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CRITERIA FOR LOW FREQUENCY NOISE

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SUMMARY
Some specific cases of low frequency noise annoyance have been the driving force for an investigation commissioned by the Dutch ministry of environment and housing into the occurrence of low frequency noise and possibilities to impose criteria. The result was a proposal for limiting levels. But then it stopped. There were no legal enforcement's. After a number of fruitless attempts to apply these criteria in environmental permits, now, after 18 years, it suddenly happened. In a single case the criteria were allowed. Since this can be important for next cases, the once formulated criteria are now relevant again.
In this paper the reasons behind the criteria will be given, an overview will be given of other criteria and some remarks will be made on the limitations of the method.

INTRODUCTION

Some 18 years ago we have done some research on limiting levels for low frequency noise (LFN). The results were published in [1] and [2]. Since then there is not much done with the proposals, at least not in the Netherlands. The client, the Dutch Ministry of Housing and Environment did not want to impose additional limiting levels for LFN. There has been some attempts to incorporate the LFN criteria in environmental permits with no success, until recently. A recent verdict suddenly makes these criteria relevant again. For this reason the background of the criteria is explained here and some remarks are made.

LEGAL ASPECTS

In the Netherlands there is legislation to prevent high noise levels in residential area's. The limiting levels are formulated in dB(A). There is no specific regulation for low frequency noise.
Industrial companies need an environmental permit. Regulations for noise are part of this permit and are based on (national) legislation on noise. However local government is to some extent free to set the conditions for this permit. In the past several attempts were made to incorporate low frequency noise limits into the conditions of the environmental permit. The court of appeal however decided these conditions had to be skipped, because of the lack of hard evidence that annoyance by low frequency noise could objectively be determined.
Recently however, in a new case, the court of appeal has made a judgment that is not in line with these earlier judgments. In this case there has been an investigation into the occurrence of low frequency noise, using the criteria described below, and the judgment states that:

- there is sufficient, reproducible, information on the dose-response relationship of low frequency noise available
- low frequency noise can be characterized as a cause for annoyance, and it can be determined in an objective way
- there are several international investigations into the criteria for low frequency noise and most of them are based on the hearing threshold
- the method used corresponds to systems adopted in other countries
- the choice for a 3-10% threshold can be justified and it substantially reduces the risk for severe noise annoyance

So in this case the judgment was made that the investigation into low frequency noise had a solid base and was accepted. Lower noise criteria proposed by the complainant were rejected. Although of little importance in this particular case, it might have as a consequence that application of the method will be also acceptable in other cases.

And although its only one verdict now and this verdict is not the same (yet) as enforcing low frequency noise criteria for all future environmental permits, the route seems to be open now.

WHAT'S SPECIFIC ABOUT LFN?

There are some specific characteristics about LFN where it may differ from normal noise. They are mentioned briefly here:

- Low frequencies usually means frequencies form 0 to 125 Hz. The range from 0-20 Hz is called infrasound, from 20-125 Hz low frequency audio range. Although frequencies below 20 Hz may be generated and can be heard, almost all cases of LFN annoyance fell in the low audio range, a few cases at 16 Hz.
- Low frequencies means large wavelengths. At these frequencies mainly large radiating structures with very high amplitudes can generate LFN at sufficient levels. Absorption is very low, so travel distances are large. Infrasound is "captured" in atmosphere.
- There is a high threshold for LFN that makes that normally LFN is hardly perceived, it's either not present (below threshold) or masked by higher frequencies. In nature LFN is produced by thunder, storm, waterfalls, avalanches. So this may be an explanation why people react more intense to LFN then to normal noise. It also means that LFN is not experienced as part of our natural surroundings. It gives a feeling that it should not be there.
- LFN is always tonal noise, since either at the source or in the transmission it is amplified by resonances (e.g. room resonances or a window resonating on the volume of the room)
- If more resonances are involved narrow band peaks with small frequency difference may occur, resulting in a throbbing noise, extremely annoying.
- Equal loudness and equal annoyance lines show that for low frequencies, especially for infrasound, there is a steep increase in loudness and annoyance of LFN, once it is perceived
- There is a significant variation in individual threshold for LFN
- This leads to a situation where some people, or just one, can hear it and is annoyed by it and other people just don't hear it
- By focussing on the sound, one can better hear it, especially since it is always tonal noise. This tuning-in effect will further increase the annoyance for the one or few individuals that hear it.
- The complaints of "LFN-sufferers" are stress-related symptoms. They might fear for collapse of their dwelling, consider to move house etc.
- There are also cases of tinnitus with similar sensation and complaints. It is difficult to distinguish between LFN and tinnitus, just on the bases of complaints. Measurements are necessary.

PROPOSED LFN CRITERIA

For the criteria proposed two frequency ranges are considered: the infrasound range (0-20 Hz) and the low frequency audio range (20-125 Hz)
For the infrasound range the consideration is that, since the annoyance is so strong once heard, it should not be heard at all. That means the threshold is the limiting value. However there is a large fluctuation between individual thresholds. From a literature review it was established that the average hearing threshold for infrasound is 96 dB at 10 Hz and has a slope of 12 dB/octave between 4 and 16 Hz,. This threshold corresponds to 96 dB(G), see [1]. The G-weighting curve [3] is a line with a slope of 12 dB/octave, from 1 to 20 Hz. The reference value is at 10 Hz. However the standard variation between individuals found in these laboratory experiments was 5 dB on average. Setting the limit on the average (50%) threshold would mean that 50% of the people can hear the noise and will be annoyed if the SPL equals this threshold. To lower this percentage to 3-10% it was proposed to set the limit to average-2s=86 dB(G).

For the low frequency audio range setting the limit to the threshold would of course be sufficient to prevent possible annoyance, but it would be a disproportionate severe criterion, not realistic since many sources exist that do not give unacceptable annoyance. A proposal for limiting levels had to be based on a good connection with the 86 dB(G) and the mid/high frequency regulations and had to be based on experience with cases of LFN annoyance.

Since all cases of LFN have a strong tonal component that is responsible for the annoyance, a single point with a level and frequency can characterize each case. A number of cases from our own (consultancy) experience and of the German LIS (Landesanstalt für Immisionsschutz) in Essen are shown in figure 1. The cases where people were annoyed are shown in dots, the situations people did not complain (any more) are shown in crosses.

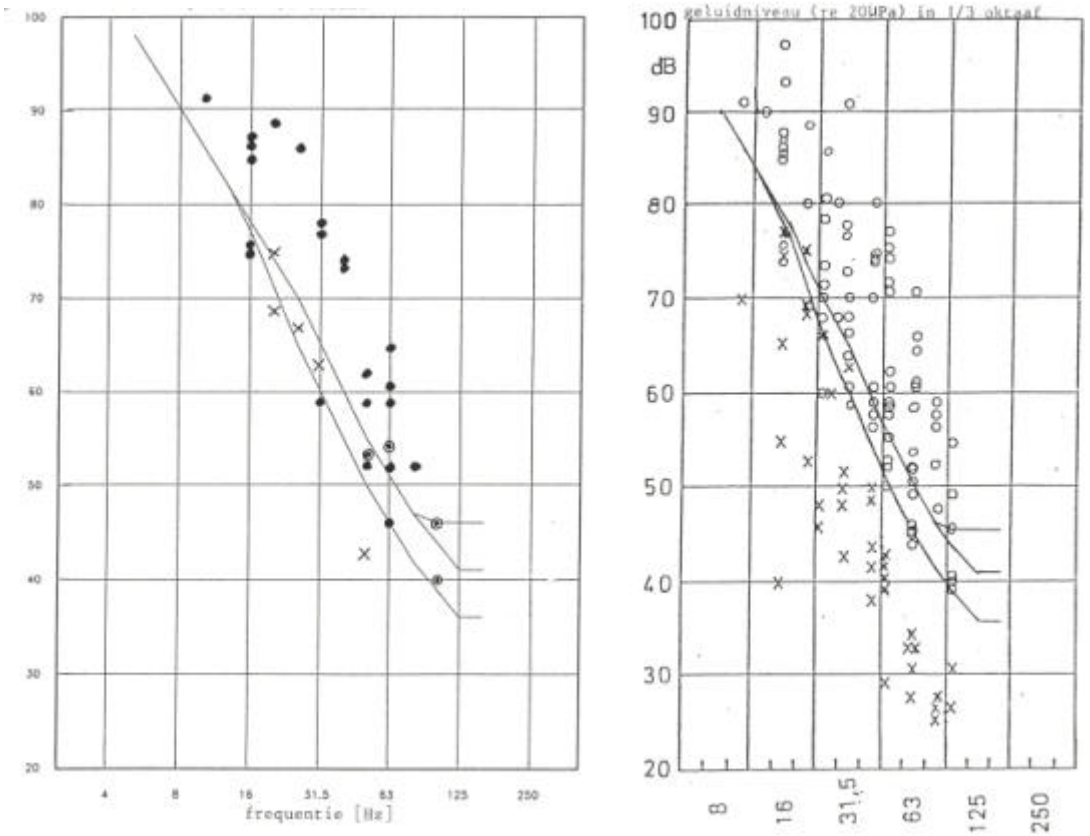

Figure 1. Cases of LFN annoyance. Left: cases from consultancy work of Peutz[1], Right: cases from LIS (Landesanstalt für Immissionsschutz des Landes Nordrhein-Westfalen, Essen, see also [8]). Dots and circles are the tonal peaks of the indoor SPL in cases the inhabitants where annoyed. The crosses indicate the situation after reduction. The lines are the 86 dB(G) for f<16Hz and the inverted 20 and 25 dB(A) curves.

To make the connection between infrasound (criterion=hearing threshold) and normal audio range (criterion is well above hearing threshold) it makes sense to use the A-weighting curve, since it is based on the 40 phon, that has a lower slope than the hearing threshold. In the figure two lines are shown: the 20 dB(A) and 25 dB(A) line. Most of the cases that people do not complain any more are around that 20 dB(A). There are some cases of annoyance around 20 dB(A), but hardly no cases under that level. So it seems that a level of 20 dB(A), limited in frequency range between 20 and 125 Hz, seems a reasonable limit. This level is 5 to 10 dB(A) lower than the "overall" dB(A) criterion in the dwelling.
To make it an easy to apply system the "dB(A)" approach for a limited low frequency range seemed to be confusing, so a system with limiting levels for third octave bands, based on the 20 dB(A) curve was proposed. In the 125 Hz octave band some adaptations might be needed to connect to the "overall" dB(A).

Since it is not practical to have limiting levels inside dwellings, there might be a need to set limits outdoors. Due to resonance's there is a strong frequency dependency for the transmission outside-inside. To be on the safe side no more than 10 dB should be added [2].

CRITERIA IN OTHER COUNTRIES

There are 4 European countries where noise criteria are set for LFN (see also [4]):
In all countries the criteria apply to limiting levels indoor for third octave bands.

Sweden

The criteria are from 31 Hz to 200 Hz. For 31 to 50 Hz these correspond to the hearing threshold, for frequencies 100-200 Hz the levels correspond to the 20 dB(A) curve. In between there is a low slope (almost horizontal).[5]

Denmark

In Denmark the method from [1] is followed, with a slight difference: 85 dB(A) and 20 dB(A). During daytime 25 dB(A) is allowed.[6]

Germany

In Germany the criteria are based on the average hearing threshold from 8 to 100 Hz. In daytime these levels may be exceeded by 5 dB (for 80Hz: 10 and 100 Hz:15 dB), during night time the levels are 5 dB lower. There are 2 additional conditions: it has to be tonal noise (1/3 octave level 5 dB higher than its neighboring 1/3 octave bands) and it has to be LFN (dB(C)-dB(A)>20 dB).

Poland

In Poland 10 dB(A) is used as a reference. The tonal noise also has to be 10 dB above background level.

The criteria are summarized in figure 2.

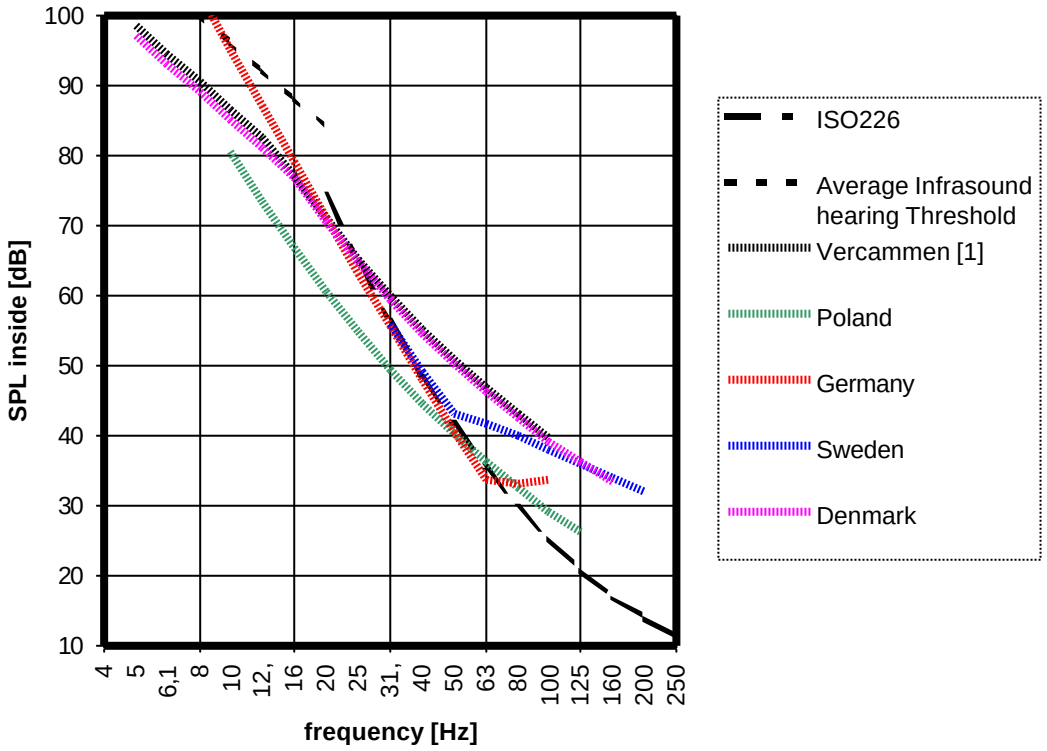

Figure 2. Overview of hearing thresholds and criteria for low frequency noise in several European countries

DISCUSSION

The annoyance of a sound is a complex matter and difficult to assess with just a limiting level (see also [10]). Criteria and regulations have to be simple however.

For infrasound there is sufficient evidence that the noise is annoying once it's perceived. So applying the hearing threshold, taking into account the individual variation of the threshold, seems to be a clear approach. This approach is followed in Denmark. In Germany the average

threshold is used in this frequency range, this seems to be inadequate to prevent annoyance. In Sweden there is no limit under 31 Hz.
The complexity of annoyance is far more relevant in the low frequency audio range. Fluctuations of the noise level and protrusion above background level are difficult to incorporate. In Poland the background level is taken into account. Denmark and Germany have the influence of the background noise implicitly taken into account by differentiating between day and night. In Germany a check is made for the tonality of the sound.
In Denmark a 5 dB penalty is given for impulsive sounds.
Another aspect is the tuning-in effect that might be important for tonal noise.
So generally these complex factors are not incorporated.
The Swedisch (31-50 Hz) and German standards are based on the average hearing threshold, which is especially in the 63 Hz octave much lower than the Danisch standards that is based on the 20 dB(A). This is relevant since many cases of LFN are actually in that 63 Hz octave band. The Polish standard is for frequencies under 50 Hz lower than the others and lower than the average hearing threshold.
It is difficult to obtain good scientific evidence what the appropriate limit should be. For now the pratical approach has been to look for cases with LFN annoyance. It has to be realized however that there are many cases where these levels are exceeded but there is hardly any annoyance, e.g. LFN due to passing busses or trucks.

CONCLUSION

In this paper the LFN criteria proposed in the Netherlands are presented. The method corresponds to criteria in Denmark. Other criteria in Germany and Sweden are higher for infrasound, which might result in unacceptable annoyance, or more strict for higher frequencies, mainly in the 63 Hz octave band.
The influence of background noise and time fluctuations should be incorporated in the system.

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