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SOME CONSIDERATIONS ON COMMON NOISE CRITERIA

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Until now the ideal noisedescriptor has not been invented. The purpose of this paper is to draw the attention of the user to some shortcomings of common noise criteria in extreme circumstances. Comments are made on the A-weighted sound pressure level L_A, the continuous equivalent sound pressure level L_{Aeq}, the sound exposure level L_{AE}, and the percentile levels L_{AN}. These comments do not affect the usefulness of these descriptors.

1. The A-weighted sound pressure level dB(A).

The sound level meter which is the most simple instrument for noise measurements gives us a lot of possibilities.

A distinction must be made between:

Frequency weighting: dB(A) dB(B) dB(C) dB(D) (see Fig. 1).

Fig. 1. Frequency weighting of the sound level meter

Time weighting: Slow: 1000 ms
Fast: 125 ms
Impulse: 35 ms (1500 ms)
Peak: 50–100 μs (see Fig. 2)

The difference in the readings will depend upon the choice of the frequency and the time weightings and on the character of the noise as show in Table 1 [1].

A number of measurements have been made in different industries with the

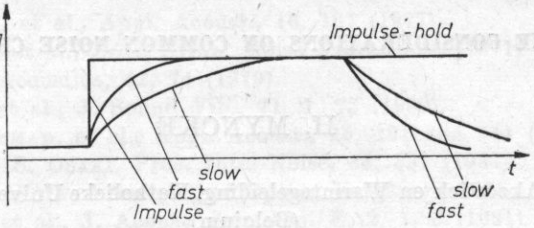


Fig. 2. Time weighting of the sound level meter

Table 1

Sound Source	Fast dB(A)	Imp. dB(A)	Imp. Hold dB(A)5 ×	Peak Hold dB(A)5 ×	Δ
1	2	3	4	5	6
Sinusoidal pure tone 1000 Hz	94	94	94	97	3
Beat Music from a gramophone	90	91	93	97	4
Modern music from a gramophone	102	103	103	105	2
Electric quitar from a gramophone	85	86	86	91	5
Motorway traffic, 15 m distance	80	80	81	89	8
Motorway traffic, 50 m distance	68	68	68	76	8
Train 70 km/h rail noise, 10 m distance	95	96	98	106	8
Train 70 km/h rail noise, 18 m distance	85	87	87	94	7
Noise in aircraft Type PA 23, cruising speed	90	91	91	100	9
Noise in aircraft Type Falco F 8, cruising speed	97	98	98	109	11
Noise in aircraft Type KZ 3, cruising speed	102	102	103	112	9
Noise in car Type Fiat 500, 60 km/h	78	79	79	93	14
Noise in car Type Volvo 142, 80 km/h	75	75	76	86	10
Lawn mower 10 HK, 1 m distance	97	99	99	116	17
Typewriter IBM (Head position)	80	84	83	102	19
Electric shaver, 2.5 m distance	92	92	92	107	15

1	2	3	4	5	6
75 HK diesel motor in electricity generating plant	100	101	101	113	12
Pneumatic nailing machine, 3 m distance	112	114	113	128	15
Pneumatic nailing machine near operator's head	116	120	120	148	28
Industrial ventilator 5 HK 1 m	82	83	83	93	10
Air compressor room	92	92	92	104	12
Large machine shop	81	82	82	98	16
Turner shop	79	80	81	100	19
Automatic turner shop	79	80	80	99	19
40 tons Punch press, near operator's head	93	98	97	121	24
Small automatic Punch press	100	103	103	118	15
Numerically driven high speed drill	100	102	103	112	9
Small high speed drill	98	101	101	109	8
Ventilator with filter	82	83	83	94	11
Machine driven saw, near operator's head	102	102	104	113	9
Vacuum cleaner Type Hoover, 1.2 m distance	81	81	81	93	12
Bottles striking each other	85	88	90	105	15
Bottling machine in brewery	98	99	101	122	21
Toy pistol (cap)	105	108	108	140	32
Pistol 9 mm, 5 m distance from side	113	114	116	146	30
Shotgun, 5 m distance from side	108	110	111	143	32
Saloon rifle, 1 m distance from side	107	110	110	139	29

use of the sound level meter B&K Type 2209 with "Hold" circuit for peak voltage measurements and, with the *A*-filter coupled in, with an averaging time of 30μs for peak measurements. The sound level meter was equipped with a 1/2″ microphone for some of the measurements, while a 1/4″ microphone was used for both high levels and the sharpest peaks. The 1/2″ microphone has a resonance frequency around 18 kHz but can be used up till 38 kHz as it is damped. The 1/4″ microphone has a resonance frequency around 34 kHz and can be used up till 65 kHz. The sensitivity was adjusted using a pistonphone as is customary.

The results are shown in Table 1. The measurements were all taken according to dB(*A*) "Fast" (125 ms), dB(*A*) "Impulse" (35 ms), and dB(*A*) "Imp. Hold" in which case the reading noted was the mean of 5 values measured with approximately 10 second intervals. Finally measurements were also taken with dB(*A*) "Peak Hold" (30 μs) with 5 to 10 second intervals and the mean of 5 measured values noted. The most interesting aspect is to ascertain how large the "Peak" value is above dB(*A*) "Fast" or dB(*A*) "Impulse". It is denoted by Δ in the Table. The larger the difference the more dangerous the noise. A pure sinusoidal tone has the same values for "Fast" and "Imp. Hold" while the "Peak" value should be and is 3 dB higher. It can be seen that beat music and other electronic music has very low peak values; the same is true for noise in aircraft and a number of (especially high speed) machine tools and woodworking machines. Larger differences are revealed by lown mowers, type writers, and naturally all types of percussion machines such as pneumatic nailing machines, bottling machines (bottles clattering against each other) and punch presses. Obviously direct impacts, gunshots and explosions manifest the largest differences. The dB(A) weighting curve corresponds more or less to the 40 phon equal loudness contour.

Mathematically we have the following relation:

$$P = a + b\,L_p + c\,L_p^2,$$

with L_p — the sound pressure level in dB of a pure tone with frequency f in Hz,

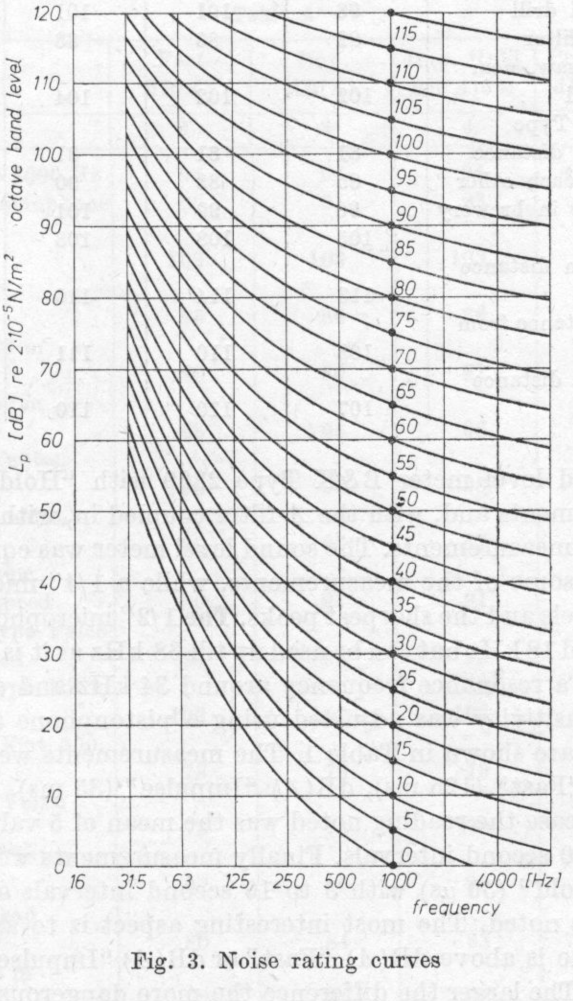


Fig. 3. Noise rating curves

P – the equal loudness level in phons, a, b, c – parameters depending upon the frequency.

Although the dB(A) is a very useful noise descriptor, one has to keep in mind that it is not always valid.

1.1. In the first example we make a comparison with the noise rating curves NR, given in the annex of ISO R 1996, which are commonly used in some countries (see Fig. 3). They correspond to the following equation:

$$L_p = a + b \times NR.$$

Again the parameters a and b depend upon the frequency as mentioned in the standard. Fig. 4 gives a comparison between the inverse of the dB(A) weighting curve and some NR-curves [2]. In the case of a broad band noise we have

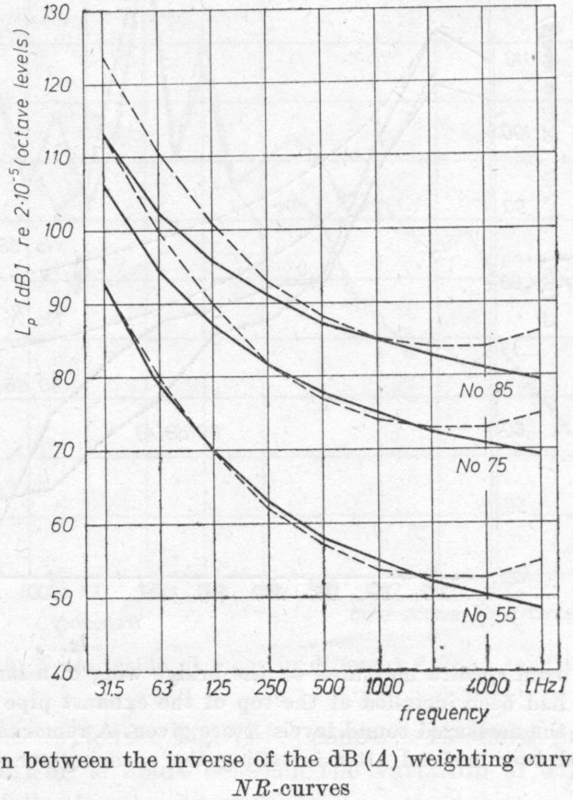


Fig. 4. A comparison between the inverse of the dB(A) weighting curve (dashed) and some NR-curves

$$\mathrm{dB}(A) \approx NR + 5.$$

A noise with a sound pressure level of 85 dB in the 1000 Hz octave band and with appreciably lower levels in the other octave bands gets the NR-number 85.

The dB(A) reading is also 85 for there is no attenuation in this frequency region. There is full agreement between the two systems in this case.

Another noise, now having 113 dB in the 31.5 Hz octave band and less than 60 dB in the other ones, gets also the *NR*-number 85, which should mean that the annoyance caused by the two sounds is equal.

The dB(A) meter reads only 74 dB, as can be seen in Fig. 4, because the attenuation for this frequency band relative to 1000 Hz is 39 dB. A large difference in acceptability for the two noises is shown by the dB(A) rating, but the same rating is given for both if the *NR*-curves are used.

Conversely, two signals with equal sound levels A but different frequencies may show a difference of 10 *NR*-numbers. Figure 5 illustrates this possibility.

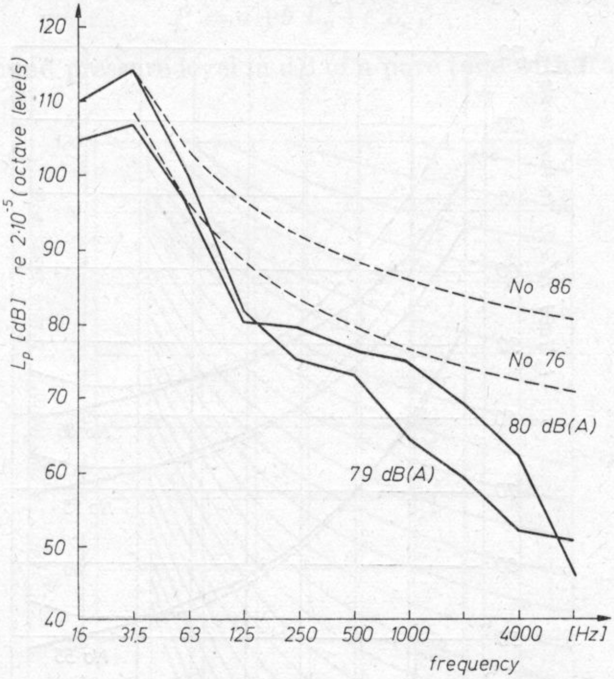


Fig. 5. Two octave band spectra measured on the bridge wing of a large motorship before and after a silencer had been installed at the top of the exhaust pipe of the main engine. Next to the spectra the measured sound levels A are given. A remarkable reduction of the noise annoyance had been noticed after installing the silencing construction (thick line)

Two octave band spectra measured on the bridge wing of a large motorship before and after a silencer had been installed at the top of the exhaust pipe of the main engine:

	NR	dB(A)
without silencer	86	79
with silencer	76	80

From this example we may conclude that in the case of high level noises (e.g. in wheelhouses and on bridge wings of motorships) a great disagreement between the two rating methods may occur. Moreover the *NR* system will give a better correlation between the physical measurements and the acoustical comfort.

1.2. The second example emphasises the advantage of the use of loudness expressed in sones for the determination of the acoustical comfort inside a motorcar (Fig. 6) [6]. Different driving conditions give the same dB(*A*) value but a difference of 10 sones in loudness, respectively 53 and 43 sones.

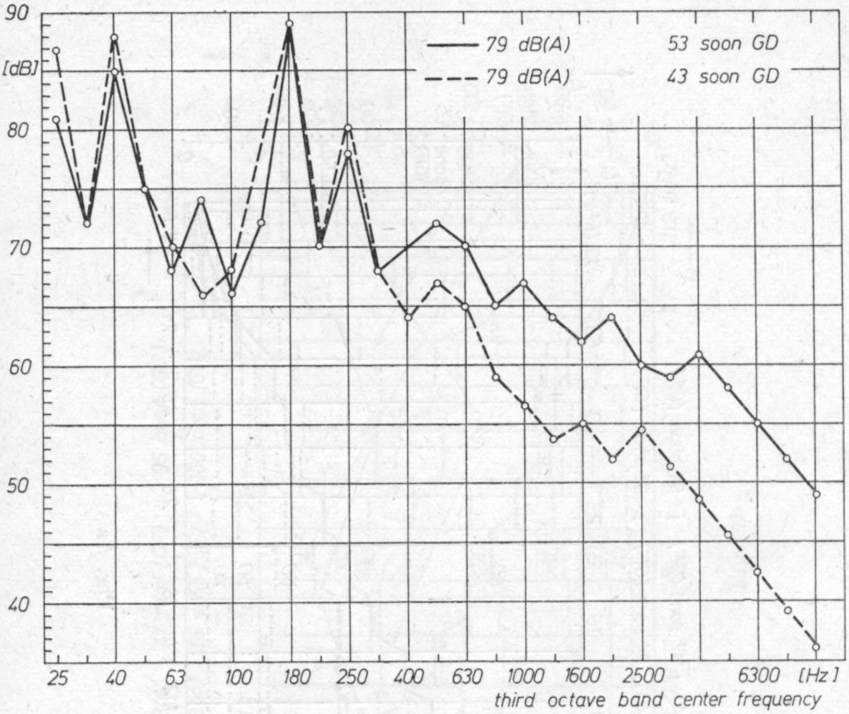


Fig. 6. Noise inside of a car in different driving conditions

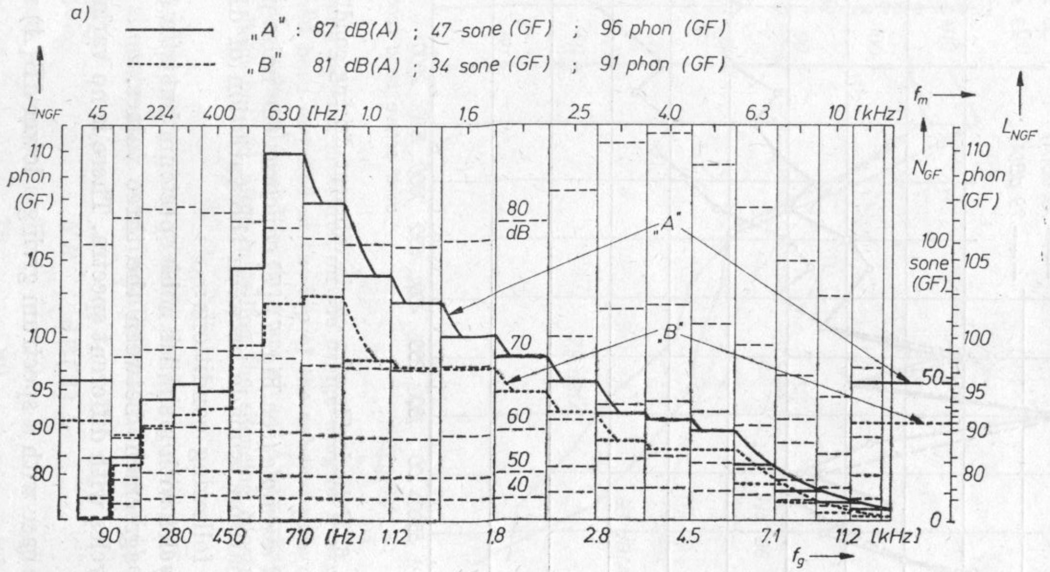
1.3. The third example (see Fig. 7) [7] concerns the noise produced by a motorcycle. A comparison is made between the variation of dB(*A*), phone (*GF*) and sone in the following conditions:

Two motorcycles with a similar noise spectrum but at a different distance. There is a good agreement between the three values.

Two motorcycles with different spectra. There is no variation in the dB(*A*) reading.

Two extreme case with a spectrum giving a lower dB(*A*) value but a higher loudness in sone.

The different results are given in the Table at the right side of the spectra.



ΔL_A dB(A)	ΔL_{NGF} phon (GF)	ΔN sone
identical spectrum Gelijkaardig spectrum		
-6	-5	-13 -28%
(87–81)	(96–91)	(47–34)

Fig. 7a

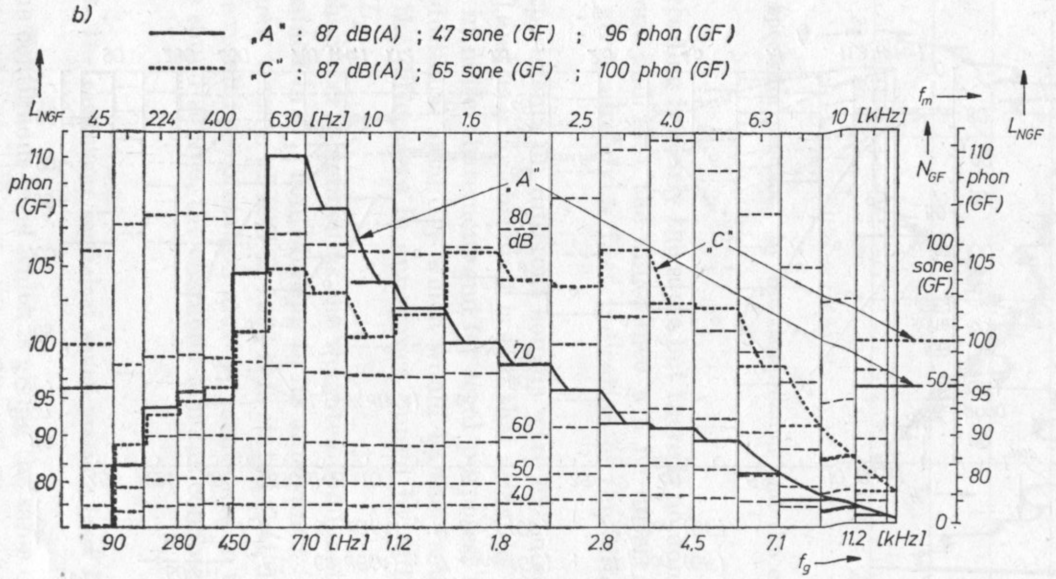


Fig. 7b

ΔL_A dB(A)	ΔL_{NGF} phon (GF)	ΔN sone
same L_A - broader spectrum Zelfde L_A - breder spektrum		
0 (87→87)	+4 (96→100)	+18 38% (47→65)

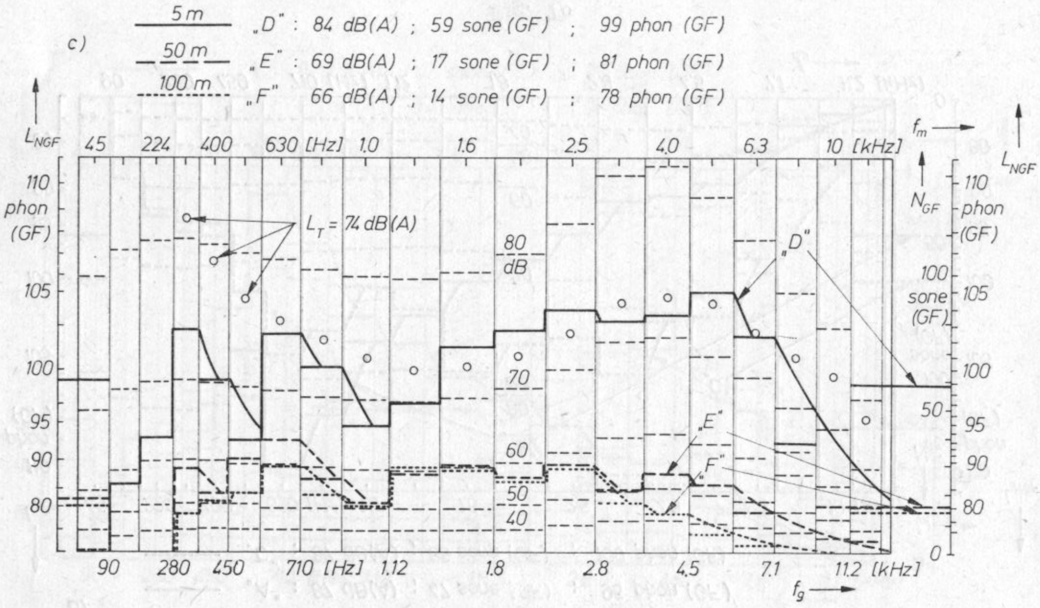
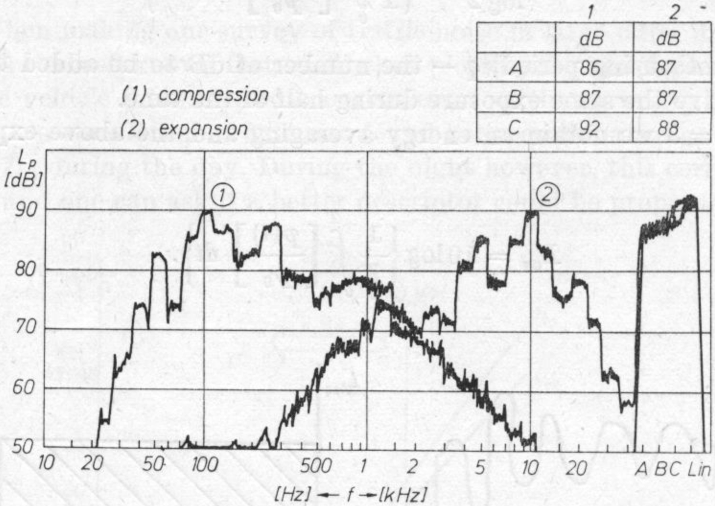


Fig. 7a-c. Spectra of motorcycles

ΔL_A dB(A)	ΔL_{NGF} phon(GF)	ΔN sone
lower L_A - encreased spectrum at higher freq. Lager L_A - naar hoge frekwen. verbreed spek.		
-3 (87→84)	+3 (96→99)	+12 26% (47→59)

1.4. The character of the sound

Fig. 8 shows the spectra of two different sounds (compression and expansion of air), presenting a maximum at respectively 100 and 10 000 Hz.



	1	2
	dB	dB
A	86	87
B	87	87
C	92	88

Fig. 8. Noise spectrum produced by the compression and the expansion of air

The dB(A) reading is nearly the same but there is no doubt that both sources sound different and that the annoyance will be different. The difference dB(C) − dB(A) gives already a first indication of the different character of both noises.

Listening experiments on different sounds were executed at the Institute of Perception [3] and as a conclusion it is said that aside the L_A readings being widely accepted in noise abatement and for legal purposes, there seems to be a need for an additional quantity which would be the "sound character", to take account of the differences in annoyance caused by different sounds that have the same L_A.

The sound character is defined as the weighted combination of all acoustic factors, not contained in L_A, contributing to its annoyance.

Also in the new version of ISO R 1996 it is stated that data which may be significant for the result interpretation must be mentioned in the report, namely the nature of the sound source, the character and the connotation of the sound.

2. The continuous equivalent sound pressure level L_{eq}

The L_{eq} is the continuous level which is giving the same exposure as a fluctuating noise during the observation period (Fig. 9). The most general formulae is the following

$$L_{\mathrm{eq}} = \frac{q}{\log 2} \log\left\{\frac{1}{T}\int_0^T \left[\frac{p(t)}{p_0}\right]^{20\log 2/q} dt\right\},$$

where T – measuring period, q – the number of dB to be added to the noise in order to give the same exposure during half of the time.

With $q = 3$ we obtain an energy averaging and the above expression becomes

$$L_{\mathrm{eq}} = 10\log\left\{\frac{1}{T}\int_0^T \left[\frac{p(t)}{p_0}\right]^2 dt\right\}.$$

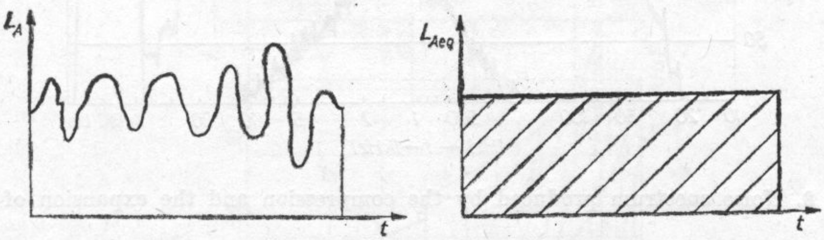


Fig. 9. Continuous equivalent sound pressure level (A-weighted or not)

The L_{eq} as a noise descriptor has been widely used during last years. In the new version of ISO R 1996 its use is highly recommended. A typical example of its usefulness is given in Table 2 where some idealized sounds are expressed in L_{eq} and in percentile levels L_N. From the last column we see that the L_{eq} varies over a range of 40 dB allowing a good measurement of different sounds.

People investigating annoyance know however, that the correlation between

Table 2. Noise descriptor values for various idealized sounds

Nature of the sound	L_1	L_{10}	L_{50}	L_{eq}
Steady sound, 40 dB	40	40	40	40
Steady sound, 40 dB, except 80 dB, 0.2 percent of time (3 min/24 h)	40	40	40	53
Steady sound, 40 dB, except 80 dB, 2 percent of time (30 min/24 h)	80	40	40	63
Steady sound, 40 dB, except 80 dB, 20 percent of time (5 h/24 h)	80	80	40	73
Steady sound, 80 dB, 100 percent of time	80	80	80	80

the physical value of the L_{eq} and the annoyance score is not always perfect. In some cases other descriptors have to be added or are to be used. Again we let follow some examples.

2.1. When making our survey of traffic noise in large cities in Belgium [4] we observed the well known fact that, when plotting L_{eq} and L_{10} levels as a function of the vehicle intensity, both curves cross as shown in Fig. 10. Above 20 vehicles/hour a correlation of 0.86 was found between the average factor scores and L_{eq} or L_{10} during the day. During the night however, this correlation is far under 0.20 and one can ask if a better descriptor could be proposed.

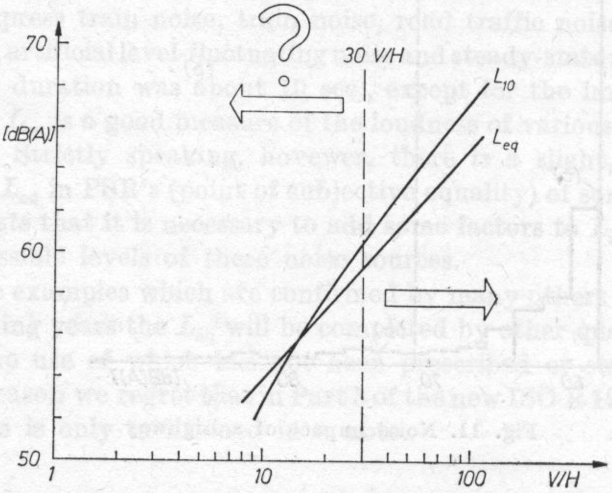


Fig. 10. Variation of L_{eq} and L_{10} as a function of traffic intensity (vehicles per hour)

2.2. Another example is this of the determination of the impact of a highway on the acoustical environment of a community in the neighbourhood. For an exact determination a distinction must be made between:

a) the background level in the community,
b) the level due to the local traffic,
c) the level due to the presence of the highway.

In order to determine exactly the impact of the highway on the acoustical environment in the community we have to eliminate $L_{\mathrm{eq}}(b)$ from our measurement and the real impact will be given by the difference $L_{\mathrm{eq}}(c) - L_{\mathrm{eq}}(a)$ (Fig. 11). We realize that taking the L_{eq} of the background noise and not its lowest value as foreseen in ISO R 1996 may not be accepted by everybody. But in the example we just described it is the only way to give the right answer to the question.

2.3. When using acoustical barriers along a highway the sound attenuation is often expressed in L_{eq}. Plotting the sound level variation as a function of time we observe that behind a barrier the diffderence between the maxima and

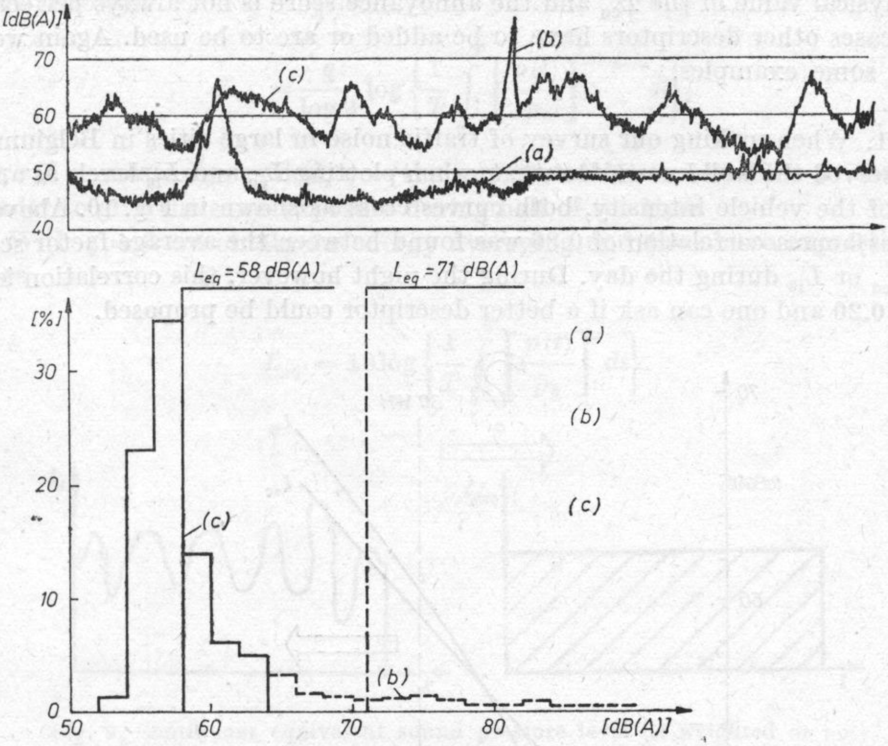


Fig. 11. Noise impact of a highway

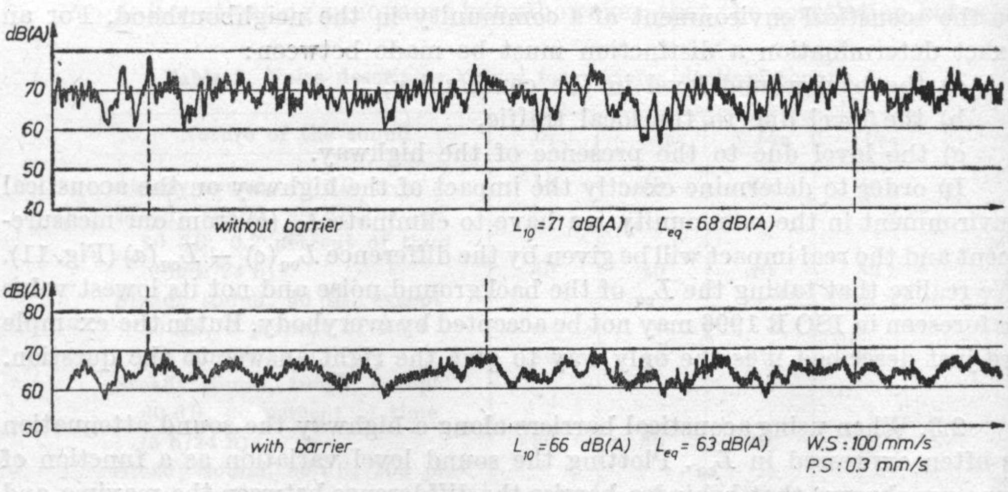


Fig. 12. Variation of the *A*-weighted sound level as a function of time

the minima will be lower (see Fig. 12). This lower "dynamic" of the noise will also reduce the annoyance. In this case the use of a percentile level such as L_{10} will be very useful.

2.4. In a quite different field, namely this of factory noise, a recent investigation, we made in our city, brought us to the conclusion that the L_{90} level produced by the factory was, in the considered case a better descriptor of the noise impact on the neighbourhood than the L_{eq} level.

2.5. In a recent Japanese study [5] the application of L_{eq} as a measure of the loudness of various noises was investigated. Nine kinds of noise source – aircraft noise, super express train noise, train noise, road traffic noise, speech, music, impulsive noise, artificial level-fluctuating noise and steady-state noise – were used as stimuli. The duration was about 10 sec., except for the impulsive noise. It was found that L_{eq} is a good measure of the loudness of various noises, as a first approximation. Strictly speaking, hovewer, there is a slight, but systematic deviation from L_{eq} in PSR's (point of subjective equality) of some noise sources. This fact suggests that it is necessary to add some factors to L_{eq} in order to decide the permissible levels of these noise sources.

From these examples which are confirmed by many others we can conclude that in the coming years the L_{eq} will be completed by other quantities we know already, but the use of which has not been prescribed or standardised until now. For this reason we regret that in Part 3 of the new ISO R 1996 the use of the percentile levels is only mentioned in a note.

3. The sound exposure level L_{AE}

This descriptor also called the single event exposure level, was firstly introduced in ISO 3891 for the evaluation of aircraft noise. Its use has recently

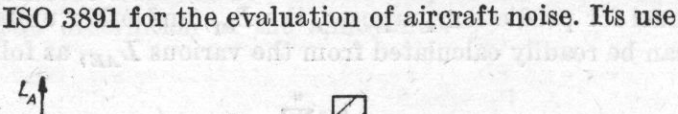


Fig. 13. The sound exposure level

become more general and it is also taken up in the new version of ISO R 1996 in respect to community noise (see Fig. 13).

L_{AE} is defined as the constant level which, if maintained for a period of one second, would deliver the same A-weighted noise energy to the receiver as the actual event itself. This is, then, basically a L_{eq}, which is normalised to a time period of one second. Mathematically we have

$$L_{AE} = 10\log_{10}\int_{-\infty}^{\infty}\left[\frac{p_A(t)}{p_{\mathrm{ref}}}\right]^2\frac{dt}{\tau_{\mathrm{ref}}},$$

where $p_A(t)$ is the instantaneous A-weighted sound pressure, p_{ref} is the reference pressure, 20 micropascals, τ_{ref} is the reference time, i.e. 1 s.

In practice the following is often used:

$$L_{AE} = 10\log_{10}\int_{t_1}^{t_2} 10^{(L_A(t)/10)}\,dt,$$

where $L_A(t)$ is the instantaneous A-weighted sound pressure level, t_1 and t_2 define the time interval in which the level remains within 10 dB of its maximum during the event.

The usefulness of this concept becomes most apparent when dealing with an environment in which a number of different types of noise events occur. These may differ because of the operating conditions or individual characteristics of the same general type of source, such as aircraft, or the occurrence of two or more totally different types of a noise source.

In either case, the knowledge of the normalised sound exposure level, L_{AE}, for each type of event, further categorised in terms of operating conditions where applicable, has many advantages. When describing any noise environment in terms of the equivalent continuous sound level, L_{eq}, or designing a mathematical model for prediction purposes, the L_{eq}, and other units based on it, such as L_{dn}, can be readily calculated from the various L_{AE}, as follows

$$L_{eq} = 10\log_{10}\frac{1}{T}\sum_{i=1}^{n} 10^{(L_{AE_i}/10)},$$

where n is the total number of events in time T, L_{AE_i} is the sound noise exposure level for the i'th event.

Therefore, this gives the advantage that the units used to describe both the individual sources and the overall environment are fully compatible, although it is implicit in the method that all sources are adequately subjectively rated by their equivalent A-weighted energy alone.

However, Fig. 14 which represents the variation of the noise level in the neighbourhood of an airport shows clearly that somewhat different movements can give the same $L_{\max}$ (94 dB(A)) and the same L_{AE} (101.8 dB(A)). The question is, will both movements produce the same annoyance?

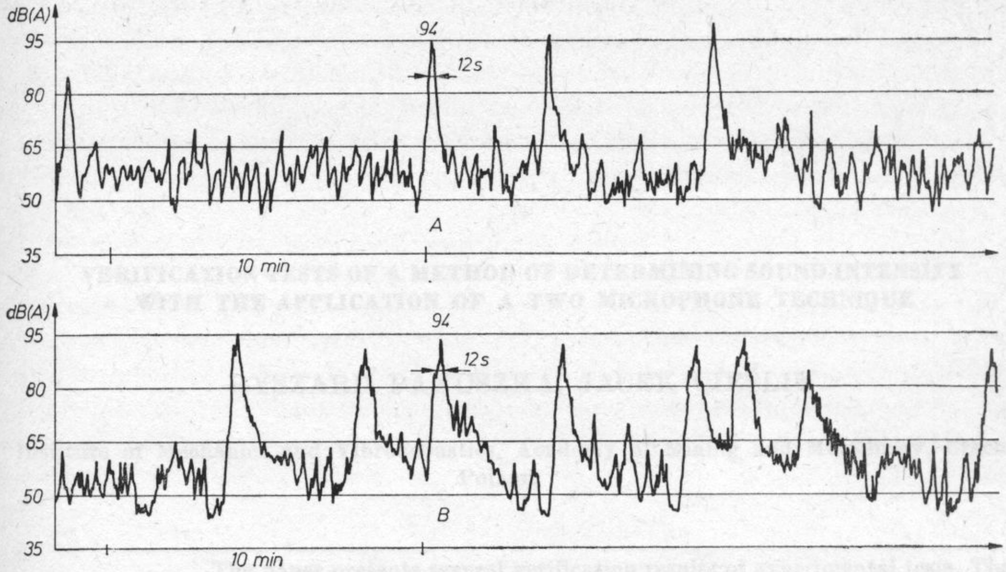


Fig. 14. Variation of the sound level as a function of time in the neighbourhood of an airport. Although the movements A and B are different, they give the same $L_A = 94$ dB (A) and the same $L_{AE} = 101.8$ dB (A)

4. Percentile levels L_N

These levels deduced from the cumulative distribution of a noise give the percentage of the duration then the level exceeds a certain value. In this respect L_1 can serve as an approximation of the average maximum level and L_{95} as an indication of the masking effect of a specific noise under consideration by the residual noise. Both levels can be a useful complement to the L_{eq} value in order to give a better description of the annoyance.

References

[1] P. V. Bruel, *Noise, do we measure it correctly?*, B&K, Naerum 1975.

[2] J. Bulten, *A proposal on noise criteria for sea-going ships*, Report No. 125 s, June 1969, TNO.

[3] B. L. Cardozo, R. A. van Lieshout, *Estimates of annoyance of sounds of different character*, Appl. Ac., **14**, 5, 323–329 (1981).

[4] H. Myncke, A. Cops, Study of traffic noise in cities and the resulting annoyance for the population, vol. **13**, 75 pages (1977).

[5] S. Namba, S. Kuwano, *Psychological study on L_{eq} as a measure of loudness of various kinds of noises*, J. Ac. Soc. Japan (E), **5**, 3, 149–155 (1984).

[6] E. Rathe, Praktische Gesichtspunkte bei der Beurteilung von Automobilgeräusche. Interkeller.

[7] E. Zwicker, *Weniger L_A = grössere Lautstärke?* DAGA 80, pp. 159–162. VDE Verlag.