and such findings are not confined to modern 'low energy' ventilation technique buildings.
- Occupants report low levels of perceived control in all aspects of the indoor environment though the techniques available, such as blind and window usage, seem under utilised. This may be in part due to poor occupant understanding of their role in the building's overall performance.
- The effort to please others may partially account for occupant reticence to adjust windows and blinds. This results in the environment not being adjusted either to suit individual occupants or a more general adaptive control of these 'low energy' buildings.
- Where interference with operation of the BMS occurred, this could have contributed to a less satisfactory overall performance of the mixed-mode ventilation system.

Occupant Well-Being

- Occupant well-being levels appear to be unrelated to this type of mixed-mode modern 'low energy' building type because both low and high levels of symptoms were found in the case study buildings.
- There appears to be no simple link between the occurrence of any particular symptom in these buildings and the modern ventilation techniques incorporated into the design.

Environmental Parameters

- From an occupant perspective, the relative instability of the temperature (inherent in mixed-mode ventilation) appears to add to the dissatisfaction levels with the thermal environment. However, the temperatures themselves are perceived as satisfactory though 23 °C is a common average value. Predicted mean vote values indicate acceptable thermal comfort levels although actual mean votes might indicate occupants to be cooler than the PMV predictions.
- Satisfaction with indoor air quality appears to be heavily influenced by the perception of stuffiness. Perceptions of odour, air movement and humidity seem less significant. However, the relationships in this case between perception and measured parameters are less easy to understand as the average air velocities are relatively low.
- Whilst perceived light levels are satisfactory, the uneven nature of the light contributes to a lower overall level of satisfaction with lighting. Average measured light levels approximate to the 500 lux often used as an office design value.
- Similarly, the noise levels are satisfactory but the intrusive nature of the sounds experienced in these open plan office types detrimentally affects the satisfaction felt with the noise environment. Specifically, as regards mixed-mode ventilation, external noise may have a significant impact when windows are open.

General Conclusions

- Occupant opinion is a good measure of the success or failure of an occupied building especially, as with the modern ventilation techniques employed in these buildings, when there is a general scepticism concerning the levels of occupant comfort which may be attained.
- The levels of temperature, air movement, humidity, air odour, light, noise and vibration are all acceptable to the building occupants of these three mixed mode buildings in both seasons. However a perception of stuffiness is a problem which decreases satisfaction with air quality.
- Variability in temperature, light level and noise all reduce occupant satisfaction with the environment despite the acceptable levels in each aspect. Better occupant education concerning the opportunities for control of the environment and what to expect in non air-conditioned buildings may increase the acceptability of a variable environment.

ACKNOWLEDGMENTS

This paper summarises some of the findings of a BSRIA Research Project entitled 'Modern Ventilation Techniques' [6] undertaken as part of the Department of Environment's 'Partners In Technology' programme.

BSRIA would like to thank the owners and staff of the monitored buildings.

APPENDIX A

Table A1 : MVT case studies; introduction to buildings

	Aspect	**Building 1**	**Building 2**	**Building 3**
Building	Building function	Large regional office building	Headquarters type office	Headquarters type office
	Occupant	Government department	Private sector	Private sector
	Building location	Town suburbs West Sussex	Greenfield site West Midlands	Greenfield site East Anglia
	Building age	Built 1993	Built 1994	Built 1994
	Building orientation	East-west	East-west	East-west
	Special considerations	On south coast so possibly exposed to high winds Nearby railway station	Limited amount of night working	Building located near dual carriageway Limited amount of night working
General design	Layout	4 floors	3 floors	3 floors
	Central atrium	✓	✓	✓
	Building floor area	7,500 m^2	11,700 m^2	4,000 m^2
	No. of people	450	600	230
	Occupancy	07:00-18:00 Mon-Fri	08:00-17:30 Mon-Fri	08:00-18:00 Mon-Fri
Winter design conditions	Internal	20°C	21°C	21±2°C
	External	-3°C (assumed)	-4°C	-3°C
Summer design conditions	Internal	22°C	Variable	25±2°C
	External	28°C DB (assumed)	27.1°C DB	28°C DB 47% RH
	BMS control	✓	✓	✓

Table A2 : Summary of Building Services

	Aspect	Building 1	Building 2	Building 3
Internal heat gains	General rating *small ** typical *** excessive	**	**	**
	Exposed internal floor slab	✓	✓	✓
	Percentage/type of glazing	Clear glazing 30% of facade	Double glazing, 55% of south facade	60% of south facade glazed
	Solar and glare control	✓	✓	✓
Ventilation method	Stack assisted natural ventilation	✓	✓	✓
	Atrium type	Enclosed	Open	Open
	Manually operated windows	✓	✓	✓
	BMS operated windows	✓	✓	✓
	Additional mechanical ventilation	✓	✓	✓
	Desk mounted fans available	✓	✓	-
Lighting	Design illuminance (working plane)	350 - 500 lux (assumed)	350 - 500 lux	350 lux
	Special control arrangements	Daylight linking	Daylight linking	Daylight linking
Noise	Background noise rating level	NR 35 (assumed)	NR 35	NR 35
	Special control arrangements	-	White noise. Acoustic luminaire fittings	Acoustic luminaire fittings
	Possible noise pollution sources	Train station	-	Dual carriageway

The general heat gain rating is based on:
* Minimum PCs, less than 1 person per $10m^2$
** 1 PC on every desk, 1 person per $8\text{-}10m^2$
*** Intensive IT use, more than 1 person per $8m^2$

Table A3 : Summary of Building Indoor Air Quality

	Aspect	Building 1	Building 2	Building 3
Control sensor locations	Internal temperature sensors	OK	OK	OK
	Outside temperature sensor	OK	OK	OK
	Wind sensors	OK	OK	OK
	Rain sensor	OK	OK	OK
Ventilation effectiveness	Design air changes per hour (Winter)	1.5 air changes per hour	3 air changes per hour	4 air changes per hour
	Fresh air supply rate (minimum)	18 $l.s^{-1}$ per person	5 $l.s^{-1}$ per person	42 $l.s^{-1}$ per person
	Assessed air quality	Good	Possible problem	Good
Details of contaminant sources	Possible external sources	Nearby road	-	Dual carriageway Rubbish site
	Fresh air intake locations	Roof level	Roof level	Roof level
	Provision for dedicated toilet extract	✓	✓	✓
	Provision for kitchen/ restaurant extract	-	✓	✓
	Provision for smoking room dedicated extract	✓	-	-

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