OCCUPANT SATISFACTION AND ENVIRONMENTAL CONDITIONS FOLLOWING REFURBISHMENT OF TWO AIR-CONDITIONED OFFICE BUILDINGS TO NATURAL VENTILATION

William B. Booth (Principal Research Engineer)
Ruth N. Williams (Research Engineer)
BSRIA, Old Bracknell Lane West, Bracknell, Berkshire. RG12 7AH

There is a considerable existing air-conditioned building stock which will require refurbishment. One possibility for such refurbishment is that the natural ventilation option, avoiding the refit of air-conditioning, should be assessed. Naturally ventilated buildings, in general, consume less energy than air-conditioned ones.1 Increasing interest in minimising the use of energy has therefore focused industry's thoughts on the possibility of refurbishing air-conditioned buildings to natural ventilation. However, problems can be encountered in this refurbishment process that would not arise in a building which had never been designed for air-conditioning. It has therefore become necessary for case studies of such refurbished buildings to be provided to supply evidence of the effects of the implementation of natural ventilation in buildings originally designed with air-conditioning. Two offices were selected for site monitoring after refurbishment from air-conditioning to natural ventilation. This site monitoring included measurements of a range of physical parameters in both the winter and summer seasons. These measurements were supplemented by post-refurbishment occupant questionnaires in the office buildings.

INTRODUCTION AND PROJECT AIMS

The aim of the project was to assess building environments following refurbishment from air-conditioning to natural ventilation. This was undertaken for each building in both the summer and winter seasons, after the refurbishment process was complete, using physical measurement of the environment and a questionnaire to collect occupant perceptions. The questionnaire study incorporated symptom reports from occupants however the project was not intended to be a causative study of building sickness.

It was not possible due to availability of suitable buildings and refurbishment timescales to formulate a classic "before and after" study. However, the occupant assessment of effects of refurbishment was addressed by setting current occupant perception of the environment into context against observations recalled from before refurbishment. The population available to report environmental conditions prior to the refurbishment was smaller than the responding target population due to unavoidable changes in personnel in the intervening time. No comparison was made between the measured environment and the brief / design conditions as occupant perception was felt to be more relevant.

Two case study surveys were performed in UK office buildings, monitoring various aspects of the environment including spot readings of thermal comfort, gridded room air velocity surveys and, in the case of CO_2, relative humidity and temperature, monitoring over several days. External weather conditions for the same period were also recorded.

The measured data was then compared with that from a self administered questionnaire survey completed by the building occupants in the two office buildings again after the refurbishment of the buildings. This questionnaire was based on the BRE Office Environment Questionnaire and included sections on building sickness and on environmental satisfaction. Additional sections collected data concerning the views of those who had experience of the building prior to refurbishment (a population smaller than the responding target population as previously described).

The results of the environmental monitoring and the questionnaire analysis are given to show the effects of naturally ventilating a building originally designed with air-conditioning. The measured environment was not held to be necessarily causal of the occupant perceptions though the two sets of data are available for comparison. Comparison of the two building environments was not the intention of this study though each data type is presented for both buildings.[1]

ACKNOWLEDGEMENTS

This paper summarises some of the findings of a BSRIA research project entitled Refurbishment Of Air-Conditioned Buildings For Natural Ventilation (Phase 1)[2].

BSRIA would like to acknowledge the support of the Department of the Environment, the British Broadcasting Corporation, E.A. Technology, the Health and Safety Executive, and the Metropolitan Police in this project.

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

BUILDINGS

Office A in Central England

This 5900 m^2 office building comprising five storeys was built in the early 1970's with air-conditioning and sealed windows. In 1991, a refurbishment was undertaken in response to the large number of occupant complaints regarding the environmental conditions and the lack of personal control particularly over the non-opening windows. The system was also deemed past its economic life and needed replacing.

Two refurbishment options were initially considered. The first possibility was the replacement of the existing induction units with a similar two-pipe system, and the second was an alternative natural ventilation design. Due to technical considerations concerning the practicality of cleaning or replacing the existing pipe system which was embedded in the concrete walls, the natural ventilation route was taken.

The refurbishment programme was phased over three years and involved the installation of openable windows, a gas-absorption chiller system to serve the few mechanically cooled areas and a new boiler to serve the medium pressure hot water system. Each occupant bay now has a radiator, TRV and an openable hopper window. The summer of 1994 was the first to be experienced with the refurbished design.

Office B in The North West of England

This 1960's 8-storey office block of approximately 4,830 m^2, previously had an air-conditioned system which supplied 100% fresh air at the rate of about 5 air changes per hour. The energy costs were high due to the lack of air recirculation and the additional chilled water required to cope with the effect of solar and internal gains. Coupled with this, the building manager reported many complaints from occupants concerning areas they perceived as hot or cold spots. This was felt by management to contribute to a general feeling of occupant dissatisfaction.

In the early 1980's, a decision was made that some form of refurbishment work was required, but total replacement of the air-conditioning system was considered too expensive.

The refurbishment strategy decided upon involved the conversion of the air-conditioning and chiller systems to a non air-conditioned system and the boiler fuel from oil to gas.

This was achieved by changing the heat input to the building from warm air to hot water system by adapting the existing chilled water system. The terminal units around the building were converted to radiators. In addition, opening louvred windows were installed to provide fresh air, local occupant control and eliminate the need for mechanical ventilation.

[1] The buildings outlined in this paper form the basis of case studies covering internal environmental conditions and operating costs. These cases studies will form part of a BSRIA publication providing design guidance for the retrofit of buildings for natural ventilation.

METHODOLOGY

The buildings were visited for monitoring periods, after completion of the refurbishment process, in both the summer and winter of 1994/5. Representative zones within each building were selected for environmental monitoring and questionnaire distribution with the objective of ensuring the best achievable spread between floors and geographical position. Open plan areas were the focus of attention since they housed the majority of occupants. Empty areas, or those subjected to recent major staff / furniture changes or other disruption, were avoided. Zones in the office buildings generally consisted of six to ten desks.

Data loggers were installed to collect data over time and spot or gridded measurements were carried out as described below. Questionnaires, linked by code numbers to seat positions, were also distributed to occupants.

During the second seasonal visit, the zones were re-visited using the same monitoring methodology. Surveys were carried out at the same positions or as close as possible to them. In general, most zones were identical with only minor changes in furniture layout having occurred in the intervening period.

ENVIRONMENTAL MEASUREMENT

Data Collected Over Time

Data loggers were installed to monitor the dry bulb temperature and relative humidity in selected zones over a period of several days. These loggers were carefully positioned in workstations to monitor the temperature and humidity conditions in the working zone. Measurements were taken every 5 or 12 minutes.

A screened temperature and relative humidity probe was mounted on the roof connected to a weatherproofed logger during the period of intense environmental monitoring. Hourly data was obtained from the nearest Meteorological Office recording station. The two sets of data were found to be in close agreement.

A combined instrument measuring carbon dioxide (CO_2), temperature and relative humidity was installed, for periods of more than one day, at various locations. A second CO_2 analyser was installed during the main monitoring period for Offices A and B. The locations were chosen to ensure readings were made on the lower and upper floors and on as many intermediate floors as feasible. Periods of at least one day for CO_2 measurement were deemed appropriate to characterise internal levels whilst avoiding over emphasis of transient effects.

Gridded/Spot Data

A comfort analyser was employed to determine the thermal comfort at a fixed height following ISO Standards 7730-1984 and 7726-1985. Measurements were made on a spot basis with the sensors being positioned at the normal work position of various occupants in turn. Predicted Mean Vote and Predicted Percentage Dissatisfied calculations were made to ISO 7730-1984. (Questions have been raised as to the suitability of this standard with naturally ventilated buildings. However, no robust alternative exists.)

Room air movement (RAM) surveys were carried out over grids marked temporarily on the zone floor. Six omni-directional anemometers with integral temperature sensors were used in a vertical array. These were mounted on a mobile stand at regular intervals between heights of 0.3 m and 1.8 m.

ENVIRONMENTAL DATA

As can be seen from Table 1 the air velocities recorded in the buildings are low in relation to those expected in a mechanically ventilated environment. Only in Office B in the Summer, where the external temperatures were excessively high, do the velocities reach this level, probably due to window opening behaviour. This high external temperature was not replicated for the summer visit to Office A. In both buildings and seasons the internal temperatures are high, reaching more than 23 °C on a mean daily level with the summer values being higher still.

For comparison, the maximum and minimum external temperatures have been given in each case in Table 2.

The CO_2 peaks for each building and season are shown in Table 3. These are notably lower in the summer than in the winter, again probably due to window opening behaviour.

Table 1 : Building Environmental Data After Refurbishment

Parameter	Office A Winter	Office A Summer	Office B Winter	Office B Summer
Vmean(am) $m.s^{-1}$	0.06	0.06	0.07	0.09
Vmean(pm) $m.s^{-1}$	0.08	0.07	0.08	0.14
Tmean(am) °C	22.80	22.48	22.42	24.43
Tmean(pm) °C	23.46	24.01	23.29	26.43

Table 2 : External Maximum and Minimum Temperatures During Building Occupied Hours

Temperature °C	Office A Winter	Office A Summer	Office B Winter	Office B Summer
Maximum	10	20	15	25 - 30
Minimum	<5	10 - 15	<5	10

Table 3 : Number of Days for CO_2 Peaks After Refurbishment

Population Group	Days Measured	<600 ppm	600-800 ppm	800-1000 ppm	1000-1200 ppm	>1200 ppm
Office A Winter	13	2	1	4	5	1
Office A Summer	17	13	1	2	0	1
Office B Winter	19	0	12	4	2	1
Office B Summer	16	11	4	1	0	0

QUESTIONNAIRES

The occupant questionnaire was based on the Royal Society of Health / Building Research Establishment questionnaire for studies of sick building syndrome though this study was not solely interested in building sickness. A log book approach to the collection of occupant symptoms has been suggested[3] but the Health and Safety Executive recommendation is that the RSH/BRE questionnaire[4] should be used.

Additional sections were added to address the refurbishment of the buildings from air-conditioned to natural ventilation. This included questions relating to the usage of opening windows. and occupant perception of the environment both before and after the refurbishment.

The whole building population was not targeted for questionnaire distribution. The building populations and response rates are summarised in Figure 1 below.

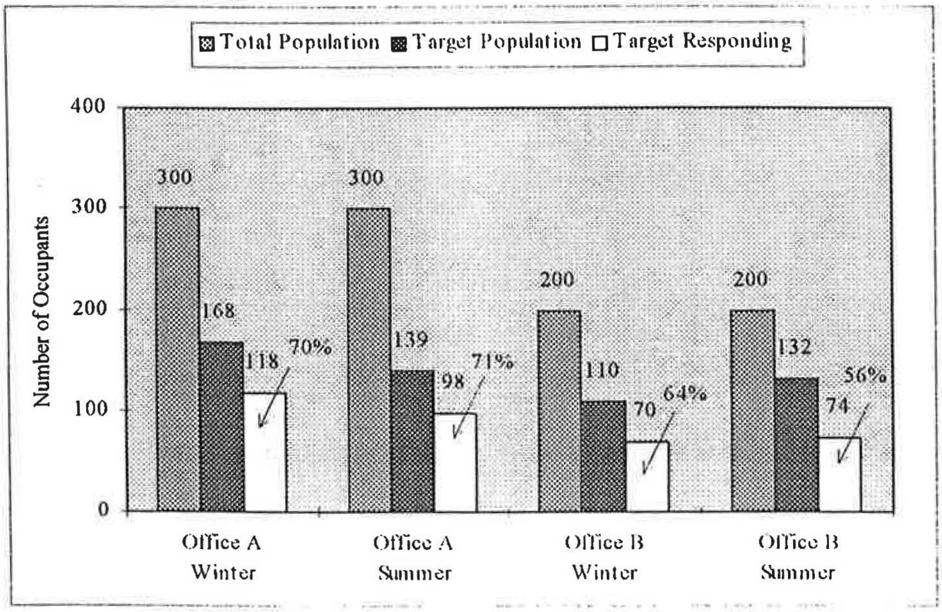

Figure 1: Study Building Populations. Target and Responding Groups

BUILDING SICKNESS DATA

Individual Personal Sickness Index (PSI(5)) values were calculated by adding the number of symptoms suffered by each respondent. The symptoms used were headache. lethargy / tiredness. dry throat, blocked / stuffy nose. and dry eyes. The Building Sickness Index. BSI(5). was found by taking the mean of the individual PSI(5) scores. BSI(5) scores can be characterised by the following levels shown in Table 4 below. Data was gathered after the refurbishment using the questionnaire.

Table 4 : Descriptors for BSI(5) Categories

Range of BSI(5) Score	Descriptor
0.0 - 1.5	Satisfactory
1.5 - 2.5	Cause for further investigation
2.5 - 5.0	Cause for concern

Both Office A and Office B fall into the "cause for further investigation" category as expressed by the BRE analysis method. However the Office B BSI(5) is significantly higher than that for Office A. This is due to the high level recorded for the Female population of this building which can be seen in Figure 2. It is not possible to say whether these women are suffering disproportionally in comparison with their male counterparts or whether they are less inhibited in reporting of symptoms.

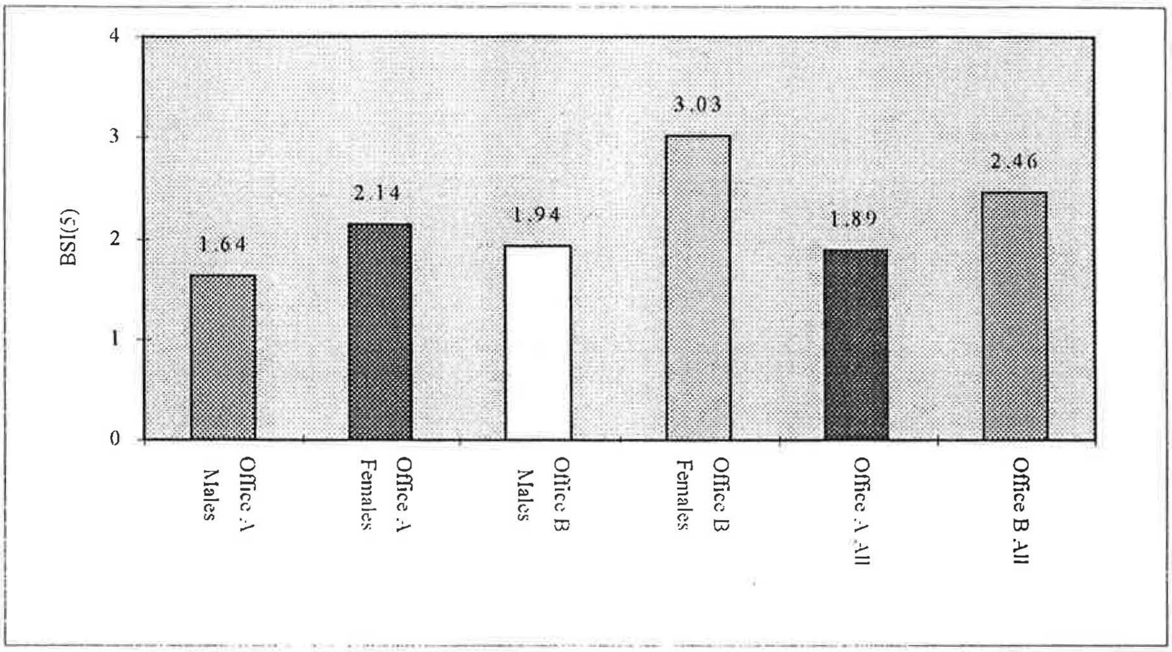

Figure 2 : Building Sickness Score by Building and Gender After Refurbishment

For each demographic group the symptom proportions were headache 20%, lethargy / tiredness 30%, dry throat 15%, blocked / stuffy nose 20% and dry eyes 15%.

The number of symptoms reported by each group is bottom heavy for most groups with most people reporting small numbers of symptoms. However, in the case of the Office B Female population this distribution is inverted with sizeable numbers reporting high numbers of symptoms. This is easily seen from Figure 3 below where 58% of this group report suffering from more than 2 symptoms.

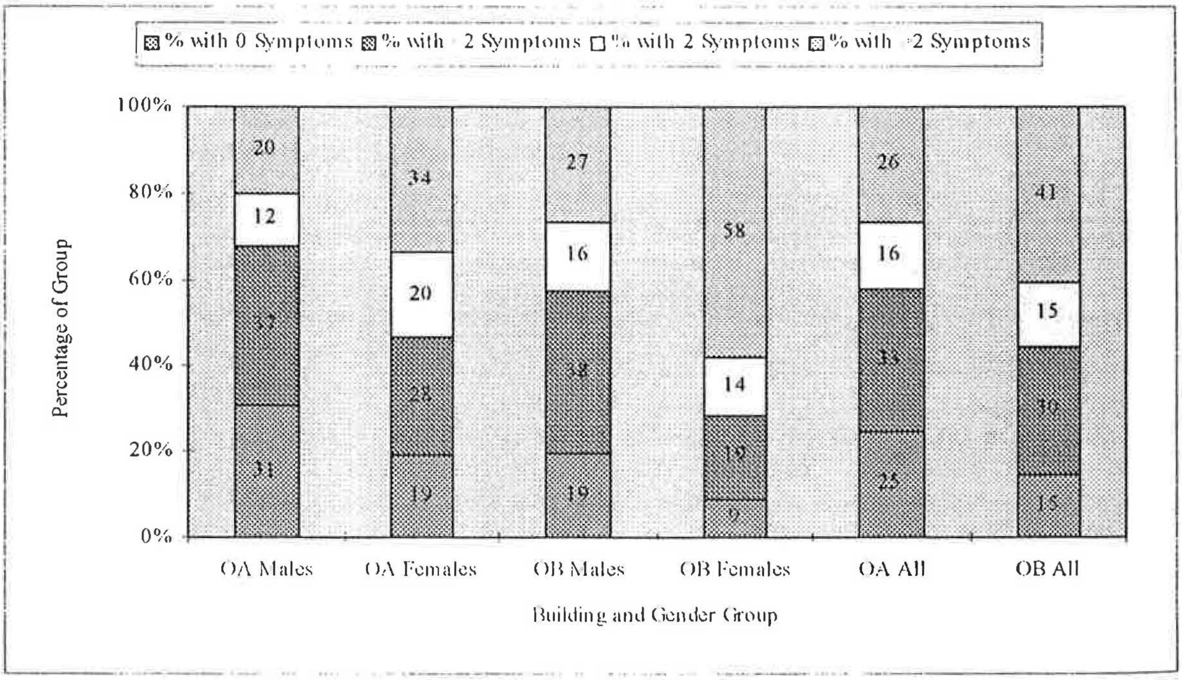

Figure 3 : Percentage of Group Suffering Numbers of Symptoms After Refurbishment

ENVIRONMENTAL PERCEPTION

Amongst others, questions concerning environmental temperature, air movement, humidity, stuffiness, light levels and noise levels were asked, as detailed Table 5 below. Dependent on the distance of the recorded mean scores from the optimum an assessment was made whether the level was "optimum"(O), "satisfactory"(S), "a cause for further investigation"(I) or "a cause for concern"(C).

Assessments were made by occupants for both the morning and the afternoon periods. The morning figures indicate "optimum" or "satisfactory" levels for temperature, air movement, humidity, light and noise but the stuffiness question gives rise to a "cause for further investigation" category across all population groups. The situation is similar in the afternoon but the stuffiness level has risen to "cause for concern" and the Office B population records a "cause for further investigation" as temperatures reach the "too hot" end of the scale.

Table 5 : Environmental Descriptions and Acceptability After Refurbishment

Population	Office A Summer		Office A Winter		Office B Summer		Office B Winter	
Question	am	pm	am	pm	am	pm	am	pm
Too hot ↔ Too cold	S	S	O	S	S	I	O	O
Too still ↔ Too draughty	S	O	S	S	S	S	O	S
Dry ↔ Humid	S	O	S	S	O	O	S	O
Fresh ↔ Stuffy	I	C	I	C	I	C	I	C
Too dark ↔ Too bright	O	S	O	O	O	S	O	S
Too noisy ↔ Too quiet	O	O	S	S	S	O	S	O

O - Optimum, S - Satisfactory, I - Cause for Investigation, C - Cause for Concern

EFFECTS OF REFURBISHMENT

Any question requiring occupant recollection of the environment before refurbishment relies implicitly upon the human memory. However it was felt necessary to make some attempt to gather this data for comparison, despite this possible confounding factor, in order to set into context the perception of the environment "after" the refurbishment.

In addition to their assessment of the environment, described above, respondents were asked to record where discomfort due to various environmental factors occurred "often", "sometimes" or "never". Some of these factors are shown below in Table 6. Codes of O, S and N are used to indicate levels tending towards these descriptions. For those occupants present in the building before refurbishment the questions were repeated for that period.

Table 6 : Levels of Discomfort Before and After Refurbishment

Population	Office A Summer		Office A Winter		Office B Summer		Office B Winter	
Question	Before	After	Before	After	Before	After	Before	After
Temperatures too high	S	S	S	S	O	O	S	S
Temperatures too low	S	S	S	S	S	N	S	S
Draughts	S	N	S	S	N	S	S	S
Stuffy air	S	S	S	S	S	S	S	S
Dry air	S	S	S	S	S	S	S	S
Humid air	N	S	N	N	S	S	S	S
Too much light	S	N	S	N	S	S	S	S
Not enough light	N	S	N	S	N	S	S	S
Too much noise	S	S	S	S	S	S	S	S
Too quiet	N	N	N	N	N	N	N	N

O - Often, S - Sometimes, N - Never

The refurbishment appears not to have affected the regularity of discomfort due to too much or too little noise. In all cases the "before" and "after" data is the same with there being "sometimes" too much noise and "never" too little. Discomfort due to stuffiness and discomfort due to dryness appear likewise to be unchanged. All cases report discomfort due to stuffiness or dryness as occurring "sometimes".

Discomfort due to the temperature being "too hot" or "too cold" is also the same before and after the refurbishment except in Office B Summer where temperatures are now "never too cold". Office B Summer occupants also reported the discomfort due to the temperature being too hot as "often" but in all other case the discomfort due to temperature was recorded as "sometimes".

Discomfort due to "humid air" has not changed in any case except Office A Summer where it has increased from "never" to "sometimes". In the winter the occupants of this building report discomfort due to humid air as "never" whereas in both the winter and the summer the Office B occupants report humidity discomfort happening "sometimes".

Discomfort due to draughtiness is unchanged in both buildings in the winter and occurs in both cases "sometimes". In Office A Summer however, discomfort due to draughts now occurs less often going from "sometimes" to "never" and in Office B Summer draughts now occur more often going from "never" to "sometimes".

Only the changes in discomfort due to too much or too little light create and obvious pattern. In general there is less often discomfort due to too much light and more often discomfort due to not enough light. This may be in part attributable to the solar gain reducing replacement glazing, which also cuts down on the ingress of daylight, fitted during refurbishment.

Questions were also put to those occupants who had been in the building before refurbishment concerning whether certain conditions occurred "more often"(M). "less often"(L). or "about the same"(S). Some of these questions are shown Table 7 below. The results show conditions being broadly the same as before but in a few cases being better with discomfort occurring less often. Only in the case of ingress of noise from outside the building are conditions described as worse than before.

Table 7 : Change in Regularity of Discomfort Between Before and After Refurbishment

	Office A Summer	Office A Winter	Office B Summer	Office B Winter
Temperatures too high	S	S	S	S
Temperatures too low	S	S	S	S
Draughts	S	S	S	S
Dry air	S	S	S	S
Humid air	S	L	S	S
Stuffy air	S	S	S	S
Too much light	S	S	S	S
Not enough light	S	S	L	S
External noise	M	S	S	S
Too much noise	S	S	S	S
Too quiet	S	S	L	S

M - More Often, L - Less Often, S - About the Same

USAGE OF OPENING WINDOWS

The main change to the way in which the occupants may interact with the refurbished building is through the openable windows. As is to be expected, respondents report opening windows mainly to cool the office, to let in fresh air and to let in a breeze. Similarly, windows are reported to be kept shut to keep the office warm, to prevent draughts, to keep out noise, and to keep out dust, dirt and pollution. Figure 4 and Figure 5 below, show the reported levels due to each listed reason for either opening or not opening windows.

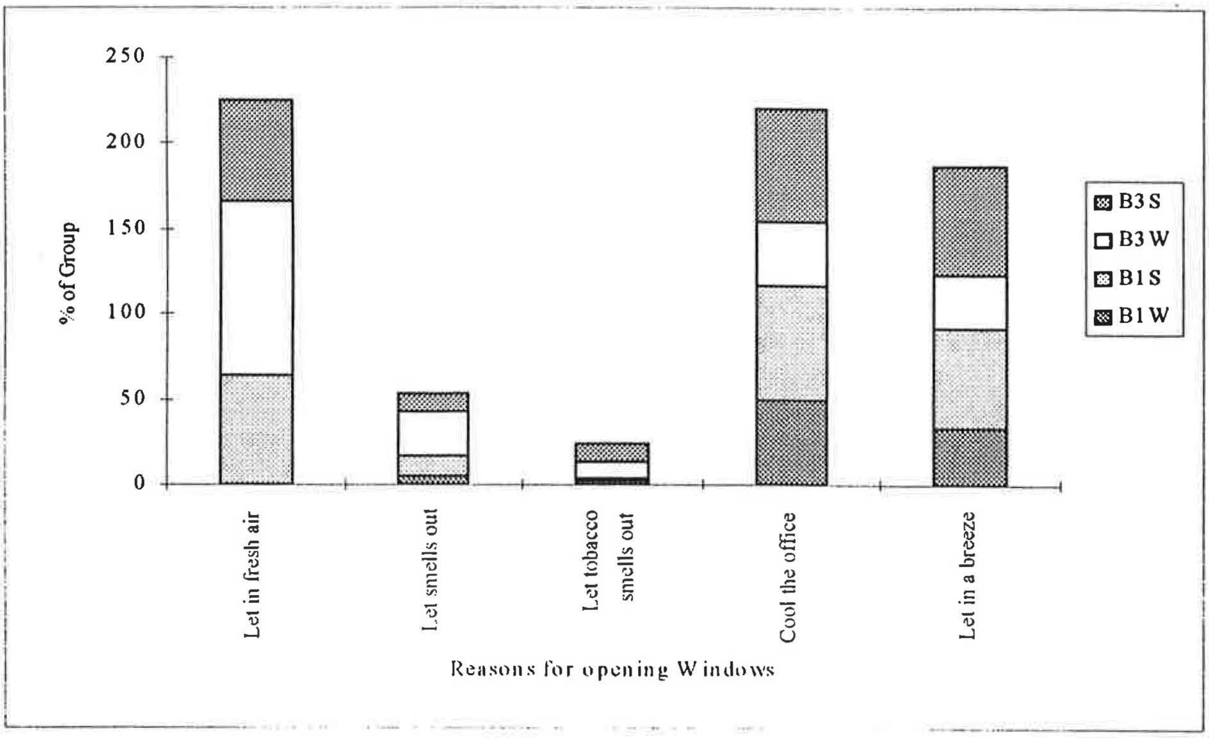

Figure 4 : Reasons for Opening Windows After Refurbishment

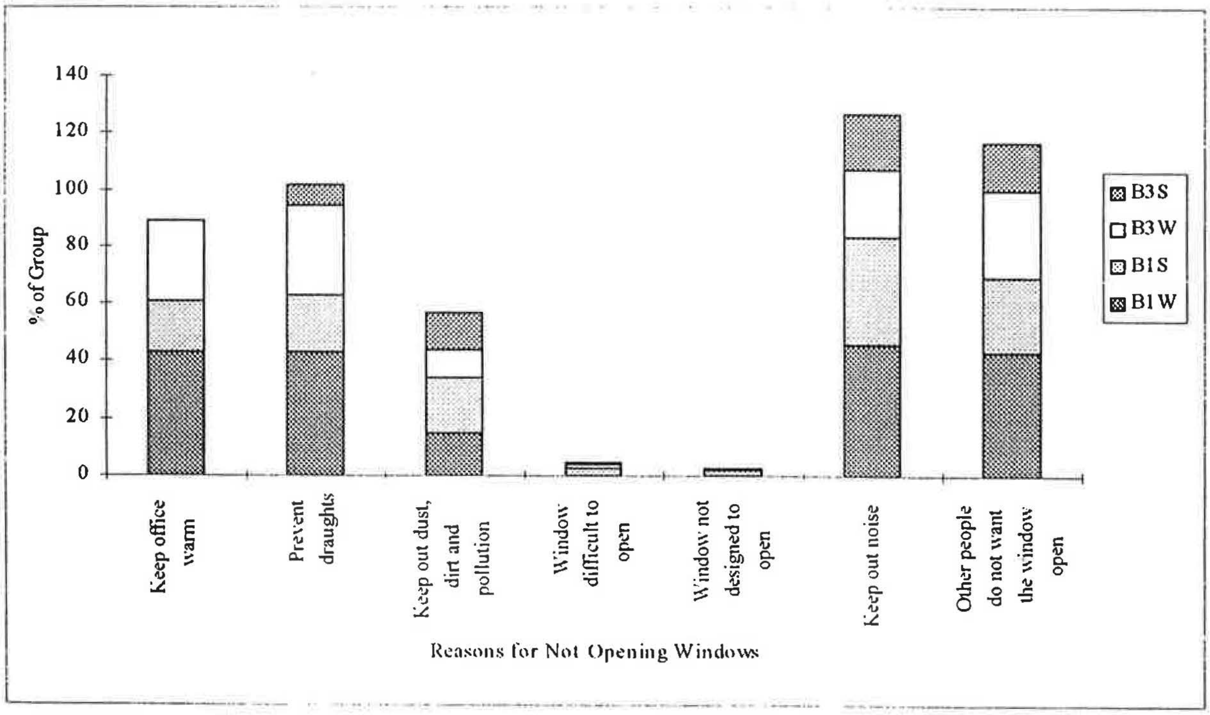

Figure 5 : Reasons for Not Opening Windows After Refurbishment

The use of windows in this way is intuitive but a further reason why the windows are not opened is more interesting and potentially important to the success of a naturally ventilated building. This reason is the wish not to inconvenience others by satisfying a personal desire to open the windows. Pressure from colleagues to leave the windows shut is the second most reported reason, following keeping out external / traffic noise, for the windows not being opened.

This indicates the need to educate occupants, in particular those who have been used to an air-conditioned environment, as to the necessity of being more actively involved in the regulation of their indoor environment. However, education of occupants cannot in itself ensure effective window opening in any building. Social pressures imposed by hierarchies and personal levels of tolerance can have a strong impact. Finally, the windows themselves must be easy to operate by design and by location.

CONCLUSIONS

Differences in building sickness scores between the buildings were apparent with Office B being slightly worse. Of course, the buildings had markedly different numbers of floors and aspect ratios. Office B occupants seemed less happy with thermal comfort and air quality levels although there were broadly similar types of responses in both buildings.

Dry bulb temperatures above 23 °C were commonplace which is in itself likely to lead to an increase in the number of reported symptoms. Air velocities were generally low (below the mean values traditionally associated with mechanical ventilation). The exception was for Office B where the period of intensive summer monitoring coincided with very high external ambient temperatures and solar gain and the measured velocities were higher. This may be indicative of some control of and response to the environmental conditions by the occupants.

Stuffiness was found to have some association with environmental conditions in that it often seemed to occur in combination with high temperatures and/or low velocities in the representative zones monitored. There appears to be some scope for enhanced window operation (particularly in summer) to increase ventilation and potentially reduce or ameliorate high temperatures and thermal discomfort without the resulting increase in air velocities producing excessive discomfort.

As is to be expected, external weather conditions clearly influence internal conditions on a diurnal and a seasonal basis. This may be of relevance if refurbishment is under consideration since the weather adds a variable aspect to the environment which may be somewhat alien for anyone moving from an air-conditioned to a naturally ventilated environment.

CO_2 peak levels for all three buildings showed a reduction from winter to summer which accords with an increased amount of ventilation (assuming similar occupancy patterns).

Neither building appears to be a resounding success but from the limited response of those occupants who had been in the buildings before refurbishment, the general conclusion is that conditions within the two offices were no worse after refurbishment from air-conditioning to natural ventilation and in some aspects may be slightly better.

With regard to buildings refurbished from mechanically cooled to naturally ventilated, thermal comfort and occupant satisfaction are only two factors in the overall benefits equation with capital and running costs and environmental "green" issues being additional factors. Proper design, use and training instruction of occupants are necessary to obtain the best out of any building but particularly so in refurbished buildings of this type where occupant behaviour (including adopting a more active role) is likely to be a major factor in its overall performance, successful or otherwise.

1 Energy Consumption Guide 19 - Best Practice Programme, Energy Efficiency Office, Department of the Environment. October 1991.

2 WILLIAMS, R.N., BOOTH, W.B. & MARTIN, A.J. : Refurbishment of Air-Conditioned Buildings for Natural Ventilation (Confidential Laboratory Report 77870/2) - BSRIA. 1995.

3 URE, J. : Questioning the Questionnaires - Building Services The CIBSE Journal. March 1995.

4 How To Deal With SBS (Sick Building Syndrome), Guidance For Employers, Building Owners and Building Managers - Health and Safety Executive. 1995.

13