Comparison of objective methods for assessment of annoyance of low frequency noise with the results of a laboratory listening test

Torben Poulsen
Ørsted•DTU, Acoustic Technology, Building 352, Technical University of Denmark, DK-2800 Lyngby, Denmark

Subjective assessments made by test persons were compared to results from a number of objective measurement and calculation methods for the assessment of low frequency noise. Eighteen young persons with normal hearing listened to eight environmental low frequency noises and evaluated the annoyance of the noises. The noises were stationary noise with and without tones, intermittent noise, music, traffic noise and impulsive low frequency noise. The noises were presented twice in a random order at L_{Aeq} levels of 20 dB, 27.5 dB and 35 dB. The assessment methods were those used in Sweden, Germany, The Netherlands, Poland and Denmark. It was found that the Danish assessment method gave the best relation to the subjective assessments made by the test persons. An important property of this method is that it includes a 5 dB penalty for noises having an impulsive character.

1. INTRODUCTION

Different measurement and calculation methods for the assessment of annoyance due to low frequency noise have been proposed during the recent years. The noise limits or criteria values used in the various assessment methods differ. As a consequence of this ambiguity the Danish Environmental Protection Agency has asked for an investigation, where the subjectively assessed annoyance due to a number of real life examples of low frequency noise was compared to the predicted annoyance using different assessment methods. Such an investigation could indicate the best suitable method for assessment of low frequency noise or it could indicate a need for an adjustment or a revision of the method presently used in Denmark. The Danish assessment method was published in Information No. 9/1997 from the Danish Environmental Protection Agency, "Low frequency noise, infrasound and vibration in the environment" [1]. Results from the project have been presented at the "Low Frequency Noise and Vibration" conferences [2], [3], [4].

In [1] a general description is given of the generation and transmission of low frequency noise and of the properties of hearing in the low frequency and infrasound region. Recommended measurement and assessment methods for annoyance are described and recommended limit values are stated for environmental infrasound and low frequency noise. Contrary to usual the measurement and assessment procedures for environmental noise, such as road traffic noise or industrial noise, measurement of environmental infrasound or low frequency noise should be made indoors in dwellings. Sound in the frequency range below 20 Hz is defined as infrasound. The G-weighting function standardised in ISO 7196 [5], relates closely to the shape of the hearing threshold in the infrasound region. The loudness and annoyance due to infrasound increase very quickly with increasing level. The hearing threshold for single tones is usually about 95 dB(G), and tones with a 20 dB higher level are expected to be sensed as very loud. It can be assumed that infrasound below the hearing threshold is not annoying.

There is an obvious need for an investigation where the subjective annoyance due to typical examples of low frequency noise are compared to different objective measures of the level of the same noises. The present investigation was restricted to low frequency noise. No infrasound was included.

2. LISTENING TESTS

The listening tests were made in a standardised listening room [6] of dimension 7.52 x 4.75 x 2.76 m. Eight different noise examples were used, presented at three different levels. All presentations were made twice and the sequence of the presentations was randomised. Prior to the listening tests, the test persons were trained using four noise examples. After each presentation the test person gave evaluations of the noises on a paper form.

2.1 NOISES

The noises are listed in Table 1 The traffic noise should serve as a reference noise, because there is a well-described relation between the level of road traffic noise and the annoyance of this type of noise. The other noises had all strong low frequency content.

Noise 1 was from a densely trafficked six-lane highway, having broadband characteristics and is almost continuous. Since it was filtered to simulate an indoor measurement, the tonal character of the engine noise from passing heavy vehicles is clearly audible and tire noise is also obvious. Noise 2 consists of a series of very deep, rumbling single blows from a drop forge. The noises 3, 4, 5, and 6 each have one tonal component. Noise 7 has three tones but two of them are at a low level. Noise 8 has a characteristic rhythmical pulsating sound due to the drums.

The duration of all the noise presentations was 2 minutes. The noises were either recorded indoors or filtered to simulate indoor noise. They were recorded on DAT tape and transferred to the hard disk of a PC where they were edited digitally. The noises were presented to the test persons at A-weighted nominal levels of 20 dB, 27.5 dB, and 35 dB. In the listening room the sounds were measured at the listening position and subsequently analysed to obtain the objective levels of the noises. The noises were played directly from the PC via a D/A converter to a crossover filter and via four separate amplifiers to two broadband loudspeakers (KEF 105)

Table 1. Description of the noises used in the listening tests

No.	Name	Description	Tones, characteristics
1	Traffic	Road traffic noise from a highway	None – broadband, continuous
2	Drop forge	Isloated blows from a drop forge transmitted through the ground	None – deep, impulsive sound
3	Gas turbine	Gas motor in a power-and-heat plant	25 Hz, continuous
4	Fast ferry	High speed ferry; pulsating tonal noise	57 Hz, pass-by
5	Steel factory	Distant noise from a steel rolling plant	62 Hz, continuous
6	Generator	Generator	75 Hz, continuous
7	Cooling	Cooling compressor	(48 Hz, 95 Hz), 98 Hz, continuous
8	Discotheque	Music, transmitted through a building	None, fluctuating, loud drums

and two subwoofers (Amadeus Sub). A detailed description of the set-up can be found in [7].

The noises were filtered in order to compensate for resonant modes in the listening room. The listening position in the room was chosen so that only one resonant mode (at 45.5 Hz) influenced the sound level. This mode increased the sound pressure level by about 18 dB at the listening position and therefore a notch filter with 18 dB attenuation at 45.5 Hz (corner frequencies at 40.5 Hz and 50.5 Hz) was used in all presentations.

An 'outdoor-to-indoor' filter was used for the noises that were recorded outdoors. The filter represents the reduction index of ordinary building materials and construction principles [8], [9] and [10] and was defined in the range 16 Hz–4000 Hz. From a subjective evaluation, the noises sounded 'natural' in the listening room. All the noises had a pronounced low frequency characteristic.

2.2 TEST SUBJECTS

Eighteen young persons (9 males and 9 females) with normal hearing were chosen for the listening tests. The age of the test persons was between 19 and 25 years. Pure tone audiometry was carried out in the frequency range 125 Hz to 8000 Hz with a Madsen Midimate 602 audiometer, equipped with Sennheiser HDA 200 earphones. The calibration of the audiometer was made using the values from [11] which are practically identical to ISO 389-8 [12]. Hearing threshold levels at or below 15 dB HL were accepted in the frequency range 125 Hz to 4000 Hz, and a hearing threshold level at 20 dB at a single frequency (including 8 kHz) was also accepted. The average hearing threshold of the listeners shows a slight decrease (less than 10 dB) at 6 kHz and 8 kHz.

In addition to the conventional audiometry, the hearing threshold in the low frequency range was determined. The tests were made using pure tones at 31 Hz, 50 Hz, 80 Hz, and 125 Hz with a Two Alternative Forced Choice method [13]. These hearing threshold measurements showed results that were less than 10 dB from the standard hearing thresholds given in ISO 389-7 [14].

2.3 SUBJECT'S TASK

Test persons were given a written

noise notes

WOOD PRODUCTS FACTORY

Nancy Smith, an Athens-Clarke County resident, asks for a show of hands Monday to gauge interest in another meeting on plans by the Louisiana-Pacific wood products plant on U.S. Highway 441 plant near the Athens-Clarke and Jackson county line to increase its emissions. Smith drafted a letter requesting the state Environmental Protection Division-hosted hearing held Monday at the Athens-Clarke County Library. Several dozen neighbours from northern Athens-Clarke and southern Jackson counties (Georgia, USA) used an interview with Louisiana-Pacific representatives Monday night to beg the company to cut down on noise and create an advisory committee of neighbours. Representatives from Louisiana-Pacific and the state Environmental Protection Division met with dozens of concerned citizens to answer questions about proposed environmental permits for the company's U.S. Highway 441 plant. Locals used the opportunity to complain about noise from the plant – an issue that environmental regulators won't consider. Government to pay for U.S. base noise The Seoul District Court has ordered the South Korean government to pay almost $2.8 million as compensation to local residents for noise coming from the U.S. Air Force base in Gunsan, North Jeolla Province. The ruling was the first case of compensation being awarded over noise from a U S. air base in South Korea. The ruling affects 1,878 of 2,035 residents who filed a class-action suit in the port city, about 275 kilometres southeast of Seoul.

Table 2. Subjective assessment by the reference group of the annoyance from the noise examples if the noise was heard at night. Annoyance rating is given on a scale from 0 (not annoying) to 10 (very annoying)

Nominal presentation level	**20 dB Subjective annoyance night**	**27.5 dB Subjective annoyance night**	**35 dB Subjective annoyance night**
Traffic noise	1.6	3.4	5.2
Drop forge	4.3	5.9	6.9
Gas turbine	0.9	2.5	5.2
Fast ferry	0.9	3.2	5.4
Steel factory	1.0	2.7	4.9
Generator	1.7	3.2	5.0
Cooling compressor	2.7	4.4	6.0
Discotheque	3.0	5.4	6.7

introduction to the tests, and they could ask about the procedure throughout the tests. A full training session was made prior to the listening tests. Information about the sound examples was given after all the tests were finalized. The tests persons answered four questions after each presentation:

- ‘How loud is the sound?’ (on a scale labelled “not audible” in one end and “very loud” in the other end)
- ‘How annoying do you find the sound if it was heard in your home during the day and the evening?’ (on a scale labelled “not annoying” in one end and “very annoying” in the other)
- ‘How annoying do you find the sound if it was heard in your home during the night?’ (on a scale labelled “not annoying” in one end and “very annoying” in the other)
- ‘Is the noise annoying?’ (answer yes or no).

The response was made by making a mark on a horizontal line. All the lines were 10 cm long, and the response was measured in cm with a ruler and thus all data are given as figures between 0 and 10.

3. RESULTS OF THE LISTENING TEST

Table 2 shows the average subjective evaluation made by the listeners of the annoyance during night. The loudness question and the annoyance at day/evening question gave similar results.

It can be seen from Table 2 that the subjectively assessed annoyance increases when the same type of noise is played at a higher level. It can also be seen that the different types of noise are not assessed equally annoying. The noises from the drop forge, the discotheque and the cooling compressor are evaluated as more annoying than the other noises. It can also be seen that the traffic noise is just as annoying as many of the low frequency noises.

A statistical analysis of the data was performed although the data were not perfectly normally distributed. It was found that the noise, the nominal level, the measured dB(A) level and the low-frequency level ($L_{pA,LF}$), are all

Table 3. Overview of the objective methods

Assessment	Type of measurement	Criterion	Impulse correct
Danish	1/3 oct. bands, 10–160 Hz, A-weighing	Limits	Yes
German A-level	1/3 oct. bands, 10–80 Hz, A-weighing of levels above hearing threshold	Limit re. hearing threshold	No
German tonal	1/3 oct. bands, 10–80 Hz, level of tone(s)	Limits	No
Swedish	1/3 oct. bands, 31.5–200 Hz	Curve	No
Polish	1/3 oct. bands, 10–250 Hz	Curve	No
Dutch proposal	1/3 oct. bands, 10–200 Hz	Curve	No
C-level	1/3 oct. bands, 10–160 Hz	(Limit)	(Yes)

significant factors in the evaluations from the test persons. The repetition number (round 1 or round 2 with the same noise presentation) is not a significant factor, which shows the absence of a training effect.

4. ASSESSMENT METHODS FOR LOW FREQUENCY NOISE

A number of different methods have been suggested for the assessment of low frequency noise. The Danish method [1] has already been mentioned. The other methods used in the present investigation are the standardised German method [15], the Swedish method [16], a recent Polish method [17], and two different methods from the Netherlands [18] and [19]. All these methods are used to assess the annoyance due to low frequency noise, based on the indoor noise level. The methods give different guidelines or criteria for the allowed noise level and the administrative procedures used in the individual countries to enforce the criteria for low frequency noise are very different.

Table 3 gives an overview of the main features of the various methods.

4.1 DANISH METHOD

The Danish method [1] gives recommended limit values for low frequency noise and infrasound. The noise is measured in several positions indoors, and is analysed in 1/3-octave bands. The nominal A-weighting corrections are added to the spectrum values, and the weighted spectrum is summed to form the A-weighted level of the noise in the frequency range 10 Hz–160 Hz. The resulting level is called $L_{pA,LF}$. A direct measurement of the A-weighted level, $L_{pA,LF}$, is not possible since the minimum limit of the tolerance for the A-weighting filter is undefined (i.e. minus infinity) below 20 Hz.

In the Danish method a table of recommended limit values is used for the assessment of the noise. In dwellings the A-weighted equivalent level (averaged over 10 minutes) shall not exceed 20 dB $L_{pA,LF}$ in the evening and the night (18–07) or 25 dB $L_{pA,LF}$ in the day period (07–18). In offices etc the $L_{pA,LF}$ level shall not exceed 30 dB, and in other rooms in business premises the limit is 35 dB. If the noise has an impulsive character, the limits are reduced by 5 dB.

4.2 GERMAN METHOD

In the German method [15] low frequency noise is defined as noise where the C-weighted noise level is at least 20 dB higher than the A-weighted level, based on either equivalent levels or maximum levels.

If the noise is evaluated as ‘low frequency’, a 1/3-octave frequency analysis is made. The method considers the frequency range 10 Hz–80 Hz, but in special situations the 8 Hz and / or the 100 Hz band can be included. The method applies to rooms in dwellings where people stay or rests. In an Annex to the method a range of limits or criteria values are given for the day period (06–22) and for the night period (22–06).

In the German method, a distinction is made between tonal noise and noise without tones. If the level in a particular 1/3-octave band is 5 dB or more above the level in the two neighbouring bands, the noise is said to be tonal.

For tonal noise, the level of the frequency band with the tone is compared to the hearing threshold (LHS) in the same band. It is then found how much the tone is above the threshold. The levels in the other frequency bands are not taken into account. The limit value for the equivalent level of the tone in the day period is: 5 dB in the 8 Hz–63 Hz bands, 10 dB in the 80 Hz band, and 15 dB in the 100 Hz band. The same assessment method applies to the maximum level of the noise; here the limit values in the same three frequency ranges are 10, 15, and 20 dB. In the night period all the limits are reduced by 5 dB, and thus the limits for the equivalent level of the tones are 0 dB, 5 dB, and 10 dB.

If the noise is not tonal, the limit for the A-weighted equivalent level (10 Hz–80 Hz) is 35 dB during daytime and 25 dB during the night. The A-weighted level is calculated by adding the A-weighting corrections to only those levels that are above the hearing threshold. As opposed to the Danish method, the contributions from levels below the threshold are disregarded. The corresponding limits for the maximum levels are 45 dB and 35 dB.

4.3 SWEDISH METHOD

The recommendations from the Swedish National Board of Health and Welfare [16] give guidance on an assessment as to whether noise under different conditions may have health effects. The recommendation comprises a criterion curve of recommended maximum levels of low frequency noise in rooms used for living. The curve covers the frequency range 31.5 Hz–200 Hz and applies to the equivalent level of the noise. A measurement method is specified and is described in a report from the Swedish Testing Institute [20]. If the noise level exceeds the criteria curve in any 1/3-octave band, the health and environmental authorities may characterise the noise as a sanitary nuisance.

noise notes

BRUSSELS ZAVENTEM

Belgian Minister Bert Anciaux has angered government colleagues by announcing a new plan to cut aircraft noise at Zaventem airport outside of Brussels without cabinet backing. The complex scheme would see aircraft using more runways at Zaventem and flying in and out of the airport on a number of different routes. The basic logic behind the plan is to reduce noise pollution under the airport's main flight paths by spreading flights over a wider area. Anciaux insisted his new plan was in line with instructions he had received from the cabinet to sort out the aircraft noise problem after Belgium's most senior court, the Conseil D'Etat, blocked an original government proposal on the issue last December. But Belgian Justice Minister Laurette Onkelinx made it clear that she believed Anciaux had overstepped his remit and should have sought cabinet clearance before unveiling his plan. Onkelinx said on Belgian television that her colleague, "had not behaved correctly" over the question. She said Anciaux had now been summoned to a special cabinet meeting to explain himself and she hinted that she could even ask the Transport Minister to resign over the issue.

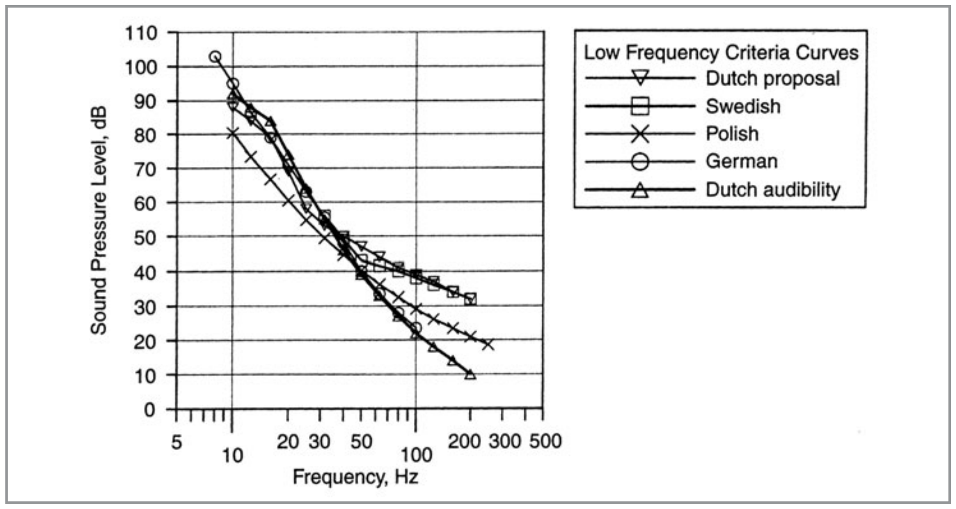

Figure 1. Comparison of criteria curves from the different assessment methods

4.4 POLISH METHOD

The Polish method applies a threshold curve. This is defined in the frequency range 10 Hz–250 Hz, and corresponds to 1/3-octave levels each giving an A-weighted level of 10 dB (i.e. 10 dB above the inverse A-weighting correction). The criterion curve is called L_{A10} [17].

The noise is considered annoying if both of these conditions are met:

- The spectrum of the noise exceeds the criterion curve LA10 in one or more 1/3-octave bands
- The spectrum of the noise exceeds the spectrum of the background noise

It is mentioned in [17] that usually the background noise is somewhat higher than the criterion curve at the highest frequencies, above 100 Hz.

4.5 DUTCH PROPOSED METHOD

The proposed method [18] is intended for use in connection with the granting of environmental permission to industries and businesses. The method uses a criterion curve defined in the frequency range 10 Hz–200 Hz. In the upper part of the frequency range the criterion curve agrees well with the Swedish criterion curve. At the lowest frequencies, where the Swedish curve is not defined, it corresponds to the hearing threshold as specified in the German method. It is expected that annoying low frequency noise will occur if the criterion curve is exceeded in one or more 1/3-octave bands.

DUTCH CRITERION FOR AUDIBILITY

This method is described in [19]. It is intended for use in cases where people complain about low frequency noise in order to decide if audible low frequency noise occurs. The aim of the method is not to verify whether the noise is annoying or not. The method employs a hearing threshold based on the best 10% of a nonselected population aged 50–60 years. The threshold curve is used in the frequency range 20 Hz–100 Hz.

4.6 C-WEIGHTED SOUND PRESSURE LEVEL

In the German method the difference between the C-weighted and the A-weighted sound pressure level is used to determine if low frequency noise is present. Similar rules of thumb have regularly been mentioned in the literature. The C-weighted sound pressure level has been included in the analysis because it has been claimed that the C-weighting should give a better description of low frequency noise than

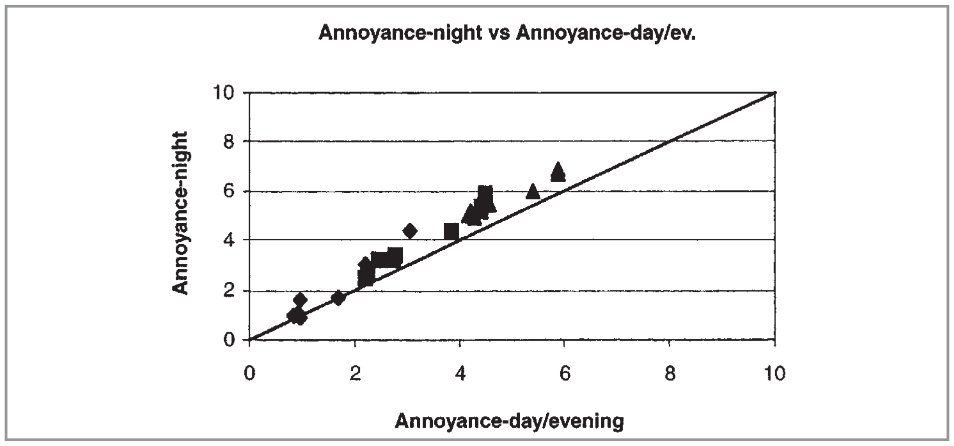

Figure 2. *Assessment of the annoyance in the day and evening period and the annoyance at night for the same noise examples*

the A-weighting.

5. CRITERION CURVES

The criterion curves from the different assessment methods are shown in Figure 1.

The 'Dutch proposal', 'Swedish', and 'Polish' are criterion curves directly aimed at assessing if the noise is annoying. The two first curves differ only in the frequency range 50 Hz–80 Hz, where the Swedish curve is clearly lower than the Dutch proposal. In the entire frequency range the Polish curve is lower than the two other curves. Here it must be remembered that the background noise is also part of the Polish criterion, which will often have a relieving influence on the criterion curve at high frequencies, but this part of the method is not considered here.

The 'German' curve is a hearing threshold curve and is used as a criterion for tones in the noise. It permits tones to exceed the curve by 5 dB during daytime, AND A HIGHER exceedence is allowed at higher frequencies. The curve 'Dutch audibility' is used in cases with complaints in order to decide whether there is audible noise in the relevant frequency range. The curve is not used to determine if the noise is annoying. It can be seen that the German and the Dutch threshold curves are almost identical, and that they almost coincide with the curve 'Dutch proposal' below 40 Hz.

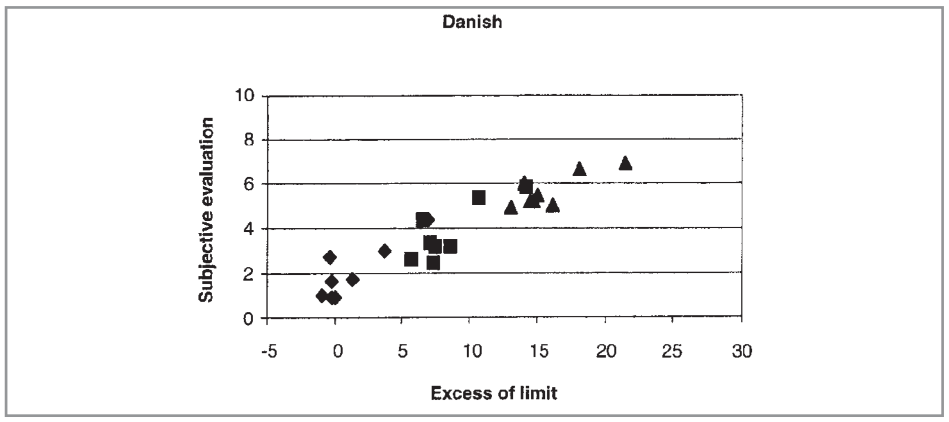

Figure 3. *Relation between the Danish assessment method and the subjective evaluation. Diamonds: low presentation level; squares: intermediate presentation level; triangles: high presentation level.*

Table 4. Subjective evaluation of the various noise examples shown together with the objective 'assessment' by use of the Danish method ($L_{pA,LF}$)

Noise	20 dB Excess	20 dB Subjective annoyance	27.5 dB Excess	27.5 dB Subjective annoyance	35 dB Excess	35 dB Subjective annoyance
Traffic noise	–0.3	1.6	7.0	3.4	14.5	5.2
Drop forge	6.9	4.3	14.2	5.9	21.5	6.9
Gas motor	–0.2	0.9	7.3	2.5	14.8	5.2
Fast ferry	0.1	0.9	7.5	3.2	15.0	5.4
Steel factory	–1.0	1.0	5.6	2.7	13.1	4.9
Generator	–1.3	1.7	8.6	3.2	16.1	5.0
Cooling compressor	–0.4	2.7	6.5	4.4	14.0	6.0
Discotheque	3.7	3.0	10.7	5.4	18.1	6.7

6. COMPARISON OF THE SUBJECTIVE EVALUATION OF ANNOYANCE WITH THE RESULT OF OBJECTIVE MEASURES

The test persons evaluated the annoyance in two situations: if the noise was heard in the day and the evening, and if the noise was heard at night. Figure 2 shows that there is a very close relation between these two assessments. Generally the annoyance at night is slightly larger than the annoyance in the day/evening. The relation between the pair of evaluations can be described by the correlation coefficient, which is as high as 0.9885. The following comparisons are therefore made only for the subjective assessment of the annoyance in the night period. The various methods, criteria and curves are used in relation to the 1/3 octave spectrum of the noises. In every analysis the objective metric is chosen as the x-parameter, and the subjective annoyance evaluation (which is the same in all cases) is the y-values.

6.1 DANISH METHOD

Table 4 shows the result of the use of the Danish method for the various noises. The second column shows the excess of the Danish limit. For the night period the limit value is LpA,LF = 20 dB, but since the drop forge as well as the discotheque are considered as impulsive noises, the limit for these noises is 15 dB. The third column gives the average assessment made by the test persons. The data from Table 4 are shown in Figure 3.

Figure 3 illustrates the subjective evaluation as a function of the excess of the Danish criteria. It is seen that a straight line (not shown in the figure) can represent the group of points. This line is found by linear regression (least squares method, function LINEST of an Excel spreadsheet). The regression line has the formula:

$$y = 1.61 + 0.26 * x$$

where 'y' represents the average subjective evaluation made by the test subjects and 'x' represents the excess over the limit in dB.

The regression line does not explain how well it represents the group

Table 5. Data from linear regression and from correlation analysis for the Danish method

Slope	Intersection (x = 0)	Degree of explanation, r2	Correlation coefficient, ρ
0.26	1.61	0.88	0.94

of points. For this purpose we can use the residuals, which are the vertical distances between the points and the line. We also use the average of all y-values and the y-values determined by the regression method for each x-value. The determination coefficient or 'degree of explanation' (r2) is defined as:

r2 = SSe / (SSe + SSr)

where SSe is the residual sum of squares, and SSr is the regression sum of squares. In practice r2 is calculated by the Excel function LINEST.

If r2 equals 1.00 there is a perfect linear relationship between the points. If r2 is close to zero, the regression line cannot be used to explain the relation between x and y. In other words, the r2 value indicates how well the points can be described by a straight line. The closer the value is to 1, the better the description.

The relation between the x- and the y-values can also be described by the correlation coefficient, ρ. This is calculated as the ratio between the covariance of x- and y-values, and the product of the x-variance and the y-variance:

ρ = covariance (x, y) / (σx * σy)

The covariance is calculated as the deviation between the x-value and the x-average, multiplied by the deviation between the y-value and the y-average. The x-variance, σx, is the deviation between the x-value and the x-average squared. Similarly the y-variance, σy, is the deviation between the y-value and the y-average squared.

The correlation coefficient is calculated by use of the Excel function CORREL. It explains the degree of relation between the x and the y values and gives a coarse indication of the shape of the swarm of points. If ρ is close to 1 (or -1) the shape of the group of points has the shape of a 'cigar' around the regression line. If ρ is close to zero, the points lie in a diffuse cloud and there is no obvious relation between x and y.

There is an important difference between the degree of explanation and the correlation coefficient. The degree of explanation, r2, assumes a functional relationship between y and x (e.g. the subjective evaluation is 'caused by' the noise). The correlation coefficient does not assume such causality and can be calculated from any two datasets.

The values calculated for the Danish method are summarized in Table 5.

6.2 GERMAN A-LEVEL

Figure 4 shows the A-weighted levels of the noise examples, calculated according to the German standard DIN 45 680. The level is calculated as the sum of the A-weighted levels of those 1/3-octave bands that exceed the hearing threshold. All the noise examples are used in this calculation, including those examples where the noise contains tones.

It is seen that the points fall in two groups (two lines); the upper points are the noise examples from drop forge, discotheque, and compressor. The German method (in the present interpretation) obviously cannot give a sufficient assessment of impulsive noise (drop forge and discotheque). The degree of explanation, r2, is 0.54, see Table 6.

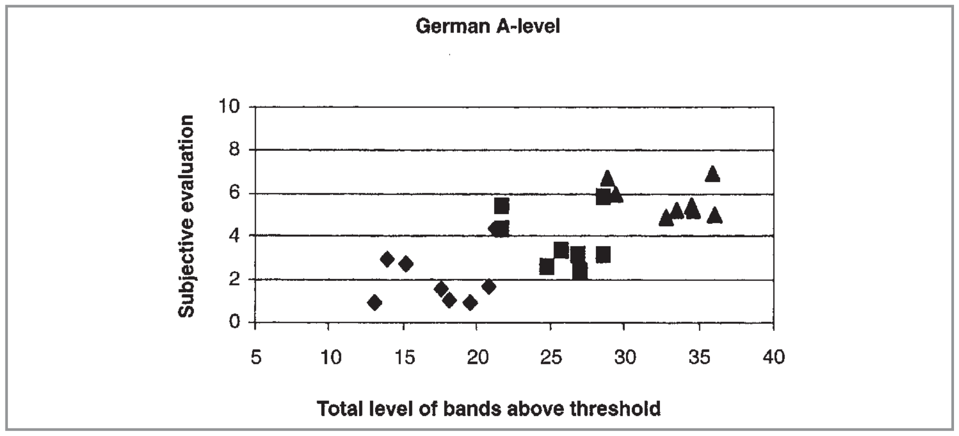

Figure 4. Illustration of the relation between the German assessment method using the A-weighted level and the subjective evaluation

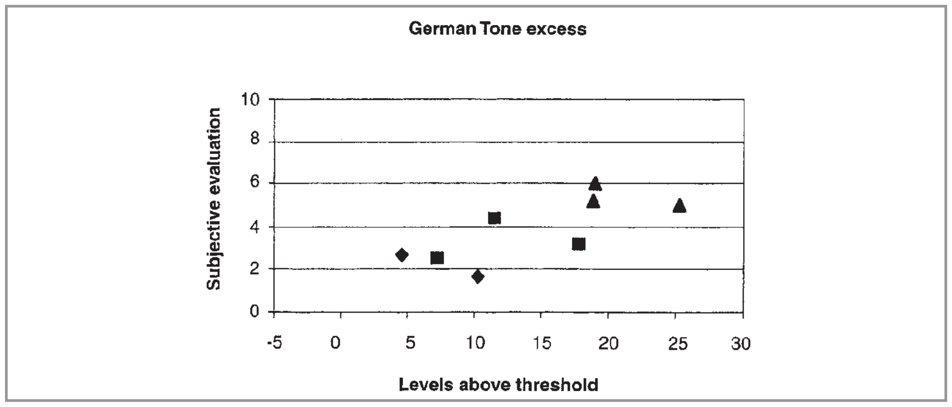

Figure 5. Illustration of the relation between the German assessment method for tonal noise and the subjective evaluation

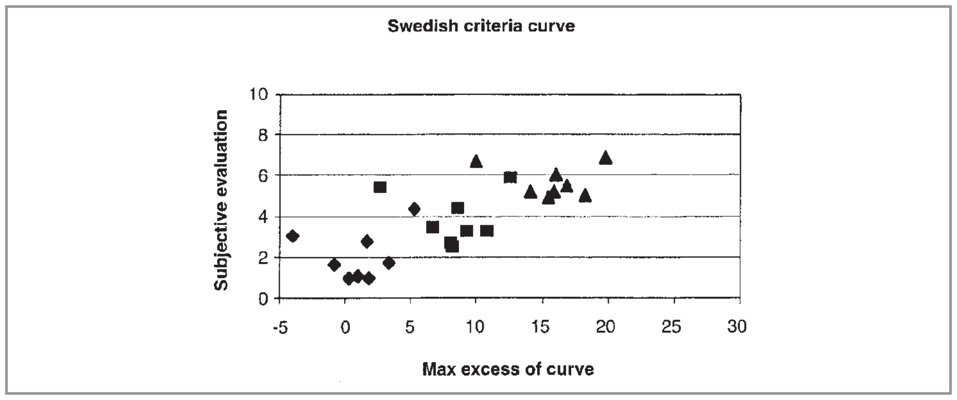

Figure 6. Illustration of the relation between the Swedish assessment method and the subjective evaluation

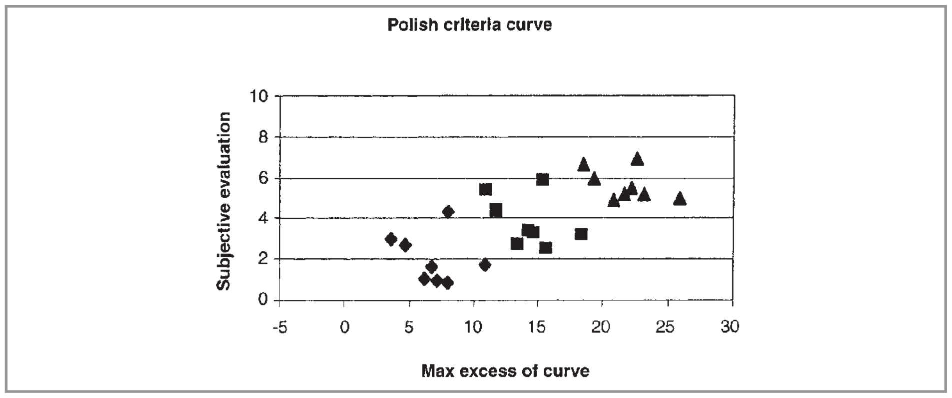

Figure 7. Illustration of the relation between the Polish assessment method and the subjective evaluation

6.3 GERMAN TONAL METHOD

Figure 5 shows the relation between the subjective evaluation and the tone level above the hearing threshold for those noises that contain tones (according to the German assessment method). In Figure 5 only one point per noise is shown. This point corresponds to the tone with the greatest excess above the threshold.

The Gas Turbine has two tones above threshold at the highest presentation level (triangle) and one at the intermediate level (square). There is no tone above threshold at the lowest presentation level.

The Generator has one tone above threshold at the highest level (triangle), at the intermediate level (square) and at the lowest level (diamond). The tone is at 80 Hz and thus the level has been reduced by 5 dB according to the German assessment method.

The Cooling Compressor has two tones (50 Hz and 100 Hz) above threshold at the highest presentation level (triangle) and at the intermediate level (squares). As one of the tones is at 100 Hz the level for this tone must be reduced by 10 dB according to the German assessment method. This makes the other tone (at 50 Hz) the greatest. There is only one tone above threshold at the lowest presentation level (diamond).

6.4 SWEDISH METHOD

The Swedish criterion curve must not be exceeded in any 1/3-octave band. Figure 6 shows the subjective assessment as a function of the greatest excess. The degree of explanation, r2, is 0.57.

It may be seen from Figure 6 that three points fall 'to the left' of the rest of the points. These three points are from the discotheque. Obviously this type of noise should have been assessed about 10 dB 'higher' for the points to fit into the rest of the points and the relative low values of r2 and • are mainly caused by these points. Removal of the discotheque points increases the degree of explanation to 0.81.

6.5 POLISH METHOD

Figure 7 shows the excess over the Polish criterion curve, which is a curve of 1/3-octave band levels each of which corresponds to an A-weighted level of 10 dB. The other part of the Polish method,

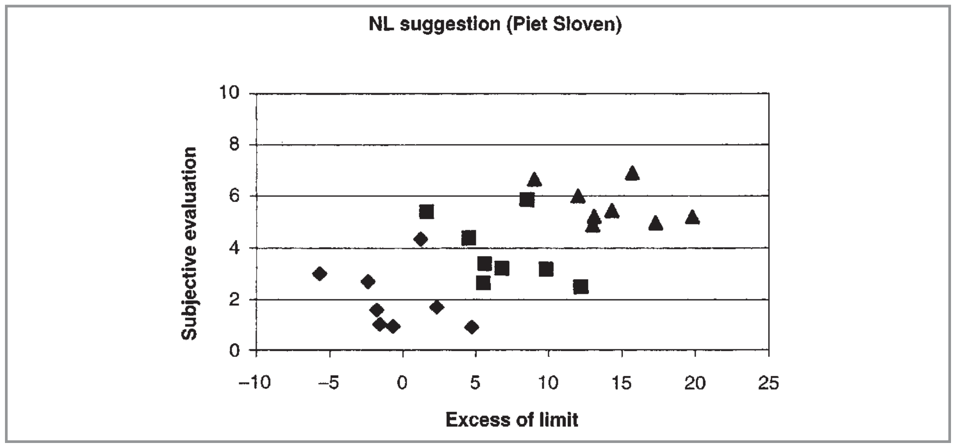

Figure 8. Illustration of the relation between the Dutch assessment method by Sloven and the subjective evaluation

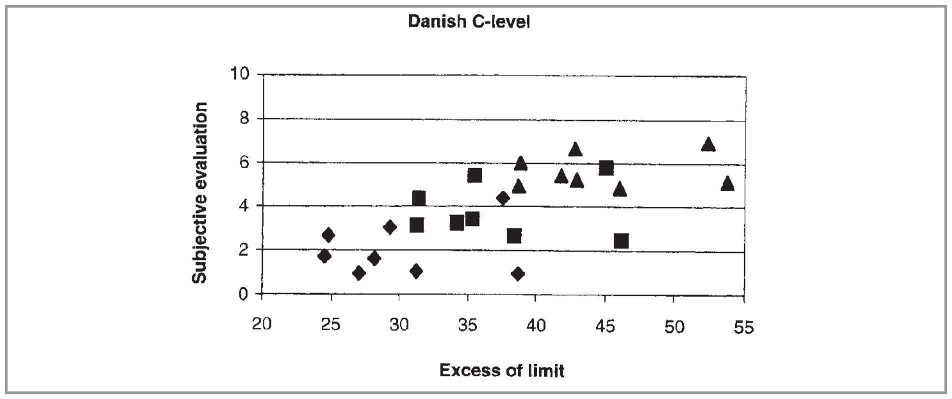

Figure 9. Illustration of the relation between the C-weighted sound pressure level and the subjective evaluation

which deals with the excess of the background noise level, has not been considered.

The noises fall in two rather distinct groups, where the discotheque, the drop forge and the cooling compressor are 'to the left' of the remaining points. They should have been assessed at least 5 dB 'higher' by the method to align with the other points. If the groups of points from each nominal level are looked upon separately (diamonds, squares and triangles), it appears that the points in each group shows a tendency to a downwards slope to the right; that is,

Table 6. Overview of the results from regression analysis of the relation between the subjective evaluations and the different assessment methods

Assessment method	Slope	Intersection (x = 0)	Degree of explanation, r2	Correlation coefficient, ρ
Danish	0.26	1.61	0.88	0.94
German A-level	0.19	–0.98	0.54	0.73
German tonal	0.16	1.58	0.52	0.72
Swedish	0.21	2.10	0.57	0.76
Polish	0.20	1.00	0.50	0.71
Dutch proposal	0.17	2.67	0.40	0.64
C-level	0.15	–1.82	0.44	0.66

the subjective evaluation decreases as the max excess increases. The degree of explanation, r2, is 0.50 for the polish method.

6.6 DUTCH PROPOSAL

The proposed assessment method for use with environmental approval of industries also employs a criterion curve. Figure 8 shows that the points are fairly spread, and no clear picture can be seen. It appears that the points from the same nominal level slope 'the wrong way' as was seen with the Polish method. As an example (filled squares) it can be seen that when the excess increases from 1 dB to 12 dB, the subjective evaluation decreases from 5.5 to 2.5. The degree of explanation is 0.40.

6.7 C-WEIGHTED LEVEL

Figure 9 shows the relation between the C-weighted level of the noises and the subjective evaluation. It can be seen that the spread of the points is very large. Only the frequency range 10 Hz to 160 Hz is included in the calculation of the C-weighted level.

OVERVIEW OF THE RESULTS

The results from the above analysis are summarized in Table 6.

The assessment method with far the best correlation between the subjective and the objective assessment is the Danish method, using the A-weighted level in the frequency range from 10 Hz to 160 Hz. The second best method is either the Swedish method, based on a criterion curve, or the German method using the A-weighted level.

7. DISCUSSION

The present investigation has been performed as a typical laboratory experiment in contrast to a field investigation. The advantage of a laboratory experiment is that it is possible to control almost all the experimental conditions (noises, levels, duration, presentation sequence, test subjects, etc). The disadvantage is that the presentations may not be realistic enough.

The response sheet contained all the questions on a single sheet. It has been argued that the different questions

noise notes

BEER GARDEN

A London licensee has made a plea for support in his fight against a council over noise. Jamie Dillon, who owns Austin's Bar in Colne Road, Twickenham, was served a noise abatement notice by Richmond Upon Thames Council last summer after a neighbour complained about noise in the beer garden. Mr Dillon appealed against the decision but Richmond magistrates dismissed his appeal, finding that a statutory noise nuisance had been caused. "This has serious implications for the trade," said Mr Dillon. "I'm not sure brewers are taking it seriously. If we don't fight it every crank who lives near a pub will believe they can take their complaint to the council and win." The council claimed that the noise levels were too high after sending officers to monitor the bar. But Mr Dillon has claimed that very little research was carried out to substantiate this claim. He said: "An officer came down to the pub and simply listened, I didn't see any equipment being used to monitor the sound. What the council is saying is that there should be no talking or laughing in the garden. It also expects us to stop the cheering if football is on. I'm going to take this through the High Court but need people in the trade to back me up because if the council wins it will have disastrous ramifications for all of us." The council stated trained officers were at the bar on three occasions before the abatement notice was served. Richmond Council's cabinet member for environment and planning, Cllr David Marlow, said: "These premises are in the middle of a residential area and the noise levels witnessed by the council were completely unacceptable to people living nearby. We take noise problems extremely seriously and will fight to protect residents' right to a good night's sleep. We ask owners of commercial premises and residents alike to consider their neighbours."

should have been on separate sheets in order to avoid biassing effect from one question to the next. Also the wording of the questions might be revised even though no test subjects reported any difficulties.

The number of subjects could be increased in order to improve the accuracy of the results but for a group of 18 it is believed that an increase of the number of test subjects would not change the general results dramatically.

The noises constitute a reasonably broad selection of low frequency sounds. The noises were selected to represent typical low frequency noises known to produce community claims. In retrospect it would have been an improvement to include more noises with an impulsive character in order to better 'test' the impulse penalty in the Danish method. All noises had clearly a low frequency character partly because of an outdoor-to-indoor filtering of the noises recorded out of doors. Traffic noise was included in order to serve as a reference noise, but due to the outdoor-to-indoor filtering the traffic noise was converted into another low frequency noise.

The criteria and evaluation methods used in this investigation are all based on some kind of measurement of the noise level. There is a clear connection between the noise level and the experienced annoyance and thus it makes sense to use such criteria and evaluation methods.

In the statistical analysis it was seen that the data deviated somewhat from a normal distribution partly caused by the saturation effect from the fixed endpoints of the scale. Despite this deviation in the distribution of the data the statistical analysis showed the expected effects and thus no attempt was made to correct for the saturation effect in the data.

The maximum excess over a criterion curve or the excess over a noise limit was used as input data for the analysis because this is the way the criteria curves and the noise limits are used in practise. In relation to a noise limits this is straightforward because the level of the noise is calculated according to some rule and compared to the limit.

For the criteria curves, on the other hand, the procedure may constitute a problem as only a single frequency band of the noise is used in the comparison and not the whole spectrum. Only the band where the maximum excess occurs is taken into account and excess at other frequency bands aw is neglected. From Figure 1 it is seen that the different criteria curves differ somewhat above 40

MORE AND CHEAPER FLIGHTS

A residents' group is urging people living in the south of Coventry to voice their concerns over the planned increase in flights. The secretary of Styvechale and District Residents' Association said the proposal was a major worry to members. Karen Reay, who became secretary of the group, which has more than 2,000 members, in December, asked people to write to Warwick District Council outlining their opposition to the plans. The authority is due to consider plans for a new passenger terminal, which will be able to cater for two million people a year, on February 16. The new airline, Thomsonfly.com, will be operating from the end of March, with flights on 131-seat Boeings costing as little as £17.99. How the EC ruling on Ryanair might affect the supply of low-cost flights is presented not clear.

ARIZONA TRANSPORTATION

A hypothecated tax in Arizona aims to raise $15.8 billion for a 'transportation package'. Most of the money is earmarked for new freeways, buses and light rail. Out of all that, only $75 million has been set aside for rubberised asphalt and noise barriers.

Hz and this means that the various criteria curves will give very different results if the excess occur in this frequency range. It also means that the excess decision will be very dependent on the inherent measurement uncertainty in the measurement of the spectrum. The calculation of a level – based on a spectrum – is much less sensitive to measurement uncertainty as the uncertainties are 'averaged' in the calculation process.

The measurement uncertainty is inversely proportional to the bandwidth of the analysing filter and also inversely proportional to the duration of the measurement (i.e. the integration time). This means that a one-third-octave analysis of a low frequency noise must be extended over a long period of time in order to keep the uncertainty below a certain limit. It is common practice to require that the standard deviation of repeated measurements shall be less then 0.2 dB. This corresponds to an integration time (in seconds) greater than 471/B where B is the bandwidth in Hertz of the analysing filter. For the one-third-octave filter at 10 Hz this means an integration time of almost five minutes. At 40 Hz a one-minute integration time is necessary and at 1000 Hz two seconds are needed. The noise signal should be stable over this period of time but this is not always the case in practice.

Uncritical use of criteria curves may be misleading. Some of the curves (e.g. the German and the Dutch) are hearing threshold curves and can therefore only be used to predict whether a noise is audible or not. The excess cannot predict the annoyance of the noise. This will depend on the shape of the noise spectrum.

The use of weighting functions (such as G- and A-weighting) will not automatically give a loudness or annoyance measure. In the conventional audible frequency range it is well known that neither the loudness level contours nor the A-weighting can predict the loudness of complex sounds. It is believed that loudness is a major component of annoyance. Loudness is related to the level and the spectrum of the noise. Annoyance is therefore also dependent on level and spectrum but annoyance is also influenced by (or dependent on) many other factors and these factors cannot be described by

noise notes

HOSPITAL UPROAR

Hospital noises during the night can approach the levels of chain saws or jackhammers, making it nearly impossible for patients to sleep, according to a new study at the Mayo Clinic. The nurses found that steps as simple as closing the door to a patient's room and stifling the clatter of clipboards can help. Cheryl Cmiel, a nurse at the clinic in Rochester, USA, started the study after hearing patient complaints. She and other researchers placed noise-measuring devices in three empty patient rooms at Mayo's St. Marys Hospital during a night shift, without the knowledge of other nurses. They found peak noise readings of 113 decibels, usually around a nursing shift change at 7 a.m. The average noise level was 45 decibels, slightly less than you might find in a library. Noise-reduction efforts reduced the peak to 86 decibels and the average to 42.

EQUIPMENT SEIZURES

Vale Royal Borough Council (Cheshire) is destroying electrical equipment seized from noisy neighbours in a fresh bid to hammer home its tough line on noise nuisance. Cllr Nigel Griffiths, chairman of Vale Royal Borough Council's Social Review Committee, took a sledgehammer to hundreds of pounds worth of hi-fis, televisions and musical equipment in early March. All of the goods were the subject of destruction orders issued by Northwich Magistrates Court. The council seized the equipment from a number of properties as a result of complaints about loud music from neighbours. The council receives more than 600 complaints a year about domestic noise nuisances with complaints ranging from barking dogs to the p l a y i n g physical measurements of the noise.

8. CONCLUSION

A laboratory investigation of the annoyance of low frequency noises has been performed and the subjective evaluations were compared to the noise limits and criteria curves for low frequency noise used in the European countries. Eighteen normal hearing test subjects listened to eight different noises and evaluated the loudness, the annoyance during the day/evening and the annoyance at night. All noises had considerable low frequency content.

The results show that the Danish measuring method describes the subjectively experienced annoyance better than the measuring methods used in other countries. This result relies on the 5 dB impulse noise penalty included in the Danish method. The decision about whether or not a 5 dB penalty shall be applied to a specific noise is based on a purely subjective judgment and therefore the Danish method could be improved at this point. The Swedish method is almost as good as the Danish method if the (impulsive) discotheque sound is omitted from the analysis. The Swedish method is based on a specified criterion curve (in contrast to the Danish noise level calculation) and as such more sensitive to random measurement uncertainties.

An almost perfect correlation was found between the annoyance at day/evening and the annoyance at night. The annoyance at night is slightly lager than the annoyance at day/evening. The difference in the annoyance ratings between day and night corresponds to a level change of about 5 dB.

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