

Quantifying Receptor Annoyance From Low Frequency Industrial Noise In The Environment

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1 INTRODUCTION

The Alberta Energy & Utilities Board has been conducting research for several years in an attempt to quantify annoyance levels from Low Frequency Noise (LFN). With this information it will then be possible to begin deliberations on a low frequency adjustment to be implemented into the next EUB Noise Control Directive. Currently the EUB Interim Directive ID 99-8 uses A-weighted energy equivalent (L_{Aeq}) to measure the sound intensity level that in turn determines if a facility is in compliance. It has long been believed that the use of the A-weighted scale does not accurately address the impact of low frequency noise (LFN) from industrial operations on nearby residents. The A-weighted scale ignores a large proportion of sound that is in the low frequency range, typically below 200 Hz. Therefore, in some situations, sound pressure levels emanating from industrial facilities measured at a resident location will not register as an A-weighted energy equivalent (L_{Aeq}) value that exceeds the regulatory requirements yet will contain a significant LFN component (which is known to be the source of annoyance) that is essentially discounted by the A-weighting metric.

2 IMPACTS OF LFN

LFN produces masking effects in the medium and higher frequency ranges. Speech sounds are strongly modified by amplitude. Conversation is disturbed although speech remains intelligible. The masking property of LFN cannot be addressed using the current A-weighting scale. For example a low frequency component measures 50 dB at 50 Hz on the linear scale (dB). When this is translated to the dBA scale it measures 20 dBA. This in turn will have little effect on augmenting the L_{Aeq} level. The 50 Hz band will have a greater effect when masking of sounds is taken into consideration than the dBA scale represents.

As mentioned previously, the purpose of the research is to establish the need to address LFN specifically within the Noise Control Directive. This research has focused primarily on physical and mental health issues related to LFN and the differential response to LFN between genders. As industry grows larger, the effects of noise grow more and more out of control. At the same time, peoples' expectancies for their quality of life increase. When these two facts coincide, the issues related to LFN problems grow exponentially.

The fundamental characteristic of LFN is that of "intrusiveness." After much research, it has been suggested that LFN contributes to annoyance responses by:

- creating a sensation of pressure in the ear,
- periodically masking effects on medium and high frequency sound with a strong modulation effect that can disturb normal conversation, and
- by creating secondary vibrating effects typically experienced within homes.

Analysis of documented noise complaints would seem to be consistent with the above suggestions. With continuous exposure to LFN, behavioral dysfunction such as task performance deterioration, reduced wakefulness, sleep disturbance, headaches, and irritation, can occur.

LFN does not need to be considered "loud" in order for it to cause such forms of annoyance and irritation. One significant characteristic of LFN is that it is found to be more difficult to ignore than higher frequency noise. Individuals suffering from LFN annoyance have been known to describe it as

omnipresent - impossible to ignore - worse indoors (due to the effects of vibration) - unable to locate, and difficult to tune out.

Unlike high frequency noise, LFN is difficult to suppress. Closing doors and windows in attempt to diminish the effects of LFN make the noise worse, due to the propagation characteristics of LFN and the low-pass filtering effect of structures. Individuals often become irrational and anxious as attempts to control LFN fail, serving only to increase the individual's awareness of the noise.

There is quite a significant difference between genders in their response to loudness. Experiments conducted by N. Broner and H. G. Leventhall concluded that males tend to react to loudness with a significantly higher response than females do. The annoyance response remains similar between genders, although males seem to be less sensitive to low noise levels and more sensitive to high noise levels than females.

3 ALTERNATE MEASUREMENT TECHNIQUES

In this section two new measurement techniques using C-weighted along side the A-weighted scale is explored. C-weighting is similar to A-weighting when dealing with frequencies above 200 Hz. However C-weighting is far more sensitive to A-weighting for detecting low frequency sounds. This is because it's linear weighting system does not try to mimic the means in which a human perceives sound, it weights all frequencies equally, with the exception for infrasound, less than 16 Hz, and ultrasound, 8000 Hz and higher.

The first technique is slightly more lenient with respect to current regulatory requirements and would leave the majority of gas plants and compressor stations in compliance. However, a few facilities that do have serious problems with LFN would certainly be affected if this new metric were incorporated into the next iteration of the Noise Control Directive. The second technique takes a more stringent approach to addressing LFN. It incorporates the same method of locating the presence of LFN however requires that a 1/3 octave band spectrum analysis be performed.

3.1 TECHNIQUE #1

The first technique calculates the difference in dBC L_{eq} and dBA L_{eq} values resulting from a comprehensive sound survey. The magnitude of difference between the two scales of measurement can determine if a low frequency component likely exists.

Our research suggests that a difference equal to or greater than 20 dB between the dBC L_{eq} and dBA L_{eq} values can be considered abnormal in comparison with the Internationally Standardized Weighting Curves for sound level meters. C-weighted and A-weighted measurements, according to these curves, begin to deviate at a frequency around the 300 Hz band increasing to a spread of 10 dB at 200 Hz and nearly 30 dB at 50 Hz. Field measurements taken at residences (under representative conditions as defined by the Noise Control Directive) that result in differences between C and A-weighted sound pressure values greater than 20 dB correlate strongly with complaints where the expressed symptoms have been consistent with typical LFN annoyance. Most of the residents where the dBC L_{eq} minus dBA L_{eq} value is less than 20 dB are able to more readily accept the remnants of industrial noise that is in compliance with the current regulatory requirements.

Usually where the value of dBC L_{eq} minus dBA L_{eq} exceeds 20 dB, a linear spectrum bar graph will display a pronounced tonal component somewhere between the 16 Hz to 200 Hz band range. This tonal component should be present to verify that a LFN situation may exist. The properties of the tonal component should be that on either side of the pronounced tone there should be at least a 5 dB difference in adjacent bands. Research suggests that without the presence of a distinct tonal component LFN may contribute to the noise environment but should not cause excessive annoyance to the average individual.

3.2 TECHNIQUE #2

The second technique is quite similar to the first except takes a more rigorous approach. The advantage of this technique is that more cases of LFN will be routinely identified reducing the likelihood of missing a genuine concern. The disadvantage of course is the probability that some cases of LFN

will result where the matter could have been solved with a less technical approach.

Technique #2 consists of using a difference of 15 dB from the dBC minus dBA readings and conducting a full frequency spectrum analysis. Many researchers say that with a difference of 15 dB between readings there is usually a LFN issue present. This technique differs from the first because in this case all 1/3 octave bands are examined particularly those in the low frequency range. The amplitude for the spectrum analysis should always be in linear units (dB L_{Leq}). The shape of the spectrum graph becomes of interest because the level of annoyance associated to LFN is directly related to the magnitude in which frequencies differ from one another. In most situations a decreasing slope of the spectral graph will be observed. If the difference between adjacent octave bands is more than 9 dB or the difference between 1/3 octave bands is more than 3 dB consecutively for at least four (4) 1/3 octave band widths an increased annoyance with LFN will likely be expressed. Research with pink noise has confirmed that annoyance levels are generally reduced where sound pressure levels at each frequency decrease at a rate of less than 3 dB/octave band.

As in the first case a tonal component must also be present in the low frequency portion of the spectrum. To qualify the tonal component must be pronounced in the graph and have at least a 5 dB difference with adjacent bandwidths. With industrial facility noise measured at the receptor location, usually some distance away, the low frequency component dominates the spectrum. If the transition in the spectrum from low frequencies to high frequencies is not gradual, then LFN is often noticed by nearby residents in the sound environment even though sound pressure levels are below the 40 dBA L_{eq} permissible limit for most rural residences.

4. VALIDATION OF TECHNIQUES

The first technique was tested using two sets of comprehensive survey data. The first survey to be analyzed was from data collected at Residence "A" at a survey conducted on July 13-14, 1999. Results are as follows; the noise level during the nighttime period was 42.1 dBA L_{eq} and 64.0 dBC L_{eq} . The difference between dBC and dBA is 21.9 dB.

This is over the 20 dB difference that the first method suggests for when a LFN component may exist. The spectrum analysis (Fig 1) showed a pronounced tonal component in the low frequency range at 63 Hz. The difference with the adjacent bands is 16.3 dB, between 50 Hz. AND 13.3 dB between 80 Hz 1/3 octave band. At 63 Hz the band is pronounced in the spectrum. This satisfies the spectrum analysis criteria clearly demonstrating a low frequency tonal component at 63 Hz.

A second set of data was analyzed again using the first technique. The data was gathered on the night of June 15-16,

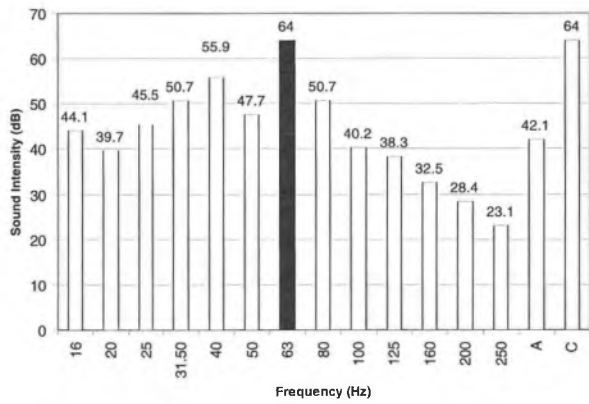


Figure 1. Low Frequency Spectrum (Isolated) LLeq Residence "A" - Nighttime Period

2000 at the Residence "B". The sound level readings were 60.3 dBC L_{eq} and 40.0 dBA L_{eq} respectively. The difference between the two readings is 20.3 dB. A spectrum analysis (Fig 2) shows that there is no pronounced tonal component. The resident confirmed in an interview that they did not experience any of the symptoms associated with LFN. Standard noise control measures at the industrial facility addressed the problem by reducing the sound pressure level at the residence to within the regulatory limits.

An Analysis using the second technique was performed for a survey conducted on the night of June 6-7, 2000 at Residence "C". In this case one of the residents complained of noise affecting sleep patterns due to its constant presence in and around the home. This technique looks at data where the difference between dBC L_{eq} and dBA L_{eq} is >15 dB. Also a full spectrum analysis is performed to determine if LFN is a major factor of the noise. The sound pressure level readings were 55.5 dBC L_{eq} and 37.7 dBA L_{eq} . The difference of dBC and dBA was 17.8 dB. While the full spectrum analysis confirmed a low frequency tonal component, the 1/3

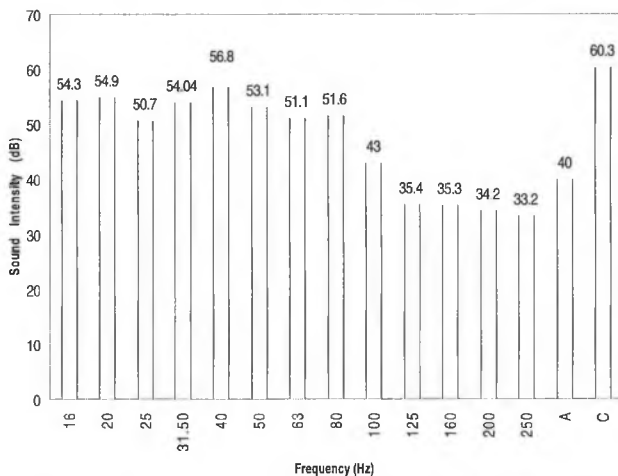


Figure 2. Low Frequency Spectrum (Isolated) LLeq Residence "B" - Nighttime Period

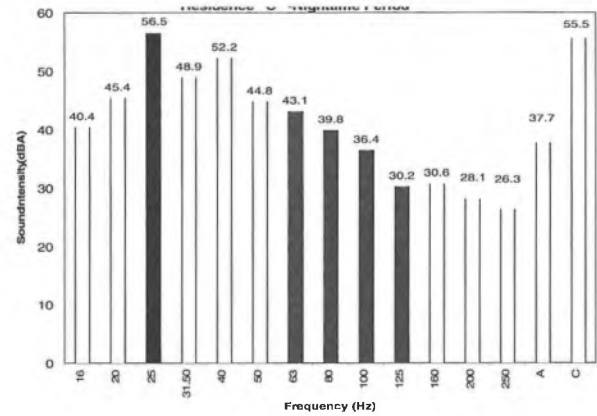


Figure 3. Low Frequency Spectrum (Isolated) LLeq Residence "C" - Nighttime Period

octave band analysis (Fig 3) was able to show a decrease of more than 3 dB for four successive octave bands between 63 Hz to 125 Hz with an overall difference in sound pressure levels of 12.9 dB which is above the 9 dB limit for technique #2.

Residence "D" was also assessed using the second technique. Data gathered on August 1-2, 2000 showed measured readings of 56.4 dBC L_{eq} and 39.9 dBA L_{eq} , a difference of 16.5 dB. Spectrum analysis (Fig 4) was performed using the prescribed method.

Analysis showed that although the difference between dBC and dBA reading is greater than the 15 dB limit and between the 40 Hz to 80 Hz bands the decrease is greater than 3 decibels per band there was not a tonal component present. In this case LFN was not identified strictly using only the results of technique #2. Unless the residents complained about excessive annoyance consistent with LFN descriptors, the industrial operator would need only demonstrate compliance with the regulatory requirements as they currently exist and not take extraordinary steps to address a specific tonal component

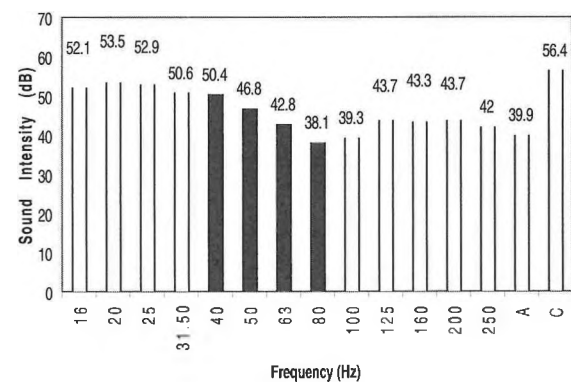


Figure 4. Low Frequency Spectrum (Isolated) LLeq Residence "D" - Nighttime Period

5. DISCUSSION OF RESULTS

The previous section tested the methods that have been proposed. The result from the first method shows that a difference of >20 dB between dBC L_{eq} and dBA L_{eq} requires a LFN assessment to be performed. In the first example the difference was above 20 dB and a tonal component in the low frequency range exists. A written evaluation of the noise should also support this claim. In the second example the difference was also above 20 dB however there was not a tonal component present. From talking to the residents from the second example and evaluating the situation first hand it could be concluded that LFN did not play a major role.

The results when using the second technique of detecting LFN also proved that a difference of >15 dB between dBC L_{eq} and dBA L_{eq} along with an appropriate spectrum analysis confirming a tonal component can yield valid results regarding the presence of LFN. Again if one of the criteria is lacking the impact on nearby residents to industrial noise should be minimal if regulatory compliance requirements are met.

It has been proposed tentatively (Lambert & Vallet, 1994) that when the difference between dBC and dBA is 10 dB or more a penalty of 5 dBA should be added for an L_{eq} that is <60 dBA. If this difference of 10 dB were put into the next intern directive almost all facilities would be over this margin. The use of 10 dB cannot be considered unless all facilities find better methods of eliminating low frequency noise. The use of 20 dB difference would be a more realistic number to be used at the present time. Method one uses a simple procedure to find if LFN is a factor in the noise environment. With the use of method two many more facilities would require a LFN assessment to be performed. This method should be implemented once the first method is firmly established and found too lax for assessing LFN.

An improvement to technique #1 would be to perform a complete spectrum analysis in the low frequency range to identify a significant tonal component that could cause a significant amount of annoyance. This is due to the fact that the threshold of hearing for humans below 31.5 Hz must have a sound intensity >60 dB in order to be audible. This could lead to only tonal components above 31.5 Hz to be used in the determination of a tonal component if the 1/3 octave band frequency analysis is used to satisfy the criteria from the first method. This may prove problematic to regulators and industry as a large tonal component in one of the bands below 31.5 Hz, could result in severe vibrations or harmonics with a dwelling causing annoyance to the resident.

An improvement to technique #2 could be determining whether the margin of 3 dB per 1/3 octave band decrease is too small when analyzing free field data. Some references state that if the hearing threshold for 50% of the population has been exceeded in the low frequency range then LFN must be reduced [2]. However others state that if a decrease of over 7.4 dB/octave band is present then a LFN problem exists [3]. The mentioned value of 9.0 dB/octave band or 3 dB per 1/3 octave band was arrived at rather arbitrarily because it was believed that 7.4 dB/octave band was too small of a decrease for analyzing field

data and it would be too hard for existing facilities to meet this standard. Further research would have to be conducted using data from the field and other references so that representative spectrum values may be established.

6. CONCLUSIONS

Low frequency noise is an issue that must be resolved to improve the current system of noise impact assessments and complaint resolution in Alberta. European standards such as those used by the Dutch Noise Annoyance Foundation are having some success in identifying LFN problem areas. In Alberta's case if technique #1 was implemented into the regulatory requirements, the major cases where LFN is a serious problem will be addressed. This is a reasonable first step in the improvement of regulating LFN related to industrial facilities. Technique #2 on the other hand would likely affect a much larger number of facilities. Using the second technique would be too onerous on regulators and industry alike. More research must be conducted to verify the validity of technique #2 using a variety of objective data to determine if it may have some role in the future.

The authors' believe that Technique #1 be considered in the next review of the Noise Control Directive as a means for addressing low frequency noise. The authors are also of the opinion that implementing such an approach into the regulations will not be overly punitive to industry in achieving compliance or complex for regulators to administer.

The outcome will hopefully result in a reduction of LFN issues with an added benefit of improved relationships between rural residents, industrial operators trying to meet regulatory requirements as well as being responsible neighbours, and regulators who want fair, balanced and enforceable policy.

9. REFERENCES

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