LOW FREQUENCY NOISE ASSESSMENT – AN UPDATE

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Abstract

Due to the incidence of complaints about HVAC duct rumble noise, ASHRAE sponsored some research to firstly, document the extent and degree of low frequency noise problems and secondly, to determine by means of psycho-acoustic testing, a method of assessment of such noise. This paper describes some of the results obtained in the second phase. Subjects listened to four HVAC stimuli with prominent low frequency spectral peaks for an hour. Subjects rated the Loudness and Annoyance of these acoustic stimuli using the method of Magnitude Estimation. At lower frequencies, Loudness habituation was more rapid than Annoyance habituation at lower sensation levels, thus emphasizing and increasing the difference between Loudness and Annoyance. It appears that this effect increases with time so that longer noise exposures result in an increase in annoyance relative to loudness. The implications of this result with respect to assessment metrics are discussed.

Introduction

Over the last decades, there has been an increase in the incidence of complaints of "rumble noise" due to the excessive energy below 250 Hz in HVAC systems. ASHRAE therefore sponsored a research study to firstly, document the extent and degree of low frequency noise problems and secondly, to determine by means of psycho-acoustic testing, a method of assessment of such noise. The Objective Phase of the study [1] documented over 70 samples of HVAC noise at sites in North America, Hong Kong, London and Melbourne. It also suggested that three factors are important in determining the subjective response of people to low frequency HVAC noise. These, not necessarily in order of importance were overall level, spectral imbalance and amplitude and temporal modulation effects. Psycho-acoustic testing to investigate these parameters with a goal of determining the most appropriate low frequency metrics for assessment of low frequency HVAC noise was also recommended.

Phase 2 of the research involved psycho-acoustic testing of Subjects [2]. This paper reports on some of the results obtained during one-hour testing conducted as part of the Pilot Study.

Loudness and Annoyance Assessment

To determine the subjective response of subjects for both loudness and annoyance, the Absolute Magnitude Estimation method was used [3]. In this method, the subject assigns a rating number to the perceived loudness or annoyance without the use of a reference. For this testing, the subjects were asked to rate loudness as follows. "For each of the sounds, record its loudness as defined as the perceptual aspect of the noise that is changed by turning the volume knob on a radio or T.V." For annoyance, the task was to "record the annoyance defined as the nuisance aspect of the sound experienced. Imagine you are in an office and are seated in your chair while working. Please estimate how annoyed **you** would feel when exposed to each sound". In addition, the Subjects were specifically told not to worry about consistency.

Because we were interested in the relative Annoyance for a given Loudness, we decided to not only note the Loudness and Annoyance but to focus on the ratio of Annoyance to Loudness ie the A/L ratio. It was felt that this measure of subjective assessment would be sensitive to low frequency noise because low frequency noise has been known to create annoyance while not being particularly loud.

The Test Room had a double wall construction and was floated on isolators so as to minimise any noise intrusion from the outside. The room is 6700 long by 3100 wide by 2350 high and is a reasonably sized meeting room. The noise stimuli were played back to the subjects via two loudspeakers, each one located above a diffuser located in the ceiling on either side of the room width-wise. Figure 1 shows a typical respondent during the testing

Figure 1: Subject rating sound stimuli in Test Room

Noise Stimuli

Four stimuli were used for the one hour testing, all with prominent low-frequency spectral peaks. These had been identified during earlier testing as having Annoyance-to-Loudness Ratios significantly greater than unity. Figure 2 shows the spectra used.

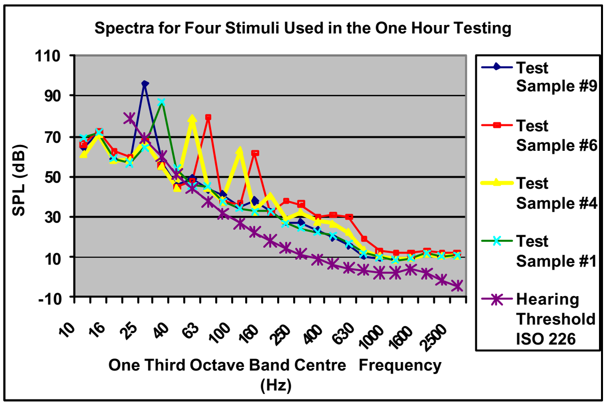

Figure 2: The Spectra used in the One Hour Testing

Subject Demographics

Six Subjects, three males and three females (average age 26.7 years) were used for these long-term Loudness and Annoyance tests. Two Subjects were relatively new at the rating task whereas four had previous experience.

All Subjects had normal hearing.

Results

First, the mean Loudness and Annoyance ratings for each of the four stimuli were calculated and plotted as a function of time. Figures 3 and 4 show the results obtained. It is evident that both Loudness and Annoyance tend to decline over time, more so for the noise stimuli containing spectral peaks at 25 and 31.5 Hz than for the noise stimuli containing peaks at 50 and 63 Hz.

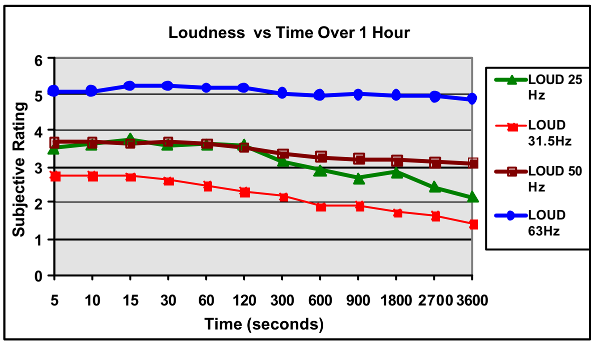

Figure 3: Change in Loudness Rating Response with Time

To obtain a clearer picture of these results, Adaptation Quotients (AQ) were determined after 60 min of exposure for each of the four test stimuli. These Adaptation Quotients (AQ) provide a measure of the degree of adaptation expressed as a percentage. The following equation adapted from Scharf [4] was used for these computations:

$$AQ(t) = 100\,(Ei - Et)/Ei$$

where Ei is the Loudness or Annoyance estimate at 5 seconds and Et is the estimate at time t after stimulus onset. A value of 100% means that the noise stimulus became inaudible (Et = 0), whereas a negative value means that the loudness or annoyance actually **increased**.

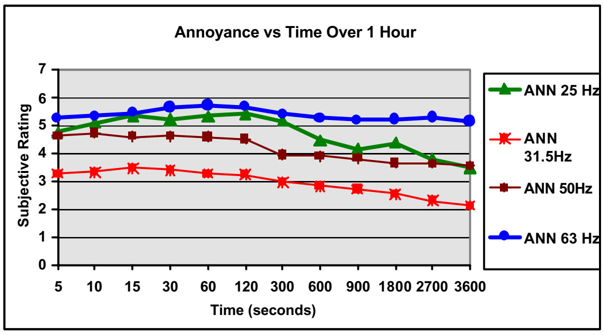

Figure 4: Change in Annoyance Rating Response with Time

Table 1 shows the results determined after the 1-hour exposure time in relation to the Sensation Levels (SL's) based on the threshold values in ISO 226 (2003) [5]. Sensation Level (SL) is the sound level relative to the threshold of audibility. Thus, threshold SPL = 0 dB SL. Also, for example, if the SPL is at 97 dB and the threshold re ISO 226 is at 50 dB, then the SL of the sound would be at 47 dB and the SL's are also shown in Table 1.

Table 1: Percentage Adaptation for Given Low Frequencies and Sensation Levels and the Annoyance/Loudness Ratio

Dominant Frequency (Hz)	Sensation Level re ISO 226 (dB)	Loudness Adaptation (%)	Annoyance Adaptation (%)
63	42.0	4	2
50	34.5	15	23
31.5	28.0	49	36
25	27.0	39	27

In accord with previous findings eg [6], Loudness decreased over time by a smaller percentage at the higher SL's than at the lower SL's of 27 and 28 dB. Annoyance adaptation followed a similar pattern. However, despite nearly similar SL's, both Annoyance and Loudness of stimuli with a dominant "tone" at 31.5 Hz declined by a larger percentage than Annoyance and Loudness of the stimulus with a dominant "tone" at 25 Hz. However, the significance of this small reversal is unclear because only six Subjects were tested and according to the work of S.S. Stevens [3], a minimum of 10 Subjects is preferred to obtain "stable" data.

Figure 5 compares Annoyance-to-Loudness ratios (A/L) for all four stimuli and shows that for the stimulus dominated by 63 Hz, the A/L ratio appears to be relatively constant with time. For the stimulus with a dominant 50 Hz peak, the A/L ratio decreased slightly with time but is always greater than 1. For both stimuli with dominant peaks at 31.5 Hz and 25 Hz, the A/L ratios increased with time so that at 3600 seconds, a ratio of the order of 1.5 – 1.7 occurred. This latter result is clearly due to the increasing Loudness adaptation relative to the Annoyance adaptation.

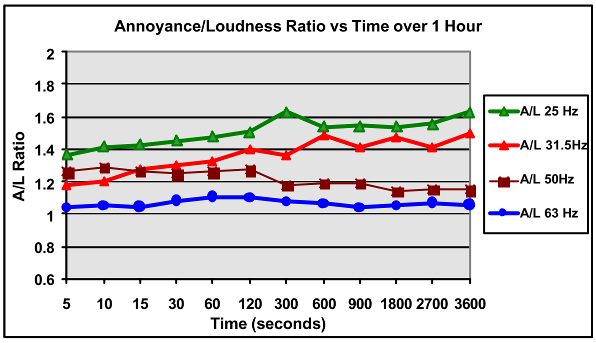

Figure 5: Annoyance/Loudness Ratios versus Time for the four low frequency noise stimuli

Given the fact that only six Subjects were tested and the large inter-subject variability typically observed in psychophysical and physiological data, the above results are interesting. It would appear that Loudness and Annoyance are not regarded as too different for spectra dominated by energy above 50 Hz but that, at lower frequencies, the Loudness and Annoyance are considered to be different. Moreover, the A/L ratio increases with time. Thus, even though the lower-frequency stimuli became softer with time, and also were at lower Loudness Levels, these low frequency sounds have an attribute other than Loudness that causes the Annoyance to decrease **less rapidly** than the Loudness. Other attributes which would clearly exacerbate the Annoyance response are the by-time variations and modulations in the noise stimuli.

The above results suggest that the Annoyance response should not be viewed in isolation but rather relative to the Loudness response. For increased low frequency noise annoyance, it appears necessary that the Loudness adaptation needs to be more rapid than the Annoyance adaptation. This effect will occur as the dominant low frequencies decrease from 50 Hz downwards and will be emphasized for modulation and time effects. It could also be that there is an increased sensitivity at 31.5 Hz. This effect has been reported previously (e.g.[7]).

Conclusions

Annoyance due to low frequency HVAC rumble is not the same as Loudness. The implicit basic assumption to date in the formulation of many metrics has been that Annoyance and unacceptability can be predicted based on a Loudness assessment. This is true for higher frequencies. The current research shows that as frequency decreases below 50Hz, for sounds containing dominant low frequency energy, this assumption breaks down. The difference between Loudness and Annoyance increases with decrease in frequency and is indeed inversely related to frequency.

At lower frequencies, Loudness habituation is more rapid than Annoyance habituation at lower sensation levels, thus emphasizing and increasing the difference between Loudness and Annoyance. It appears that this effect increases with time so that longer noise exposures result in an increase in Annoyance relative to Loudness. This phenomenon is important when considering the impact of low frequency noise and its assessment.

References

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