Evaluation of low-frequency noise in dwellings. New Polish recommendations

Marianna Mirowska

Building Research Institute, Department of Acoustics, Ksawerow 21, 02-656 Warsaw, Poland. e-mail: akustyka_itb@zigzagpl

This paper presents new Polish recommendations for the estimation of low-frequency noise (LFN) penetrating into dwellings from appliances installed inside or outside the building (Recommendation No 358/98 of the Building Research Institute). The proposed new assessment criteria were based on the measurement data of annoying noises, investigation of the effects of noise on the health of the exposed inhabitants, laboratory tests of thresholds of narrow and broad-band noise perception and a review of the present literature. In order to assess the noise spectra measured in dwellings, the A10 characteristic has been accepted as the rating curve. Its levels, L, for one-third-octave bands are determined by the relation $L_{A10} = 10 - k_A$, where k_A is the A-weighting. Low-frequency noise is annoying when the sound pressure levels of the noise exceed the A10 curve and simultaneously exceed the background noise level by more than 10 dB for tonal noise and by 6 dB for broadband noise.

Introduction

Results of many tests indicate that low-frequency noise (LFN) penetrating into dwellings is more difficult to tolerate, and is perceived as more annoying, than other noise. Moreover, commonly used methods of noise assessment using a single-number index such as the A-weighted sound level are unsatisfactory. They do not correspond to the subjective evaluation of the low-frequency noise. That is why many countries[7,8,10] have introduced separate criteria for low-frequency noise assessment.

In Poland there has been a recent study on new criteria for the evaluation of low-frequency noise penetrating into dwellings. The final result of the investigation is the Building Research Institute Instruction No 358/98 entitled "Assessment of the low-frequency noise in dwellings"[6]. The instruction comprises methods and criteria for evaluation of the annoyance of the low-frequency noise coming into flats from appliances installed in a residential building or in its vicinity.

The paper further describes significant results of the tests performed as well as the general principles and the criteria for the noise assessment presented in the above-mentioned Instruction.

Foundation of determination of the limiting levels of LFN

A programme of study to determine the limiting levels of LFN contained:

- identification of the main sources of annoying noise in residential buildings,
- noise measurements in flats and objective and subjective evaluation of noise nuisance,
- medical inquiries about the effect of long-lasting low-frequency noise on human health,
- determination, under laboratory conditions, of the threshold values for low-frequency noise perception in silence and in the presence of masking noise, which approximates the background noise in flats in the daytime.

The results of the tests are discussed in publications[1–5]. The significant conclusions from the tests are as follows:

Measurement results

A result from the analysis of complaints about noise in dwellings is that most of them concern noise coming from appliances like pumps, transformers, fans and refrigerator units installed inside or outside the building. The measurement results[1,4] have confirmed that the noise from these sources was LFN containing components down to 16 Hz. Regular noise with infrasound components of significant levels was not observed in the flats investigated. At the same time, it was shown that, in many cases, noise at very low levels generally regarded as acceptable, was the subject of

complaints. So, in order to develop new criteria for the assessment of LFN and to define its acceptable levels, an epidemiological investigation was performed among those exposed to LFN in residential environments.

Results of the epidemiological investigation

The aim of the study was to evaluate the noise subjectively and to determine if a long-lasting exposure to LFN at low levels is a potentially important health risk for the dwellers. The investigation was performed by the Department of Epidemiology of the Medical Academy in Warsaw[2]. The method of questionnaire investigation, (inquiries) was applied to evaluate the state of health and subjective noise nuisance. The tests referred to adults (over 18) living in dwellings where LFN occurred from appliances installed in the building and at least one person from that flat complained about the noise nuisance (group tested, designated Group T). By means of the matching method each individual of Group T was matched with a person of the same gender, of similar age, living in the same block of flats in a dwelling with a comparable level of background noise but without the LFN (control group, designated Group C).

In spite of the relatively small group of the individuals examined (about 60 persons) explicit results from the investigation showed that:

1. LFN, even at levels approximating to the detection thresholds and not exceeding the acceptable values of A-weighted sound levels, is perceived as annoying or very annoying and creates a potential health hazard for the dwellers.
2. Among the individuals exposed to LFN the following symptoms testified to a worse state of health:
   - they more often defined their state of health as bad,
   - they more often declared heart ailments
   - chronic insomnia was more frequent.
3. Objective psychological tests among the individuals exposed to LFN revealed:
   - occurrence of features predestinating towards the so-called A type i.e. increased risk of heart infarct (Wrzesinski's test to examine a complex of behaviours and attitudes)
   - essential reduction in mood which may be both a cause and a result of a sickness process (Beck's test to measure the state of possible depression).
4. The exposure to low-frequency noise may create depressive states or intensify a degree of depression already existing, but of which the person is unaware (moderately serious and serious depression occurred among some individuals exposed to LFN).

Results of laboratory tests on detection thresholds of LFN

It was concluded from the LFN measurements and a public opinion poll, that LFN in flats may be annoying and may create a potential health risk for dwellers, even though the sound pressure levels in the low-frequency bands are in the region of the detection thresholds and only slightly exceed the background noise. As a subjective criterion of noise annoyance assessment it was assumed that noise which cannot be tolerated is annoying, even though it is barely audible or just perceptible in the room.

In order to objectively assess this criterion it was necessary to determine the values of SPL for which the LFN will be audible (perceptible) in residential rooms with average background noise. So, the next research stage, leading to the development of

Hearing loss in the UK

About 8% of men aged 55 to 64 and 4% of women the same age have severe hearing loss, often attributable to working for years in a noisy environment, UK researchers report. Overall, nearly half a million people in the UK – 387,000 men and 97,000 women – have either severe hearing loss or ringing in the ears, according to Dr. K. T. Palmer and colleagues of Southampton General Hospital, in a paper published recently in Occupational & Environmental Medicine. The hearing loss adds a significant burden to the public health system, one that would be significantly lifted if employers and employees followed hearing loss prevention strategies. "Our observations highlight the public health impact of occupational exposure to noise and the need for close attention to preventive measures," the authors write. Palmer and colleagues sent questionnaires to 22,194 adults, asking them about the number of years spent working at a noisy job, and whether they had hearing problems, persistent tinnitus, or wore a hearing aid. Persistent tinnitus is a condition marked by chronic ringing, buzzing, or whistling in the ear. The investigators found that 2% of people who completed the questionnaire said they had severe hearing problems, defined as needing a hearing aid, or having difficulty hearing people talk in both ears. Hearing problems were more common in men than in women, and the rate of problems appeared to increase as people aged, the report indicates. While only 1% of men and women aged 35 or younger had severe hearing loss, 8% of men aged 55 to 64 and 4% of women the same age had severe hearing loss. Men over the age of 35 who spent at least 10 years at a noisy job were almost four times as likely to have severe hearing problems as those who never worked at a noisy job. Based on results from the questionnaires, Palmer and colleagues estimate that 153,000 male and 26,000 female UK residents between the ages of 35 and 64 have hearing problems, and 266,000 men and 84,000 women have tinnitus as a result of their jobs. "The national burden of hearing difficulties attributable to noise at work is substantial," the authors conclude.

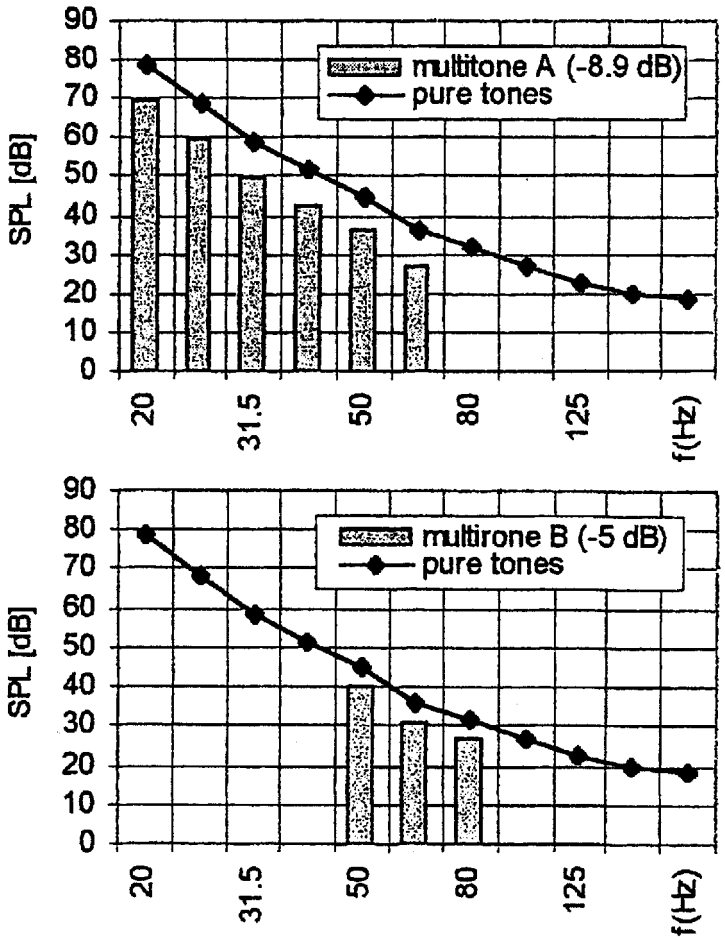

Figure 1. Comparison between the detection thresholds for tonal signals and multi-tones A and B in silence

new assessment criteria and a determination of permissible levels of the LFN in flats, was the laboratory investigation of detection thresholds of LFN.

The aim of the investigation was to determine:

- a difference between the detection thresholds of the LFN and tonal signals as given in the literature eg ISO 226,
- whether the noise may be audible if the sound pressure levels of their tonal components are below the detection thresholds,
- when LFN is audible against a background noise and by how many decibels the SPL of tonal components of noise should be above the background noise in order to distinguish the noise from background.

Laboratory tests were performed in an anechoic chamber of the Musical Academy in Warsaw[3]. The detection thresholds of tonal signals and five low frequency multi-tones with components in the range of 20 – 200 Hz, were determined in silence and in the presence of the masker (broad-band noise with a spectrum approximating to the background noise in flats in the daytime). The 2AFC method was used. Figures 1–3 present the selected results of the experimental study obtained for four auditors.

The following conclusions stem from the analysis of results of the investigation:

1. Noise of a multi-tonal nature may be audible even though the sound pressure levels of particular tonal components are below the detection thresholds. (Fig.1). Even

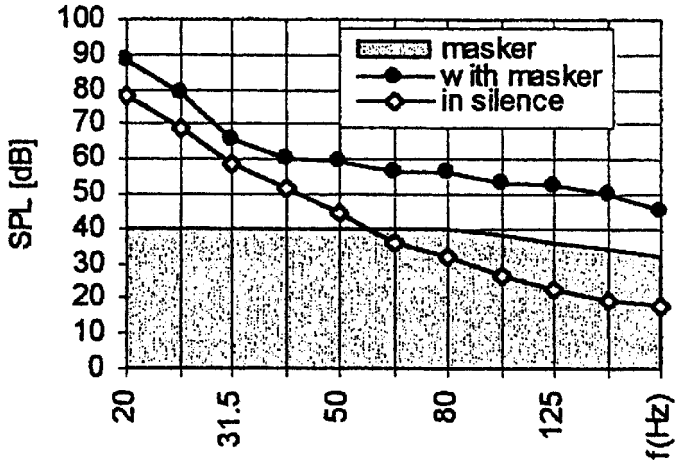

Figure 2. Comparison of levels of the detection thresholds for tonal signals in silence and in the presence of a masker

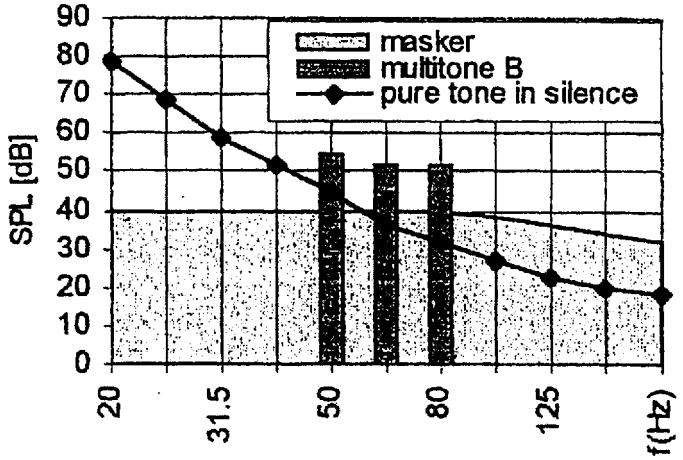

Figure 3. Levels of the detection thresholds for multi-tone B in the presence of a masker

noises with tonal components lower than the threshold of hearing by 10 dB may be audible.

2. The more low-frequency components in noise the more a decrease in its detection threshold.
3. In the presence of masking sounds, LFN of a tonal nature is audible when the SPL of particular tones is about 12–16 dB above the SPL of masking sounds (Fig. 2).
4. Noise comprising more tonal components is audible when the SPL of tonal components is 7–11 dB above the SPL of masking sounds. Also in this case, the more tonal components in the low-frequency range, the lower the levels of its detection (Fig. 3).

The results of the above investigation, together with results of the detection thresholds for infrasound (Watanabe and Moller[9]), and the permissible values of the LFN accepted in other countries: Germany[10], Sweden[7], Holland[8], as well as the accessible measuring equipment, were the basis for the determination of levels limiting LFN in residential rooms.

A fundamental criterion for low-frequency noise evaluation

The evaluation of low-frequency noise is based upon the results of sound pressure level measurements made in one-third-octave bands in the range 10–250 Hz during the presence of the noise source when it is absent (background noise).

To evaluate the noise, the characteristic one-third-octave bands level, corrected with the A-weighting, was given by

$$L_{A10} = 10 - k_A \qquad (1)$$

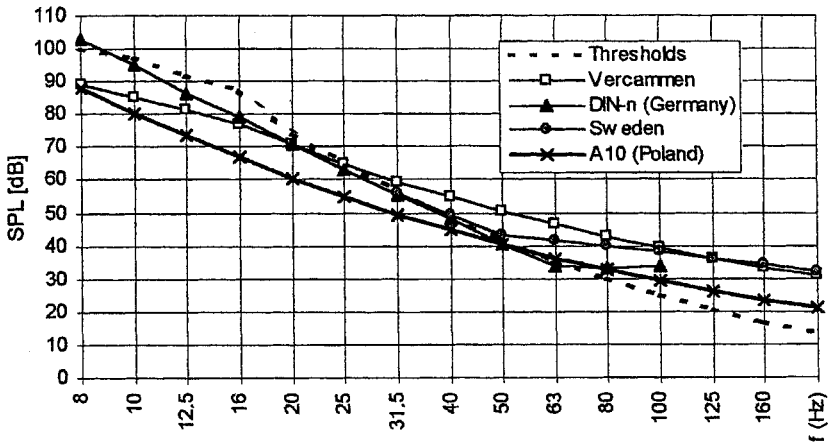

Figure 4. Permissible (recommended) SPL of low frequency noise inside dwellings proposed in different countries

where: L_{A10} is the measured sound pressure level in one-third-octave bands,
k_A is the values of the A-weighting for the centre frequencies of one-third-octave bands.

This characteristic defines the limit of the recommended (safe) levels. It is denoted as A10 and corresponds to a curve of constant, corrected sound pressure levels L_{Af} = 10 dB. It means that, in practice, it can be evaluated from the A-weighted sound pressure level in one-third octave bands.

Figure 4 shows a comparison of the A10 characteristics proposed by Poland with curves representing the permissible (recommended) sound pressure levels at the low-frequency noise inside dwellings, suggested by other countries.

The characteristics described by relation (1) satisfy the following conditions:

1. The sound pressure levels at values lower than the values determined by this curve seem, in the light of the tests, not to be a danger for living environments, those at higher values may be already regarded as annoying;
2. The sound pressure levels determined by the A10 curve correspond to rather comfortable acoustical conditions in dwellings. Average levels of background noise at night for frequencies above 50 Hz are comparable with or lower than the levels determined by this curve. For lower frequencies they lie below this characteristic;
3. This characteristic in the frequency range above 80 Hz is similar to the isophonic curve of 10 phons, and it lies below the threshold curve for frequencies under 63 Hz;
4. For a spectrum, all of whose components in the range of infrasound frequencies (above 10 Hz) would lie on the A10 curve, the infrasound Level L_G = 83 dB;
5. For a spectrum, all of whose components in the range of audible frequencies (20 – 20000 Hz) would lie on the A10 curve, the low-frequency noise index $L_{FA} \simeq 21$ dB and the A-weighted sound level $L_A \simeq 25$ dB.
6. The A10 characteristic corresponds to the curve of equal corrected sound pressure levels, L_{Af} = 10 dB. It means in practice that the A-weighted sound pressure level in

one-third octave band is subject to evaluation;

7. The A-weighting characteristic is commonly known, so in many analyzers it is possible to read-out the spectrum corrected by the A-weighting. This makes it possible to carry out a rough assessment of the low-frequency noise hazard under conditions of field measurements.

It can be seen that the sound pressure levels, determined by the A10 curve, lie below the perception thresholds for frequencies below 50Hz and they are the lowest among the proposed ones, but it is known that the detection for pure sinusoidal signals differs from that for pulsating noise or broadband noise where many spectrum components occur. (The thresholds for multiple tone detection, established in laboratory conditions, were even lower than those for pure tones detection by 10 dB).

However, the A10 characteristic is not a sufficient criterion for noise assessment. The levels of the low-frequency noise detection also depend on the background noise level (masking noise). At night, the background noise levels in the range of low frequencies are usually below the A10 curve. In the daytime, the background noise levels are higher and lie between the A10 and A20 curves. So, in practice the sound pressure levels are greater for the annoying noise than those for the A10 curve, especially in the range of higher frequencies where the background noise level is greater. That is why it is necessary to take into account the background noise level in the noise assessment or actually the difference between the sound pressure level of noise and the background noise level.

In order to estimate the low-frequency noise it is necessary to determine:

- ΔL_1 – difference between the measured sound pressure level of noise and the sound pressure level determined by the A10 curve,
- ΔL_2 – difference between the sound pressure levels of noise and the background noise.

The noise should be regarded as annoying when the following conditions are simultaneously satisfied:

- $\Delta L_1 > 0$
- $\Delta L_2 > 10$ dB for tonal noise or $\Delta L_2 > 6$ dB for broadband noise.

Principles of low-frequency noise assessment

A two-stage assessment of low-frequency noise is recommended.

- preliminary evaluation (graphic assessment),
- appropriate evaluation (complete assessment).

The preliminary evaluation enables one to select a spectrum of the loudest noise among the spectra measured at the particular points in a room and permits determination of:

- whether there is a low-frequency noise in the room under examination,
- if it is advisable to perform the complete assessment.

The complete assessment is performed when the preliminary evaluation indicates the occurrence of low-frequency noise in a room. In the complete assessment, the difference between the values of a sound pressure level of noise and background is also taken into account. The assessment is of a computational character. It gives a numerical determination of values by which the

noise notes

Silent night

If the experts are right, people will sleep better, overall health will improve, children will have a chance to learn more and job performance will go up – all because Mayor Michael Bloomberg is putting the big ssshhh on New York City. In a targeted crackdown that could become a model for cities coping with mounting noise pollution, the mayor is putting a lid on the deafening din in 24 of the loudest parts of the city. Charting tens of thousands of noise complaints, the Police Department and the Department of Environmental Protection used the data to pinpoint where and what the problem is. In parts of Astoria in Queens and on Staten Island, the noise comes from motorcycles. In Greenwich Village and the Lower East Side it's clubs and restaurants, and in Brooklyn, cars with steroid-pumped sound systems and honking horns. Elsewhere in the boroughs, the list includes car alarms, barking dogs and effusive public drunkenness. Will it work? Who knows. What matters at this point is that noise has finally arrived on a major U.S city's agenda. Where New York leads, others will follow!

limit of the recommended levels is exceeded, as well as the background noise level, and states if the low-frequency noise in a room is qualified as annoying.

Preliminary (graphic) evaluation

The preliminary evaluation is carried out graphically, by putting together a noise spectrum (sound pressure levels in one-third octave bands) and the A10 curve of the recommended levels. If there are noise components in the frequency range 10 – 250 Hz at the levels above those determined by the A10 curve, then it may be stated that a low-frequency noise occurs in a room. So, it is necessary to carry out the complete assessment.

By means of the A10 curve a noise spectrum may be evaluated in a wider range of frequencies (above 250 Hz). The frequency range where the loudest components of noise spectrum exist can then be found.

The graphic assessment may be also carried out in field conditions, when the measurements are made with a real-time analyzer equipped with a filter to give an A-weighted noise spectrum. If there are components in the one-third octave bands in the range 10 – 250 Hz, whose corrected sound pressure levels exceed the A10 curve then the occurrence of low-frequency noise in a room is presumed (especially at night) and it is necessary to make an appropriate noise evaluation (complete assessment).

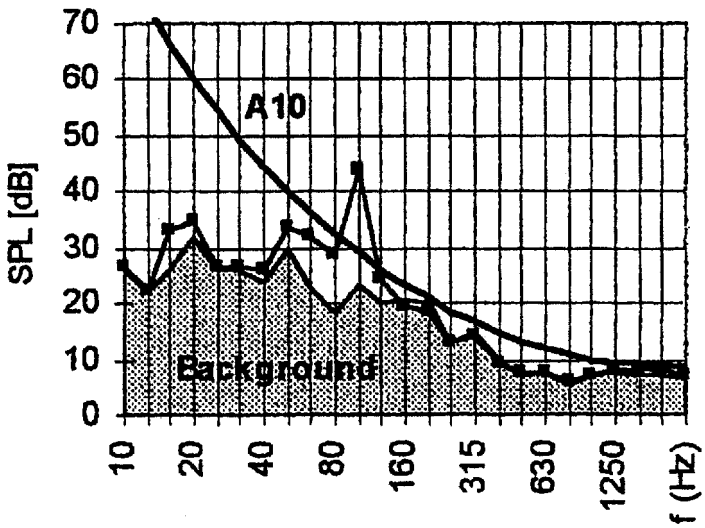

Figure 5. An example of graphic assessment of noise. A comparison between spectra of transformer noise, background and the A10 curve determining the limit of safe levels

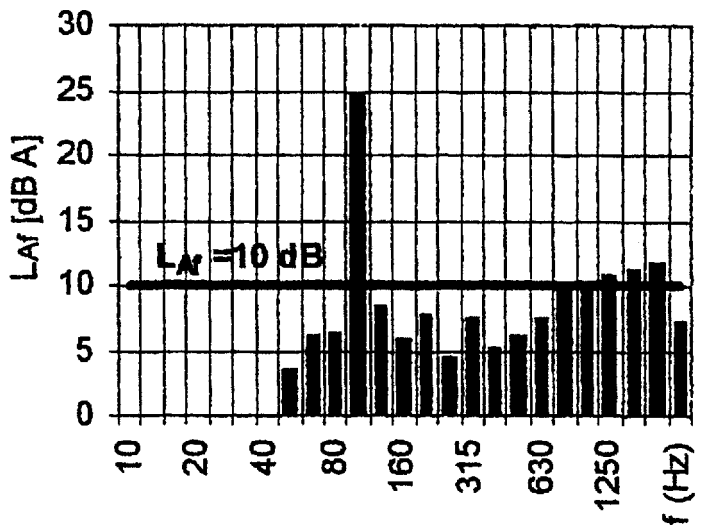

Figure 6. The A-weighted spectrum of the noise shown in Fig. 5. An example of the preliminary visual evaluation of low frequency noise by means of a real-time analyser

Table I. An example of the complete assessment of low-frequency noise

Frequency, Hz	L_T	L_H	L_{A10}	ΔL_1	ΔL_2
10	26.0	26.4	80.4	–54.0	0.4
12.5	22.1	22.2	73.4	–51.2	0.1
16	26.0	33.3	66.7	–33.4	7.3
20	32.0	34.7	60.5	–25.8	2.7
25	26.0	26.6	54.7	–28.1	0.6
31.5	26.0	26.4	49.3	–22.9	0.4
40	24.0	25.9	44.6	–18.7	1.9
50	29.6	33.6	40.2	–6.8	4.0
63	23.0	32.2	36.2	–4.0	9.2
80	18.5	28.7	32.5	–3.8	10.2
100	23.4	43.8	29.1,	+14.7	20.4
125	20.2	24.6	26.1	–1.5	4.4
160	20.5	19.3	23.4	–4.1	–1.3
200	20.2	18.6	20.9	–2.3	–1.6
250	13.0	12.9	18.6	–5.7	–0.1

Figures 5 and 6 illustrate an example of the graphic assessment of noise spectra. They present spectra of transformer noise and background noise measured inside a flat at night.

As may be seen, there are noise components exceeding the A10 curve in the range of low frequencies. It means that a low-frequency tonal noise occurs in a room and it is necessary to carry out the complete assessment of this noise.

Complete assessment of low-frequency noise

The complete assessment of low-frequency noise consists in the evaluation of the following differences:

- $\Delta L_1 = L_H - LA_{10}$ difference between measured sound pressure level in one-third octave bands for noise (L_H) and the appropriate sound pressure level for the A10 rating curve determined by formula (1)
- $\Delta L_2 = L_H - L_T$ difference between the sound pressure level for noise (L_H) and the background noise level (L_T)

It is necessary to calculate the above differences for all one-third-octave bands in the low frequency range from 10 Hz to 250 Hz.

Table I presents an example of the complete assessment of a noise. It compares the spectra of transformer noise (L_H) and background noise (L_T) which were measured in a dwelling (see Figs 5 and 6): It then shows the calculated ΔL_1 differences between the sound pressure levels of noise and the A10 curve as well as the ΔL_2 differences between the sound pressure levels of noise and background.

As can be seen in Table I this is a tonal noise with a 100 Hz component exceeding both the A10 curve and background noise by 14.7 dB and 20.4 dB, respectively. So, from this, the result is that an annoying low-frequency noise occurs in the room.

Conclusions

Limiting levels of low-frequency noise were accepted based on the results of this study as well as the test results of major world laboratories (especially with reference to the infrasound range). In the light of these tests the values

presented seem to ensure rather comfortable acoustical conditions in flats that do not constitute a potential health risk. In developing the assessment criteria, efforts were made to take into account the technical specifications of the measuring equipment and to adapt the criteria for performing preliminary evaluation of low-frequency noise hazard under field conditions.

REFERENCES

1. *Mirowska M. (1998). An Investigation and Assessment of Annoyance of Low Frequency Noise in Dwellings, J. Low Freq. Noise Vib. 17, (3), 119–126.*

2. *Mirowska M., Mroz E., Nidzinska-Mroz W. (1998). The Influence of Low Frequency Noise on Health of Exposed Inhabitants. Proc. of Noise Control 98. CIOP, AGH, Krakow-Poland, 289–294.*

3. *Fidecki T., Misdiewicz A., Zera J. (1997) Investigation of perception of low frequency noise at low loudness. The research report for Grant ITB No. 7T07B 043 Chopin Musical Academy. Warsaw, (in Polish).*

4. *Mirowska M. with team (1998). Investigation of noise, in frequency range from 2 to 125 Hz in building engineering, in order to develop the noise assessment criteria and a degree of noise annoyance. Grant No 7 T07B 043 supported by the Polish Committee for Research Projects (KBN). The final report. Parts I–V. ITB. Warszawa (in Polish).*

5. *Mirowska M., (1998) A study of perception thresholds for low frequency noises, Proceedings of the XXVI School of Vibroacoustic Control, 145–149 (in Polish).*

6. *Mirowska M. (1998) Evaluation of low frequency noise in dwellings. Instruction No 358/98 Building Research Institute. Warsaw (in Polish).*

7. *Persson Waye K., (1997) Estimation of Environmental Low Frequency Noise – A comparison of Previous Suggestions and the New Swedish Recommendation. Proceedings of the 8th International Meeting on Low Frequency Noise & Vibration. Gothenburg, Sweden, 135–141.*

8. *Vercammen M.L.S. (1992) Low Frequency Noise Limits. J. Low Freq. Noise Vib. 11 (1), 7–15.*

9. *Watanabe T., Moller H. (1990) Low Frequency Hearing Thresholds in Pressure Field and in Free Field. J. Low Freq. Noise Vib. 9 (3), 106–115.*

10. *DIN 45680:1997. Messung and Bewertung tieffrequenter Gerauschimmissionen in der Nachbarschaft.*

noise notes

Small fire in Malaya – no casualties

Incensed by his noisy housemate, an irate burger seller decided to silence him by throwing a Molotov cocktail into his room, Malaysian Police said. The small fire at a house in Lebuh Teik Soon was quickly doused by the housemate. Police have detained a 43-year-old suspect for arson. He is suspected of making the bomb with kerosene, and throwing it into his housemate's room.