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COMPLEX NOISE INDICATOR FOR NOISE MAPPING BASED ON THE EU WORKING GROUPS' AND POLISH RESULTS OF THE ANNOYANCE INVESTIGATIONS

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The Noise Directive 2002/49/EU includes obligations for noise mapping for agglomerations above 250 thousand citizens in the first step and later – above 100 thousand people. The noise map of the city consists of, at least, 4 layers of information. Each layer, in graphical form, represents different kinds of noise distribution, for traffic, railway, air and industrial noise.

One can ask how to assess the complex exposure for all noises from all layers of the map? The proposition of the complex index evaluation is developed in the paper. At first, it was assumed that the basic indicator for complex description of the acoustic conditions is the sum of the weighted noise exposures connected with the L_{DWN} level from different category of noise. The weights for the complex indicator were worked out on the basis of the results of the noise annoyance investigations, carried out by the European Working Group on health and socio-economic aspects, published in position papers (year 2002 and later).

However, one can ask if the European relation between noise levels and noise annoyance is correct for Polish conditions?

In the second part of the paper the results of the comparisons between EU's and Polish annoyance curves are presented. The curves were obtained as the correlation's product of the subjective assessments (query) and L_{DWN} levels measurements and calculations. These investigations in Poland were carried out as a part of the annually project called "Noise Monitoring System" (coordinated by Chief Inspectorate of Environmental Protection). Their background results are characterized in the paper.

Keywords: environmental acoustics, outside noise, noise indicator, long-term noise indicator, noise annoyance, L_{DEN} level, day-evening-night noise level, complex noise indicator, noise map, noise mapping, sum of noise effects, complex noise map.

1. Introduction

Pursuant to the requirements of the Directive 2002/49/EU [1], by mid 2007 the first phase of noise mapping should be completed. The first phase involves development of noise maps for the conurbation with the population above 250 thousand people and for major arteries, railway lines and airports. The completion of maps development (diagnosis of environmental noise status) is at the same time the point of departure for development of noise control action plan for a certain area.

The determination of the optimum noise control action plan given the limited technical and economic measures that are available in the first row puts in the foreground the question of adopting selection criteria for the areas covered by corrective actions. The essential, natural prioritisation criterion in the case in question should be the current quality status of noise conditions. The adoption of such criterion may, however, be a bit problematic.

The Directive 2002/49/EU requires the development of noise maps separately for four sources of noise: traffic (street) noise, railway noise, aircraft noise and industrial noise. If in the analysed area there is only one type of noise, the assessment of noise conditions and determination of priority lists is relatively straightforward. The things get more complicated when a certain area is exposed to various noise types for which separate noise maps are developed.

The carried out tests with their findings published in the European Commission position papers indicate that various types of noise sources cause various reactions of people (varied level of annoyance). Generalised results of these tests, with reference to the long-term day-evening-night level L_{DEN}, for traffic noise, railway noise and aircraft noise are shown in Fig. 1 (according to [2, 3]).

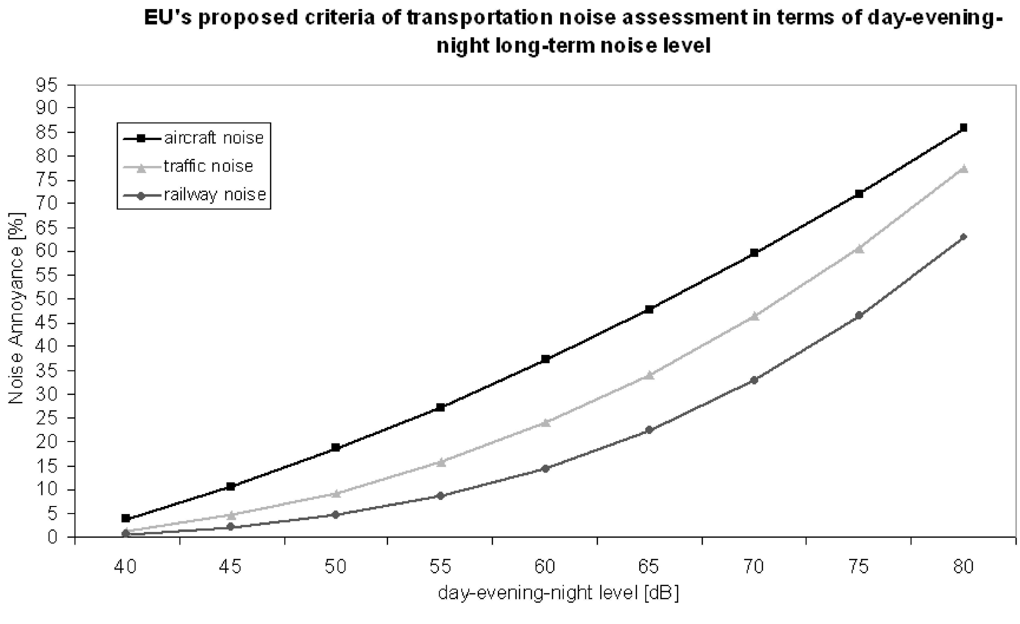

Fig. 1. Noise annoyance curves for L_{DEN} indicator of noise from various sources (proposed by the European Commission [2]).

Similar curves were also developed for noise conditions at night-time, with reference to the long-term night level L_N. These curves are shown in Fig. 2 (according to [4, 5]). Please note that these curves reflect only traffic (street) noise and railway noise. In accordance with the source test results [5], aircraft noise at night-time should be assessed using rather different techniques. Meanwhile with regard to industrial noise there is practically no grounded experience.

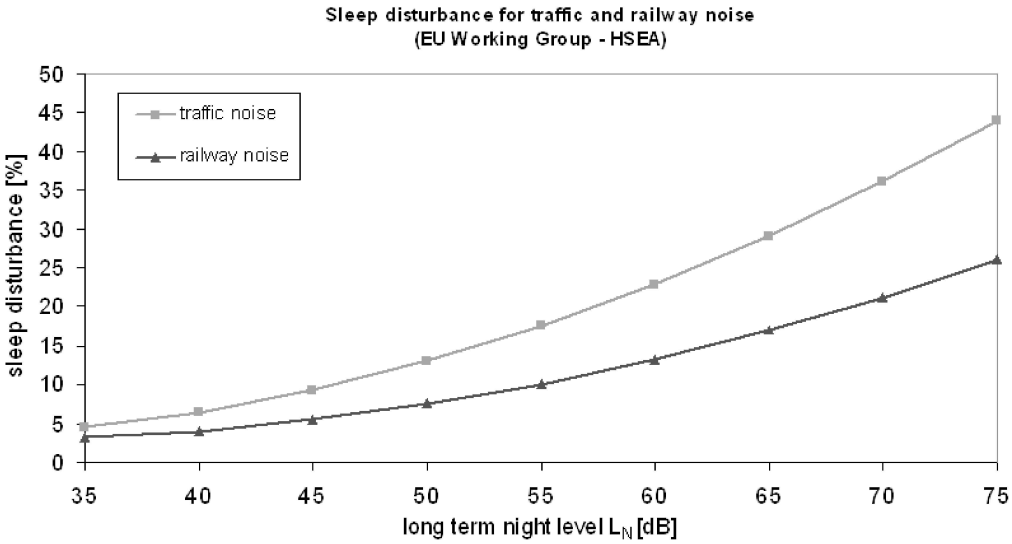

Fig. 2. Sleep disturbance assessment curves, for L_N indicator depending on the type of source of transport noise (proposed by European Commission [4]).

The analysis of curves presented in the figures shows explicitly that noise assessment by the population vary depending on the type of noise we deal with. This conclusion indicates also the fact that direct combining (by means of logarithmic sum) of noise levels from various sources is incorrect approach.

2. Complex indicator concept

The complex indicator concept is based on the essential assumption that the assessment of a certain type of noise should consider not only physical properties of sound, but also the specific nature of its impact on the population (inhabitants). The following formula was proposed for the complex indicator:

$$L_{\text{Complex}} = 10 \lg \left(\sum_{i=1}^{n} w_i \, E_i \right), \tag{1}$$

where n is the number of noise category given for consideration, E_i is the relative noise exposure, that means:

$$E_i = 10^{0.1L_{Ai}}, \tag{2}$$

L_{Ai} is the noise index for given category of sound; it was assumed in the paper that the L_{DWN} level is the basic indicator for single noise assumptions. w_i is the weight that value depends on the noise annoyance.

The options of using the indicator proposed by the above formula (1) depend on the determination of individual weights w_i.

Proposed determination of weights were developed using annoyance curves, specified in the Position Papers of the EU Working Group, that are presented in figures above.

Both day-time and night-time curves were examined with consideration given to constraints introduced by the authors.

The analysis of inputs referring to the night-time [5] led to the conclusion that noise impact at night-time is a very complex phenomenon and that various sleep disturbances depend on many characteristics of noise disturbances rather than only the value of long-term (annual) value level. This conclusion and no relevant correlation for other types of noise, apart from traffic noise and railway noise, indicated that at present it would make more sense to focus on average daily impact (on annual basis), proportionally to the day-evening-night value level.

The concept of determining weights w_i on the grounds of formula (1) is based on two premises:

- adoption of baseline (reference) noise exposure,
- determining weights in such manner that the impact i.e. annoyance determined for noise exposure to a certain source was, after weighting, equal to the annoyance for reference exposure. This can be expressed using the following formula:

$$E_{\mathrm{ref}} = w_k\, E_k(L_{\mathrm{DEN}k}), \tag{3}$$

where E_{ref} is the reference, relative exposure, $E_k(L_{\mathrm{DEN}k})$ is the relative exposure of the given noise source with the day-evening-night level equal $L_{\mathrm{DEN}k}$, w_k is the weighting factor.

It was determined in an arbitrary manner that the reference exposure will be the exposure to road traffic noise (most common type of noise in natural environment). Consequently in the formula (1) the value of weighting factor should be:

$$w_{\text{traffic noise}} = 1,$$

where $w_{\text{traffic noise}}$ is the weighting factor for road (street) traffic noise.

Meanwhile the values of weighting factors for the rail traffic noise and aircraft noise can be determined based on the curves shown in Fig. 3. These curves represent approximation of dependency polynomial developed on the grounds of runs shown in Fig. 1.

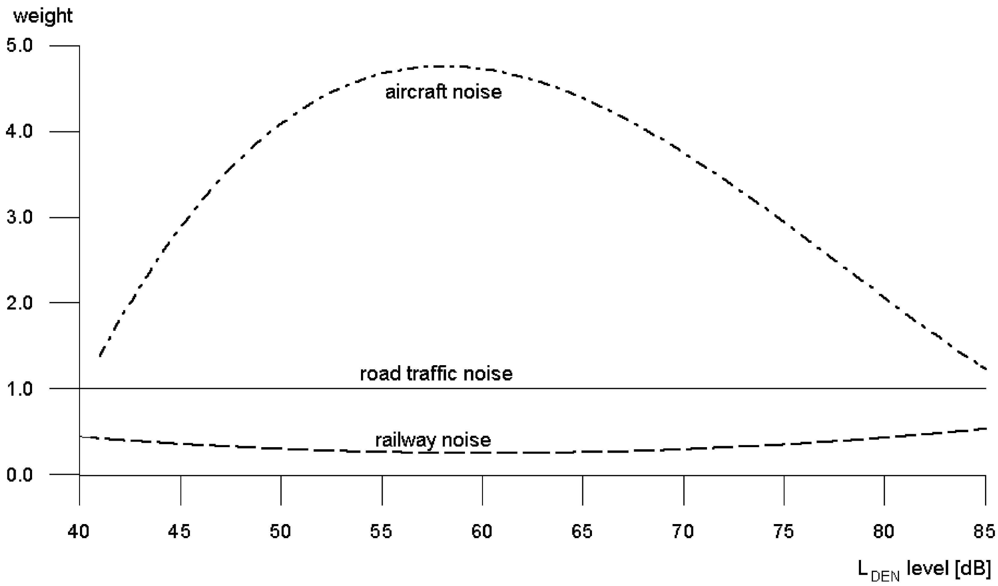

Fig. 3. Proposed weights w_i taken from the formula (1) as functions of L_{DEN} value level.

Pursuant to Directive 2002/49/EU the strategic noise maps should be developed for four basic environmental noise categories:

- road traffic (street),
- railway traffic,
- aircraft traffic,
- industrial noise.

The above concept proposes techniques for determination of complex indicator covering three types of noise. However, the ways for determining weighting factor for the industrial noise were not described. The reason for that is the absence of analogous curve, as shown in Fig. 1, for transportation noise.

To address the issue of industrial noise it might be helpful, at least initially, to use findings of surveys carried out in a few European countries [6], summed up in Fig. 4. It should be noted that highways noise and ordinary road traffic (street) noise is assessed differently. The noise emitted by the highways traffic is tolerated much worse than urban noise. Most probably the reason for that is different time characteristics of both acoustic signals. The acoustic signal generated by the express road traffic is in the form of monotonous drone with a more or less stable level and in terms of annoyance is classified similarly to the aircraft noise. On the other hand one can notice certain, perhaps not close, parallels to industrial noise, characterised by almost stable sound level and steady impact. Practically speaking such signals are much more irritating than e.g. street noise.

Given the above observations it can be preliminary assumed, until detailed results of tests of industrial noise impact are known, that its impact when designing complex

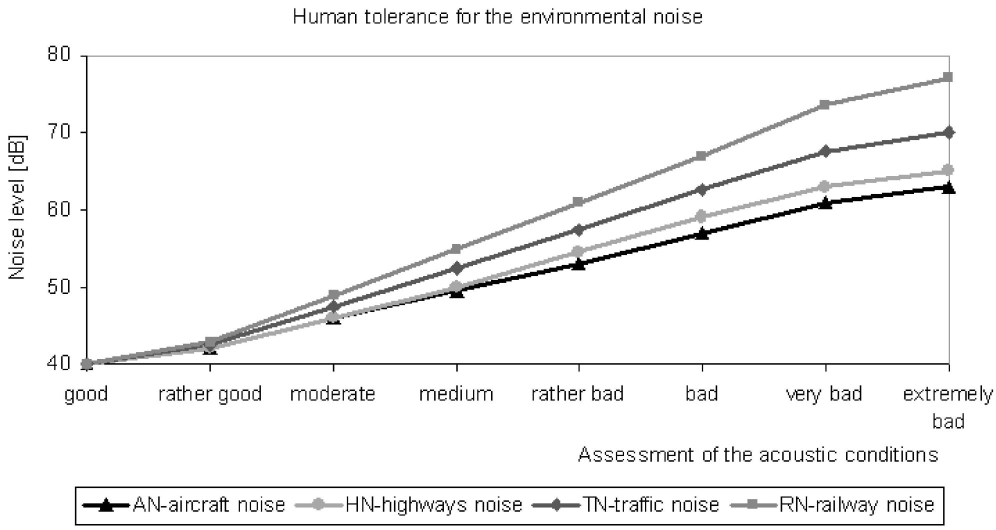

Fig. 4. Assessments of the different categories of noise, European survey [6].

indicator expressed by the formula (1), will be estimated according to weighting curve such as for the aircraft noise.

3. European noise annoyance curves vs. Polish test results

In the previous section, when designing weighting curves for noise exposures by sound source by tacit agreement it was assumed that source curves shown in Fig. 1 are appropriate for Polish conditions. Meanwhile such assumption does not necessarily have to be true. Consequently during the tests carried out in the previous years of the impact of noise in the cities on the evaluation of its annoyance, an attempt was made to revise the results of European tests. The tests were carried out in 2004–2005 as a part of the Environmental Monitoring Programme performed by the Institute of Environmental Protection [7]. The major objective included the tests of symptoms indicating worsening health condition of the population in correlation with sound levels with the use of self-assessment technique. The surveying technique was used in correlation with field noise measurements. The survey questionnaire was designed in such manner to take up an opportunity and evaluate not only the incidence of worsening health condition symptoms, but also – subjective assessment of noise annoyance.

The tests were carried out for the apartment buildings with many housing units. They included approx. 500 questionnaires (to be more precise 472 questionnaires) in 10 difference areas with varied acoustic conditions:

- from almost perfect conditions for the city of Warsaw size (sound level at night was $L_N = 43$–44 dB, whereas $L_{\mathrm{DEN}} = 55$ dB),
- for conditions hard to accept (sound level at night was $L_N = 72$ dB, whereas $L_{\mathrm{DEN}} = 79$ dB).

Data summing up the result category in our interest is shown in Fig. 5. It should be noted that assessments of acoustic conditions at the place of living were concerned with a few selected noise categories specific to urban environment:

- road traffic (street) noise – predominant,
- neighbour noise,
- community noise,
- noise from the technical equipment of the building.

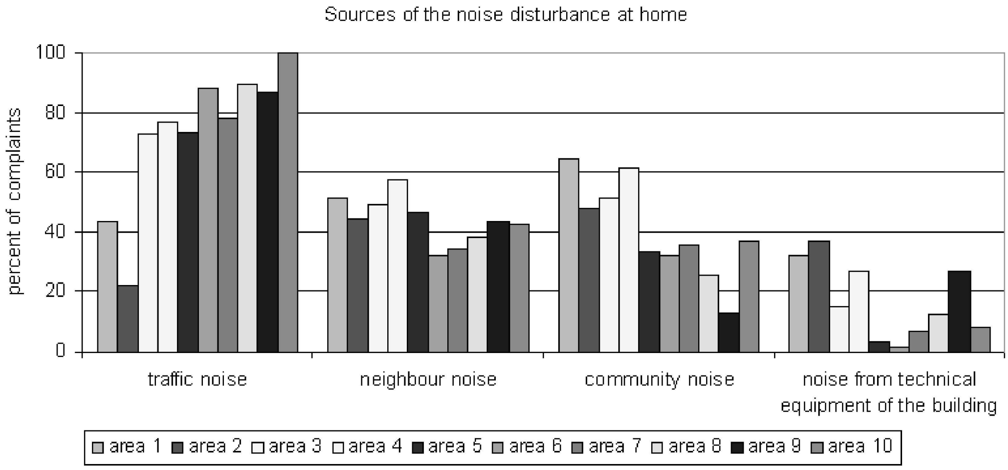

Fig. 5. Distribution of assessment of noise annoyance depending on noise type and origin.

Given the obtained results of the surveys and noise measurements a correlation was developed between noise disturbance at the place of living and long-term day-evening-night level. The analytical results are shown graphically (Fig. 6). This figure also shows:

- a curve proposed by EU Working Groups,
- a curve approximating the results of Polish tests.

It should be noted that good correlation exists for high sound levels. Meanwhile for lower sound levels the assessments stemming from the Polish survey are, by all means, more negative. This state of affairs is explained by the analysis of assessments not limited exclusively to the street noise. When the street noise become a lesser problem, the city dwellers start paying attention to other sources of noise including primarily neighbour noise and community noise (see Fig. 5).

Therefore another analysis was carried out with the aim to eliminate other noise disturbances excluding traffic noise. The results of analysis are presented in table below and presented graphically (Fig. 7).

The analysis of obtained results shows that assessments of the living conditions only with reference to street noise:

- show convergence with the European curve,
- are "smoother" for the range of lower sound levels.

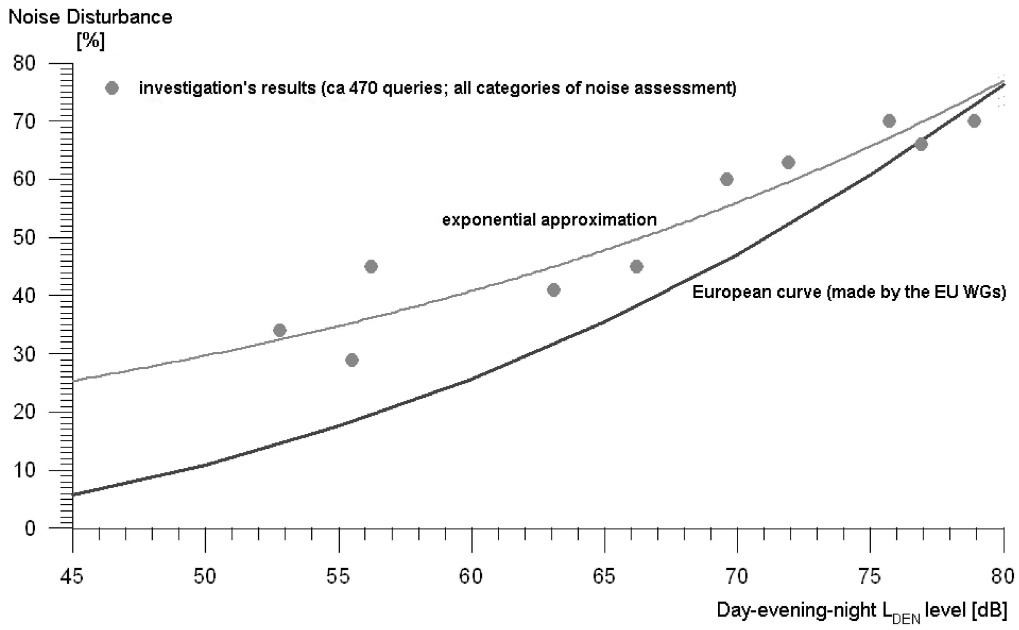

Fig. 6. Results of survey on noise disturbance in the cities along with approximated curve [7] at the background of street noise annoyance curve developed by EU Working Group.

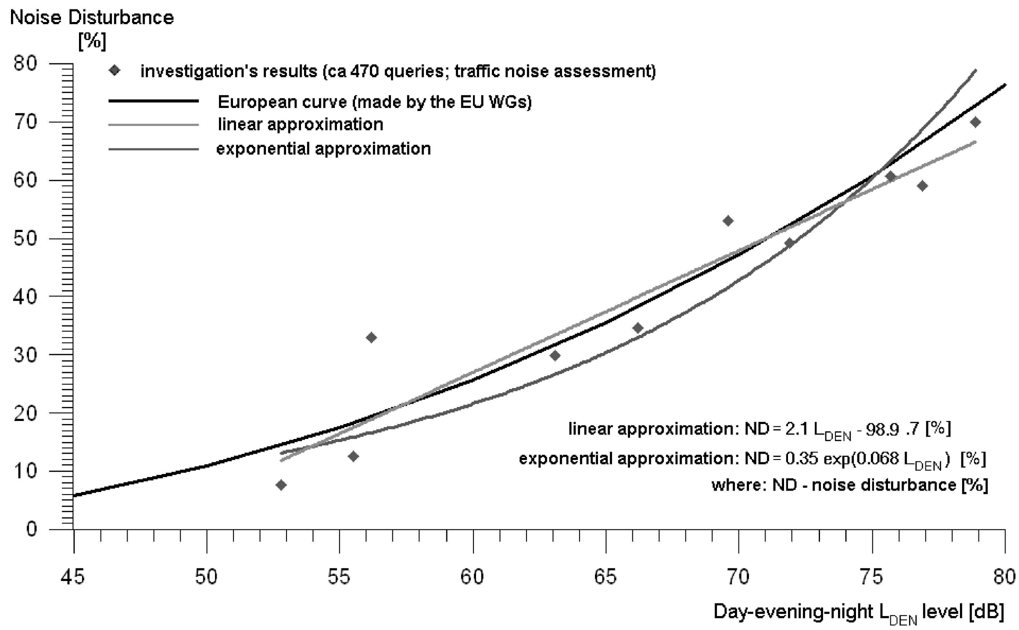

Fig. 7. The results of survey on annoyance of exlusively traffic noise in the cities along with approximation curves [7], at the background of the street noise annoyance curve developed by EU Working Groups.

Table 1. Results of street noise annoyance tests correlated with the value of day-evening-night sound level.

Area No	Percentage of negative assessments of traffic noise (annoyance)	L_{DEN} level [dB]
area 1	43.2	55.5
area 2	22.2	52.8
area 3	72.9	63.1
area 4	76.9	56.2
area 5	73.3	66.2
area 6	88.2	69.6
area 7	78.1	71.9
area 8	89.4	76.9
area 9	86.7	78.9
area 10	100.0	75.7

To sum up it can be said that (some conclusions from the paper [7]):

1. Practically speaking in all tested areas road traffic (street) noise is major nuisance.
2. Tabular data shows unambiguously that:
   - annoyance at the level of 1/3 (34%) is present at the level of day-evening-night indicator at the level of approx. 53 dB and long-term night indicator at the level of approx. 43 dB. These are values close to the criteria proposed by WHO: 55 dB and 45 dB.
   - the annoyance at the level of 50% (5 points on a 10 point scale) is registered at the level of 66 dB (L_{DWN}) and 57.5 dB (L_N). These values correspond to the levels recognised to be critical i.e. in the range > 65 dB, and for the night-time > 55 dB.
3. The obtained results also suggest a relatively high mental tolerance of the population of noise.
4. The tests were carried out for apartment buildings. In the housing units covered by tests the conventional window frames were predominant. It is likely that for the window frames more soundproof the street noise tolerance can be higher.

Additionally the results of the tests carried out in the scope described above confirm that European curves proposed by EU Working Group for road traffic (street) noise are adequate for the Polish realities. Thus they can be used for noise mapping purposes to determine complex environmental noise assessment indicator.

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