MEASUREMENTS OF BACKGROUND NOISE LEVELS IN NATURALLY VENTILATED BUILDINGS, ASSOCCIATED WITH THERMAL COMFORT STUDIES : INITIAL RESULTS.

M Wilson(1), F Nicol(2), R Singh(2)

(1) Low Energy Architectural Research Unit, University of North London
(2) Dept. of Architecture, University of East London

INTRODUCTION

It is becoming accepted that different standards of thermal comfort apply in free-running buildings than in air-conditioned buildings. This has important consequences in energy consumption. Under the new proposed Section L of the Building Regulations air-conditioning of buildings is to be limited in buildings over 500 m². As naturally ventilated spaces are re-introduced into city environments with high noise levels the tolerance levels for the acoustic response need to be examined in greater detail. Background noise levels in the air-conditioned office are maintained by the air-conditioning system with appropriate facade insulation designed to prevent the ingress of road traffic or other environmental noise above this level. Pilot studies have looked again at thermal comfort in free-running buildings which at the same time has afforded an opportunity to look at the noise levels and acoustic satisfaction in these spaces. Of particular interest is the general comfort question when windows are opened to allow ventilation to eliminate overheating and the noise level rises. While not intended at this stage to produce a sophisticated analysis some insight has been provided into occupied and unoccupied levels in a modern busy office and variation in response across different climatic regions.

THERMAL COMFORT

International standards for thermal comfort provide methods to predict comfortable temperatures in buildings from a knowledge of the activity of the occupants and their expected clothing (1,2). Because these cannot be known in advance, typical values are assumed. The result is a desirable temperature for a particular building type.
Such standards are causing concern for a variety of reasons:
- The standards can only be achieved in buildings with full control of the indoor climate. They therefore act as a strong incentive to air-condition buildings.
- Global climate change and other environmental concerns have become of such international significance that large reductions in the energy consumption of buildings are necessary.
- The theoretical models underlying the standards have not performed well when attempts have been made to verify their predictions in everyday life in real buildings. These errors can lead to unnecessary heating in buildings in winter and therefore needless cooling in summer. Current standards therefore waste energy (3).
- In naturally ventilated buildings the lack of correlation between predicted and measured thermal comfort conditions is particularly wide. In addition they cannot provide the control of indoor temperature the standards require.

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An 'Adaptive' approach to thermal comfort was developed at the BRE during the 1970's (4,5,6,7). The adaptive approach starts from the view that, given the opportunity, people will take action to avoid thermal discomfort. The types of action fall in to four broad categories:
1) modification of metabolic heat production (changing activity)
2) modification of the rate of body heat loss (changes in clothing or posture)
3) modification of the thermal environment (by using controls)
4) selecting a different environment (changing position in one space or moving to another space)
Thermal discomfort will only arise if none of these options is available, or if the possible range of action is insufficient to achieve comfort. The implication of the adaptive model is that given time, people will 'adapt' to the average temperature they experience(8). Indoor temperatures in unheated naturally ventilated buildings reflect the outdoor weather as modified by the building fabric. Consequently the temperatures that people find comfortable will vary in sympathy with weather and season.
The adaptive approach provides a model that encompasses the complex range of variables that impact on thermal comfort, including cultural, economic, temporal and social factors, while providing simple guidelines for the assessment of acceptable indoor temperatures in buildings based on field surveys of temperatures experienced in particular locations. Numerous field studies have confirmed predictions of thermal preference based on this approach.

ACOUSTIC COMFORT

The adaptive or acclimatisation mechanisms in thermal comfort are not yet fully understood and it cannot be assumed that similar mechanisms operate in the acoustic environment. However it cannot be denied that occupants in free-running buildings in noisy environments are having to make decisions about changing their thermal environment which will affect their acoustic environment. Fanger(9) has already developed his climate chamber approach to include the acoustic environment and asked his subjects to rate thermal and acoustic environments in terms of relative discomfort. The subjects made their judgements after short term exposure to noise and Fanger admits to the subjects being 'unadapted'. In view of the difficulties at the moment in reconciling the climate chamber and field study approach some doubt must exist on the applicability of the results.

What questions do we need to ask about the acoustic environment in offices?

1) Are the present background limits specified in BS 8233 (1987) applicable to free-running as well as air-conditioned buildings? In an earlier paper(10) it was argued that there may be increased tolerance of noise because of a preference for naturally ventilated over air-conditioned buildings.

2) The equivalence of road traffic noise and air-conditioning noise needs to be evaluated. Studies of the equivalent annoyance of various environmental noises in domestic buildings using the same measures have produced different levels. Kryter(12) presents results showing that aircraft noise based on L_{dn} was regarded as 5-15 dB worse than traffic noise.

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3) What is the noise gradient between a window position and a position some distance from the window? Would a window position be more highly regarded for its view and possibly greater environmental control or less regarded for its noisier location?

4) If the windows are open for some time during the summer to limit or avoid overheating would higher noise levels be temporally tolerated? This may be akin to the development of overheating criteria for thermal comfort. Normal background levels of ventilation can be provided by trickle ventilators or passive stacks which provide reasonable sound attenuation (13).
5) If a noisy environment is unavoidable is there benefit in providing a quiet environment where the worker may retire to perform some of the office functions? Is a more flexible approach to office work required?

6) Should BSI or CIBSE (or ASHRAE) standards be recommended outside the UK?

The present pilot study could not answer all these questions. The acceptability of noise levels in naturally ventilated buildings would require a wide ranging study and the issue of the equivalence of road traffic noise and air-conditioning noise allied to this. A full study of sound propagation in offices was not undertaken, but the response at different office positions could indicate whether this is an issue. No attempt was made to assess the relative desirability of location. Subjective responses throughout the working day would give information on questions 4) and 5) whereas a general assessment of acoustic discomfort would not.

BACKGROUND

It has been concluded (11) that in general noise annoyance in offices is already substantial at about 55 dBA and that 35-40 % of the employees in office buildings are seriously annoyed by noise in the range 55-60 dBA. No distinction is made between office types and the 'limited' research was no doubt done in northern Europe.

Beranek(14) puts an absolute limit of NC 60 (Approx 68 dBA) on office and communication situations for steady noise.

While annoyance in offices is mainly due to communication disturbance, startle and vibration and clearly not sleep disturbance, which is additionally very important in dwellings , more research has been done on noise exposure in residential buildings and it is worth examining some of the work.

Beranek(14) has reported varying tolerances to noise in domestic premises related to climate. Investigations in southern Europe (France and Italy) compared to northern Europe (England and Scandinavia) showed a 5-10 dBA greater tolerance to noise in the former, ascribing this seemingly to the amount of time the windows are open. This difference was also noticed in the USA between findings in Los Angeles and Detroit and Boston, though he is apparently not so confidant of the particular factors involved here. In specifying external noise conditions appropriate to building function Kryter(12) suggests that 5dB should be subtracted from the recommended maximum levels if the building is to be constructed in a warm climate where windows would be regularly open.

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Since the increased attenuation with a reasonably sealed single glazed window should normally exceed this by at least 5 dB it appears that some increased toleration of noise in warmer climates is being allowed for. A day-night external average of 65 dBA is quoted as being compatible with normal office development with 75 dBA as marginally compatible. This is 5-10 dBA higher than the levels associated with residential development.

A recent study at the BRE has looked at the types of noise giving annoyance in domestic buildings (awaiting publication). While road traffic noise effected the most people, in relative terms of actual annoyance, noise from neighbours caused the maximum annoyance. It appears that many people regard road traffic as an inevitable part of the environment while noise from neighbours is not and therefore less acceptable. Noise from building works external to the office environment are now a fact of life in city centres as offices and shops are so frequently refurbished. This touches on the question of control. While overall population disturbance is well correlated to exposure to noise individual annoyance is widely dispersed. Identified as important in producing this disturbance are 'fear of noise source, the conviction that the noise exposure could be reduced by third parties (abuse of power), the individual sensitivity to noise, the degree in which an individual believes to be able to control the noise and , to a lesser extent, the recognition that the noise source gives rise to other problems than mere noise exposure, and that it represents an important economic activity'(11). In air-conditioned offices there is no possibility of control, so a badly attenuated air-conditioning system may be relatively more disturbing than other noise sources predicted from simple noise levels. A naturally ventilated office offers some control (in opening or not opening windows) though potentially at some thermal discomfort. Additionally the individual may view building work noise in a different way to traffic noise.

RESULTS

As part of the Comfort Task of the EC PASCOOL Project(15), organised by the Martin Centre, Cambridge, pilot field studies were undertaken investigating individual thermal comfort experience over one week periods in naturally ventilated buildings located in Exeter, Lyon and Athens. At the same time some limited acoustic measurements were made. Alongside this project, a similar thermal comfort study was being undertaken in Pakistan by a group from Oxford Brookes University and they were also able to make some acoustic measurements. The pilot studies were designed to test methodology and identify the parameters worthy of further investigation. The sites had originally been chosen simply for the thermal comfort tests and were only ideal in one case for the acoustic tests.

15 minute data was collected over at least two 24 hour periods (except for Pakistan). At this pilot stage only internal levels were measured. Though various statistical values were collected, of main concern was the 15 min. L_{Aeq}. Hourly and overall subjective acoustic responses were obtained.

The pilot study in Lyon was in the School of Architecture rather than an office and the external noise level was low. In Athens the tests were made in a small cellular office

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again in a relatively quiet location. In Exeter the study was made in an office belonging to the Housing Corporation alongside a busy urban road. The orientation of the glazing onto the road was towards the south west. It is this latter location together with some individual observations in Pakistan that are discussed.

The noise environment during a day in the measurement period in the office in Exeter in May 1993 is shown in Fig 1. The external temperature was about average for the time of year and a few windows were open. A plan of the office is shown in Fig.2 together with the location of the four main participants who answered questions every hour dur-

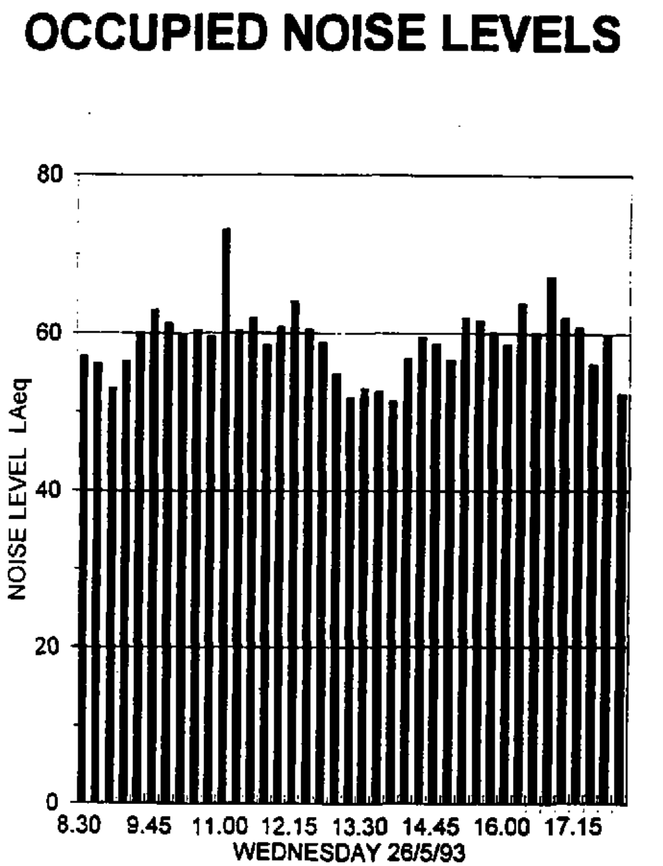

FIGURE 1

BACKGROUND NOISE LEVELS IN NATURALLY VENTILATED BUILDINGS, ASSOCCIATED WITH THERMAL COMFORT STUDIES. INITIAL RESULTS.

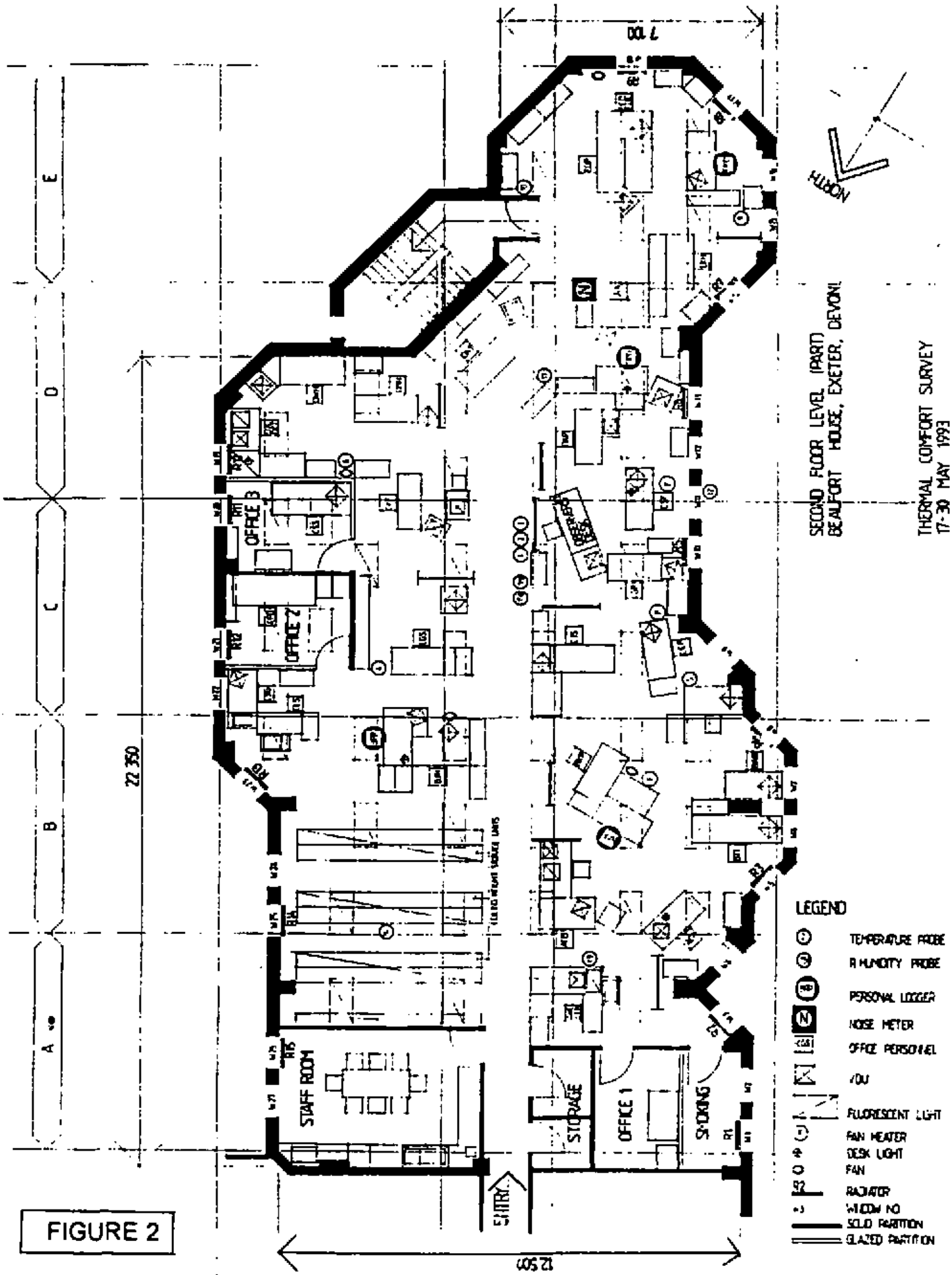

FIGURE 2

BACKGROUND NOISE LEVELS IN NATURALLY VENTILATED BUILDINGS, ASSOCCIATED WITH THERMAL COMFORT STUDIES. INITIAL RESULTS.

ing working hours for a week on their thermal and acoustic environment (one participant was away for the last two days of the week).The four main participants were asked to score their thermal and acoustic environment on a seven point scale on an hourly basis. This is quite easily understood with the thermal environment, a seven point scale from too cold to too hot with 4 as neutral. Acoustically the scale represented too quiet, understood as a lack of privacy, to too noisy. Those scoring 6 or 7 were selected as representing too noisy. It would be fair to say that the participants did not fully understand the concept of 'too quiet' though the study was not essentially about privacy. However it is worth noting that the full office survey, itself indicating some difficulty with the concept of privacy, did produce a high number of complaints even in the traffic noise affected office. This would indicate that even high levels of road traffic noise as well as high general office noise are little use as masking noise.

The south west glazed wall faced onto a noisy road while the north east glazed wall faced a quiet area. The S.W. windows which were open and the timings were also noted. The noise level was only measured at one location (at about 2m from the south west window wall) but it is suggested by the relatively few complaints from the one participant away from the south west window wall compared to the average of the three close to the south west wall that there were lower levels away from that wall (chi-squared 5% significance). The annoyance from traffic noise is confirmed by a survey of all the office staff (table 4), where 30 occupants in the measured office were compared to 20 occupants of another block of offices away from the road. Workers were asked to comment on external and internal noise, frequency of annoyance, whether they had problems with acoustic privacy and noise in general.

The office was unoccupied at lunchtime allowing some estimate of the unoccupied background levels. Measurements were also made when the building was unoccupied on a Saturday. These were in the range 51-55 dBA during the lunchtimes and similar on the Saturday. Internal levels during occupied hours were generally in the range 59-62 dBA with some increase round 1600 hs to between 65-69 dBA. It would appear that the occupied levels are between 5-10 dBA higher than the background road traffic noise level though the traffic is identified as at least as irritant a noise source as the internally generated noise in the office (table 4). There was no correlation between the measured internal noise and the number of S.W. windows open.

The participants responded for an aggregate total of 151 times at hourly intervals. Approximately 10-15% of the time was spent off the premises. On 38 occasions (25%) 'too warm' was recorded and 22 occasions (15%) 'too noisy' recorded. Of those 22 'too noisy' occasions 10 were also 'too warm'. There was a greater chance of complaining about being warm if it was also perceived to be noisy. The relative frequency of concurrence between noise and thermal discomfort was tested using the chi-squared test and found to be significant at the 2% level. There seems little evidence that windows were being opened or shut on a short term basis to balance being too hot with being annoyed by the noise. This might have been accounted for by the participants putting up with the noise for a short period as they allowed for ventilation to reduce the overheating and therefore recorded simultaneous dissatisfaction over a short period. It was not possible to establish whether external noise affected the opening or closing time of the windows as the internal level was so high, but the complaints were mainly sporadic. In general the windows were open for long periods, a half day or more, whereas on only one occasion

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were complaints about noise made in three sequential hours by the same person and on another in two sequential hours. This would suggest that the perception of one environmental discomfort facilitated the perception of the other. The particular week was not a very warm week, and out of a potential 16 S.W. windows to open, the maximum recorded was 5. Whether thermal discomfort was being tolerated because of a reluctance to tolerate more traffic noise will have to wait until full evaluation of the thermal comfort results. The S.W. window states and complaints are tabulated in tables 1 and 2. Table 3 shows the cumulative S.W. window open hours and complaints. The number of complaints have been adjusted on a simple proportion basis in this table as one of the participants was absent from work on the Thursday and Friday. A small increase in the number of complaints was noted as the cumulative number of window hours increased (correlation = .82).

In the full staff survey (table 4), 47 % complained about noise in general with 37 % and 40 % registering a high frequency of noise complaint about external and internal noise respectively. This compares with 15 % frequency of complaint when based on hourly responding of the four main participants. Although the questions asked were different, and the four main participants may have been unrepresentative, overall noise perception might be determined by a relatively small time period of dissatisfaction. The noise dissatisfaction results obtained from the full staff survey were in line with those indicated in reference (11). When the full office survey staff were divided into those closer to the south west wall and those closer to the north east wall 70 % of those closer to the south west wall found the external noise unsatisfactory compared to 52 % in the general survey. This would confirm the suggestion from the individual survey that the external noise decreased across the office.

NUMBER OF WINDOWS OPEN IN EACH HOUR

	MON	TUE	WED	THURS	FRI
9	1	1	1	3	0
10	1	0	1	4	0
11	3	1	1	4	1
12	5	1	1	4	1
13	5	1	1	4	3
14	5	1	1	4	3
15	5	1	1	4	3
16	5	1	2	4	3
17	5	1	1	4	3

TABLE 1

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NUMBER OF COMPLAINTS ABOUT NOISE IN EACH HOUR

	MON	TUE	WED	THURS	FRI
9		1			
10	2				1
11			1		
12		2		1	
13	1				1
14	1	1		1	
15	2		1	1	1
16	1			1	1
17			1		

TABLE 2

CUMULATIVE NUMBER OF WINDOW OPEN HOURS AND COMPLAINTS

	MON	TUE	WED	THURS	FRI
window open hours	35	8	10	35	17
complaints	7	4	3	5.3 (corrected)	5.3 (corrected)

TABLE 3

In addition to their comfort perceptions, the four main participants were asked to name their main activity during the preceding hour. The major activities are shown in table 5. Walking (31 hours) and writing (40 hours) were the major activities. In the former activity 16% and in the latter 10% of the hours were noisy. Most of the walking was out of the office, at lunchtime or for travel, but as this resulted in an average number of complaints, the difficult task of what not to include was avoided. Meetings/talking/phoning accounted for 24 hours with 33% noisy hours. Photocopying accounted for 6 hours with 33% noisy hours. The difference between these 'noise generating'(photocopying) and speech communication tasks and others in producing discomfort was tested using chi-squared and found significant at the 0.1% level. This would suggest that speech communication and machine noise were important factors in determining the noisiness perception, while activities requiring individual concentration such as writing were much less affected.

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SURVEY OF ALL OFFICE STAFF

No. of Respondents: Traffic Noise Affected Office 30 (20 nearer noise affected wall); Unaffected Office 20*

	Traffic Noise Affected %	Traffic Noise Unaffected %	Office area closer to noise affected wall %
External Noise Distictive	62	10	75
External Noise Unsatisfactory	52	16	70
Internal Noise Distinctive	47	55	
Internal Noise Unsatisfactory	48	35	
Frequency of Dissatisfaction with External Noise	37	10	
Frequency of Dissatisfaction with Internal Noise	40	45	
Privacy	53	44	
Too Noisy Overall	47	35	

* Only approx. 50% of the staff answered the question on acoustic privacy

TABLE 4

In Pakistan three subjects in an office block were asked to evaluate their acoustic discomfort. Two were in a 3rd floor office and one on the fifth floor. Measurements of the L_{Aeq} were made in three consecutive 15 min periods prior to being asked about noise The major source of noise was identified as traffic. They were not presented with a rating scale but asked for their comments. The results based on averaging the three L_{Aeq} were:

3rd floor 1. Noise level 74.5 dBA Comment: About right
2. Noise level 71.3 dBA Comment: About right

5th floor 1. Noise level 69.3 dBA Comment: Rather noisy

NUMBER OF COMPLAINTS RELATED TO ACTIVITY

	Walking	Writing	Meeting,Talking,Phoning	Photocopying	Others e.g. filing,w.p
Number of Hours	31	40	24	6	50
Number of Complaints	5	4	8	2	3

TABLE 5

Despite the very limited sample it is clear that perception of noise is quite different to that in northern Europe. This would reinforce the view expressed by Beranek that noise tolerance was related to the number of windows generally open but additionally also to the general ambient noise level. A clear similarity exists here to the adaptive effects in thermal comfort where previous work in Pakistan have shown neutral temperatures of 30°C and more(6).

CONCLUSIONS

The unoccupied background noise levels experienced in the office were in the range 51-55 dBA, above the recommended levels of 40-50 dBA in BS 8233 (1987). Internal levels were measured as 59-62 dBA. The dissatisfaction, expressed as the fraction of hourly complaints, was 15% (biased 3 to 1 in favour of the area close to the noise affected wall), or in the full staff survey 47% recorded general dissatisfaction. The complaints, based on the hourly survey , increased slightly with the cumulative number of noise affected windows open, although the number only varied from 0 to 5 out of 16. There was no evidence to suggest that the measured occupied levels were affected by traffic noise. In the full staff survey 52% complained about the external noise in the survey office, while only 16% in the office away from the main road. However 48% and 35% respectively complained about the internal noise indicating that internally generated noise may be as big a source of complaint as the external noise.

From the hourly survey speech communication activities together with those affected by machine noise seemed the most affected but then only on 1/3rd of the occasions. Noise complaints showed a tendency to coincide with thermal comfort complaints. While the recommended levels of BS 8233 (1987) seem fair when judged by the full staff survey it is clear that with regular responding office functions are differentially affected, and annoyance is restricted. In future studies it is proposed to make an estimate of the actual contribution of the traffic noise to the occupied level from the number of windows open

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and the external traffic noise. This might give some indication whether the windows were being closed or opened as a response to traffic noise, that the action was simply related to the thermal environment or whether trade-offs were being made.

Overall the main participant in the north east part of the office complained of noise much less than the average of the three participants close to the window. Additionally the complaints in the full office survey about external noise came mainly from the part of the office closer to the south west wall. This would indicate that there is a decrease in the traffic noise away from the window.

The observations in Pakistan indicated a very high tolerance of noise which, despite the very small sample, would indicate that adaptive effects are at work along a similar pattern to those discovered in thermal comfort field studies. It will be interesting to compare these with further observations in the Mediterranean area.

While systems continue to be developed to improve acoustic insulation through the opened window, office function and space planning will need to play a greater role. The idea of the completely flexible air-conditioned space isolated from the external environment will need to be reviewed.

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