An Investigation and Assessment of Annoyance of Low Frequency Noise in Dwellings

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Appliances installed in residential buildings such as transformers, air–conditioners and freezers are often sources of low frequency noise. Although sound levels inside dwellings from these sources are low, the dwellers evaluate the noise as annoying. This paper presents the results of an investigation of annoying low frequency noise in dwellings. Measurement results are shown and methods of annoyance assessment are discussed.

Introduction

According to the current Polish Standard [4], the equivalent A–weighted sound levels of noise penetrating into dwellings should not exceed:

– at night

L_{Aeq} = 25 dB – from appliances installed inside and outside the building,

L_{Aeq} = 30 dB – from all sources together,

– in the daytime

L_{Aeq} = 35 dB – from appliances installed inside and outside the building,

L_{Aeq} = 40 dB – from all sources together.

But in order to assess the noise, its level has to be 3 dB higher than the background noise.

However, one finds more and more frequently that noise is audible in the dwellings although the permissible levels are not exceeded. The dwellers “feel” this noise and regard it as annoying. Most of all, it concerns the noise radiated by the equipment installed inside and outside the building. It was suggested that it might be due to low frequency noise. That is why the investigations were undertaken, in the Acoustic Department of the Building Research Institute, with the aim of identificating low frequency noise sources occurring in residential buildings and the development of assessment criteria. The investigations have been conducted within the confines of the research program financed by the Committee for Research Projects (KBN). The paper presents results of work which has so far been carried out and gives the directions of further investigations.

Scope and Methodology of Investigations

Noise measurements are carried out in the buildings whose residents complain about noise penetrating to their apartments from appliances installed inside and outside the building.

In many cases it concerns dwellings in which the Local Health Authorities had made measurements of noise and did not observe that permissible A–weighted sound levels were exceeded.

The measurements of noise are carried out with a portable Real Time Analyzer – B&K 2144 or Polish SVAN 912.

Noise spectra are recorded in one–third–octave bands in the range 2 – 1000 Hz in the dwellings close to the source (if its identification is possible).

For the preliminary assessment of the noise spectrum or low frequency noise hazard use is made of the harmless level limit curve (HLL) determined for one–third–octave bands from the formulae:

$L = 75 - k_G$ (dB) – for frequencies 4 – 16 Hz (1)

$L = 10 - k_G$ (dB) – for frequencies 20 – 10000 Hz (2)

Where k_G and k_A are the G and A frequency weightings respectively.

One defines also the other indices of noise assessment such as L_A, L_{FA}[5], sones GD and phons GD [2], Lφ [1].

If noise spectrum measured in the dwelling contains components exceeding levels determined by the HLL characteristics in low frequencies band – up to 250 Hz then the noise is qualified as low frequency noise and the case is examined with greater care. Sometimes vibration measurements on the partitions are carried out. The residents are also asked about noise.

The Chosen Results of Low Frequency Noise Measurements. Case Studies.

Most often the residents complain about the following sources of low frequency noise: fans, transformers, pumps for central heating and warm water, freezers installed in shops or restaurants.

Transformer stations situated in residential buildings are typical sources of low frequency noise. Figures 1 and 2 present examples of the noise spectrum measured in the transformer station.

Although the A–weighted sound level in transformer station is not high (LA< 65 dB) the noise penetrating into the room is audible in many cases and evaluated as annoying.

Figure 3 presents a noise spectrum measured at night, in one room of apartment adjacent to the oil transformer station (from Fig.1). The calculated indices of noise assessment in the apartment are given in the table.

As may be seen from the figure, there are two dominant components, 100 Hz and 200 Hz in the noise spectrum. They are considerably higher than a background noise but they lie below the isophonic contour 20. Although the permissible level is not exceeded (L_A = 25 dB, LF_A = 20 dB), the noise is audible in the room, especially at night (in the daytime it is more perceptible than audible) and is evaluated as annoying.

Not only the dwellings directly adjacent to the transforming station are exposed to transformer noise. In Figs. 4–5 are shown spectra of the transformer noise, measured in two rooms of the apartment situated over the transformer station on the second floor.

The transformer noise was clearly audible in all rooms of this two room flat (most of all in the bathroom), but the distribution of noise levels in rooms was not uniform (differences in sound pressure at 100 Hz, between the points in the living room, reached a dozen or so decibels, and the differences in the A–weighted sound level 0 up to 5 dB. In the case of this apartment the noise levels exceeded the permissible values.

The penetration of the relatively loud noise of transformer resulted probably from the lack of an expansion gap between the transformer compartment and the building construction (the transformers were mounted on rubber shock absorbers – maybe improperly). As a result of flanking transmission the noise was propagated all over the building (in the transformer station, L_A = 58 dB).

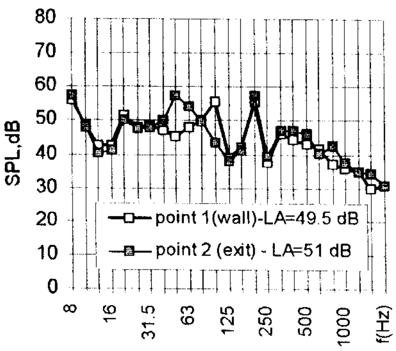


Fig. 1 Typical noise spectrum measuredin a station of oil transformersinstalledin the residential building

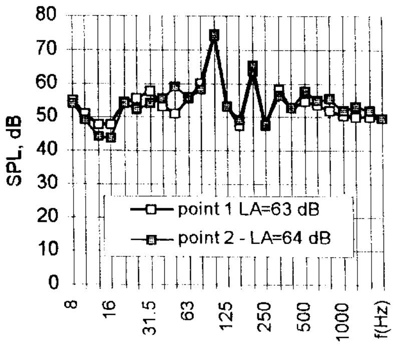
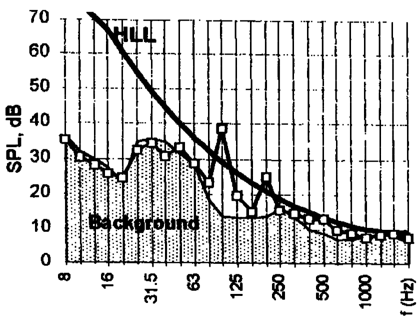
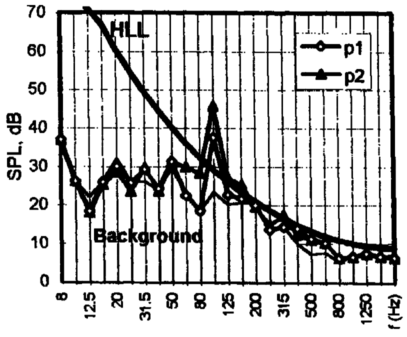


Fig. 2 Typical noise spectrummeasured in a station of drytransformersinstalled in the residential building



	background	transformer
lin	58,2	53,3
L_A	19,6	23,5
LF_A160	8,2	19,7
L_G	45,1	43,4
Lϕ	21,7	26,7
sones GD	0,28	0,43
phons GD	22,8	29,8

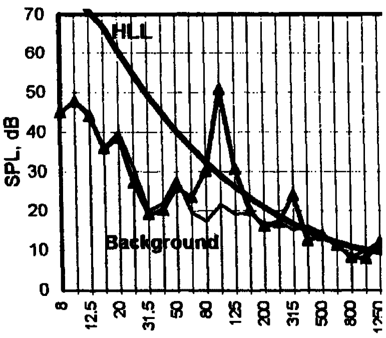
Fig. 3 Noise spectrum of transformer in a room adjacent to the transformer station.



	background	transformer point 1	transformer point 2
lin	41,8	40,6	46,4
L_A	20,6	22,6	27,7
LF_A160	12,6	19,3	26,9
L_G	48,5	41,9	40,8
Lϕ	22,6	25,5	33,3
sones GD	0,23	0,33	0,67
phons GD	23,7	27,2	34,8

Fig. 4 Noise spectrum of transformer in the livingroom of the apartment situated over the transformer station on the second floor.

Noise measurements in a flat on the first floor directly over the transformer compartment were not carried out, since its dweller did not complain about noise, he was not interested in noise measurements and did not allow the measuring team to enter the flat at night.

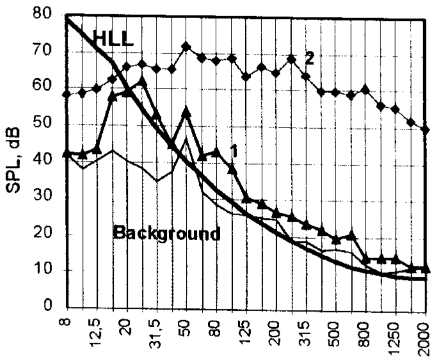


	background	transformer
lin	50,3	53,2
L_A	23,3	32,2
LF_A160	9,6	31,6
L_G	54,1	53,3
Lϕ	25,6	39,5
sones GD	0,46	1,11
phons GD	30,5	41,5

Fig. 5 Noise spectrum of transformer in the bathroom of the apartment situated over the transformer station on the second floor.

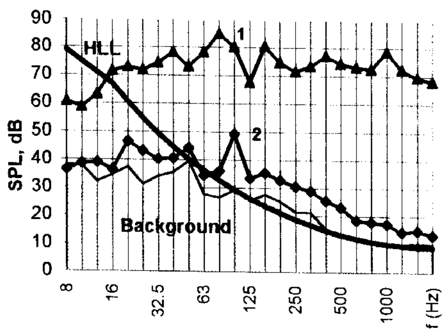
Fans are the other devices creating a low frequency noise hazard. But, the fans emit broadband noise, distinct from transformers which are classified as the typical sources of low frequency noise with distinct components in this frequency range. Fan noise is characterized by high sound pressure levels in the range of low and medium frequencies, diminishing with increasing frequency.

In assessment of subjective loudness (phons) the components from the medium frequencies range are the loudest. However, in the spectrum of noise from fans measured in dwellings also single distinct low frequency components often occur (sometimes even at 16 Hz). But these low frequency components are not in the least dominant in the noise spectrum of the fan itself. However, these components may have an effect on the assessment of fan noise annoyance although their subjective loudness is low. Figure 6 shows examples of such spectra for roof fans, measured inside the dwellings under the fan and on the roof near the fan in the daytime.



	background	fan 1 room	fan 2 roof
lin	67,8	71,0	80,4
L_A	28,4	30,3	67,7
LF_A160	23,7	28,1	56,1
L_G	59,6	70,4	77,7
Lϕ	31,2	33,0	76,2
sones GD	0,98	1,19	24,5
phons GD	39,7	42,5	86,2

Fig. 6 Noise spectrum of roof fan measured inside the dwelling under the fan and on the roof in the daytime.



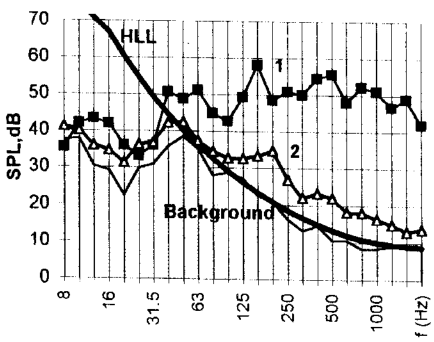
	source (1)	flat (2)	background
lin	90.6	54.8	50.2
L_A	83.2	33.8	24.5
LF_A160	69.2	31	17.7
L_G	84.8	56.7	49
Lϕ	89.9	40.4	28.3
sones GD	67.8	1.76	0.58
phons GD	101	48.2	33.1

Fig. 7 Noise spectrum of refrigerating unit, measured close to the unit in the cellar (1) and in a flat over the shop (2) at night.

It is difficult to understand how these components appear. They may result from resonances of partitions, rooms or standing wave formation.

Sometimes, a similar situation may also be observed in the spectrum of noise penetrating dwellings from freezers installed in shops or restaurants located on the ground floor of multistory residential buildings. (Fig. 7)

Many complaints concern noise from pumps installed in hydrotechnical systems compartments situated in cellars of residential buildings. Figure 8 shows the noise spectrum of the foundation pump measured inside the dwelling and in the hydrotechnical system compartment close to the pump at night.



	source (1)	flat (2)	background
lin	64,6	58,0	53,6
L_A	59,2	30,0	22,5
LF_A160	45,0	23,3	17,0
L_G	53,3	48,6	43,4
Lϕ	66,3	35,8	25,1
sones GD	12,4	1,16	0,35
phons GD	76,3	42,1	27,7

Fig. 8 Noise spectrum of central heating pump measured at night close to the pump in the hydrotechnical system compartment (1) and inside the dwelling over the hydrotechnical system (2).

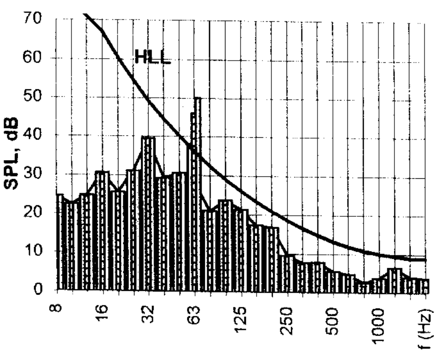
Problems of Annoyance Assessment of Low Frequency Noises

Our investigations show that annoying noises penetrating into apartments from stationary appliances, installed in residential buildings or outside the building are more annoying than, for instance, traffic noise.

Residents complain about noise at sound pressure levels corresponding to the threshold of hearing or slightly higher, but they may tolerate traffic noise with considerably higher levels. In practice, it may be assumed that noise from appliances may be annoying if it is audible or hardly perceptible.

Based on the analysis of collected spectra of noise penetrating into dwellings, two types of low frequency noise spectra may be distinguished:

1. Spectra of noises in which single low frequency components appear (as in Fig. 7, 8) apart from the subjectively louder broadband noise in medium and sometimes high frequency bands.
2. Spectra of noise in which only single low frequency components appear (one, some times two – as in Fig. 3).



	1	2	3	4
$L_{63\ Hz}$	28.3	38.0	46.0	50.0
lin	44.5	45.3	48.1	50.9
LA	18.6	19.4	22.2	24.9
LFA	11.3	14.3	20.3	24.0
LG	42.6	42.6	42.6	42.6
$L\phi$	20.2	20.5	23.5	27.4
sones GD	0.14	0.16	0.26	0.40
phons GD	20.3	20.9	25.0	29.1

Fig. 9 Spectrum of background noise at the level of 18,6 dB A (1) and theoretical spectra of low frequency tonal noise with sound pressure levels high than background noise: 2 – DL63 Hz = 10 dB, 3 – DL63 Hz = 18 dB, 4 – DL63 Hz = 22 dB.

The sound pressure level for these components is considerably higher than background noise and often slightly higher than the threshold of hearing, especially in cases when the permissible A–weighted sound levels are not exceeded.

In the case of these single low frequency components, no single–number noise assessment index, being a sum of acoustical energy in the whole of a broad band of acoustical frequencies, corresponded with subjective noise loudness (dBA, phons, and even LF_A).

We show for instance a theoretical example presented in Fig. 9, where tonal noise with a single component appears under conditions of normal background noise at night (18.6 dBA). Calculated values of indices of assessment for background and noise are given in the table.

As may be seen from this example, a noise with a sound pressure level higher by 18 dB than background noise (for one component) increases the A–weighted sound level by 3.5 dB but it is still not qualified as noise exceeding the permissible values. And this noise will be surely audible.

Therefore, it is necessary to find another index of noise assessment which will better respond to changes in sound pressure levels of single components in noise spectrum and determine the permissible values inside the dwellings.

Until the new index is developed the assessment of the whole noise spectrum will be necessary.

For a preliminary assessment of low frequency noise hazard in dwellings it is enough to use the characteristics based on the A–weighting network i.e. characteristics given by formula:

According to IEC 651 the A weighting network is determined in the range from 10 Hz, and in most of analyzers at least for the frequency range 6.3 – 20000 Hz. (In B&K 2144 Analyzer even from 0.4 Hz).

This characteristic best represents the feeling of annoyance to noise at low levels (up to 40 dBA). Average background noise levels at night (18 – 25 dBA) lie below this characteristic (see Fig. 10). Noises at sound pressure levels higher than background noise levels may be annoying. Especially low frequency noises may be audible due to relatively low background noise even if levels are lower than threshold levels, as a result of summation of acoustical energy in the whole critical band.

Fig. 10 Average background noise levels inside dwellings – at night, threshold curves and the proposed characteristics for assessment of noise spectrum according the A–weighting network, defined in B&K 2144 Analyzer.

We have not yet got a sufficient number of investigation results to allow us to determine the values of permissible sound pressure levels in dwellings. The accidental low frequency components appear, at different sound pressure levels, in noise spectra, which are measured by chance in dwellings, most often in the presence of louder, also annoying medium frequency noises. So, it is difficult to determine a correlation between annoyance and sound pressure level for each frequency band.

Currently, laboratory tests of low frequency noise perception are carried out. Their aim is to determine the perception thresholds of low frequency noise and the typical noises occurring in dwellings in the presence of masking noises i.e. under acoustical conditions which approximate to conditions inside the dwellings. Also a preliminary evaluation of low frequency noise influence on the state of health of residents exposed to this noise is in progress.

However, a determination of permissible low frequency levels requires broad medical research which could state if the long–term effect of a low frequency acoustical signal, at high sound pressure levels (above 80 dB but inaudible), may influence the health of exposed individuals.

Conclusions

The following conclusions result from our investigations of low frequency noise in dwellings:

1. Noise from appliances installed in residential buildings is more annoying than other kinds of noise e.g. traffic noise.
2. Noise penetrating into rooms may be annoying if it is audible or hardly perceptible, even if its level is comparable with the threshold level of perception.
3. The greater annoyance of low frequency noise is due to the occurrence of single components, in the noise spectrum at levels higher than background noise level, which are underestimated in objective assessment by means single–number "energetic" indices like dBA or phons.
4. Until the new index of low frequency noise assessment is developed, the noise spectrum should be evaluated i.e. respective frequency components of noise.
5. For preliminary assessment of low frequency noise hazard it seems sufficient to use the characteristics based on the A–weighting network given by a formula: $L = 10 - k_A$
6. A determination of permissible levels of low frequency noise in dwellings requires not only establishing thresholds of narrow–band noise perception, occurring in the presence of other masking noises. Also, the broad medical research has to be done in order to determine the effect of long–term low frequency acoustical signals (even if they are inaudible and imperceptible) at high sound pressure levels on the health of dwellers.

References

1. Grigo, Reiner: Measuring, weighting and calculating of low frequency noise with equal – loudness curves – theory of dB(F) method and examples. Proceedings of Low Frequency Noise Conference. Edinburgh. 1993.

2. ISO R. 532. Procedure for calculation loudness level.

3. Mirowska M.: Results of Measurements and Limit Proposal for Low Frequency Noise in the Living Environment. Journal of Low Frequency Noise & Vibration. vol.14, no.3, 1995.

4. PN–87/B–02151/02. Polish Standard. Building acoustics. Noise protection of apartments in buildings. Permissible values of sound level.

5. Vercammen M.L.S.: Low–Frequency Noise Limits. Journal of Low Frequency Noise & Vibration. vol.11, no.1, 1992.