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Proposal of assessment of acoustic comfort – one of basic subcategories of the social aspect of sustainable housing construction*

Key words: assessment, sustainable construction, social aspect, health and comfort, acoustic comfort, used buildings

Introduction

According to the Regulation of the Minister of Infrastructure (of 12 April 2002 on technical requirements of building and their surrounolings Rozporządzenie 2002...) "the building and its related devices should be designed and constructed in such a way that the noise level to which users or people in their vicinity are exposed does not pose a threat to their health and enables them to work, rest and sleep in satisfactory conditions". Due to the subjectivity of these concepts, a number of standards have been developed that can generally be divided into two categories: standards specifying acceptable sound levels in rooms and requirements that building partitions must meet to ensure adequate protection against noise. Another group is made up of standards that are concern on the measurement of noise and acoustic insulation.

Based on regulations and standards, it is proposed to assess the perception of noise occurring inside the building and those coming from the external environment – detailed specification is shown on Figure 1.

The acoustic requirements that buildings should meet are determined by individual countries (i.e. Poland, Germany, Italy, France and the Netherlands) and

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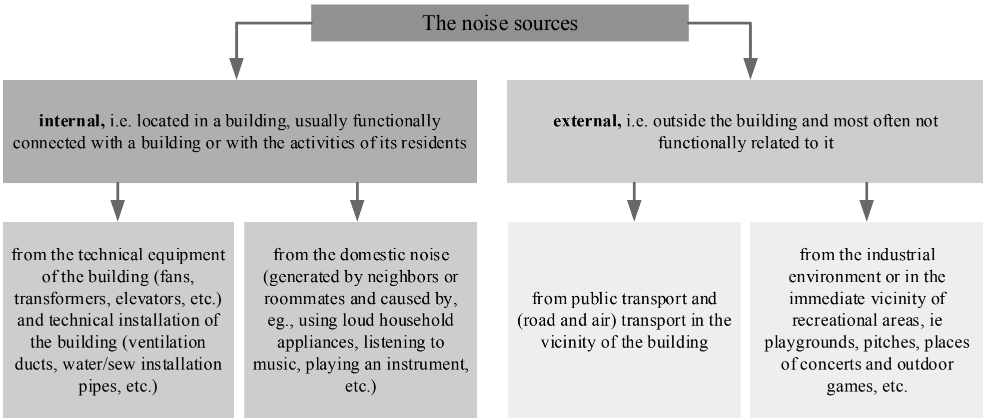

FIGURE 1. The noise sources occurring in residential buildings (based on acoustic lectures)

quite varied (i.e. both the method of calculation and the required values are set differently) depending on the economic opportunities of a the country. So far, it has not been determined what insulation should be so that it meets the expectations of all users: most often, this issue is determined on the basis of the percentage of satisfied residents (Nowicka, 2015).

Currently, the measurement methods, assessment parameters and calculation methods are determined at the global or European level, as part of the work of the Standardization Committees ISO/TC43//SC2 "Building acoustics" and CEN/TC 126 "Acoustic properties of building elements and of buildings". Implementation of standards EN/ISO into Polish standardization is dealt by Technical Committee PKN 253 "Architectural acoustics, which cooperates with these committees". In many European countries, more and more often, especially in the case of residential buildings, the so-called acoustic classes are/ have been introduced (differing from each other by 3 or 5 dB). Currently, in our country, also has been completed work on the new standard PN-B-02151-5:2017, which is to be used to determine the acoustic classification for residential buildings with a higher acoustic standard (Nurzyński, 2017).

Ensuring acoustic comfort is associated not only with the fulfillment of the standard requirements, but also with the subjective assessment of satisfactory acoustic conditions by users of the apartments. Noise assessed qualitatively allows residents to provide a sense of intimacy, peace and security. The consequence of using this concept is the need to determine sufficient acoustic insulation of building partitions to provide these conditions (Nowicka, 2015).

The authors propose to assess acoustic quality in residential buildings, being in exploitation phase, at two scales – both qualitative and quantitative. The first one will be based on the opinions of users of dwellings, the other is based on the new standard (PN-B 02151-5:2017) at the same time taking into account the classifications that exist in other EU countries. The proposals for evaluation are discussed in the following part of the article.

Airborne and impact sound insulation in a building

Sounds in buildings are propagated through the air and the material. Airbourne sounds are directly transmitted through the walls or leaks in these partitions as well as through the ventilation ducts. The source of airborne sounds is most often everyday noise (i.e. conversations, music, screams). Material sounds are caused by impacts on the walls, vibrations of devices or steps (Hassan, 2009). Their transmission is performed through elements of the building's structure (i.e. walls, slabs). To determine the insulation from airborne sounds inside the building, among others, are used standards, i.e.: PN-B 02151-3:2017; PN-EN ISO 16283-1:2014; PN-EN ISO 717-1: 2013; PN-EN 12354-1:2002. For the assessment of acoustic insulation of internal partitions, according to standards, the values of R'_{A1} are most often determined. The acoustic parameter characterizing the impact sound insulation of floors in the buildings is the normalized impact sound pressure level indicator $L'_{n,w}$ determined according to PN-EN ISO 140-7:2000. Table 4 of the standard PN-B-02151-3:2015 specifies the values of the permissible level of impact sounds, depending on the function of the building and the living quarters separated by the analyzed slab (Szeląg, 2015).

Numerous studies show that the sounds below 35 dB (i.e. the sound of water, the noise of fluorescent lights, the sound of arranged dishes in the kitchen, etc.) are not harmful to health, however they may be noticeable and annoying for some people. While the noise at the level of 35–70 dB creates conditions in which a person may feel tired, hinder speech intelligibility or disturbs in resting.

The most common ways to protect the living quarters from internal sources of noise is the use of appropriate building solutions in the construction of buildings and installation of special acoustic protections to reduce the noise of equipment and machines. From year 2018 partitions with appropriate acoustic properties should be designed in accordance with the guidelines of the standard PN-B-02151-3:2015.

The proposed acoustic classification of buildings is based on the assessment of such parameters as: sound insulation of internal partitions, sound level from the technical equipment in the building and reverberation time in the room. According to the subjective perceptibility of living sounds (Nowicka, 2015), both airborne and impact, appropriate ranges of values of acoustic insulation coefficients for acoustic classes were determined.

Classification proposal of noise insulation according to the subjective perceptibility of so-called living sounds presents Table 1.

Classification into acoustic classes depending on the sound level in the room coming from the building technical equipment is shown in Table 2.

In the acoustic assessment, it was also decided to include an evaluation of the reverberation time (Table 3). Reverb, associated with a large number of sound reflections from room boundary surfaces, is a phenomenon of gradual disappearance of sound energy after switching off the sound source. The size, geometry and acoustic absorption of room cladding materials influence the extension of the reverberation time. Interestingly, in

TABLE 1. Proposed division into acoustic classes of acoustic insulation of internal partitions (according to the subjective perceptibility of living sounds, based on Nowicka, 2015)

Type of noise	Acoustic classes of residential building (AQ – acoustic class)				
	E^{AQ}	D^{AQ}	C^{AQ}	B^{AQ}	A^{AQ}
Loud conversation/screams/loud music	clearly understood, onerous	understood well, clearly audible	partially understood, generally audible	incomprehensible, partly audible	incomprehensible, still audible/inaudible
Normal conversation/music	understood, clearly audible	partially understood, audible	incomprehensible, partly audible	incomprehensible, audible	inaudible
The sounds of users during the normal functioning	onerous audibility	clearly audible	audible	yet audible	
Children play		very clearly audible	clearly audible	audible	still audible/ /generally inaudible
Sound of footstep		clearly audible	audible	still audible	generally/ /completely inaudible
Required values of single-number indicators describing acoustic insulation [dB]					
Floor R'_{A1}* $L'_{n,w}$*	< 43 > 60	≥ 43 ≤ 60	≥ 48 ≤ 55	≥ 55 ≤ 47	≥ 62 ≤ 40
Walls between dwellings and between dwelling and the common parts in the building (without door) R'_{A1}*	< 43	≥ 43	≥ 48	≥ 55	≥ 62
Wall with door R'_{A1}*	< 38	≥ 38	≥ 41	≥ 44	≥ 47
Door to the dwelling with (without) separated hallway $R'_{A1,R}$*	< 30	≥ 30	≥ 35	≥ 40	≥ 45

*Indications should be measurred: $R'_{A1,R}$, $L'_{n,w,R}$ (for slabs and walls inside the apartment); R'_{A1}, R'_{A2}, $L'_{n,w}$ (for other partition associated with indirect transfer of sound).

TABLE 2. Proposed division into acoustic classes of acoustic insulation (according to the subjective perceptibility and of single-number indicators) for noise sources from installation devices generated inside the building (based on Nowicka, 2015)

Type of noise	Acoustic classes of residential building				
	E^{AQ}	D^{AQ}	C^{AQ}	B^{AQ}	A^{AQ}
Technical devices, i.e. fans, elevator Installations (e.g. water)	onerous audibility	clearly audible	audible	still audible	inaudible
The permissible sound level A [dB]					
Rooms $L_{A,eq}$**	> 40	40	35	30	25
Kitchen and sanitary rooms $L_{A,eq}$	> 45	45	40	35	30

*When the kitchen is open to the living room, the acceptable noise level can be taken as for the kitchen.
**Indication should be measured.

TABLE 3. Proposed division into acoustic classes (according to the subjective perceptibility and of single-number indicators) due to the reverberation inside the building (based on the new standard PN--B-02151-4:2015)

Type of noise	Acoustic classes of residential building				
	E^{AQ}	D^{AQ}	C^{AQ}	B^{AQ}	A^{AQ}
Reverberation in interstate corridors and stairwell	partial understanding of speech at closer distances	understanding speech at smaller distances	inaccurate speech understanding at larger distances	understanding speech at larger distances	very clear understanding of speech at long distances
The maximum reverberation times T [s] in the frequency bands 125; 250; 500; 1,000 i 2,000 [Hz]					
Staircase, communication corridor between residential premises*	> 1.6	1.6	1.3	1.0	0.6

*If it is possible to separate a corridor from a staircase (e.g. a door), both rooms should be measured separately and assume lower grade in the assessment

Poland, the standard regarding this issue was published for the first time in 2015. Reverb is important in public buildings, especially such as schools or collective residential buildings. It seems reasonable to take into account the measurement of the reverberation time occurring in the common parts of residential buildings.

Evaluation of building acoustic insulation against outside sounds

Sound insulation is a measure of how well the building structure (system) protects/isolates the room from noise coming from other rooms or from the surroundings – Figures 2 and 3. Acoustic insulation from air sounds corresponds to the difference in the sound pressure level on both sides of the barrier. Procedures for measuring acoustic insulation are presented, among others in standards: PN-EN ISO 16283-1:2014; PN-EN ISO 16283-3:2016 and PN-EN ISO 10140-2: 2011 to which the Regulation of the Minister of Infrastructure of 12 April 2002 is referred.

Required sound insulation of external walls and flat roofs should be deter-

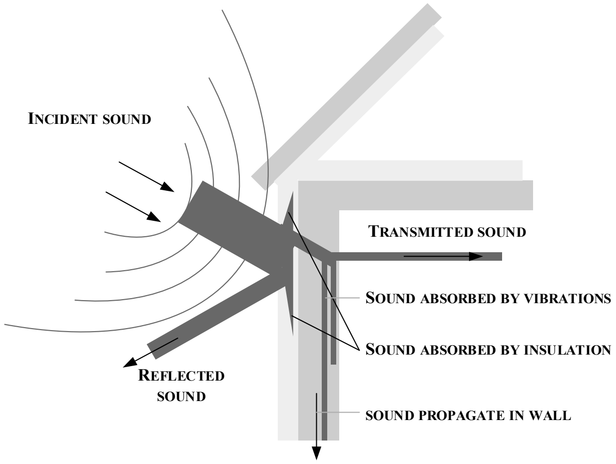

FIGURE 2. Transmission of sound energy through the outer partition (based on acoustic lectures)

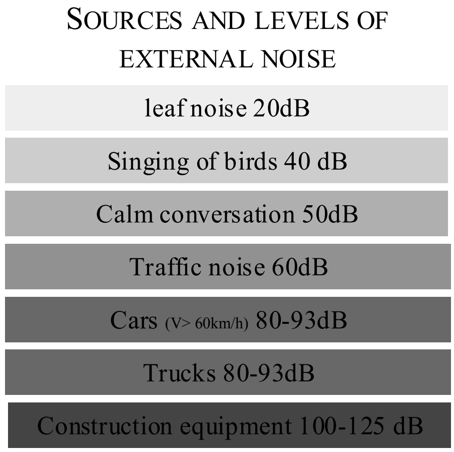

FIGURE 3. Examples of sources and noise levels generated in urban areas (own elaboration based on Skanska SA, 2016)

mined based on standard PN-B-02151-3::2015. It depends on the reliable level of external A sound, determined depending on the type of its source. To determine the level of reliable sound level, you can use acoustic maps for the area in which the building is located. Acoustic maps can be found on websites for all cities in Poland, e.g. Miejski System Informacji Przestrzennej Urzędu Miasta Krakowa[1]. These maps show the distributions of long-term average sound levels for the day-evening-night period LDWN and the night time LN measured by Voivodship Environmental Protection Inspectorate (WIOŚ) and they are to be used for future repair plans and prevention of harmful noise impact on urban residents. Using the information given in these publications sources of noise and their size/intensity can be determined more quickly.

The last element that composes a comprehensive assessment of the acoustic comfort of flats – one of the criteria of the social aspect of sustainable construction, concerns sources of noise generated outside the building and is presented in Table 4.

Determination of acoustic characteristics

Ultimately, the building will be classified to a given acoustic class by a two-stage procedure consisting in determining the acoustic class for each of the distinguished noise sources (presented on Tables 1–4) and then adopting this acoustic class, in which it obtained the lowest parameters.

What is important, the authors propose two ways to assess acoustic comfort, where the first is a qualitative assessment, which should be carried out through the implementation of surveys among users. Data obtained from the questionnaires that will result in the classification of the building to the E^{AQ} or D^{AQ} class should be a contribution to conducting *in situ* research (the second way). Measurements, that confirming the results of the classification, are informed of the need to take steps to improve the acoustic parameters in the examined building.

For the evaluation characterizing the acoustic comfort of used apartments described by two criteria: K_{331} (sound insulation against impact and airborne from inside of the building) and K_{332} (acoustic nsulation against sounds from outside the building), it is proposed to take a five-level discrete scale, with the following levels: 5 – high (very good) degree of insulation; 4 – good degree of insulation; 3 – sufficient degree of insulation; 2 – low degree of insulation; 1 – unacceptable level of insulation (Table 5).

Procedures used to improve the acoustic comfort

Currently, in newly built residential buildings, developers often use the system solutions proposed by the producers. The use of this type of solutions carries enormous benefits thanks to the acoustic parameters tested by the manufacturers (Stowarzyszenie na rzecz Lepszej Akustyki w Budynkach, 2017).

[1]Miejski System Informacji Przestrzennej Urzędu Miasta Krakowa, http://mapa-akustyczna.um.krakow.pl:280/mapa_k/mapa.php.

TABLE 4. Proposed division into acoustic classes classes (according to the subjective perceptibility and of single-number indicators) for noise sources from the outside of the building (based on Nowicka, 2015)

Type of noise	Acoustic classes of residential building				
	E^{AQ}	D^{AQ}	C^{AQ}	B^{AQ}	A^{AQ}
Public transport, i.e. buses, trams, train	clearly understood, onerous, can cause damage to health	clearly audible	audible	still audible	generally/ /completely inaudible
		very clearly audible	clearly audible	audible	still audible/ /generally inaudible
Medium speed car traffic, highways					
Air traffic*					
Screams/music	clearly understood, onerous	understood well, clearly audible	partially understood, generally audible	generally incomprehensible, partially audible	incomprehensible, still audible/ /inaudible
Recreational areas, public facilities, i.e. school, kindergarten		clearly audiblea	audible	still audible	generally/ /completely inaudible
Industry, installations					
The values of reference levels that should be obtained inside the building (These values refer to a reliable equivalent sound level A, external noise (PN-B-02151-3:2015) and are used to determine the minimum values of approximate indicators of the resultant acoustic insulation of external walls with windows)					
Day (6:00–22:00)** $L_{Aeq,wew,16h}$	> 45	45	40	35	30
Night (22:00–6:00)** $L_{Aeq,wew,8h}$	> 40	40	35	30	25

*For air traffic, 15 dB higher values should be used.
**L_{Aeq} should be measured or counted.

TABLE 5. Assessment of acoustic characteristics of residential buildings based on the division into created acoustic classes

Grading scale	Acoustic class of the building				
	E^{AQ}	D^{AQ}	C^{AQ}	B^{AQ}	A^{AQ}
5					+
4				+	
3			+		
2		+(–)			
1	–				

+ the requirements in the standards PN-B-02151-3:2015; PN-EN ISO 16283-1:2014; PN-EN ISO 717-1:2013; PN-EN 12354-1:2002; PN- EN ISO 140-7:2000 are met.
– the requirements contained in the above-mentioned provisions are not met standards.

Difficulty arises when we are dealing with an existing object, in which frequently used solutions have not been designed and verified in terms of their acoustic insulation. In such situations, when the noise is reported by users, it is recommended to conduct tests and determine the acoustic insulation of the building/flat. In case of obtaining bad acoustic parameters of partitions, depending on the diagnosed cause, the improvement is most often performed by:

- increase of the partition surface mass [$kg \cdot m^{-2}$] – the higher the mass, the better the noise suppression, but not the impact sound, (e.g. by adding/lining an additional massive layer of the partition);
- the use of additional layers of light sound-attenuating materials[2] (e.g. lightweight layered walls filled with a sound absorbing material);
- application of acoustic insulation at the partition contacts;
- making floating floors.

Conclusions

The article presents acoustic classification of buildings by testing the insulation of building partitions taking into account various sources of noise. Due to the determination of acoustic comfort for exploited residential buildings, it seems reasonable to use existing classifications (acoustic classes) to evaluate it. However, the acoustic classes proposed in the standard (PN-B 02151-5: 2017) only apply to objects with a higher acoustic standard, which, according to the authors, does not allow to classify many objects into any of the classes. Therefore, according to the authors, it was necessary to create individual proposal for assessment, which results from the specificity of a group of existing objects being analyzed. This classification is based on existing divisions operating in many EU countries and studies/articles (Szudrowicz & Niemas, 2011; Rasmussen, 2014; Nowicka, 2015). This division is proposed to be taken into account in the assessment of category "Acoustic comfort", which is one of the subcategories describing the category "Comfort and health" – one of the main components of the assessment of the social aspect of sustainable construction for residential buildings being in exploitation phase.

[2]Mounting the same insulation on a wall with a surface mass of 100 $kg \cdot m^{-2}$ will increase the noise attenuation by 12 dB, while on a wall with a surface mass of 200 $kg \cdot m^{-2}$ only by 6 dB.

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Summary

Proposal of assessment of acoustic comfort – one of basic subcategories of the social aspect of sustainable housing construction. The article presents a proposal to assess acoustic comfort as one of the subcategories characterizing the social aspect of sustainable construction. The authors, considering the actual values of acoustic indicators existing in residential buildings being in operation phase, proposed their own classification scale. At the same time, the authors refer to the guidelines contained in regulations, standards, publications, and their own *in situ* research and, in particular, to normative values in the newly published standard PN-B 02151-5:2017.

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