Social assessment of environmental low frequency noise

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Summary

In order to assess lfn properly it is necessary to have knowledge of lfn, of the social impact and of the legal and juridical possibilities. In many cases to what limit a certain level of lfn is acceptable is questioned. A quite common aid to assess lfn are curves in which levels (dB's) are related to frequencies (Hz). In cases in question hearing thresholds, degree of annoyance and the used 'normal' A-weighted standards have to be regarded. In the Netherlands there are some lfn-curves. This article elucidates how one of those curves is constructed. The first development of that 'EPA-curve' took place in 1998. Revised in 2011. Following those principles of construction enable to fit lfn-curves to an acoustical climate one wishes to be admissible. Examples of factors are: degree (percentage) of coverage, emphasis on protection of certain people or on the living space, the A- and C-weighted general limits, avoiding 'all' noise or even granting wishes about quietness.

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1. Assessment of lfn

These days the most common assessment of noise is based on the A-weighted standards - even in the new European unit Lden in which the "dB(A)" was drastically cut back to "dB". Not all those simplified assessments satisfy. Exceptions, supplements and punishments to get assessments of a higher quality survived this political wave of retrenchment. The Lnight outlived too. Noises judged as extra annoyingly as tonal and impulsive noises are weighted more severe. Unfortunately, low frequency noise - lfn - escaped attention. Though there are enough cases in which lfn plays a role and even determines the degree of disturbance. Possibly up to 11% of the cases [1]. Even in traffic noise lfn is important. In the well noise protected Dutch situations and just regarded motorways, a substantial percentage of 9% of the dwellings has to deal with some degree of lfn (C-A>20 dB) [2]. To put it briefly: lfn needs extra treat.

Many methods are developed to help the judgments on lfn. Aids are listening and measuring. To quantify the 'amount' of lfn, there are 'lfn-curves' - charts with noise levels (dB), and frequencies (Hz) on the co-ordinate system. Each curve has its special accents, bases and limits. Examples: infra-lfn, dB(G), 'tonal' lfn (DIN), hearing. Many times users are glad to find such curves but don't have time to go deeply into that subject. As soon as a more transparent system of assessment is available the barrier for use is decreased. There are nice examples of protocols: old (Netherlands [4]), and younger (UK [5], Japan [6]). To get an opinion whether a lfn may be judged as general troublesome a transparent criterion suitable for the case under consideration such as a curve is advisable.

2. Goal

Most criteria have been developed for initial screening lfn, whether noise is annoying or not but here objective is a design of a curve which is broad usable in granting permits. Or a set of them ..... Thus formulated the demands are: (a) explainable, logical, (b) suitable to the other - non-lfn - standards, (c) enough pragmatical, (d) recognizable in the lfn field. Without formulating these claims at forehand a first curve of this kind was developed in 2000 [4]. In the meantime a lot of new information turned up, but without affecting the foundation of the curve. In fact 'just' some figures had to be readjusted.

3. Starting points

Bases are a few practical facts and basic assumptions. Some of them possibly typically Dutch, but recognizing this, transformations to other circumstances are possible. Things are as follows.

- Development of a curve which covers the most pregnant lfn: at night inside houses [7].
- Bearing comparison with standards in health care, but in conformity with 'normal' acoustical

standards as well: a small number of people bothered by lfn will not be protected.
- Aim is to protect the circumstances of living: not a certain or special person.
- There is an analogy between human annoyance and hearing: both dependent of frequencies of noise and both liable to logarithmic courses.
- Work safe: cover the broader lfn spectrum at once: even in cases in which the problem seems to be limited. Use the three-partition [8] : (i) infra lfn, octave bands 8 & 16 Hz, (c) centre lfn, bands 31 & 63 Hz, (a) audio lfn, bands 125 & 250 Hz.
- If necessary to take decisions on accuracy of parts of the curve then accentuate the centre lfn because most of the lfn problems occur ([e.g. [1]).
- Another treatment of infra-lfn compared to centre lfn and audio lfn: if audible the lfn is bothersome.
- Principle of natural continuity: the curve will not show kinks.
- Suited to regular equipment: measurements or calculations in third-ocavebands as a base.
- A soft switch to already existing standards: transferable to the normal A-weighted world.
- Focus on lfn which is part of the acoustical climate: lfn with some recurrence
- Use existing experience on lfn: many times there is small lfn - one third octave band is dominating.
- Concentrated to assessment of living: not the working conditions.

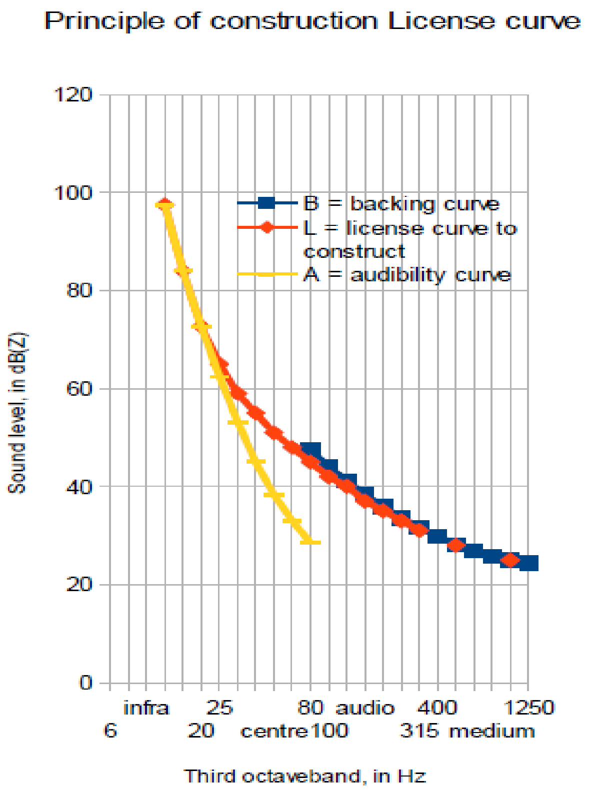

Figure 1 Principle of construction

In many cases the A-weighted limits lead the way. Use only an extra lfn judgment if necessary. In those cases there is a 'mismatch' or a gap between a lfn criterion and the A-weighted standards. To be pictured as values 'B' – 'L'.

4. Elaborations

The former formulations enable us to figure the rough shape of of the requested curve.

a. At night a broad accepted standard of 25 dB(A) stands to characterize a 'good' acoustical climate. If this value is exceeded this standard serves and a special assessment on lfn is not necessary. Though it may be important to know whether the bothering source has strong lfn components. Indication: dB(C) [9] or (seldom) dB(G). In practice the inverse curve of 25 dB(A) is an upper limit. Following the A-weighting at each third-octave band the value of 25 dB(A) is pictured. Once an exceeding in one of them: the limit of 25 dB(A) isn't kept. The lfn curve goes over to the 25 dB(A) curve at higher frequencies.

All this influences mostly the right side of the lfn curve; the audio lfn.

b. At the opposite there is infra lfn. One is bothered as soon as hearing this lfn. In fact this part of the curve is a hearing threshold. But which? An average of the typical lfn victims, so most elderly? A certain part of the population?

The room in question should be liveable by most of potential residents. The whole population is the base. Which part to protect? 75%? 90%?, 99%? This is part of an important balancing with ethical and political aspects. The impact of lfn is more penetrating. Making people social and mental invalid, chronically or temporally, is one of the possible consequences. So the percentage should give a stronger protection than at 'normal' noise. Those standards are correlated to 15 to 30% of severe annoyance. In fact the same percentage of noise sensitive people [10]. Thus on lfn, 10% or 5% is not strange. A Dutch lfn curve to assess audibility of lfn [11] used 10% (of a target group) because the lower the percentages the lower the reliability of figures. The difference between 5% and 10% is about 1,5 dB. To go further here 5% is chosen. In this forced choice the significance of infra lfn plays a part and also the experience that in many cases a significant number of decibels are decisive.

Thus the left part of the lfn curve is constructed. That is to say the 5% audibility of the whole population. The standard deviation sd on figures of audibility is used. Which are higher at lower frequencies. Thresholds of audibility are best known of (well hearing) youngsters. The mean population will hear worse. A difference of 1,5 dB is used to transfer the figures from 'youngsters' to 'whole population'.

c. The construction of the centerpiece of the curve has two aspects: the frequencies to hook up and the extent of bending. The junction on the infra lfn should be in the border region: next to 20 and 25 Hz. The other junction, on the audio lfn lapses from 250 to 1000 Hz and is less sensitive because in practice the A-weighted standards are suited to overcome lfn in the higher frequencies.

The way of the bow of the centre lfn curve is made dependent on the course of hearing. It is to say: smaller differences at lower frequencies. The quantification of the course of the curve is derived from those differences. The contraction of the isophons is leading.

Table 1 Derived contractions at 25 phon

third oct. part – Hz	C(25) phon/dB	Cf(25) 10*log
infra 20	1,92	2,84
centre 25	1,74	2,40
centre 31	1,60	2,04
centre 40	1,49	1,74
centre 50	1,39	1,43
centre 63	1,32	1,22
centre 80	1,25	0,97
audio 100	1,20	0,81
audio 125	1,16	0,63
audio 160	1,12	0,51
audio 200	1,09	0,39
audio 250	1,06	0,27
audio 315	1,05	0,20

The centerpiece hides an implicit transition: going from 5% protection (infra lfn) to the higher percentage which belongs to the level of 25 dB(A) (audio lfn). In fact a matter of policy. If there is a need to change those figures - the reason doesn't matter - one may use the same lines of thought to construct another curve. I tried some but the differences are not spectacular.

Having done those calculations some curves appear. All close together. With differences of tenth of dB's. Important was the choice of the point of transition. Used is the point between 20 Hz (infra lfn) and 25 Hz (centre lfn). Eventually the regarded principle of a continuous course - it is to say 'smoothly' - is decisive to construct the final curve. A further detailed explanation follows below at "Daytime".

Table 2 License curve. Acoustical climate inside houses at hours with a desire of rest.

Third oct.	Backing	License	Third oct.	Backing	License
infra 12	88,4	94,3	audio 125	41,1	39,1
infra 16	81,7	80,8	audio 160	38,4	36,8
infra 20	75,5	69,5	audio 200	35,9	34,6
centre 25	69,7	61,9	audio 250	33,6	32,7
centre 31	64,4	57,8	audio 315	31,6	31,0
centre 40	59,6	54,0	med 400	29,8	–
centre 50	55,2	50,6	med 500	28,2	27,9
centre 63	51,2	47,2	med 630	26,9	–
centre 80	47,5	44,4	med 800	25,8	–
audio 100	44,1	41,5	med 1000	25	25,0

In practice the lowest part of the lfn range (octave band 8 Hz) isn't used besides the figures of audibility are very high and open to question.

5. Comparisons

Most lfn criteria are developed to objectify complaints: "Are complaints reasonably?" (e.g. [12]). Which pass over the fact in case of 'normal' noises annoyance, sleep disturbance and complaints are tolerated. But nevertheless some comparisons with other curves.

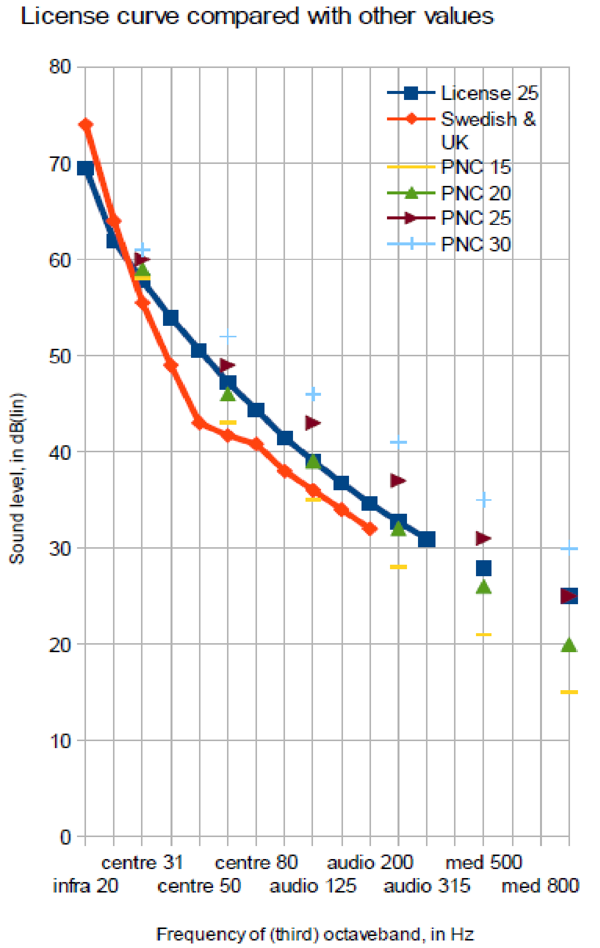

Figure 2 Comparisons

Due to the principles mentioned above the Swedish curve with status of recommendation to examine lfn cases, is more stringent. There is a firm accentuation around 50 Hz. For use in UK the curve is relaxed by 5 dB in case of steady (non fluctuating) sounds. Consequently that curve is drawn up close to that of the License curve.
The Preferred Noise Criterion Curves (PNC) are used to judge the acceptability of e.g. ventilation noise. PNC are more stringent than Noise Criterion (NC) curves. The PNC 20 corresponds best with the 25 dB-license curve. Not surprisingly if one bears in mind that roughly spoken lfn requires a punishment of values around 5 dB(A) in cases the common A-weighted limits are used [9].
In cases of infra lfn (20 Hz and lower) the G-weighting is in use. With values at third octave bands 6 to 20 Hz: -8, -4, 0, +4, +7.7, +9 dB. So in the lfn of interest a slope of about 9 dB per octave. While the license curve counts around 25 dB/octave.

6. Diversification's

The base curve to limit lfn is constructed to serve the most common circumstances: nighttime, level of disturbance as of 25 dB(A), inside houses, a non rocking lfn with an impact of continuous noise and with one dominant frequency compared to the curve. So enough to vary.
Protecting another percentage than the operated 95% will influence the curve. Especially the left part: the region around the infra lfn.
A special case would be created if special groups of inhabitants would be moulded. Not impossible because giving houses a noise label could tend to a movement in which people being noise sensitive won't live there. E.g. certifying houses around airports could stretch to a certain degree of grouping.

a. Broad lfn
Not one frequency in the appearing lfn dominates the annoyance; not 'small' lfn but 'broad' lfn. The appearance of this 'broad' lfn is indicated [1]. About 22% of the lfn sources would lead to an assessment as broad lfn. Indicated, not proven, because the percentage is that of the part of different sources. If such lfn sources are quite common in practice then the percentage may increase. Because adverse combinations of 'traffic & transmission path & meteorological circumstances & receiver' may cause lfn in third octave bands of 80 and 100 Hz as well, this may appear.

If two or more measured (or calculated) lfn values approach the assessment curve their joint energy could cause effects. To be safe here is the added method of "the advancing octave band" or "shifted band". At - and in the neigbourhood of the suspected area next procedure should be followed.
- Determine the frequency area of special interest.
- At each third octave band calculate the sum (energetic) of that band and its two neighbours.
- Compare that value with the highest limit level of those three bands, to be that of the lowest band.
- If there is an overrunning the lfn is still regarded as troublesome.

As soon as the need makes itself felt incorporate this sub procedure in a computable standard.

third oct.	First examination			Detailed test		
	L	R	E1	T	C	E2
infra 20	69,5					
centre 25	61,9					
centre 31	57,8					
centre 40	54,0	40,2	-13,8	57,8	–	–
centre 50	50,6	43,2	-7,4	54,0	48,8	-5,2
centre 63	47,2	46,5	-0,7	50,6	49,3	-1,2
centre 80	44,4	43,1	-1,3	47,2	48,3	1,1
audio 100	41,5	34,2	-7,3	44,4	44,0	-0,4
audio 125	39,1	32,6	-6,5	41,5	–	–
audio 160	36,8					
audio 200	34,6					

Table 3 License 25. "Broad lfn". Green values suspicious and indicating broad lfn.
L = License
R = Result of measurements / calculations
E1 = Exceeding R-L
T = Test value
C = Calculated value
E2 = Exceeding C-T

Due to the point of departure the examination of lfn is limited to 25 dB(A). In this invented example the total amount of the showed part of lfn is already 25,1 dB(A) so the normal A-weighted method is sufficient. This exemplifies the limited use of this additional method.

b. Dominant border values
As many other methods to evaluate lfn do this method uses third octave bands. In most cases this is adequate, but it may happen that the dominant part of the lfn is splitted up in two adjoining bands. Experienced reviewers will remark and recognize this and it is always better to measure e.g. in 12th octave bands to trace such cases. In fact the same assessment may be used. A small shifting of bands, or 'enforcing' this lfn within one band are possibilities.

c. Daytime

To make more clear what happens hereinafter the index i is used to indicate the numbers of the third octave band [13].

The former developed curve is suited for times in which the desire of rest is dominant (night, late at night, early morning); based on the acoustic standard of 25 dB(A) at nighttime. At daytime that standard is increased with the 'normal' 10 dB(A). To follow the same philosophy some things has to change to get the *'daytime curve'*.

Again the inverse 35 dB(A) curve is used as a backing for the right part - at the higher frequencies.

To get the part at the left side (infra lfn) likewise somewhat more lfn would be permissible. To get an equivalent of that 10 dB(A) difference night <> day, see the loudness curves. And the contractions at lower frequencies. This 10 dB at non-lfn frequencies corresponds with 'differences' d(i) = 4, 5 or 6 dB at (about) 5, 25, 45 Hz. Initially the infra part of the night curve with values L(i) are increased with those numbers d(i). Each of the new numbers (every third octave band) corresponds with a percentage of audibility. More than 5% because this was the starting point of the night values. Differences in those percentages P(i) are used to round off the dB's and smoothen the range of percentages. Ending in about 17% audibility. According this method the differences between the infra curves day <> night run from 4 to 5 dB.

The differences between the laboured curve and the backing curve of the inverse 35 dB(A) are called mismatches m(i). Each value H(i) of the higher parts (centre lfn and audio lfn) of the laboured curve at third octave band i is the subtraction of its 35 dB(A)-value and m(i). In accordance with the appointments before at 1000 Hz applies: i = 30, m(30) = 0 and H(30) = 35 dB.

An important pin-point of the curve is that at the frequency where the infra lfn ends. At that pin-point with value H(p) and known difference m(p) to the 35 curve. All in dB.

The arrangement was to use the contractions of isophons, the contraction-factors c(i) [3]. Again, no contraction at 1000 Hz: cf(30) = 0. Going from the lowest frequency p up to 30 the mismatch m(i) = cf(i)/cf(p) * m(p). The higher part of the curve consists of values *'35 dB(A) value minus m(i)'*. Formulated more popular: “license = backing - mismatch”. The difference at the utmost right side of lfn, at 315 Hz (i = 25) is about 4 dB with the backing curve, but has no significance because in practice in that frequency range the A-weighted standards are effective to assess lfn.

The result is a lfn curve consisting of two parts. The infra lfn at the left side and centre lfn plus audio lfn at the right side. With a possible kink at the transitional frequency i = p. To follow the principle of natural continuity with the aim to get a somewhat more smoothed curve, the whole process may be done once more with a somewhat lower or higher pin-point. Here the importance comes forward of computerizing this whole process.

d. Not continuous lfn [15]

Point of departure is a received lfn being part of the acoustical climate. Normally periods out of operation - without noise - at a timescale of 'day' are balanced by using a deduction Co = 10*log(t/T) in dB, in which t/T is the part of the period with noise. All under the assumption that those periods of rest will mitigate the bother. But this comes up otherwise with some special characters of noise such as music and lfn. Those sounds have a *'penetrating and anchoring effect'*: when the sound disappears effects remain for some time. In case of lfn very well known. Thus be reserved with such an 'operation correction Co'. Even in case the lfn isn't audible for a few hours per night since the effects of annoyance and on sleep are quite the same. In many lfn cases it is recommended to start with Co = 0 dB.

If necessary reason by analogy and use the relations between number of sleep disturbing events and their noise levels. Showing that not very much noise events have a lot of influence.

e. Outside house

Licensing in the Netherlands involves setting primal noise limits outside houses. Which are easily computable and, if necessary, to measure without asking permission of the resident and making appointments with inhabitants. To become a further integration of the lfn limits to the A-weighted world a 'translation' to limits outside is useful. There are several ways to achieve this goal. Most correctly is to measure the facade and roof of the houses in question. Another way is by estimating the effects. As done in researches [2] and[1, part 2.4] by making three classes of isolation: 15, 21 and 27 dB(A) (bad, moderate and good) with their lfn figures. Characteristics of the house from an acoustical point of view are leading.

A more enforcing method is to use one default value (specified in third octave bands). Thus parties involved are challenged to prove differences and .... doing the work of measurements and calculations to gain their advantage

7. Recommendations

a. The license curve with a base of 25 dB(A) is founded on a plausible chain of several calculations. The result is acceptable because (1) not too far from the 'normal' 25 dB(A) and (2) forthcoming to the general opinion *"the A-weighting is not appropriate at lower frequencies"*. To get a better idea of the workability of these curves more use in practice is needed.
b. If parts of the above mentioned "chain" will be tested in order to know the sensitivity or in case of changes, computerizing the process will help.
c. Compared to some other lfn criteria the license curve grants more noise. To get a good impression of the acceptability I propose to use the panel construction. Otherwise these criteria will all stay too theoretical items. It is to say: expose two batches of people to lfn in practice. One batch is a mixed group of inhabitants. The other one a group of acousticians and policymakers.
d. In the meantime the license curve may be used because it does justice to the first amount of lfn above the worse A-weighted limits, gives protection in the most severe cases, challenges in culpable negligence cases of lfn and involves acousticians compelling in the matter of lfn.
e. Due to the principle of audibility the infra part of the curve is less strict than the 'standard' 85 dB(G) (e.g. [14]). Though the significance of that standard is not very clear replacement of the lowest part by taking in account the G-weighting, is to be discussed.
f. The developed method does not take in account other mechanisms of experiencing lfn than that of the course *'sound > normal hearing > nuisance'*. As soon as it is clear other tracks exist in being bothered by lfn the method should be corrected.
g. Presenting absolute numbers (dB's) and accompanying colours in pictures is often seen, but are always quite confusing to understand the impact of lfn. High numbers get too much attention. To reach a better understanding should be showed and be incorporated in noise level meters and calculation programs the relative numbers, compared to limits.

References

[1] P. Sloven. 2006: Prove of the importance of lfn in noise policy.

[2] E. Schreurs, T. Koeman, J. Jabben. 2008: Lfn impact of road traffic in the Netherlands.

[3] The contraction c(i) at frequency i = distance in dB between isophons at 1000 Hz divided by that at frequency i. To get a workable contraction-factor cf(i) there is the demand that the factor is zero at 1000 Hz. Thus cf=10log c. Complication: c(i) depends somewhat of the phon levels too. At night the base is 25 phon (25dB at 1000Hz). Denotable as c(i)25 and cf(i)25.

[4] P. Sloven. 2000: Structured approach of lfn complaints in the Rotterdam region.

[5] A. Moorhouse, D. Waddington, M. Adams, 2005: Procedure for the assessment of lfn complaints.

[6]http://www.env.go.jp/en/rep/noise/low_noise2004/index.html > Air Quality / Transportation > 2004

[7] The night is the most important period to protect and probably the vulnerable period in which noise is active (three of five cases in [1, part 3.7]).

[8] 3-parts. Infra lfn is audible but needs high noise levels. It is associated with large sources. Generally well known. To measure infra sound accurate one should examine the whole chain of instruments. Centre lfn is the part in which the most lfn problems originate. The lower the dominant frequencies the more difficult the measurements are. Vibrations may cause lfn in the octave band of 31 Hz. Audio lfn is often audible to many visitors - not excepted to 'the victim'. The source of this lfn may be situated in lower frequencies. Example: transformers. Many cases are covered by the general A-weighted standards. In most lfn cases the exterior frequencies (octave bands 8 and 250 Hz doesn't matter. To assess general annoyance most cases deal just with the centre lfn. This segmentation of lfn has become quite normal (e.g. [13].

[9] P. Sloven. 2004: Lfn and the A-weighting. (Presented lfn&vibr 2004, published J. lfn 2005).

[10] M. Heinonen-Guzejev. 2009: Noise sensitivity - medical, psychological and genetic aspects. Dep Public Health Univ Helsinki.

[11] LFN guideline according to the Dutch Association for Noise Annoyance (NSG), 1999.

[12] C. Roberts. 2004: Ecoacces guideline for the assessment of lfn. Proceedings of acoustics Australia.

[13] In fact mid frequencies as deci-decades. Expressed as 10^(i/10) Hz. Examples: i = 0 <> 1 Hz, i = 10 <> 10 Hz, i = 20 <> 100 Hz, i = 30 <> 1000 Hz. The same for j as octave bands In which j = i/3.

[14] J. Jacobsen: Danish guidelines on environmental lfn, infrasound and vibration. Journal LFN 2001, 148.

[15] Kind of lfn. Behaviour in time. Q = quasi-continuous. Effects comparable to those of continuous lfn. Example: several hours lfn at night resulting in not sleeping and a level of stress avoiding sleep. R = repetitive. E.g. passing trains or cars. S = single pulse. E.g. explosion.