NOISE LEVELS IN URBAN CANYONS AND PERMITTED OFFICE BACKGROUND LEVELS: THE POTENTIAL FOR NATURAL VENTILATION

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ABSTRACT: In urban areas the natural ventilation of buildings is often compromised by high traffic noise levels outside. Designing buildings to produce comfortable conditions without the need for air-conditioning is an important element in the effort to restrict energy use in order to combat global warming. Within a recently completed EC funded project 'URBVENT', a study was undertaken of the acoustic environment in the congested urban streets of Athens. A prediction technique was developed to estimate the noise level at various heights above the road in streets of different dimensions. Information gathered within an earlier EC funded project 'SCATS' arising from extensive office comfort surveys and noise measurements in four EU countries has made it possible to estimate noise level which building occupants will find acceptable. This means that the potential for natural ventilation in terms of the noise climate can be predicted. The paper will also question whether an adaptive approach should be made to acceptable background noise levels with a variable rather than a single value being recommended for tolerable background level depending upon whether the building is in an urban or rural setting.

1. INTRODUTION

Throughout history people have developed structures to protect themselves from the climate, rain, wind, heat, cold, light and noise. The 20th century saw massive changes in how people lived and worked and with that there developed criteria guiding the construction of the buildings and shelters that they inhabit. Technological advances enabled people to keep our buildings warm or cool, allowed them daylight (or possibly more appropriately some visual contact with the outside world) and protection from noise that the modern world created with transportation and industrial growth. Design guides from the last century give lists of the criteria that are to be used, be it temperature, light or noise (1). These criteria were usually established through traditional laboratory experiments. Fanger (2) established the temperatures which we would find comfortable, lighting level guidelines went up and down, daylighting was occasionally specified (3). Sometimes in deep plan buildings these guidelines were completely ignored. Background noise criteria are specified in the British Standards or CIBSE publications. Yet increasingly these criteria are found to be inappropriate or are ignored.

BS 8233:1987(4) mentions maximum intrusive background levels of LAeq=40-45dB for private offices and LAeq = 45-50dB for large offices. BS8233:1999 mentions 'reasonable conditions for study and work requiring concentration e.g. cellular office': good 40 dB reasonable 50dB, meeting rooms and executive offices 35 (good)/40 (reasonable)- all LAeqs. Note that these are intrusive levels. It is generally accepted that a noise 10dB below another noise will not be noticeable. So for 50dB intrusive noise you only need 60dB internal office noise and it would not be noticeable. But who is to say that traffic noise is more unbearable than office noise. Certainly any acoustic disablement (i.e. not being able to undertake a telephone conversation) is noise type independent (but not necessarily frequency independent). Speech is understood at the high frequencies- traffic noise has a high low frequency component- but maybe we such not get into that argument at the moment. The main problem is acoustic not disablement but simply potential annoyance.

2. ADAPTATION TO TEMPERATURE AND LIGHT

The threat of global warming has made most sensible architects reconsider building design. But the issue goes deeper than that. Since 1970 some physicists have challenged the basis of Fanger's thermal comfort theory (5, 6, 7). At the BRE, Humphreys and Nicol produced field test results from the UK, Iraq, Singapore and India which contradicted Fanger's theory (8). After collecting further results Humphreys found that occupants of free-running buildings (neither heated nor cooled and naturally ventilated) appeared to adapt to the climatic conditions, the comfort temperature being highly correlated with the external temperature (9). Only in air-conditioned buildings did occupant prediction at all correlate with Fanger's theory (10). Fanger is now trying to suggest that occupants in very best buildings must have low asymmetric radiation. Why do most people therefore want to sit next to a window, certainly the position in an office with the highest asymmetric radiation and probably also the noisiest?
So what about light? The amount of light has been traditionally specified as so many lux on the working plane. But the demands on lighting of the development of VDUs meant that the luminaires designed to achieve 500 lux on the working plane produced dim environments and complaints. This resulted from the sharp cut off angles on the louvres designed to avoid screen reflections depriving the vertical wall surfaces of light. So the whole luminous environment suddenly became more important (we are not suggesting that many researchers had not tried to encourage this approach before computers were commonplace). The question of daylighting is however much more interesting. As about 30% of the total energy consumed by an office is for the provision of lighting, daylighting has become a very important issue in the construction of low energy office buildings. There have been criteria around for many years by which one could predict whether discomfort glare and disability glare would exist with an artificial lighting scheme. Most artificial light sources were small and an alternative prediction method was developed for large area sources (Hopkinson’s Cornell formula).
This was applied to daylighting to predict discomfort glare from windows. Some earlier laboratory tests (11) suggested that the formula was okay but that there was greater tolerance of glare from windows than from artificial light. Field results have however produced startling difference between prediction and practice (12, 13). Field results from visibility (disability) studies (e.g. Sutter) generally agree with the laboratory tests (14) but a rethink is needed when it comes to what is uncomfortable, but not disabling. What is it about a window that is comfortable whereas if you replaced it with a large source of uniform artificial light of the

same luminance it would be uncomfortable? Physiologically there should be no difference so maybe we should be taking a psychological rather than physiological approach. One suggestion that some researchers are looking at now is that it may be due to the information content of the window, what might be described as the view. The view may be good or bad, but that is not the whole story. Good view or bad view the window provides contact with the outside world.

3. THE CASE OF ACOUSTICS

So where does this leave us with acoustics, particularly acoustic comfort in relation to background noise levels? Air-conditioned buildings are typically heavier consumers of energy and producer of CO2 emissions than the equivalent naturally ventilated building. If we stick to present guidelines on background levels in offices it means that many of them will almost certainly have to be air-conditioned because we could never open the windows. But many traditional naturally ventilated buildings still exist in city centres without complaints about noise and if there is it almost certainly comes from internal noises such as business machines which air conditioning will, if anything, add to. If the window provides visual contact with the outside such that the predicted visual discomfort of the window is not experienced then contact with the expected external noise environment may again mitigate the predicted acoustic discomfort. If you are in a relatively rural location with views to fields you might find the noise from a busy but maybe obscured road beside the building uncomfortable. If you are in a city you might like to feel psychologically part of that city with its traffic and other street noises (15). This is an aspect of noise which laboratory studies will not help with, as the subjects are removed from their normal surroundings.

Part of a city is the noise. Most but maybe not all of us would like there to be less noise. But it is also true to say that a city would not be a city without noise. Outside urban areas the noise levels are expected to be lower. Living in a rural area with city levels of noise would create major complaints (and does). So why do we insist that intrusive background levels in offices in urban areas and in non-urban areas should have the same criteria applied? The trend away from sealed air-conditioned buildings may partly be a response to global warming but also reflects concerns about sick building syndrome and the personal loss of identity in these buildings. Giving people more personal control, letting in more (variable) daylight, providing openable windows, providing more intermediate spaces (neither inside nor out) is a preoccupation of today's energy and environmentally conscious architects.

So if we permit more variability in temperature light, why not noise? Maybe permit is not the right word. These spaces are in increasing demand. Think for instance away from offices and you find the BEDZED housing development being short-listed for the Stirling Prize.

If the internally generated noise level in an office is much higher than the intruding noise- traditionally one would say more than 10 dB, there would be no communication of the outside world (acoustically). Realistically one might say that that the internally generated noise should be similar to the outside noise for recognisable psychological communication with the outside.

3.1. Evidence From the Field, the SCATs Project

The EU-funded SCATs (Smart Controls and Thermal Comfort) project was designed to investigate the relationship between the comfort of building occupants and the physical world in five European countries, France Greece, Portugal, Sweden and the UK. It was principally directed at thermal comfort, but measurement of noise level were taken and the noise comfort was polled on the following two scales:

NF.	How do you find the noise level?	NP.	What would you prefer to have?
1	Very noisy		
2	Noisy	1	Much quieter
3	Slightly noisy	2	A bit quieter
4	Neither noisy nor quiet	3	No change
5	Slightly quiet	4	A bit noisier
6	Quiet	5	Much noisier
7	Very quiet		

Some 4600 noise votes were collected from the subjects. About 2500 were accompanied by measurements of LA90 and LA10. It was intended also to record LAeq but in the end, because of a software fault, only about 580 values of Leq were collected. No noise measurements were made in Greece. We have briefly presented the results from the SCATS project before (16). The offices studied were mainly in urban situations and a wide variety of indoor noise levels were recorded (table 1).

Table 1 - *Mean and standard deviation (sd) of noise level measured in the SCATs project for different countries and for different building types and configurations. The values for UK buildings are given separately. Values for the Leq are estimated from the L10, except in the case of the UK where about half of the offices were measured when Leq was available*

	Mean L_{A10}	sd L_{A10}	Estimate L_{Aeq}	Mean L_{A90}	sd L_{A90}
All buildings	60.0	7.05	57.5	49.5	5.80
All buildings - France	53.5	6.09	51.0	43.3	3.43
All buildings - Portugal	61.2	5.19	58.7	49.8	3.73
All buildings - Sweden	54.2	6.74	51.7	44.1	3.98
All buildings - UK	65.4	4.17	62.9	55.7	3.85
NV buildings	61.2	6.58	58.7	50.6	5.57
AC Buildings	60.0	7.05	57.5	49.5	5.80
NV Buildings - Windows open	62.4	6.27	59.9	51.9	5.12
NV Buildings - Windows closed	60.8	6.64	58.3	50.1	5.65
AC Buildings - AC on	60.2	8.13	57.7	50.2	6.34
AC Buildings - AC off	55.9	8.23	53.2	45.8	6.23
UK NV buildings	65.6	4.01	63.5	55.8	3.97
UK AC Buildings	66.3	4.22	64.2	55.3	3.77

Table 1 (cont.)- *Mean and standard deviation (sd) of noise level measured in the SCATs project for different countries and for different building types and configurations. The values for UK buildings are given separately. Values for the Leq are estimated from the L10, except in the case of the UK where about half of the offices were measured when Leq was available*

	Mean L_{A10}	sd L_{A10}	Estimate L_{Aeq}	Mean L_{A90}	sd L_{A90}
UK NV Buildings - Windows open	66.3	4.08	63.8	56.0	3.62
UK NV Buildings - Windows closed	65.3	3.93	63.2	55.8	4.13
UK AC Buildings - AC on	66.5	4.44	64.4	55.4	3.69
UK AC Buildings - AC off	65.7	3.59	63.5	55.1	3.96

The overall results shown are from a mixture of air-conditioned and naturally ventilated offices. In Sweden most of the offices were air-conditioned and in Portugal mostly naturally ventilated. In the other countries there was an even split. It has been argued sometimes that people in naturally ventilated offices will tolerate a higher level of background noise than those in air-conditioned offices on the assumption that poorer noise environment is sacrificed for greater individual control. There is little evidence in these data to support this contention (see below. This paper seeks to show that Office workers are more tolerant of noise that is predicted by BS8233, and that the noise level considered acceptable is a function of the mean noise level, as proposed by Dubiel et al (15).

3.1.1. Sensitivity to increasing noise level

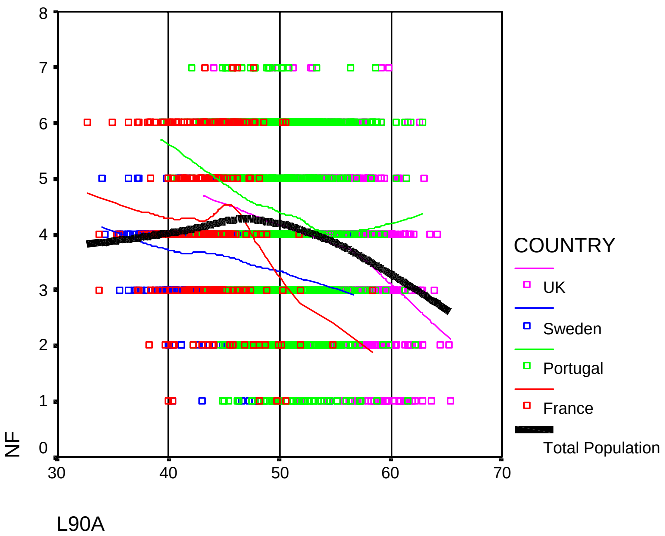

Figure 1 - *Mean noise response on the NF scale (see above) as a function of L90 noise level. Above about 50dB there is a steady increase in the perceived noise with increasing measured noise*

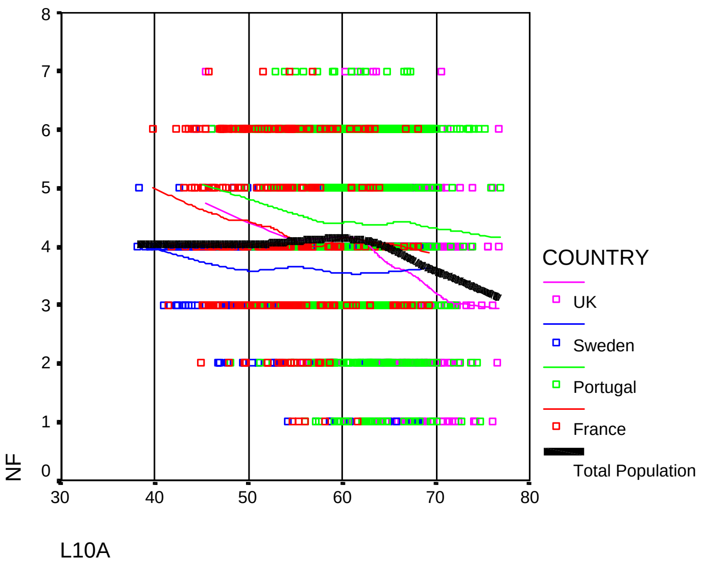

Figure 2 - *Mean noise response on the NF scale (see above) as a function of L_{10} noise level. Above about 60dB there is a steady increase in the perceived noise with increasing measured noise*

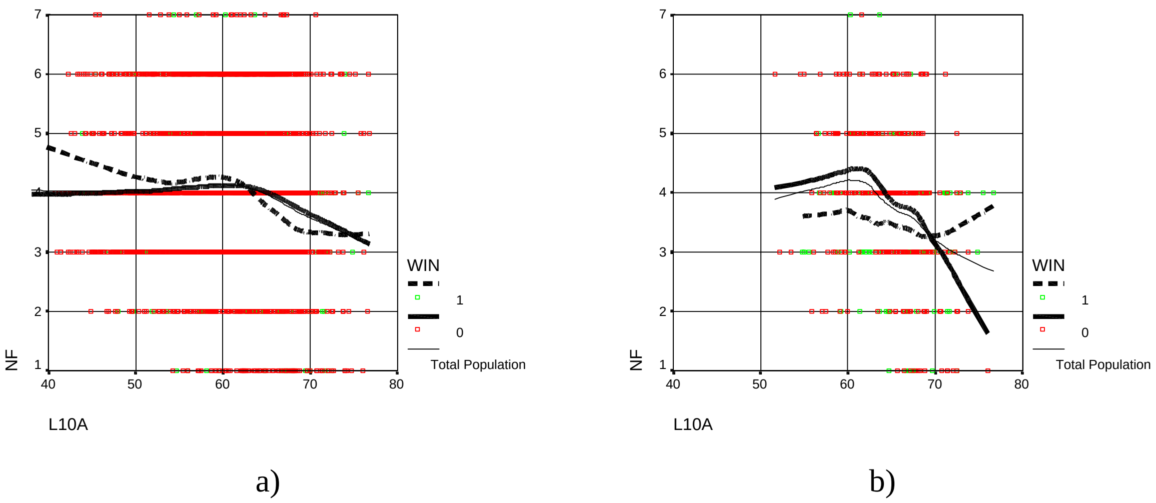

Figure 3 - *Noise feelings (NF) as a function of L_{A10} with windows open and closed: (a) for all buildings in the survey and (b) for UK naturally ventilated buildings only*

The use of natural ventilation in buildings means that much of the noise in an office will come from outside the building in the case where ventilation is provided by an open window. This raises the possibility that occupants may be more or less sensitive to external, than to internal noise. The SCATs data were used to look at this case. Figure 3 shows the L10 sensitivity of subjects when the windows were open (win = 1) and closed (win= 0) for two conditions (a) all buildings (where little effect is shown) and (b) in NV buildings in the UK only. The UK NV subjects seem to record a greater sensitivity to noise when windows are open, suggesting a greater aversion to noise originating from outdoors. The effect is statistically significant, however this effect response in the case of open windows seems almost independent of noise level, suggesting an adaptation to external noise.

3.1.2. What noise level is considered comfortable?

The SCATs data demonstrates an adaptation by the subjects to their normal level of noise. In table 2 are shown the mean noise level in each of the offices in the survey. For each office the level of noise which occupants will find 'neither noisy nor quiet' has been estimated using linear regression. Taking the total population both the LA90 and LA10 results (figs 2 and 3) show a line of zero gradient at a vote of 4 (neither too quiet nor too noisy) until an LA90 of about 50dB and an LA10 of about 60dB.
Because of the low correlation in many of the offices between comfort and noise level, and in some cases the number of measurements (N) is low, many of the resulting estimates of comfort level (LComf10 and LComf90 in Table 2) are non-significant. Results which are significant at the 5% level are shown in bold typeface. The correlation between L10 and LComf10 is 0.35 if all the results are used rising to 0.62 where only significant values of LComf10 are used. The equivalent correlations between L90 and LComf90 are zero and 0.85. This gives clear evidence of adaptation to higher noise levels in more noisy environments.

Table 2 - *Values of the mean noise level (L_{A10} and L_{A90}) recorded in each building in the SCATs survey, together with the values predicted by linear regression for a noise comfort response of 'neither noisy nor quiet' (L_{Comf10} and L_{Comf90}), significant values in* ***bold*** *(all values in dB). Also shown are the numbers of reliable measurements made in each building (N)*

Building	N	L_{10}	L_{Comf10}	N	L_{90}	L_{Comf90}
F1	113	52.9	113.17	113	44.2	51.16
F2	102	53.1	**56.86**	102	42.0	46.73
F3	15	54.9	62.23	15	41.5	45.37
F4	6	60.0	66.75	6	48.0	798.20
F5	44	54.9	65.23	44	43.8	**45.42**
P1	101	58.5	**55.86**	122	47.6	**43.91**
P2	100	62.7	81.91	114	49.3	83.16
P3	93	58.8	70.32	105	47.7	62.43
P4	602	62.1	94.14	682	50.9	**55.49**
P5	145	59.9	70.55	196	49.1	**51.34**
S1	114	55.7	**37.59**	114	43.1	**38.03**
S2	140	54.3	30.36	140	45.1	213.98
S3	113	51.1	-995.88	113	42.4	**34.62**
S4	79	58.3	**38.08**	79	48.8	-22.64
S5	77	51.9	110.24	77	41.1	13.49
U1	116	63.2	66.24	116	55.7	**57.45**
U2	146	66.6	**60.47**	146	55.4	**51.29**

Table 2 (cont.)- *Values of the mean noise level (L_{A10} and L_{A90}) recorded in each building in the SCATs survey, together with the values predicted by linear regression for a noise comfort response of 'neither noisy nor quiet' (L_{Comf10} and L_{Comf90}), significant values in* **bold** *(all values in dB). Also shown are the numbers of reliable measurements made in each building (N)*

Building	N	L_{10}	L_{Comf10}	N	L_{90}	L_{Comf90}
U3	140	64.9	**63.57**	140	53.7	**52.84**
U5	78	65.8	**59.70**	78	55.3	**50.69**
U6	199	66.1	**60.80**	199	51.4	**53.32**

Table 3 - *Values of the mean noise level (L_{A10}, L_{eq} and L_{A90}) recorded in each country in the SCATs survey, together with the values predicted by linear regression for a noise comfort response of 'neither noisy nor quiet' (L_{Comf10} and L_{Comf90}), significant values in* **bold** *(all values in dB). Also shown are the numbers of reliable measurements made in each case (N)*

Building	N	L_{10}	L_{Comf10}	N	L_{eq}	L_{Comfeq}	N	L_{90}	L_{Comf90}
France	280	53.5	**61.6**	-	-		279	43.3	**48.7**
Portugal	1041	61.2	82.9	208	58.7	**63.5**	1219	49.8	**55.4**
Sweden	523	54.2	**30.8**	97	52.8	-10.2	523	44.1	**35.2**
UK	679	65.4	**61.5**	276	63.4	**59.5**	677	55.7	**52.5**

The use of regression analysis on data with a low correlation between the dependent and the independent variable can give misleading results, and the extremely low levels of the values of LComf10 and LComf90 for the Swedish offices suggests that this is the case for these data. An alternative, but also flawed, method is to take the mean values of noise level which were measured when the subjects' voted 'neither noisy nor quiet' on the NF scale or for 'no change' on the preference (NP) scale. This was the method suggested by Dubiel at al. Table 4 shows these values for the and the close correlation between these values and the mean measured values is evident.

Table 4 - *Mean L_{10} noise levels for NP = 3 ('no change') and NF = 4 ('neither noisy nor quiet') compared to the mean noise level for each building*

Building	N	L_{10}	L_{10} for NP = 3	L_{10} for NF = 4
F1	113	52.9	52.6	52.8
F2	102	53.1	52.3	53.4
F3	15	54.9	55.3	56.1
F4	6	60.0	58.7	56.9
F5	44	54.9	54.9	56.5
P1	101	58.5	57.2	58.0
P2	100	62.7	62.5	61.3
P3	93	58.8	58.7	58.7
P4	602	62.1	62.3	62.6

Table 4 (cont.) - *Mean L_{10} noise levels for NP = 3 ('no change') and NF = 4 ('neither noisy nor quiet') compared to the mean noise level for each building*

Building	N	L_{10}	L_{10} for NP = 3	L_{10} for NF = 4
P5	145	59.9	59.5	60.7
S1	114	55.7	54.8	54.8
S2	140	54.3	54.5	54.4
S3	113	51.1	51.5	51.8
S4	79	58.3	58.0	57.6
S5	77	51.9	51.9	51.6
U1	116	63.2	63.1	63.4
U2	146	66.6	66.0	66.3
U3	140	64.9	64.7	64.9
U5	78	65.8	65.5	65.5
U6	199	66.1	65.5	66.1

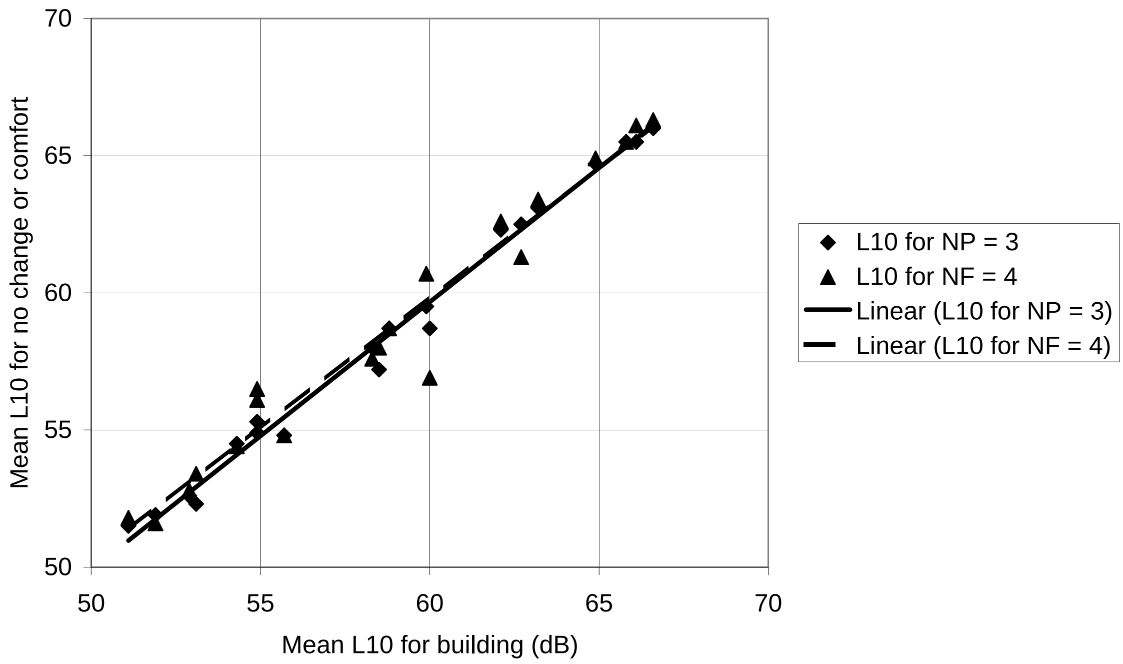

Figure 4 - *Showing the close relationship between the mean noise level, and for comfort values of NF and NP*

3.2. Discussion of the SCATs Results

3.2.1. International evidence

The evidence from the international comparisons in the SCATs results (see table 1) is that in different European countries there is a big variation in the noise level found in offices. In general the noisier the environment, the higher the noise level which is considered neither noisy nor quiet. This is suggested both by a comparison of the predictions of regression analysis (tables 2 and 3), and also by looking at the mean noise levels when subjects are voting NF = 4 or NP = 3 (tables 3 and 4).

In some cases the acceptable noise level predicted by regression is clearly inaccurate (as in the case of Sweden), and the correlation between noise comfort and noise level is often non-significant. This is in itself an indication of adaptation to noise level: if noise comfort was dependent solely on the noise level a significant relationship would exist in any context with a variable noise climate.

3.2.2. Acceptable noise level in UK Offices

A look at the predicted comfort noise levels in UK offices shows an L10 of 60-62dB or slightly more (see tables 2,3,4 and 5), and where available, and Leq some 2-3 dB below that. This accords with the overall values suggested in section 3.1.1, though a rather lower value is suggested for offices where the outdoor noise predominates (fig 3). This suggests that a realistic intrusive 'reasonable' recommended background level for Leq in UK offices might be increased to 55dB. Allowing for a noise reduction of 10-15dB by the window, this would mean that windows could be opened for ventilation when the outdoor noise level was 65-70dB.

Interestingly, and in contrast to those subjects with a closed window, people with an open window (win = 1) are adapting to outdoor noise so that the response NF is between 'neither noisy nor quiet (4)' and 'slightly noisy (3)' irrespective of the noise level. This may be seen as an acceptable trade-off for a more comfortable thermal environment.

4. NOISE IN URBAN CANYONS

Canyon-like streets in cities such as Athens vary considerably in width and in the height of the buildings which border them. The facades themselves also vary considerably, some plain and some with balconies. At ground level the situation can be more complex. The ground floor is often set back with colonnades and paper stalls and other objects litter the pavement.

Between the 13th and the 18th of September 2001 measurements were made of noise level outside the windows of buildings in 9 street canyons in thee central area of Athens. The aim of these measurements was to assess the effect of height above canyon floor on the noise level. The measurements were taken in canyons with aspect ratios ranging between 1 and 5 and with a variety of traffic loads.

The rationale behind these noise measurements is that the external noise climate is an important constraint to the opening of windows. This in turn means that the external noise level is a factor in the ventilation potential of an urban site. This paper aims to provide

guidance about the effect on the external noise climate of the street width, aspect ratio and the distance of the site above street level. This requires some evaluation of the relative importance of the direct sound path from the source and the reverberant noise level within the street. Also important are the traffic density and its correlation with noise at street level.
Instruments used for the measurements were SIP95 high-resolution logging sound level meters manufactured by 01dB, Lyon and logging 0.125 second Leq. For each measurement four persons were involved.
First a building was selected for use in the measurement and access to the building was secured.
One person was deployed on each of two floors of the building. They were positioned by an open window on the street side of the building.
One person was deployed to measure noise level at street level with the sound level meter mounted on a 1.2m tripod 1m in front of the facade
The fourth person was deployed across the street to co-ordinate the noise level measurements at the three sites and time the collection of data for 15 minutes at each site.
The number 1] motorcycles, 2] heavy vehicles and 3] cars and light goods vehicles were counted over the 15 minutes using hand-held counters.
Data were downloaded onto a project laptop computer.
Because of traffic management policies in Athens heavy goods vehicles are restricted to early deliveries. At the time of the measurements the number of heavy vehicles is very low, being mainly buses, but there is a high incidence of low power motorcycles (around 50% see table 1) which appear to be the major source of noise. Vehicle speeds varied, traffic lights regularly interrupting the flow and the roads were often congested. No sensible estimation of vehicle speed could be made but made little sense anyway with the motorcycles. The noise spectrum in one of the streets was found to be similar to that used in BS/EN1793 but with a smaller contribution at higher frequencies (17).

4.1. Simple Model of Noise in Canyons

The road traffic noise as measured at various locations in the canyons is a combination of the direct sound and quasi-reverberation in the canyon. The term quasi-reverberation is used to denote a type of reverberation which is not diffuse but consists primarily of flutter echoes between the facades lining the street.
Thus we could say that:

$$p^2 \propto W(dc + rc) \qquad (1)$$

where p is the sound pressure and W is the sound power, dc is the direct component of the sound and rc is the reverberant component.

The direct component may be treated in two ways depending on whether the traffic is considered as a line source (where the traffic stream is considered as the source) or point source (where each vehicle was separately responsible for the noise). Both these possible scenarios were considered. For a line source dc is inversely proportional to the distance from the source, for the point source dc is inversely proportional to the square of the distance. If the street width is w and h the height of the measuring position above the ground, assuming a line source in the middle of the road the distance between source and receiver is:

$$d = \left(\left(\tfrac{w}{2} \right)^2 + h^2 \right)^{\frac{1}{2}} \qquad (2)$$

For the reverberant sound the noise is approximately inversely proportional to the absorption area1. The main area for absorption is the open top of the canyon which is assumed to be a perfect absorber and whose area per metre of street is w, the width of the street. A further sophistication may be to include absorption of the road surface and facades. With an absorption coefficient of 0.05 this would be lead to the absorption area of (1.05w + 0.1H). Alternatively if we use the aspect ratio (AR = H/w) of the street the expression becomes:

$$w' = w(1.05 + 0.1 * AR) \qquad (3)$$

The sound power is assumed proportional to the number of vehicles per hour (n). We have two possible expressions: for line sources (attenuation according to linear distance) or point sources (attenuation according to square of distance). The linear source model was found to correlate best in these data. The expressions were developed into the form:

$$L_p = 10\log_{10} p^2 = 10\log_{10}\left(n\left(\frac{a}{d_1} + \frac{b}{w'} \right) + c \right) \qquad (4)$$

a, b c are constants where c represents any general environmental noise. In general the contribution of c will be small. Measurements on the rooftop of a building in a pedestrian area behind vehicular streets in the centre of Athens gave LAeq = 55dB. In the vehicular streets few noise levels below LAeq = 70dB were recorded. L90 averaged 66dB.

The purpose of this investigation is to provide a method for estimating the fall-off in noise level which height of the window opening up the wall of the urban canyon. In equation (4) the value of Lp relates to height above the canyon floor (h) through the variable d1. An estimation the values of the constants a, b and c will enable the change of Lp with h to be determined. The values of the constants a, b and c have been estimated using multiple regression analysis.

4.2. Calibrating the Theoretical Model

In order to determine how these results accord with the theoretical model presented above, values were calculated for n/d (D), n/w (rv) and n/w' (rvx) (w' as in equation 3 above). In the case of D, different values were calculated depending whether the noise is best considered to be coming from the middle of the road (as in equation 2), or one third, one quarter or two-thirds the way across the street. Regression analyses were performed for p2 against combinations of these variables, initially to determine which combination has the best

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[1] Strictly this applies to diffuse sound sources clearly only approximate in this context.

explanatory power. Inspection of the regression equations suggests that rv is less important than D in determining p2. A value for p2 against D alone has been added.
The exact value of D or rv us not important. The high coefficients of determination (in the region of 0.81) compared to the straight linear regressions for Leq on h and n suggest that the theoretical relationship developed above provides a good model of the spatial variation of p2. The change in R2 suggests that there is an advantage in including the term in rv.
The regression equation for p2 on D2 and rvx using the data from the whole 15 minutes is:

$$p^2 = 17.4*10^4.D_2 + 6.34*10^4.rv_x - 411*10^4 \qquad (5)$$

$$\text{Where } L_{eq} = 10*\log_{10} p^2 \qquad (6)$$

Leq is the noise level at height h above the street. D is a function of three variables, h, w and n, the number of vehicles. n is assumed to be proportional to the noise generated. Two of these variables (n and w) are also included in rvx together with AR the aspect ratio of the canyon. Figure 5 shows that the measured value is well predicted by the calculated value (R2 = 0.75).

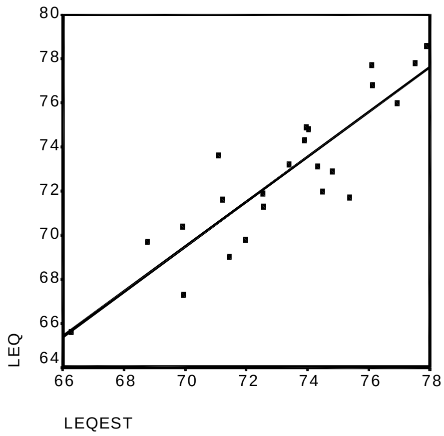

Figure 5 - *Showing the measured Leq (LEQ) against the predicted (LEQEST) (dB).(R^2 = 0.75))*

In order to help with the visualisation a simplifying assumption has been made that the traffic level is a function of street width. In these data the correlation between n (vehicles per hour) traffic flow and street width w (m) was 0.88 and the regression relationship was:

$$n = 137*w - 306 \qquad (7)$$

Using this simplifying assumption, the expected noise level becomes purely a function of the geometry of the street. Figure 6 shows the expected noise levels in Athens at different street widths and heights above the street streets.

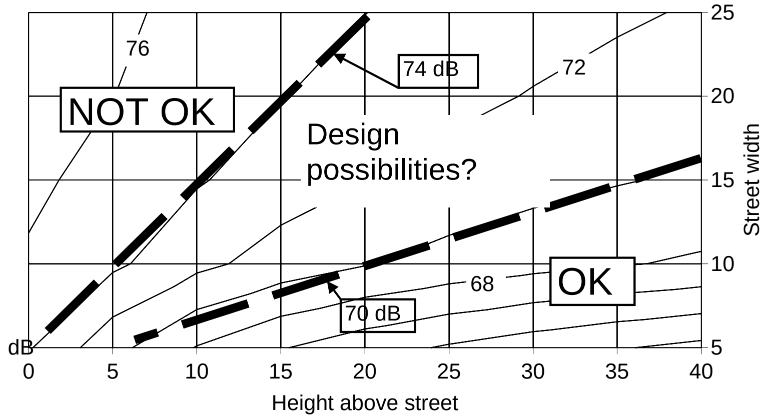

Figure 6 - *Contours of noise level at different heights above the street and street widths. Configurations in which natural ventilation is possible are indicated (OK) as are those in which it is ruled out (NOT OK). Between these two extremes is a region in which there are possibilities for design solutions*

Results from the EU SCATS (18) project suggests that the tolerable noise level in European offices to be around 60dB (19). At the same time the noise attenuation at an open window is accepted as 10dB. Thus outdoor noise of 75dB or less is likely to be acceptable. Using special methods a further 3-5 dB attenuation may be possible. In Figure 6 the implications of these rules-of-thumb are indicated. Street widths that will give acceptable conditions at heights above the street are indicated (OK). Street widths that will give unacceptable conditions for buildings with open windows near street level are indicated (NOT OK). Between these two there are possibilities for acceptable condition with careful design.

4.3. Calculating the attenuation IN Leq, L10 and L90 at different heights in the Canyon

Using the calculation for noise level at different heights in the canyon it is possible to calculate the noise attenuation from street level at different heights in the canyon. For a given value of the aspect ratio there is a maximum value of the attenuation at the top of the canyon. This maximum value can be calculated using the theoretical approach presented above. Consider the difference between Leq at the top of the canyon (h = H) and the bottom (h = 0). Because Leq is a logarithmic function, the difference is in fact 10Log10 of the ratio of the two values of p2.

$$dleq_H = leq_0 - leq_H = 10\log_{10}\left({p^2}_0 \big/ {p^2}_H \right) \qquad (8)$$

$$dleq_H = 10 Log_{10}\left(\frac{\left(2a + b/(1.05 + 0.1 * AR) + cw/137w - 306\right)}{\left(a/\sqrt{\left(AR^2 + (1/2)^2\right)} + b/(1.05 + 0.1 * AR) + cw/137w - 306\right)}\right) \tag{9}$$

Note that though dleqH is a function of AR and w its variation depends principally on AR (see figure 3) except where the width of the street is small.

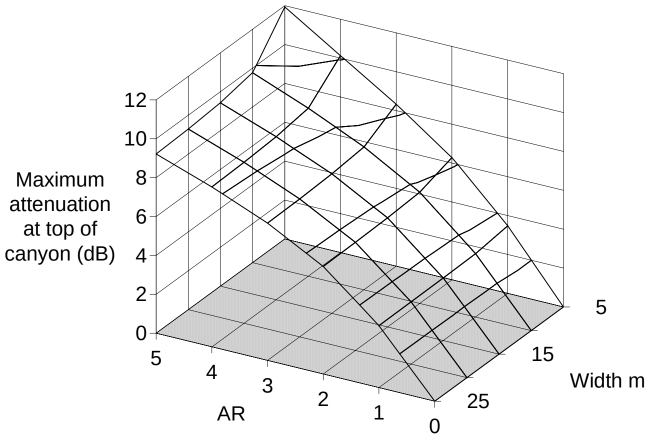

Figure 7 - *Variation of $dleq_H$, the maximum value of the attenuation at the top of buildings bordering on an urban canyon, with the aspect ratio AR and the street width in metres*

A similar analysis to that above can be applied to the data for L10 and L90 and gives the values of the constants a, b and c for the three different measures of noise. In the cases of Leq and L10 the terms for b are not statistically significant, suggesting that the direct component of noise predominates. In L90 both terms are significant.

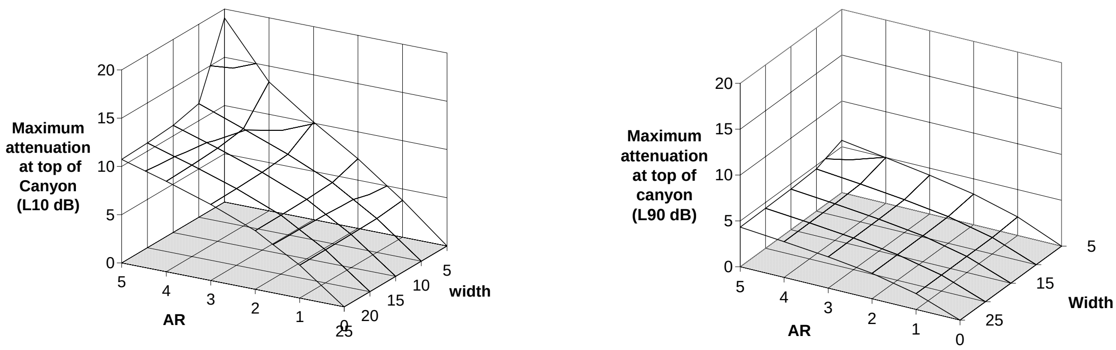

Figure 8 - *Variation of maximum level of attenuation of L10 and L90 with aspect ratio (AR) and street width (m)*

5. CONCLUSIONS

In line with the findings of Dubiel et al (15), the noise level where there is a preference for 'no change' or that which is considered 'neither noisy nor quiet' depends on the mean value of the noise level in any office.
Naturally ventilated offices had a higher noise level when the windows were open, however their response \was between 'neither noisy nor quiet' and 'slightly noisy', whatever the noise level.
Uk subjects were more sensitive to noise when the window was open suggesting that they are more sensitive to outdoor noise and that the contribution to the internal noise level from outdoor noise should be kept to a minimum.
Values for outdoor noise level are compatible with ventilation through open windows if the outdoor noise level is 65-70dB or less.
These results from the field suggest that maximum 'reasonable' intrusive LAeq levels in UK offices will not risk discomfort if they were raised from the current BS8233 level to 55dB.
This initial study of the traffic noise measurements in urban canyons in Athens. Further work is necessary, but from this study it is possible to draw a number of tentative conclusions.

1. High levels of noise can be found in these canyon-type streets and show a predominance in the low-frequency end of the noise spectrum
2. The noise level in canyon streets increases with traffic density and decreases with height above the canyon floor
3. The attenuation in noise level compared to that at street level increases with the distance from the canyon floor, but decreases with increasing street width.
4. These relationships are well represented by a simple model of noise level comprising a direct component and a reverberant component.
5. The direct component is assumed to be from a line source at or near the centre of the road whose power falls off with the inverse of the distance from this source
6. The reverberant component is assumed to act as if the street were a two-dimensional room with the canyon roof acting as a perfect absorber.
7. In addition there may be a small additional noise component from the general environmental noise.
8. The simple model, calibrated from the measured data, shows that the noise attenuation (LAeq) is almost entirely a function of street width and height above the canyon floor (Figure 7)
9. The maximum value of the attenuation is almost entirely a function of aspect ratio (Figure 9) with a small effect of street width in narrow streets.
10. Similar considerations apply when predicting the attenuation of L10 and L90. Relative to Leq, the rate of attenuation with height is greater for L10 and less for L90.

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