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CRITERIA AND QUALITY FOR LOW FREQUENCY NOISE

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INTRODUCTION

Many noise complaints are about low frequency noise. These include environmental noise and noise heard from sources in buildings, of which HVAC and sounds from neighbours are examples. Some industrial noise exposure, for example of machine operators, includes mid to high frequency tones from rotational systems and impact or pressure release type of sources, for which the dBA may be an adequate assessment of potential hearing damage.

The dBA does not assess low frequency noise, which is in the range up to about 500 Hz, but often limited to 250Hz, and is a major contributor to noise complaints. The infrasonic and low frequency regions overlap around 20Hz and one can consider:

Infrasound	< 1Hz to 20Hz
Low frequency noise	10Hz to 250Hz or higher.

This low frequency range covers the main noises from:

- pumps, compressors, diesel engines
- combustion
- building services
- fans
- structure borne noise
- the other side of a dividing wall between apartments
- environmental noise heard indoors.

Propagation attenuation, both over distance and through dividing walls, tends to give emphasis to the low frequency components of a noise, whilst increase of hearing loss with increasing frequency emphasises the low frequency content. At 20Hz, the hearing range from threshold to discomfort is compressed into about 70dB range, compared to nearly twice this range at 1000Hz. Further, the equal loudness contours at low frequencies are closer together than at middle frequencies, leading to a more rapid growth in loudness sensation at low frequencies than occurs at middle frequencies.

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A RESPONSE MODEL

A simple response model is shown in Fig.1. There are three stages to the model: detection, perception and response.

Detection: Here the noise input is detected and transformed into whatever form is necessary to give the sense of perception.

Perception: This is where we conclude that there is a noise and analyze some of its attributes, loudness, frequencies, location, fluctuations, etc.

Response: This is how we react to what we have perceived. The response is conditioned by factors other than the physical attributes of the noise alone, including personal and situational elements, which may vary from time to time. The 'quality' of the noise is influenced by our perception and response reactions.

SOME CONTRIBUTORY FACTORS

Spectrum balance. It has been considered that the spectrum slope, i.e. rate of fall-off from low to high frequencies is a major factor in perceived sound quality (1,2). However, later work has queried this (3) and it is probable that both spectrum slope and sound level interact to give the total effect.

Frequency composition. Some work has indicated that sounds in the frequency range 30 to 60Hz are less acceptable than sounds of the same level at immediately lower and higher frequencies (4,5). The definition of a low frequency weighting scale for sound level meters included an allowance for this effect as shown in Fig.2, curve LF2 (6). Again, there is an uncertainty as to the influence of sound level.

Fluctuations. A sound which is fluctuating in level is more annoying than a steady level of the same frequency and magnitude. Fluctuations may result from beating between adjacent frequencies, (e.g. two machines of slightly different speed), inherent time variations (e.g. some combustion noises), band limited effects of a narrow band of noise or propagation irregularities. Fluctuations may be perceived as "rumble", a well-known effect in HVAC systems.

INTERNAL AIR QUALITY.

Noise may be considered as one component of the internal air quality and is a potentially detrimental factor on work performance. Recent Swedish work has compared subjective responses for air conditioning noises of similar NC/NR/dBA Rating but different low frequency content(7). In a pilot study of 14 healthy subjects with an average age of 26 years, low frequency noise interfered more strongly with performance than medium frequency noise of similar rating criterion. This indicated that low frequency noise has an additional effect on cognitive elements and that the effect develops over time sufficiently to become apparent during the 1 hour exposure periods of the work.

Fig.3 shows average value of the individual *differences* of response times for tasks in the two air conditioning noises during a verbal reasoning test. The x-axis is equivalent to a time scale where each unit is about 4 minutes. The response times in low frequency noise were 10 - 20% greater than in the absence of the low frequency. Subjects also had a poorer 'social orientation' in that, at the end of the exposure period, they felt more disagreeable, irritated, less cooperative or helpful. The quality of the noise was degraded by the presence of low frequencies.

CRITERIA

A number of criteria, intended as full audible band criteria, give some attention to the low frequencies. These are NR (8), NC (9), PNC (10), RC (11) and NCB (12). These all permit increase of level as the frequency decreases, but at different rates so that the criteria show their main differences at the lower frequencies. This is illustrated in the comparison of Fig.4, from which it can be seen that at 31.5Hz the NR35 curve is nearly 20dB more lenient than RC35.

Other criteria have been designed specifically for low frequency noise (13, 14, 15), imposing a more stringent limit on the low frequency levels than is given by the wide band general criteria. The LFNR curves are similar to the NR above 125Hz, but allow for a range of increased sensitivity below this. The RSQ (Room Sound Quality) curves (Fig.5) are similar to the RC curves but level off below 31.5Hz. The implication is that, when attention is focused on low frequency noise, one comes up with more control than when the whole audible band is considered.

At the present time there is some discussion about the importance of low frequency noise in HVAC systems, two main proposals being Blazier's RC Curves and Beranek's NCB (16, 17). The difference is in the rate at which the criteria permit noise to rise into the low frequencies, RC being more restrictive than NCB. Blazier(17), also proposes an analytical methodology as a first step toward assessment of the spectra of HVAC system noise in terms of particular sound quality attributes. He derives a Quality Assessment Index for low frequencies (16-63Hz), mid frequencies (125-500Hz) and high frequencies (1-4kHz).

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CONCLUSIONS

Whilst all noise, whatever the frequency, has the potential to have a disturbing quality, there is evidence that there is a difference between the ways in which we react to lower frequency and higher frequency noises. Low frequency noise is often the dominant factor in noise complaints, especially for noise heard indoors. Complaints are more frequent in the presence of low frequency noise (18) and there are increased socio-psychological factors. Low frequency noise should be accepted as an important ingredient in the assessment of the quality of a noise, particularly for noise heard indoors, whether from external sources (eg industry, transport, entertainment) or internal sources (eg HVAC, structure borne noise).

REFERENCES

1. BRYAN, M.E. (1976) "Low Frequency Annoyance" in 'Infrasound and Low Frequency Vibration'. W. Tempest (ed)., Academic Press London, 65-96.
2. TEMPEST, W. (1973) "Loudness and Annoyance due to Low Frequency Sound", Acustica, 29, 205-209.
3. GOLDSTEIN, M., KJELLBERG, A. (1985) " Annoyance and Low Frequency Noise with Different Slopes of the Frequency Spectrum", JLFNV, Vol.4, 43-51.
4. BRONER, N., LEVENTHALL, H.G. (1984) "The Annoyance and Unacceptability of Lower Level Low Frequency Noise", JLFNV, Vol.3, 154-166.
5. BRONER, N., LEVENTHALL, H.G. (1985) "Annoyance, Loudness and Unacceptability of Higher Level Low Frequency Noise", JLFNV, Vol.4, 1-11.
6. INUKAI, Y., TAYA, H., UTSUGI, A., NAGAMIVI, N. (1990) " New Evaluation Method for Low Frequency Noise", Proc. Inter Noise 90, 1441-1444.
7. PERSSON-WAYE, K., BENTON S, LEVENTHALL, G, RYLANDER, R (1996) " A Pilot Study Evaluating Effects On Performance due to Low Frequency Ventilation Noise", *Seminar on Acoustic Stressors*, ASHRAE Winter Meeting, Atlanta GA, February 1996.
8. ISO (1971) "Assessment of Noise with Respect to Community Response" R 1996 (withdrawn by ISO)
9. BERANEK, L.L., (1987) "Revised Criteria for Noise in Building", Noise Control, January 1957, 19-27.
10. BERANEK, L.L., BLAZIER, W.E. and FIGWER, J.J. (1971) "Preferred Noise Criterion (PNC) Curves and Their Application to Rooms", JASA, 50, 1223-1228.
11. BLAZIER, W.E.(1981) "Revised Noise Criteria for Application in the Acoustical Design and Rating of HVAC Systems", Noise Control Eng J, Vol.16, No.2, 64-73.
12. BERANEK, L.L.(1989) "Balanced Noise-Criterion (NCB) Curves", JASA, 86(2), 650-664.
13. DAWSON, H. (1982) "Practical Aspects of the Low Frequency Noise Problem", JLFNV, Vol.1, 28-44.
14. BRONER, N., LEVENTHALL, H.G. (1983) "Low Frequency Noise Annoyance Assessment by Low Frequency Noise Rating (LFNR) Curves", JLFNV, Vol.2, 20-28.
15. BRONER, N. (1994) "Determination of the Relationship between Low Frequency Noise and Comfort in Occupied Spaces". ASHRAE Contract Report 714-RP
16. BLAZIER, W., (1995) "Sound Quality Considerations in Rating Noise from Heating, Ventilating and Air Conditioning (HVAC) Systems in Buildings" Noise Control Eng J, 43 (3) 53-63.
17. BLAZIER, W., (1996) "Noise Criteria. The importance of Temporal Variations in Low Frequency Sounds from HVAC Systems" To be presented at Noise-Con 96, Sept 30-Oct 2 1996, Washington, USA.
18. PERSSON, K., RYLANDER, R. (1988) "Disturbance from Low Frequency Noise in the Environment: A Survey Among the Local Environmental Health Authorities in Sweden", J.Sound Vibn. 121, 339-345.

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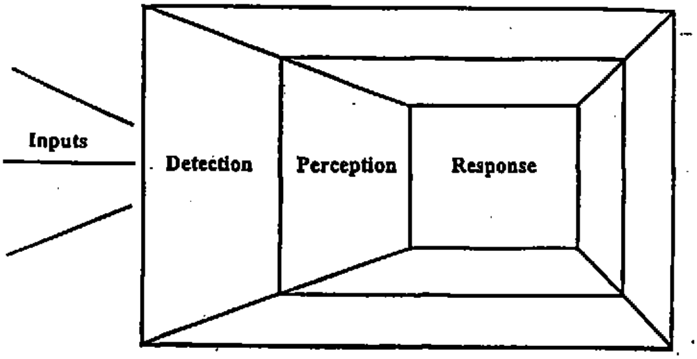

Fig.1
Simple Response Model

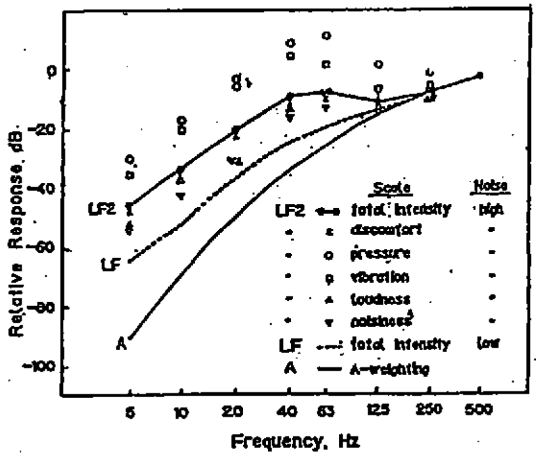

Fig.2
Relative Response of
A-weighting and
SLM Low Frequency Weighting

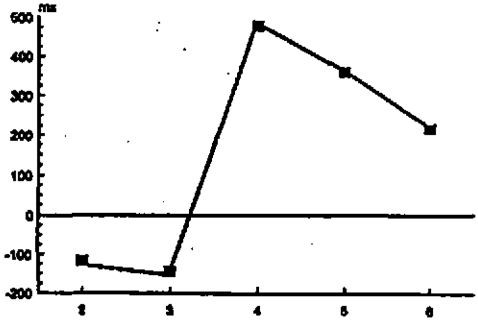

Fig.3
Comparison of response times
in low frequency and
mid frequency noise

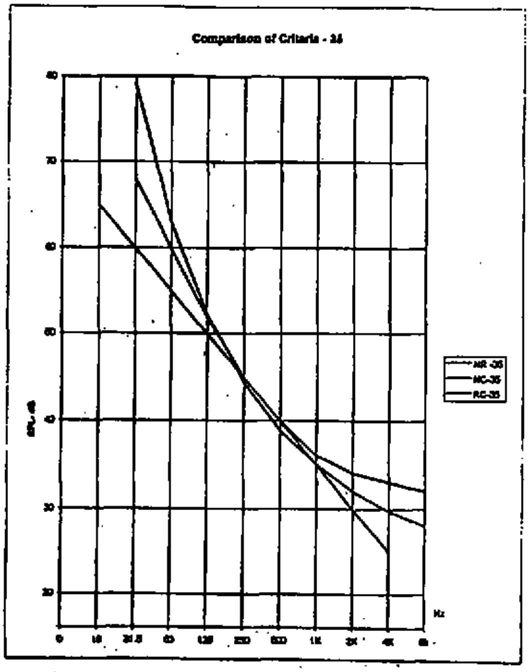

Fig.4
Comparison of criteria

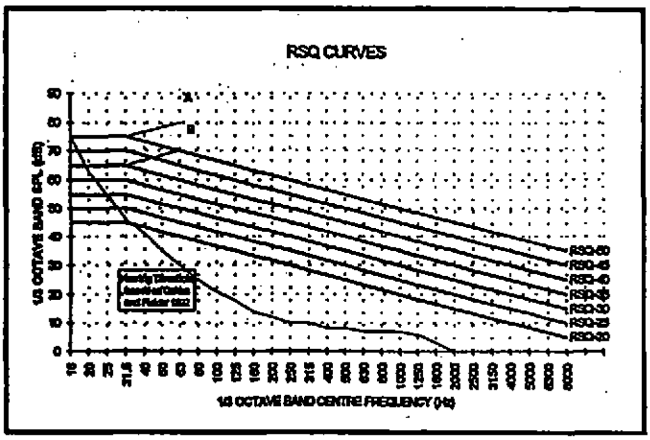

Fig.5
Room Sound Quality Curves