VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2024.2.10
Vibrations in Physical Systems, 2024, 35(2), 2024210

Noise testing of ventilation systems in teaching rooms on a laboratory scale

Artur NOWOŚWIAT, **Rafał ŻUCHOWSKI**, **Marcelina OLECHOWSKA**, **Michał MARCHACZ**

Silesian University of Technology

Corresponding author: Artur NOWOŚWIAT, email: artur.nowoswiat@polsl.pl

Abstract The article presents the measurement results of reverberation time, acoustic background and noise level of the tested ventilation installations in a teaching room. The research was carried out as part of the "Ventilation for schools and homes" project financed by NCBiR. The aim of the research project is to develop innovative ventilation systems dedicated to individual classrooms and apartments. The used solutions are intended to improve low air quality in schools and multi-family buildings while reducing the demand for energy necessary to heat them. For the purposes of the research, an actual-sized model room with various development options was built. The applied ventilation systems are to meet, in accordance with the imposed project guidelines, the requirements for an equivalent sound level not exceeding 40 dB. The conducted research allowed for a preliminary assessment of the acoustic quality of the room. The introduced solutions to increase the acoustic absorption of the interior allowed to obtain background acoustic levels of 20.8 dB. For the tested types of the operating ventilation, the equivalent sound level was 32.2 dB, 37 dB and 29.7 dB, respectively.

Keywords: ventilation noise, equivalent sound level, room model, ODEON.

1. Introduction

Room acoustics play Hygrothermal conditions play a very important role in the perception of verbal sound. The main parameter that describes the interior acoustics is the reverberation time [1], which is the parameter most frequently studied [2, 3]. The reception of verbal sound plays a very important role in school classes [4, 5]. Furthermore, people working indoors are constantly exposed to sound [6]. Conversations of people in rooms, loud industrial noise, or the constant hum of HVAC installations can be distracting [7], causing stress [8] or fatigue [9]. Hygrothermal conditions play a very important role in sound propagation in a room [10], which affect the reverberation time and the speed of sound wave propagation. The biggest indoor problem is the exposure of people to environmental noise [11], which is usually broadband [12, 13], and noise from technical building equipment. Another problem is the noise from fans or other mechanical means of air circulation [14, 15]. However, the choice of ventilation strategy for indoor air quality is of particular importance for schools [16]. The thermal environment has an impact on the health and satisfaction of school-aged children, as well as on their academic performance [17]. The use of mechanical ventilation usually results in higher ventilation rates and lower CO2 concentrations [18]. Furthermore, the problem of using mechanical ventilation is noise [19]. The sound spreads through the conduit, radiates into the room at the outlet and is a nuisance to people staying in the building [20]. Therefore, the author's team in this article investigated the noise from mechanical ventilation located both in living quarters and school classrooms. This article only attempts to present the results of preliminary research, which will be the basis for further research in 2023 and 2024.

2. Methodology

The work includes the study of two basic parameters that illustrate the acoustic quality of rooms and their equipment. The noise issue generated by the operation of installations related to the optimization of indoor air quality and the reduction of energy losses by exchanging air with the external environment was considered. For this purpose, the sound level inside the room was measured. Furthermore, the influence of reverberation noise was considered by examining the reverberation time in the room considered. It should be noted that the research methodology was based primarily on the principal guidelines (NCBiR). They mainly concerned ensuring that sound level measurements were made at six reference points located inside the room and ensuring good reverberation conditions inside (preparing the room for a series of tests, the reverberation time in the room was relatively low). The sound level tests were based, following the client's guidelines, on the methodology contained in the PN-B-02156: 1987 standard [21, 22]). The reverberation time measurements were based on the methodology contained in the PN-EN ISO 3382-2:2010 standard [23]. The measurements were carried out using the interrupted noise method and the impulse response method. Additionally, the measurement was supported by the Swept Sine technique. A detailed description of the research methodology was introduced in sections 2.3 and 2.4. The carried out research is summarized in the table below.

Table 1. List of the reverberation time and sound level measurements.

Date of measurement	Reverberation time			Sound level					
	ISO 3382-2			PN-B-02156-2 1987		PN-EN ISO 10052: 2021-12			
	Impulse response - gun shot	Impulse response - Swept Sine	Interrupted noise	L_{Aeq}	Back ground	$L_{Aeq,nT}$	Back ground	$L_{AFmax,nT}$	Back ground
2022_09_09	X	V	V	X	X	X	X	X	X
2023_03_03	X	X	V	X	V	X	X	X	X
2023_04_11	X	V	V	V	V	V	V	X	X
2023_04_12	X	V	V	V	V	X	X	V	V
2023_04_18	X	X	X	V	V	X	X	V	V
2023_05_08	V	X	X	2V *	V	X	X	2V *	V
2023_05_25	V	X	X	V	V	X	X	X	X

* measurements was done for two situations, before silencing air conditioning device and after silencing acd.

2.1. Research room

The research room was built in the laboratory building of the Faculty of Environmental and Energy Engineering of the Silesian University of Technology. Figure 1 shows the room with the sound source and measurement points located.

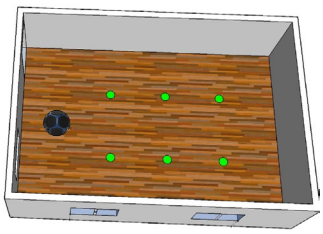

Figure 1. Test room with sound source and measurement points.

The room is adapted for a school classroom. The dimensions of the floor are: length 9 meters, width 6 meters. Room height 3.5 meters. The mechanical ventilation ducts from ventilation and air conditioning devices will be suspended from the ceiling. The arrangement of the room will make it possible to lower the ceiling to a height of 2.5 meters, and to divide the room into smaller areas simulating the layout of the apartment (bathroom, kitchen, room).

For the conditions presented above, test measurements were carried out of the interior reverberation (interrupted noise method and impulse response – rows one and two in table 1) and the acoustic background level (described in more detail in [24]). Having obtained quite long reverberation times (described in more detail in point 3 of the article), it was recommended to modify the room by introducing hanging curtains and elements increasing the acoustic absorption of the interior (as presented in Figure 2).

2.2. Measuring apparatus

The tests were carried out using a measuring system whose components meet the metrological requirements for instruments of accuracy class 1 [25]. The transmitting part of the system consisted of the following elements: loudspeaker column with spherical Norsonic radiation characteristics; pink and white noise generator with an amplifier by Norsonic; percussion signal gun. The receiving part of the system included the following elements: four-channel sound level meter SVAN 958, No. 15810, made by Svantek; 1/2" microphone, type SV22, 2 pcs, no. 4013121 and no. 0413114, by Svantek; 1/2" SV12L microphone preamplifier pcs. 2, no. 18899 and no. 18898, by Svantek; Svan 979 sound level meter with accessories; 1/2" SV22 microphone, No. 4013121 by Svantek; acoustic calibrator, type SV03A, no. 2524, made by Svantek,; PC with official SvanPC ++ software 3.3.31. The devices had type approval and valid calibration certificates. In addition, during the reverberation time measurements using the "Swept Sine" method, a measurement set based on a PC computer with REW V5.20 software, UMIK-1 measurement microphone No. 709-6266 with a calibration file was used as a sound source.

2.3. Reverberation time measurement

The reverberation time measurements were performed using both the intermittent noise method and the room impulse response method. The arrangement of measurement points and sound sources was based on the recommendations contained in the standard [23]. Preliminary measurements were carried out with the application of an approximate method using a single sound source setting and 6 measurement points (6 repetitions in each – for the intermittent noise method). The actual tests were performed in accordance with the precise method acc. [23]. The standard allows for the use of so-called intermittent noise or impulse response methods. Measurements were made using both methods, depending on the measurement possibilities in a given measurement cycle. Stimulation of the room was used by means of a sound impulse in the form of a pistol shot, respectively, for the impulse response method. The Swept Sine method was also used for comparison, where the signal that stimulates the room is a sinusoidal signal. In the case of the intermittent noise method, broadband noise was used, shaped in such a way as to obtain an approximately pink reverberant sound spectrum in the steady state in the range covering 1/3 octave bands with center frequencies of 50 ÷ 5000 Hz. The source produced a sound pressure level sufficient for the decay curve to start at least 35 dB above the background noise in the appropriate frequency range. The sound source for both methods was located in two points symmetrically located in both halves of the considered interior. For each position of the loudspeaker sphere and the location of the gun, six independent points for the location of the measuring microphones were assumed. Measurement points were placed at a height of 1.2 meters from the floor and at least 1 meter from the wall surface. The sound source in the form of a loudspeaker sphere was placed at a height of 1.5 meters from the floor. Pistol shots were fired from the hand. For the intermittent noise method, 6 repetitions of the measurement were performed in each of the independent measurement positions to minimize the influence of the randomness of the excitation signal. Based on the performed measurements, the reverberation time of the room was determined. For practical reasons, due to the difference that can be achieved in in-situ tests between the steady-state level of the entire sound pressure spectrum and the acoustic background level, the reverberation time T30 was adopted.

2.4. Sound Level Measurement

The sound level measurements were basically based on the methodology contained in the standard [21]. Furthermore, the methodology contained in the standard [22] was used. Noise measurements in the test room, according to the standard [21], were performed using the sampling method and recording elementary noise samples at the reference time, in accordance with the requirements of the standard [21]. The apparatus used for the tests had the following settings: frequency response A and C and time constant F (fast). Measurements were carried out during the day, determining the A sound level values for elementary noise samples in L_{Ai} (dB), and then, based on them, the equivalent noise level L_{Aeq} values (dB) were determined [21]:

$$L_{Aeq} = 10\log\left(\frac{1}{6}\sum_{n=1}^{6} 10^{0.1L_{AE,n}}\right), \quad (1)$$

where: n – measurement point, n = 1, 2, 3, 4, 5, 6; L_{Aeq} – equivalent sound level in the room, $L_{AE,n}$ – average sound level at particular points.

Due to the continuous nature of the operation of the equipment during the day, the time intervals tp required by the standard were distinguished, in which the sound level stabilizes and was caused only by the operation of the analyzed devices, which constituted the technical equipment. To determine the value of the L_{Aeq} equivalent noise level, the time intervals tp were assumed for the daytime period as 8 most unfavorable hours following each other. Based on the time t_p adopted, measurements were made using the sampling method for a single measurement time to, which was 60 s.

Measurements were made according to the assumptions of the standard [21]:

- with closed doors and windows,
- there were no more than 2 people in the room during the measurement,
- the location of the measurement points was in accordance with the standard requirements.

Figure 2 shows a photo taken during noise measurements in the room.


Figure 2. View of the location of measurement points P1 and P2 in the room.

For each of the six measurement points P1÷P6, two measurement repetitions were performed: n = 2 elementary noise samples. Based on the obtained measurement results, the study was supplemented with the values of indicators determined based on the standard [26]. This standard uses two indicators. The maximum sound level reference A is given by:

$$L_{AFmax,nT} = L_{AFmax} - k, \tag{2}$$

where: L_{AFmax} is the maximum sound level measured by the measuring device in a time interval of 30 s with the time constant fast. On the other hand, k is the so-called reverberation index, which is determined from the following relationship:

$$k = 10\lg\frac{T}{T_0}\ \ [dB], \tag{3}$$

where T is the reverberation time of the tested room, understood as the arithmetic mean of the averaged reverberation times for frequencies 500, 1000, 2000 Hz. T_0 is assumed to be 0.5 s for rooms of residential character (for other types of rooms, values according to the standard [27]).

The reference equivalent sound level A is given by:

$$L_{Aeq,nT} = L_{Aeq} - k. \tag{4}$$

Here L_{Aeq} is the equivalent sound level A and k is the reverberation factor as above. It is assumed, according to the current state of knowledge, that the indicator $L_{AF\max,nT}$ better corresponds to the subjective feeling of loudness and noise both in rooms and in the environment.

3. Results and discussion

The first test measurements of the reverberation time made during the preparation of the test room allowed us to set the right direction for the adaptation works. The results of these measurements are not included in Graph 3, however, it can be said that the average reverberation time was initially relatively long in the context of existing recommendations for this type of room. Initial measurements were made for two situations with and without a suspended ceiling. In the first case, an average of about 1.9 s was obtained, in the second, about 2.4 s. The recommended reverberation times for classrooms with a volume similar to that of the research room should be in the range of 0.6 s – 1 s. It is worth noting that the reality is often significantly different. For example, the reverberation times of the classrooms in one of the schools in Zabrze [26] can be given, that is, 125 Hz – 2.55 s; 250 Hz – 2.29 s; 500 Hz – 2.11 s; 1000 Hz – 1.94 s; 2000 Hz – 1.65 s; 4000 Hz – 1.19 s. Also, didactic rooms at the Faculty of Civil Engineering of the Silesian University of Technology significantly deviate from the preferred criterion. Reverberation times in these rooms are at a level that exceeds 2 seconds in the entire frequency band. Thanks to the preliminary measurements, the test room was adapted to increase its acoustic absorption. This allowed to significantly reduce the reverberation time of the interior. The results of the interior reverberation time measurements are summarized in the form of a graph below (Figure 3). It can be seen that the tests carried out on May 25, May 8 and April 12 fit well into the optimal reverberation time for such a room. As for the measurement methodology and the results obtained, the authors referred to in their conclusions.

Table 2 presents the results of elementary samples of noise level measurements and the equivalent average sound level without air supply (background noise).

Figure 3. Reverberation time measurement results for subsequent measurements: IR-GS (impulse response, gun shot); IR-SS (impulse response, swept sine); IN (interrupted noise).

Table 2. Summary of the results of the noise level measurement in the classroom room in points P1÷ P6 for measurement situations with the average level of the acoustic background (no airflow – acoustic background).

Date	Parameter	P1	P2	P3	P4	P5	P6	Parameter value	Average background
2023_04_11	L_{Aeq}	45.5	46.8	45.4	46.9	45.2	45.4	43.9	23
2023_04_11	$L_{AF\max,nT}$	45.5	45.4	45.2	45.6	44.3	45.2	45.5	23
2023_04_12	L_{Aeq}	44	44.9	43.5	42.4	38.5	38.4	42.6	21.2
2023_04_12	$L_{AF\max,nT}$	45.2	45.3	43.4	42.4	44.8	42.5	44.1	21.3
2023_04_18	L_{Aeq}	36.7	35.9	34.1	35.7	33.5	34.4	32.2	22.7
2023_04_18	$L_{AF\max,nT}$	38.5	37.4	35.9	37	35.8	37.1	34	22.7
2023_05_08	L_{Aeq}	40.2	38.8	38.1	37.2	36.2	36.3	38	21.9
2023_05_08	$L_{AF\max,nT}$	40.8	38.8	41	41.4	38.6	42.3	40.7	21.9
2023_05_08	L_{Aeq}**	38.5	37.3	37.1	36.5	36.2	35.7	37	21.9
2023_05_08	$L_{AF\max,nT}$	37.2	38.1	36.5	37.2	37.6	40.8	38.2	21.9
2023_05_25	L_{Aeq}	30.2	29.4	31.9	29.3	28.2	28.3	29.7	21.9

** measurements was done for two situations, before silencing air conditioning device and after silencing acd.

The initial test measurements of the tested device (shown in the installation in Figure 2b) showed a very high sound level of up to 50 dB. This was due to the simplified way of building the device. After the initial improvement in the soundproofing of the buildings, the noise emission level of the ventilation device was still high and averaged 43.9 for the equivalent level, while the standard A-weighted equivalent sound level was 45.4 dB, with an average background noise level of 23 dB. This is more than the 40 dB requirement assumed by the client for the equivalent noise level according to characteristics A. In connection with the above, attempts were made to further improve the development. Another measurement made on April 12 brought a decrease in the equivalent level of slightly more than 1 dB. Also, this test did not meet expectations (threshold of 40 dB). The next research attempt was made for the considered device after a fundamental change in the way of installation. Among others, more efficient soundproofing material. The results of April 18 met the expected requirement. The equivalent level reached 32 dB.

Then another type of ventilation device was built and installed. The results from 8 May turned out to be slightly worse than for sample 1. The level of equivalents was 38 dB, and after the correction of the building it dropped to 37 dB. The last sample was tested on 25 May with the best result. The equivalent level was 29.7 dB. It should be noted that the considered devices differed in execution, assembly, and installation method.

4. Conclusions

The article presents a model of a room with real dimensions built in the laboratory building. This model should reflect real school classrooms and, after appropriate adaptation (by adding elements of walls separating the rooms), also living rooms. For this purpose, preliminary measurements of the acoustic background and reverberation time were made in order to "tune" the model to real conditions and perform such acoustic adaptations so that the sound reception conditions correspond to real school classrooms. The second assumption of the research was to perform preliminary measurements of selected ventilation systems, which in the future will be modified to reduce noise emissions.

The following conclusions can be drawn from the presented research:

- The reverberation time of the considered interior has little impact on the noise levels obtained if it remains within the range indicated for the given type of room.
- The shift in the whole spectrum between the measurements on April 11 and 12 results from the increase in acoustic absorption of the interior at that time by additional soundproofing materials. Reverberation time tests using impulse response methods gave more similar results. Under specific conditions, the measurement of the reverberation time using the intermittent noise method may differ from the measurement using the impulse response method. In the present case, this discrepancy is visible for low frequencies. This may be related to the geometric and material specificity of the room in question. Dimensions and perpendicular arrangement of the walls favor the formation of standing waves. The construction of walls in the form of foam-steel panel panels may cause, when delivering a large amount of acoustic energy (and this is the case when using a high-power loudspeaker ball for the decay method as a sound source), additional vibrations and vibrations affecting the final measurement result. The standard uncertainty at a frequency of 100 Hz for the series of measurements 2023_04_11 IN was 0.48, for 2023_04_12 – 0.27. In the case of impulse response methods for the above measurements, it was 0.2 and 0.07, respectively. In the remaining measurement ranges, the standard uncertainty values usually remained well below 0.1. The measurement made using the Swept Sine method (2023_04_12 IR-SS) is consistent with the measurements made in later tests using the impulse response method (a gun shot was used to excite the room) – 2023_05_08 IR-GS and 2023_05_25 IR-GS (the standard uncertainty of those measurements was between 0.3 and 0.15 for low frequencies, and it had values well below 0.1 for other frequencies). The reverberation time for low frequencies from those measurements has lower values than the tests performed using the decay method (2023-04-12 IN).
- Studies of noise levels in the considered interior showed the usefulness of using a 1 to 1 room model for such applications. It should be noted that the imposed measurement criteria (noise levels below 40 dB) were also met. The ventilation and cooling devices considered, after proper assembly, showed a sufficiently low noise level. This illustrates the usefulness of the created room model, e.g. in the context of prototyping methods of assembly, arrangement, and development of the considered devices.

In conclusion, it should be emphasized that the preliminary research on the construction of a real-scale laboratory model allowed the identification of additional problems. Thanks to this, the model is "tuned" and prepared for the possibility of using new mechanical ventilation systems. In the next article, which will be a continuation of this work, the results of innovative solutions of ventilation devices as equipment for residential and educational buildings will be discussed.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. A. Nowoświat, M. Olechowska, J. Ślusarek; Prediction of reverberation time using the residual minimization method; Applied Acoustics, 2016, 106, 42–50; DOI: 10.1016/j.apacoust.2015.12.024
2. M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik, E. Elsarrag; Impact of indor environmenal quality on occupant well-being and comfort: a review of the literature; Int. J. Sustain. Built Environ., 2016, 5, 1-11; DOI: 10.1016/j.ijsbe.2016.03.006
3. R. Doggett, E.J. Sander, J. Birt, M. Ottley, O. Baumann; Using virtual reality to evaluate the impact or room acoustics on cognitive performance and well-being; Front. Virtual Real., 2021, 2, 620503; DOI: 10.3389/frvir.2021.620503
4. A. Nowoświat, M. Olechowska; Estimation of reverberation time in classrooms using the residual minimization method; Archives of Acoustics, 2017, 42(4), 609-617; DOI: 10.1515/aoa-2017-0065
5. M. Caniato, N. Biasetton, L. Salmaso, A. Gasparella; Visual placebo-like effects on subjective assessment of room acoustics: Sound absorption in classrooms; Building and Environment, 2022, 226, 109647; DOI: 10.1016/j.buildenv.2022.109647
6. J. Reinten, P.E. Braat-Eggen,M. Hornikx, H.S.M. Kort, A. Kohlrausch; The indoor sound environment and human task performance: A literature review on the role of room acoustics; Building and Environment 2017, 123, 315-332; DOI: 10.1016/j.buildenv.2017.07.005
7. A. Kjelberg, U. Landström, M. Tesarz, L. Söderberg, E. Akerlund; The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work; J. Environ. Psychol., 1996, 16(2), 123-136; DOI: 10.1006/jevp.1996.0010
8. P. Leather, D. Beale, L. Sullivan; Noise, psychosocial stress and their interaction in the workplace; J. Environ. Psychol., 2003, 23(2), 213-222; DOI: 10.1016/S0272-4944(02)00082-8
9. M. Tesarz, A. Kjellberg, U. Landström, K. Holmberg; Subjective response patterns related to low frequency noise; Journal of Low Frequency Noise; Vibration and Active Control, 1997, 16(2), 145-149
10. A. Nowoświat; Impact of temperature and relative humidity on reverberation time in a reverberation room; Buildings, 2022, 12, 1282; DOI: 10.3390/buildings12081282
11. X. Jin, H. Fang, X. Yu, J. Xu, L. Cheng; Reconfigurable origami-inspired window for tunable noise reduction and air ventilation; Building and Environment, 2023, 227, 09802; DOI: 10.1016/j.buildenv.2022.109802
12. X. Yang, Y. Wang, R. Zhang, Y. Zhang; Physical and psychoacoustic characteristic of typical noise on construction site: "how does noise impact construction workers' experience?"; Front. Psychol., 2021, 12, 1-13; DOI: 10.3389/fpsyg.2021.707868
13. H.P. Lee, Z. Wang, K.M. Lim; Assessment of noise from equipment and processes at construction sites; Build. Acoust., 2016, 24, 21-34; DOI: 10.1177/1351010X16678218
14. G. Zhai, B. Zhang; The design of ventilation and sound insulation window; Noise Vib. Control., 2004, 34, 45-46
15. Z. Jie, X.I.E. Zhuwei, T. Yajun, L.U. Jun; Performance analysis of a new sound insulation ventilation device; J. Harbin Inst. Technol., 2020, 52, 195-200; DOI: 10.11918/201901053.
16. B. Cabovská, G. Bekö, D. Teli, L. Ekberg, J.O. Dalenbäck, P. Wargocki, T. Psomas, S. Langer; Ventilation strategies and indoor air quality in Swedish primary school classrooms; Building and Environment, 2022, 226, 109744; DOI: 10.1016/j.buildenv.2022.109744
17. P. Wargocki, J.A. Porras-Salazar, S. Contreras-Espinoza; The relationship between classroom temperature and children's performance in school; Build. Environ., 2019, 157, 197-204; DOI: 10.1016/j.buildenv.2019.04.046
18. E. Oldham, H. Kim; IEQ field investigation in high-performance, urban elementary schools; Atmosphere, 2020, 11, 81; DOI: 10.3390/atmos1100081

19. L. Wu, L. Wang, S. Sun, X. Sun; Hybrid active and passive noise control in ventilation duct with internally placed microphones module; Applied acoustics, 2022, 188, 108525; DOI: 10.1016/j.apacoust.2021.108525
20. P. Gardonio, J. Rohlfing; Modular feed-forward active noise control units for ventilation ducts, J. Acoust. Soc. Am., 2014, 136(6), 3051-3062; DOI: 10.1121/1.4900571
21. PN-B-02156:1987 Akustyka budowlana. Metody pomiaru poziomu dźwięku A w budynkach.
22. PN-EN ISO 10052: 2021-12 Akustyka – pomiary terenowe izolacyjności od dźwięków powietrznych i uderzeniowych. Ochrona przed hałasem w budynkach. Część 2: Wymagania dotyczące dopuszczalnego poziomu dźwięku w pomieszczeniach
23. PN-EN ISO 3382-2:2010 Akustyka. Pomiar parametrów akustycznych pomieszczeń. Część 2: Czas pogłosu w zwyczajnych pomieszczeniach
24. A. Nowoświat, R. Żuchowski, M. Olechowska, M. Marchacz; Badania pomieszczeń testowych w skali laboratoryjnej o przeznaczeniu mieszkalnym i dydaktycznym; Inżynieria i Budownictwo, 2003, 11/12, 648-651; DOI:10.5604/01.3001.0054.1382
25. PN-EN 61672-1:2014-03 Elektroakustyka. Mierniki poziomu dźwięku. Część 1: Wymagania
26. PN-B-02151-2:2018-01 Akustyka budowlana. Ochrona przed hałasem w budynkach. Część 2: Wymagania dotyczące dopuszczalnego poziomu dźwięku w pomieszczeniach
27. PN-B-02151-4:2015-06 Akustyka budowlana. Ochrona przed hałasem w budynkach. Część 4: Wymagania dotyczące warunków pogłosowych i zrozumiałości mowy w pomieszczeniach oraz wytyczne prowadzenia badań
28. M. Olechowska, A. Nowoświat, M. Marchacz, K. Kupczyńska; Indicative Assessment of Classroom Acoustics in Schools Built in Reinforced Concrete Technology on The Example of a School Building in Zabrze; IOP Conf. Series: Materials Science and Engineering, 2021; DOI: 10.1088/1757-899X/1203/2/022007