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LOW FREQUENCY NOISE IN DOMESTIC ENVIRONMENT: MEASUREMENT RESULTS AND ASSESSMENT OF ANNOYANCE

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Abstract

The paper presents results of investigations of low frequency noise coming into dwellings from appliances such as fans, air-conditioners, transformers, refrigerator units, pumps installed in buildings. Noise at home, even at very low levels, nearby threshold, may be perceived as annoying and causes different health disturbances among exposed individuals. There are discussed the methods of evaluation of noise annoyance and the results of noise spectra measured in dwellings whose inhabitants complained about noise from appliances.

1. Introduction

Noise is danger not only when is loud and causes the damage of the auditory organ. It is also harmful when it is not danger for the auditory system, sometimes when it is barely audible, perceptible, but it affects people for a long time in their dwellings. One says about such a noise that it is annoying, disturbing but too little attention is given to its effect on health.

A more threatening to living environment is low frequency noise. It results from the fact that it propagates for long distances due to a large wavelength and it is slightly attenuated by partitions. This noise easily penetrates the interiors and even may be increased there due to resonances of partitions or rooms.

Investigations [3] and own observations have shown that about 70% of complaints, about noise occurring in dwellings, concerns the low frequency noise from appliances installed in or outside buildings, such as fans, air-conditioners, transformers, refrigerator units, pumps.

The assessment of low frequency noises by means of the single-number index as A-weighted sound level is insufficient and it does not correspond to subjective feeling of annoyance. In many cases the noise in dwellings is audible and perceived as annoying though the permissible A-weighted sound levels are not exceeded (25 dB - at night, 35 dB - in the daytime). That is why it is necessary to develop new assessment criteria, especially concerning the low frequency noises.

At present our Institute has been conducting the investigations on low frequency noise occurring in rooms of residential buildings. The scope of these investigations is to identify the sources of low frequency noise and develop the assessment criteria of their annoyance.

The paper presents the test results we have obtained until now.

2. Test methodology

Noise measurements are made in buildings whose inhabitants complained about the noise coming from the appliances installed inside and outside the building.
The measurements are carried out with the portable Bruel & Kjaer Analyser type 2144 or Polish Company SVANTEK Analyser type SVAN 912.
Noise spectra are recorded in one-third-octave bands in the range 2-10000 Hz in flats and at the source (if its identification was possible). Sometimes vibration of partitions is measured and for pulsating noise a multi-spectrum is determined for longer periods. The noise is classified as low frequency noise if there are components at adequately high levels for low frequencies in noise spectrum. Then, the case is analysed precisely and inhabitants exposed to such noise, are inquired by the co-operating with us physicians. (The frequency of 315 Hz was taken as the upper limit of low frequency noise, because the one-octave band of 250 Hz is still classified as low frequency band in building acoustics).

For each measured noise spectrum there are determined the following indices of noise assessment:

- L_A (dB) - A-weighted sound level,
- LF_A (dB) - A-weighted sound level of low frequency noise, calculated for frequency range 10-160 Hz, according to [5],
- P (phons GD) - loudness level, according to ISO 532 [2],
- S (sones GD) - loudness according to ISO [2],
- L_N (phons) - loudness level for the loudest spectrum component, calculated according to ISO 226 [1].

3. Procedure of low frequency noises assessment

In order to evaluate initially the measured noise spectrum and assess whether there is low frequency noise hazard in a dwelling, the trial was taken up to determine the limit of harmless sound pressure levels below which the noise is not danger to living environment and above which it may be regarded as annoying.

Establishing harmless levels it was assumed that infrasounds as well as audible noises are annoying if they are audible or perceptible. It results from the literature [5], that infrasounds may be harmful even if their levels are equal to, or slightly higher than threshold of perception. Basing on this assumption we should accept the thresholds of perception as permissible values. But with respect to the individual differences in the aural perception and the spreads of infrasound threshold values it is advisable not to use the average threshold values but the smaller ones relating to the perception threshold attainable by 90-95% the population. Such threshold values correspond approximately to the sound pressure levels lying on the G86 curve, that means on the curve determined by formula:

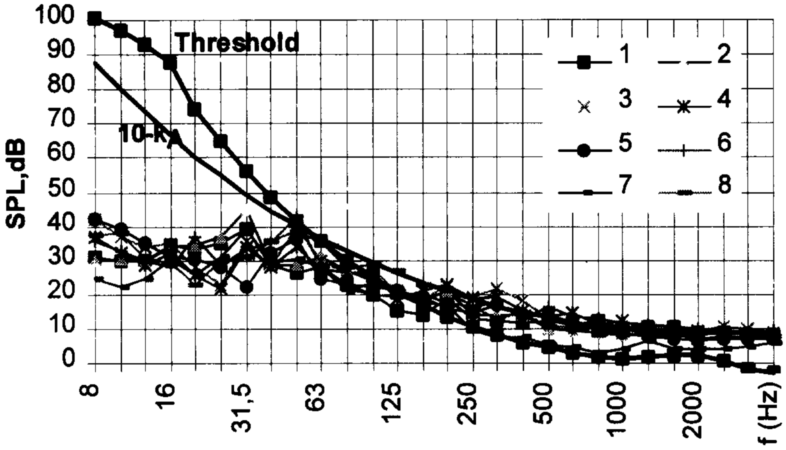
$$L = 86 - k_G \text{ (dB)} \qquad (1)$$

where: k_G - values of G-weighting characteristics

For audible sounds at low frequencies, a rough limit of not annoying sound pressure levels was established, basing on analysis of measurement results.

It followed from many studies carried out by our Institute [4] that in dwellings in which acoustic conditions were regarded as relatively comfortable, the A-weighted sound level of background noise at night was from 18 to 24 dBA, except the flats situated nearby the roads.

Then, the sound pressure levels of background in one-third-octave bands at frequencies above 50 Hz are usually between the threshold curve and the A10 curve and at low frequencies below 50 Hz they are smaller than threshold levels (look Fig.1).



	L_A	LF_A	S	P
	dB	dB	sones	phons
1	22,0	8,7	0,36	28,0
2	21,7	13,1	0,34	27,4
3	24,1	14,3	0,55	32,4
4	23,3	12,8	0,41	29,4
5	21,5	11,9	0,33	27,2
6	23,8	14,6	0,52	31,9
7	18,6	11,3	0,14	20,3
8	22,5	17,0	0,35	27,7

Fig.1. Typical spectrum of background noise in flats - at night, threshold curves and the proposed characteristics for noise spectrum assessment.

So, the A10 curve, determined for one-third-octave bands by relation:

$$L = 10 - k_A \text{ (dB)} \quad (2)$$

where: k_A - values of A-weighting characteristics,

was accepted initially as the limit of not annoying noise levels in flats at night..

According to IEC 651, the A-weighting network characteristics is determined in the frequency range 10-20000 Hz. The curve determined with the relation (2) may be used in this frequency range to the visual assessment of measured noise spectrum, as a rough limit of not annoying levels.

In spite of the high values of correction, introduced by the A-weighting characteristics for low frequencies, the loudness of individual tones at low frequencies and low sound pressure levels (which usually occur in dwellings) is overestimated by the A-weighted sound levels than by subjective indices such as for example phons. It illustrates Fig.2 in which the isophonic curves and the curves of equal A-weighted sound levels (dBA=const) are presented. The A10 curves, determined by relation (2) meets the following conditions:

1. sound pressure levels at values lower than the values determined by this curve seem (in the light of experiments conducted until now) not to be danger for living environment and those at higher values may be regarded as annoying,
2. this curve, in the frequency range above 80 Hz, is similar to the isophonic curve of 10 phons, and for frequencies lower than 63 Hz - lies below the threshold curve,
3. for a spectrum in which all components in the range of infrasound frequencies (above 10 Hz) would lie on the A10 curve, infrasound level $L_G \approx 86$ dB,
4. for a spectrum in which all the components in the range of audible frequencies (20 - 20000 Hz) would lie on the A10 curve, a value of the low frequency noise index LF_A=20 dB and the A-weighted sound level - $L_A = 25$ dB,
5. the A-weighting characteristics is commonly known, so in many analysers it is possible to read-out the spectrum corrected by the A-weighting; it enables to carry out the preliminary assessment of low frequency noise hazard under conditions of field measurements,
6. sound pressure levels, determined by the A10 curve, correspond to relatively comfortable acoustical conditions in dwellings ($L_A < 25$ dB).

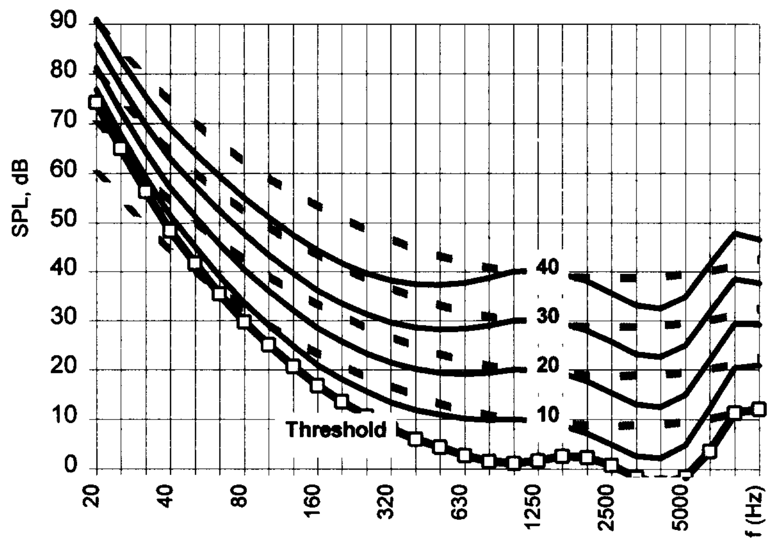


Fig.2. Comparison of isophonic curves (continuous lines) and curves of equal A-weighted sound levels (dashed lines).

Although the sound pressure levels, determined by the A10 characteristics, lie below perception thresholds for noises with frequencies below 63 Hz, one should notice that threshold values and isophonic curves were determined for pure tones and there is another perception of pulsating noises or noises with spectra comprising many components.

Low frequency noise may be perceived, especially by persons with high aural sensitivity, even if sound pressure levels of individual components are below perception thresholds, in result of the loudness summation of components within one critical band. Also pulsating noise is perceptible and regarded as annoying at sound pressure levels lower than the noise at steady level (constant in function of time)

Thus, it seems that the A10 curve assesses quite well the annoyance of noises at low levels, especially at night. This curve is plotted on graphs of the measured noise spectra as the characteristics of reference, and it is used to the preliminary visual noise assessment as well as to the determination of noise spectra components which considerably affect loudness and annoyance of noise.

4. Results of noise measurements in dwellings

It results from investigations of annoying noises which penetrate dwellings that noise coming from the equipment installed in or outside the residential buildings is more annoying than traffic noise. Inhabitants complain about noise coming from appliances even if their sound pressure levels correspond to the threshold of hearing while the traffic noise is tolerated at considerably higher levels.

In practice, it may be stated that if the noise from appliances is not tolerated then it may be annoying when it is audible or barely perceptible.

People mostly complain about the following low frequency noise sources: fans, air-conditioners, transformers, heat pumps, refrigerating units installed in shops, restaurants situated in residential buildings.

Infrasounds in dwellings at danger levels (SPL>75 dB) for frequencies lower than 16 Hz were not observed in the measurements made until now; even for flats placed near the roads.

Basing on analysis of noise spectra obtained until now, one may distinguish two types of low frequency noise spectra:

1. noise spectra in which single low frequency components occur apart from the subjectively louder broadband noise at middle or sometimes high frequencies,
2. spectra of tonal noises in which only single low frequency components occur (one, sometimes two).

A sound pressure level for low frequency components is much higher than background noise and it is often slightly higher than thresholds of hearing, especially in cases when the permissible A-weighted sound levels are not exceeded.

Figs. 3-6 present examples of low frequency noise spectra measured in residential buildings. There were chosen the flats in which the noise was audible and annoying although the A-weighted sound level did not exceed the permissible values.

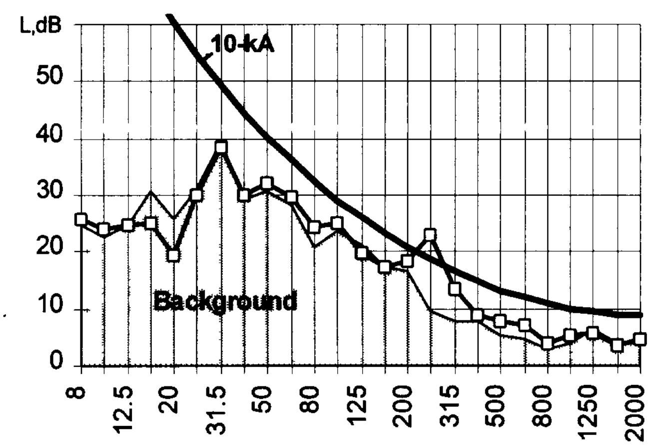
The calculated indices of noise assessment are given in the table close to the figures.

Values given in the tables do not indicate the annoyance of low frequency noise for none of mentioned, recommended to use, indices of noise assessment - neither A-weighted sound level being objective index nor subjective indices correlated with a feeling of sound loudness - loudness (sones GD) and loudness level (phons GD).

The values of these indices for noises regarded subjectively as annoying are comparable and even lower than the values obtained for background noise.

It results from the fact that indices are a sum of acoustical energy in the wide range of frequencies (10-20000 Hz - for A-weighted sound level, 25-12500 Hz - for loudness and loudness level). The same value of index may be obtained for a noise with clearly audible single tonal components with low background noise level, as well as for background noise at the slightly higher sound pressure level.

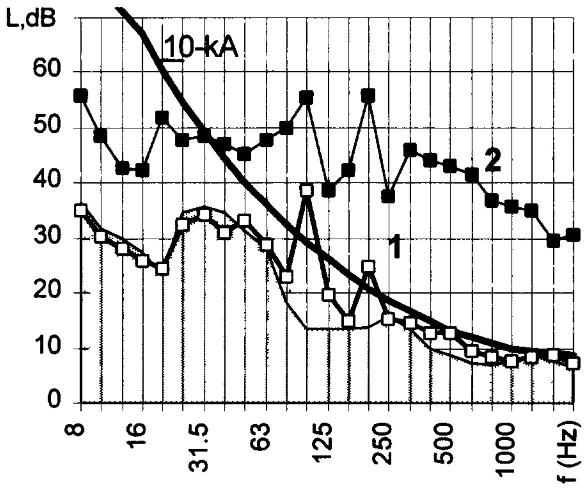
Figure 3 shows a noise spectrum of refrigerating unit, measured inside the dwelling over the shop at night. It is a case of annoying low level noise, barely audible at night. A single component appeared at 250 Hz in this noise spectrum.



Indices		Background	Refrigerator
L_{lin}	dB	44.5	44.5
L_A	dB	18.6	20.5
LF_A	dB	11.3	11.9
S	sones GD	0.14	0.26
P	phons GD	20.3	24.9
Ln max	phons	12.4 (4000Hz)	20.4 (250 Hz)

Fig.3. Noise spectrum of refrigerating unit, measured in a flat over the shop at night.

Fig.4 illustrates the spectrum of transformer noise measured in the transformer station situated on the ground floor of residential building and in the room adjacent to the transformer station. The transformer operates 24 hours and. noise measurements were carried out at night.



Indices		Background	Transf. (1)
L_{lin}	dB	58,2	53,3
L_A	dB	19,6	23,5
LF_A	dB	8,2	19,7
S	sones GD	0,28	0,43
P	phons GD	22,8	29,8
Ln max	phons	12 (2000Hz)	24 (100 Hz)

Fig 4. Spectrum of transformer noise in the room adjacent to the transformer station (1) and in the transformer station (2).

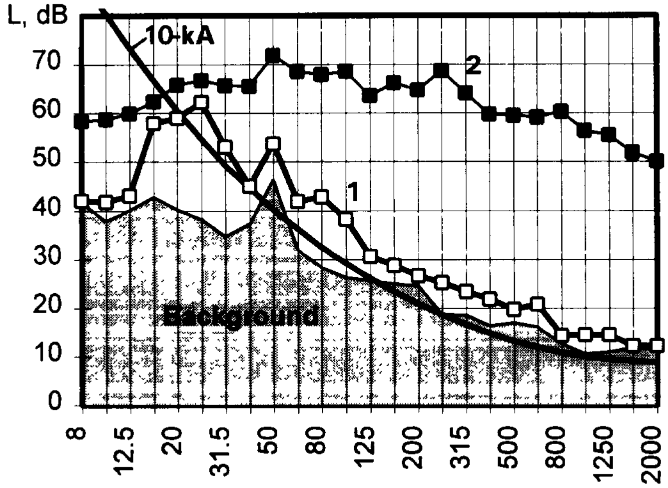
As may be seen from the figures, the transformer noise is a typical tonal noise. There are two dominant components - 100 Hz and 200 Hz in its spectrum and they determine the audibility and annoyance of this noise. Although the A-weighted sound level in transformer room is not high, (L_A=51 dB) and the noise penetrating the flats does not exceed the permissible value (L_A<25 dB), it is audible especially at night (in the daytime it is rather perceptible than audible).

Fans and air conditioners, installed in buildings, are other appliances creating low frequency noise hazard in blocks of flats. But opposed to transformers which are classified as typical sources of low frequency noise with respect to distinct components in this frequency range, fans produce broadband noise at high sound pressure levels, in the range of low and middle frequencies, diminishing with frequency increase.

However, in the spectrum of noise coming from fans to dwellings, the single distinct low frequency components (sometimes even at 16 Hz) often occur and they were not in the least dominant in the noise spectrum of fan or air conditioner itself. The occurrence of these components may be caused by resonances of partitions, rooms or standing wave formation.

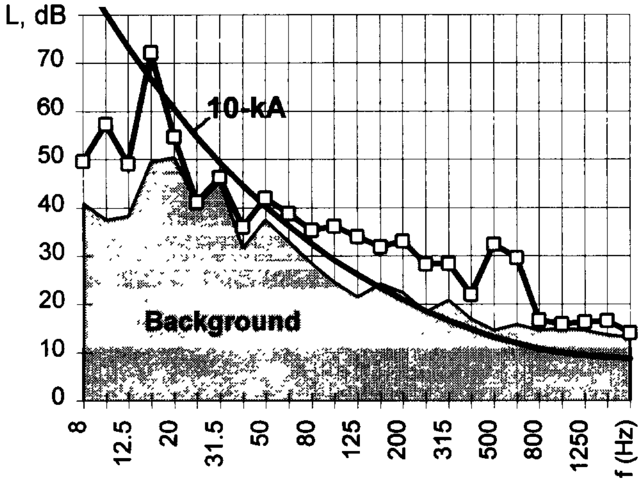
These components may affect the nuisance of noise though their loudness is subjectively low, often lower than the loudness of components from the range of middle frequencies which are masked by the background noise. Figures 5 and 6 show examples of such spectra for roof fans, measured inside the dwellings under fans in the daytime.

Fig. 6 presents a noise spectrum of the roof fan of a restaurant, measured in the daytime, in the dwelling situated on the top floor of the building, close to the fan system. It is seen from the figure that in this case the components from the 500 Hz range decisively influence the loudness and audibility of this noise. However, a distinct component of 16 Hz appears in a spectrum of this noise. Also the analogical component appears in spectra of vibration accelerations on walls, a floor and a ceiling of the room. Fig. 7 shows a spectrum of vibration acceleration measured on the floor of this room. Although the sound pressure level as well as vibration acceleration values lie below threshold values, it cannot be explicitly stated that these values do not create a noise hazard for the dwellers.



Indices		Background	Fan (1)
L_A	dB	24.5	33.8
LFA	dB	17.7	31
L_G	dB	49	56.7
S	sones GD	0.58	1.76
P	phons GD	33.1	48.2
Ln max	phons	19 (630Hz)	24 (50Hz) (630Hz)

Fig.5. Noise spectrum of roof fan measured inside the dwelling under the fan and on the roof near the fan in the daytime.



Indices		Background	Fan
L_A	dB	25.8	33.9
LFA	dB	15.9	24.5
L_G	dB	61.8	80.3
S	sones GD	0.73	1.7
P	phons GD	35.8	47.6
Ln max	phons	20.5 (320Hz)	36.4 (500Hz)

Fig. 6. Noise spectrum of roof fan measured in the room of the flat close to the fan system in the daytime.

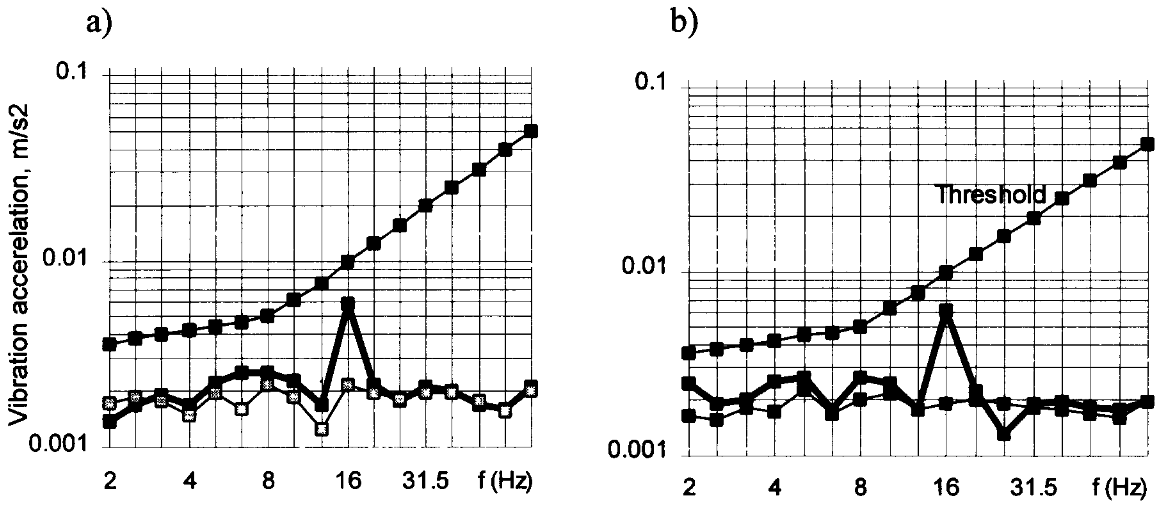


Fig. 7. Vibration acceleration on the floor (a) and on a wall (b) of the flat under the roof fan.

Although the sound pressure level as well as vibration acceleration values lie below threshold values, it cannot be explicitly stated that these values do not create a noise hazard for the dwellers.

Basing on the opinion poll carried out by physicians, within the confines of our research project, we want to obtain a reply to a question: „How does the low frequency noise (even at levels close to the perception thresholds) affects the health of exposed inhabitants?".

The permissible values of low frequency noise in dwellings will be established on the basis of medical and laboratory studies of perception thresholds for typical low frequency noise sources occurring in residential buildings.

5. Conclusions

The following conclusions result from the investigations of low frequency noise hazard in residential buildings carried out in our Institute until now:

1. Such appliances as fans, air conditioners, transformers, refrigerating units, installed in residential buildings create low frequency noise hazard for inhabitants.
2. Noise coming from these appliances is more annoying than that one from traffic and even at very low levels close to perception threshold it may be considered as very annoying and it may cause different disturbances in exposed dwellers.
3. Intensive vibration of room partitions may accompany the low frequency noise occurrence in a room at the same frequencies.
4. Currently applied criteria of noise assessment and determined values of permissible A-weighted sound levels do not correspond to subjective feelings of noise annoyance and it is necessary to develop new assessment criteria related to low frequency noise.
5. Until the new index of low frequency noise assessment will be developed, the whole noise spectrum has to be determined and assessed.
6. In order to assess provisionally the noise spectra measured in dwellings and to determine the possible low frequency noise hazard, the A10 characteristics may be accepted. Its L levels for one-third-octave bands are determined by relation $L = 10 - k_A$.
7. The development of new assessment criteria and new permissible values of low frequency noise assessment will be preceded by the investigations of noise effect on health and studies of perception of noise from appliances installed in residential buildings.

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