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An energy-efficient sound system in the opera hall in Poznań

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Abstract: The object of the research was to create a computer model of the Stanisław Moniuszko Grand Theater in Poznań. The scope of the study included changing the parameters of the ceiling over the orchestra pit, while not significantly changing the acoustic parameters of the entire interior. The study attempted to determine whether in the existing (or recently designed) hall, modifying the ceiling parameters could improve the sound quality for the audience. The main parameter was the specific weight of the ceiling. The influence of repositioning the inclined ceiling, its angle of inclination and size was also examined. The result of the conducted tests was unambiguous. The acoustic properties of the hall correlated with the weight of the ceiling acoustically connecting the orchestra with the audience. This is worth noting during the design stage of a concert hall.

Keywords: acoustics in theater spaces

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Introduction

The NOSPR (National Polish Radio Symphonic Orchestra) hall has a very heavy ceiling over the orchestra, which significantly improves the acoustic properties for the musicians as they listen to themselves. Consequently, the theoretical assumption is that a similar effect can be achieved for the audience by introducing a heavy ceiling over the orchestra pit (increases the effect of sound reflection) that inclines towards the onlookers. The study was carried out by modelling the Grand Theater in Poznań with the use of computer software CATT Acoustic.

1. Acoustic properties of materials relative to specific gravity and surface textures

All materials absorb and reflect sound waves to some extent. The absorption coefficient α is a measure of the material's effectiveness in sound absorption. It is the ratio of the energy of a wave absorbed to the energy of a wave falling in a unit of time (Kulowski, 2007)

$$\alpha = E_{pochl} / E_{pad} \tag{1}$$

If this coefficient is, for example, 0.7, this means that 70% of the energy of the acoustic wave is absorbed and 30% is reflected.

The sound absorbing properties of a material depends on many factors, including the frequency of incident sound, the surface structure of the material layer, its texture, thickness, specific gravity and its method of fixing to the wall (including the occurrence of air voids).

Due to the fact that the listener in the hall is receiving sound waves not only directly from the source but also through reflections from the walls and other surfaces (the sound coming from a real source overlaps the reflected sounds), the room will amplify that sound.

The sound level in the reverberant field of a hall can be a dozen or so decibels higher than the level created by the same source in an open space. The amplification depends on the acoustic absorption A of the room (Kulowski, 2007):

$$A = \alpha \cdot S \tag{2}$$

where:
α – reverberant sound absorption coefficient,
S – surface of the material, m^2.

The higher the absorption capacity, the quieter the room is.

2. An acoustic model of the Grand Theater in Poznań

Description of the study object: The Grand Theatre in Poznań is a historic building that is under the management of the monument conservator. The facility consists of a large number of rooms, including a stage with stage pockets, back-up, under-stage, over-stage, technical spaces, orchestra pit, auditorium, foyer, rehearsal rooms, dressing rooms, technical and administrative rooms. The Grand Theater in Poznań is an opera theater, in which operas, ballet performances, symphony concerts and special events regularly take place.

Fig. 1. The Grand Theater Stanisław Moniuszki in Poznań (*photo: author*)

Parameters of the building:
- the area of the main stage – about 400 m^2,
- volume of the main stage – about 10.000 m^3,
- surface of the orchestra pit – about 90 m^2,
- the area of audience seating – about 265 m^2,
- the volume of audience seating – about 4400 m^3,
- number of seats – 860.

For the purpose of analyzing the acoustic conditions, a room model was prepared in the CATT Acoustic program. Figure 2 shows the views of the modelled hall.

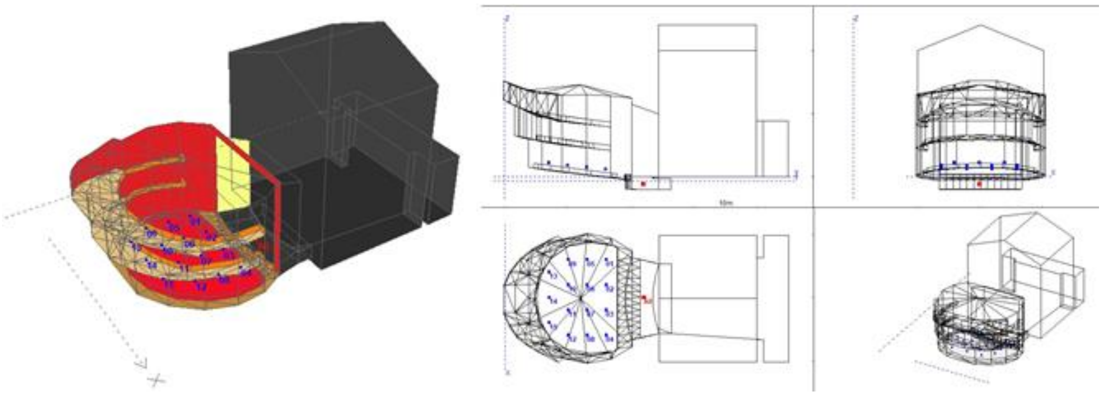

Fig. 2. Model of the Grand Theater in Poznań (*prepared by the author*)

The geometry of the room was created based on inventory drawings. The type of finishing materials for the individual surfaces were selected based on project documentation and local observations.

On the basis of literature data (Beranek, 2004; Long, 2006; Mehta et al., 1998; Sadowski, 1976) and the cathode charts of applied or similar materials, the acoustic parameters of individual materials were selected.

The simulation was performed with a sound source placed in the orchestra pit (o) and a source placed on the edge of the stage (s). The sounds from the sources were not studied in the depth of the stage due to the high impact of the scene on the results of the research. Tests done on an empty stage or with a specific set design differ significantly from one another. The calculation points were only placed at the lower part of the audience seating area, because sound reflection from the ceiling above the orchestra pit mainly reached that point, as shown in Figure 3.

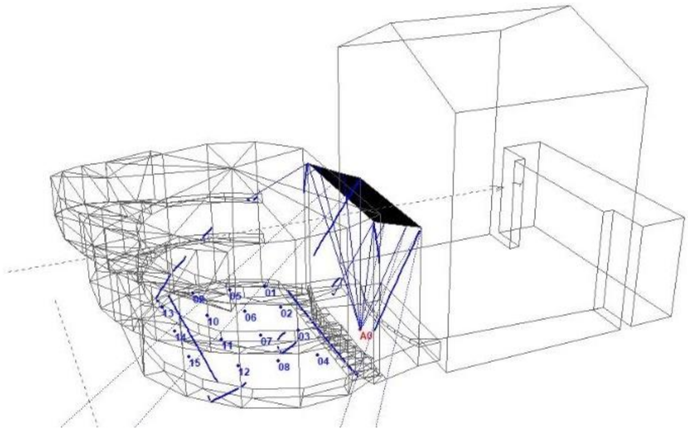

Fig. 3. The range of the sound wave reflected from the ceiling for a source placed in the orchestra pit (*prepared by the author*)

3. Testing of the acoustic properties of the audience seating area taking into account the variable parameter of the weight of the ceiling over the orchestra pit

For concert or theater halls the key issue is the natural acoustics of the interior. One should strive to fill the room with sound as evenly as possible. In the case of very large rooms, electroacoustic support is obviously necessary. The element that must be remembered when designing or adapting such a room is sound reflection (not absorption), so it is worth using hard and heavy materials that reflect sound. It can be, for example, a ceiling, as in the case of the NOSPR hall. In this case, it reflects the sound of the orchestra, being a natural monitor for the musicians (so that they can hear each other) and at the same time directs part of the sound towards the audience.

Sound dissipation is also very important in such rooms, especially for medium and high frequencies (e.g. by sculpting walls).

As such, in the presented hall, an attempt was made to change the weight of the ceiling over the orchestra pit, using the example of the Grand Theater. Stanisław Moniuszko in Poznań, in order to improve the acoustic properties of the room. Changing the weight of the ceiling over the orchestra pit and angling it towards the audience should increase the reflection of the sound directed towards the audience.

For this purpose, a three-dimensional acoustic model of the auditorium was created and a series of simulations were carried out.

The scope of the study included changing the parameters of the ceiling, while not introducing any significant changes to the acoustic parameters of the entire interior. The study aimed to determine whether in the existing (or newly designed) rooms, modifying the ceiling parameters could improve the sound quality in the audience seating area. The essential acoustic requirement for the opera hall is the adequate reverberation time of the room with the audience, which is why the measurements focused mainly on this parameter. The frequency response of the reverberation time should be balanced, raised at low frequencies to increase the warmth of the sound and a reduction at high frequencies, which is caused by sound absorption by the air. Simulation results with variable ceiling parameters were compared to the existing situation. In addition to the simulation of the T-30 reverberation time, a comparison was made for the time of early decay of EDT, sound power G and speech intelligibility index STI.

The studies compared a number of acoustic parameters for four cases:

a) existing status
b) theoretical state 1 (ceiling lighter than the existing one)
c) theoretical state 2 (ceiling heavier than existing one)
d) theoretical state 3 (ceiling significantly heavier than existing one)

and for two positions of the sound source:

(o) – the source placed in the orchestra pit
(s) – source placed on the edge of the stage

The simulation results are presented below.

3.1. Reverberation time

For the source placed on the stage a longer reverberation time in the audience was obtained (Fig. 4).

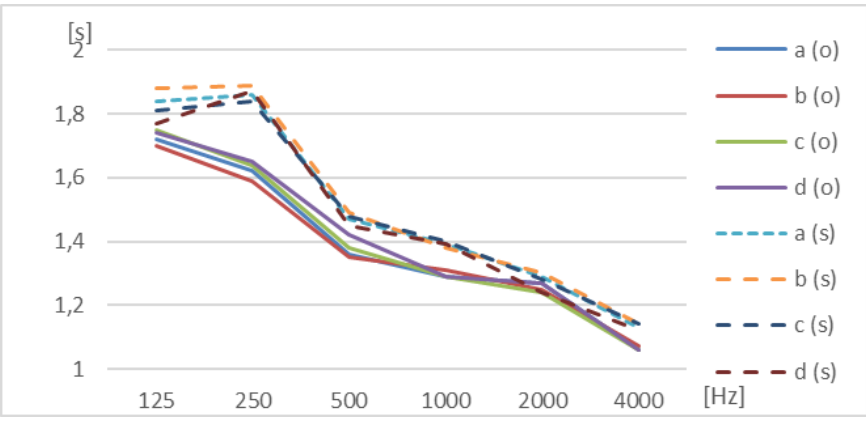

Fig. 4. List of characteristics of the average reverberation time (T-30) in the audience seating area (*prepared by the author*)

The presented results of the reverberation time show that the change in the weight of the ceiling over the orchestra pit does not introduce significant changes in the reverberation time. These differences were noted only for low frequencies. For a source placed in the orchestra pit, the maximum, amounting to only about 0.1 s, occurs at 500 Hz. However, for the source on the stage, these differences only occur at 125 Hz.

3.2. Time of early disappearance of EDT

EDT is considered a better indicator of reverberation than reverberation time. Figure 5 compares average EDT for the entire audience.

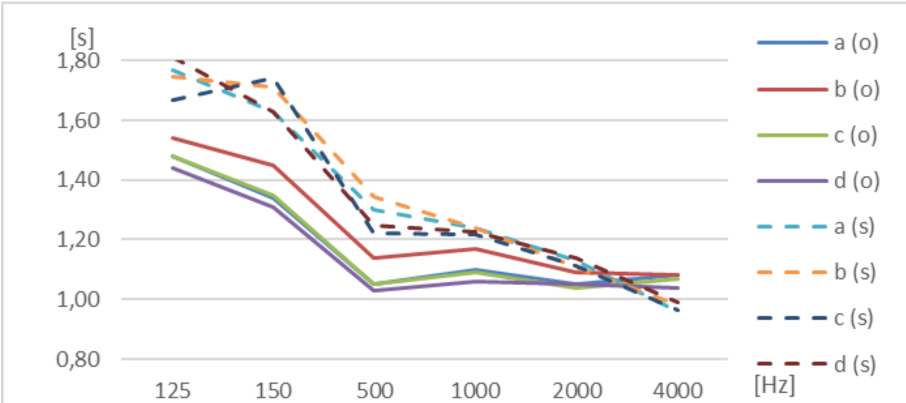

Fig. 5. Comparison of EDT averaged for the whole audience (*prepared by the author*)

For a source placed in the orchestra pit, higher values were obtained at about 0.1 s for situations with a ceiling that was lighter than the existing one. In all other cases, (including the sources on the stage), there was a greater variability of the EDT parameter than the T-30 for a wider frequency range.

3.3. The strength of sound G

The sound power G describes the difference in sound level in the room and the level in the free space at a distance of 10 m from the source (Fig. 6). A positive value of this parameter determines the sound amplification by reflections inside the room. The concert hall recommends G > 3 dB in the medium frequency range of 500-1000 Hz. Changes in the G-value at different points of the audience should not exceed $\Delta G = 3$ dB. In the simulated room, the gain of sound energy assumes values consistent with this assumption.

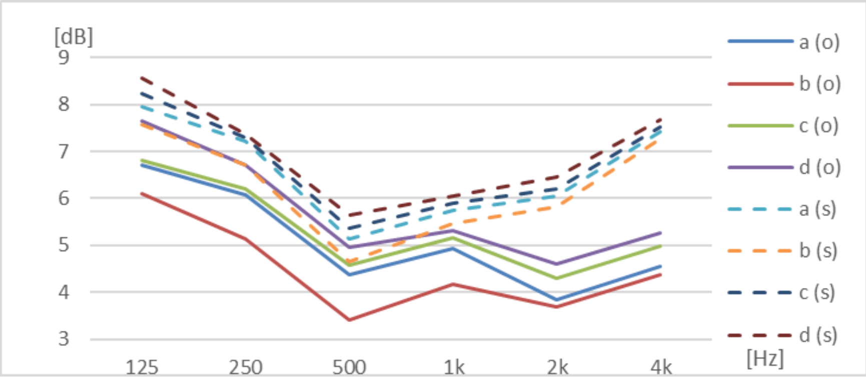

Fig. 6. Frequency response G(f) averaged for the whole audience
(*prepared by the author*)

3.4. Speech intelligibility indicator STI

The STI indicator is used to assess speech intelligibility. It takes values from 0 to 1. For good speech intelligibility, it must be at least 0.6. The results of the STI parameter are presented in Figure 7.

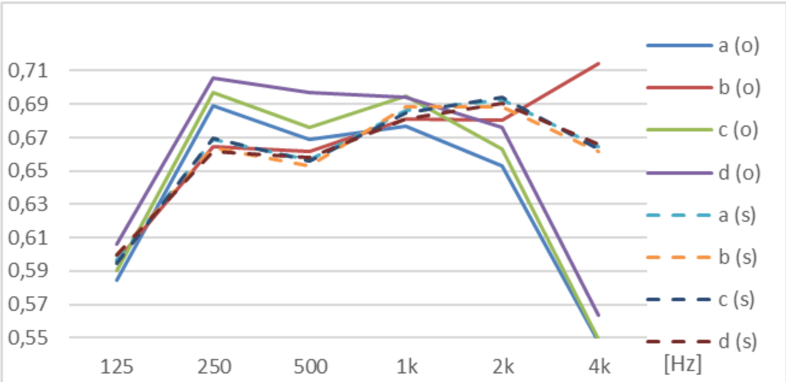

Fig. 7. STI speech intelligibility indicator averaged for the whole audience area
(*prepared by the author*)

From the Figure 7 it can be seen that the intelligibility of speech throughout the room is at least good. Lower values are accepted only for 4 kHz frequency for a source placed in the orchestra pit. The improvement of intelligibility for high frequencies was obtained only for the lighter ceiling, but at the cost of a slight deterioration of intelligibility for the low frequency range. For a source on the stage, the change of the ceiling's weight practically does not change the intelligibility of speech.

All parameters tested for the source located on the edge of the stage show slight changes in relation to the existing situation, while for the source placed in the orchestra pit, the differences are greater.

In order to make the analysis as insightful and as exhaustive as possible, the height of the ceiling, its size and angle of inclination were also changed. The analysis was performed only for the source in the orchestra, due to the greater variation in the results obtained.

Different situations were tested for the weight of the existing ceiling (a) and for the heavier ceiling (d). The situations considered were as follows:
- h1 – the original ceiling height,
- h2 – the ceiling is lowered by 2 m and tilted so that the sounds reflected from the ceiling cover more or less to the same part of the audience as in the case of h1,
- h3 – reduced and inclined ceiling (as in the case of h2) and enlarged towards the audience area by 1m in order to check whether the size of the ceiling plays a significant role. The ceiling can be enlarged only towards the audience due to the mechanisms from the side of the stage (mainly the curtain),
- h4 – the ceiling at the original height but enlarged (towards the audience by 1 m).

The obtained results are presented in Figures 8-11.

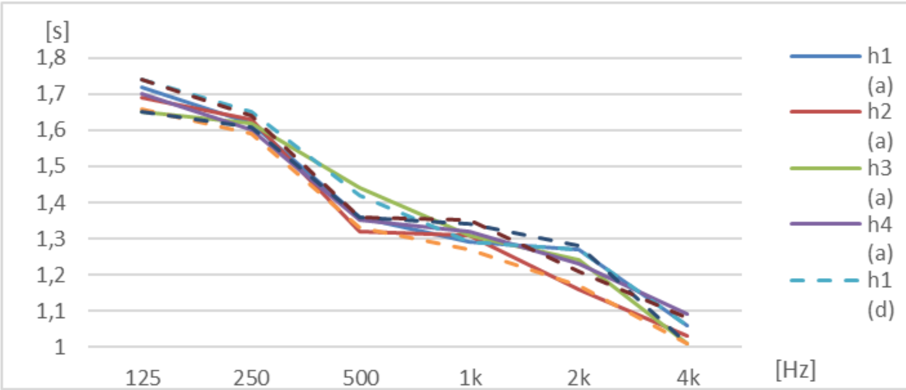

Fig. 8. The frequency response of the T-30 reverberation time for two types of ceiling weight (a and d) and its different location over the orchestra pit (*prepared by the author*)

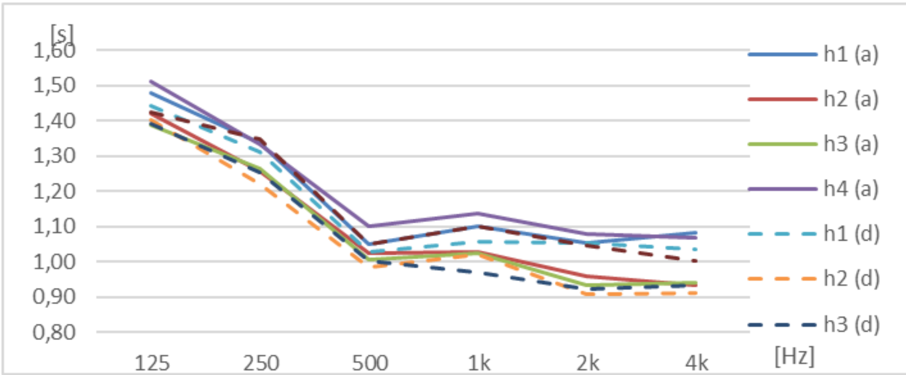

Fig. 9. Comparison of the average EDT parameter for the entire audience area for two types of ceiling weight (a and d) and its different location over the orchestra pit (*prepared by the author*)

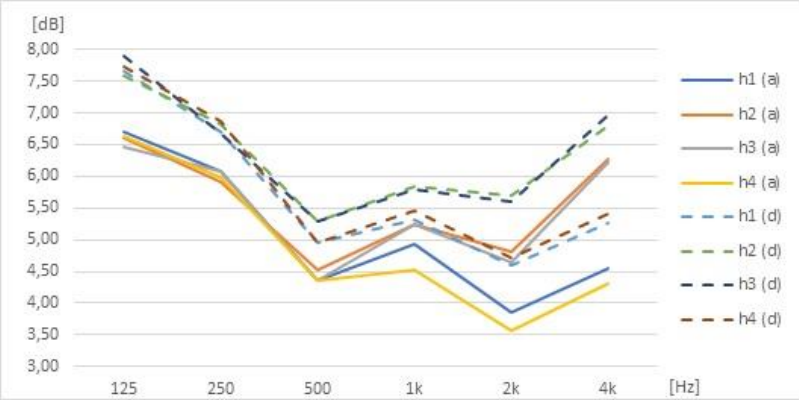

Fig. 10. Frequency characteristics of sound power G(f) averaged for the whole audience area for two types of ceiling weight (a and d) and its different location over the orchestra pit (*prepared by the author*)

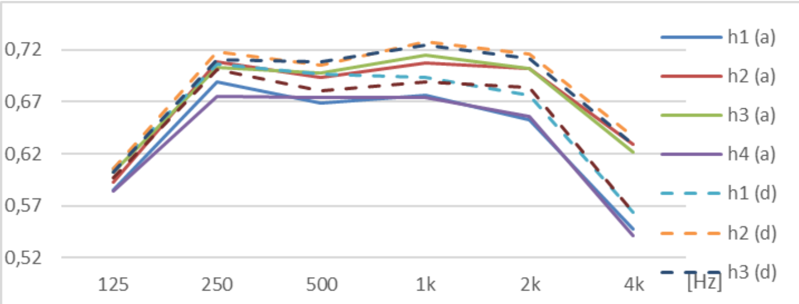

Fig. 11. Speech intelligibility index STI averaged for the whole audience area for two types of ceiling weight (a and d) and its different positioning above the orchestra pit (*prepared by the author*)

4. Interpretation of test results

From the above diagrams it can be seen that changing the parameters of the ceiling itself in the hall (its size, position, inclination, specific gravity) can slightly change its acoustics. Reverberation time changes by up to 0.15 seconds. Changes in early decay time reach a maximum of less than 0.2 seconds. Differences in these parameters are small. The strength of sound can vary by up to 2 dB. The increase of the sound strength indicates the improvement of the sound emission from the stage and the orchestra to the audience. Larger values of this parameter were obtained for higher specific weight of the ceiling, reducing the distance between the orchestra and the ceiling (i.e. lowering the ceiling) and increasing its surface. Speech intelligibility can be slightly improved with such changes. Figure 11 shows that better speech intelligibility was obtained with almost all changes. Increasing the specific weight of the ceiling improves the intelligibility of speech. This parameter has adopted higher values, however, it is always in the range of 0.6-0.75, which means good intelligibility of speech. The greatest improvement was obtained for high frequencies. If a significant change in the acoustics of the room is required, it is not enough to only change the parameters of the ceiling itself.

Conclusions

Parameters of the acoustic properties of the room are correlated with the weight of the ceiling acoustically connecting the orchestra with the audience. The reverberation time averaged for the whole audience area is practically the same for each of the cases studied. The frequency response of the reverberation time T(f) changes slightly, which does not improve the acoustic conditions of the audited room. The biggest discrepancies were obtained for the sound pressure parameter G and speech intelligibility STI. Increasing the specific weight of the ceiling over the orchestra pit influences the increase of the G sound power in the audience seating area and improvement of speech intelligibility. In addition to increasing the specific weight of the ceiling, you can change parameters, such as location, size, and angle of inclination, which can also shape the acoustics inside the room.

For halls with orchestras pits, by introducing a heavy ceiling acoustically linking the orchestra pit with the auditorium, the acoustic properties of the hall can be slightly improved. It is worth remembering this at the stage of designing the hall. On the basis of the conducted research, it was found that it is possible to obtain sound amplification without the use of electrical devices, which undoubtedly contributes to increasing the energy efficiency required in modern architecture.

Bibliography

Barron, M. (1993) *Auditorium Acoustics and Architectural Design*. London, E&FN Spoon.

Beranek, L. (2004) *Concert Halls and Opera Houses*. Springer Science+Business Media.

Egan, M.D. (1988) *Architectural Acoustics*. New York, J. Ross Publishing.

Everest, A. (2010) *Podręcznik akustyki*. Katowice, Sonia Draga.

https://opera.poznan.pl/pl/o-teatrze-wielkim (30.12.2020).

Kulowski, A. (2007) *Akustyka sal*. Gdańsk, Wydawnictwo Politechniki Gdańskiej.

Long, M. (2006) *Architectural Acoustics*. Elsevier Inc.

Makrinienko, L.I. (1994) *Acoustics of Auditoriums in Public Buildings*. Am. Inst. Physics.

Mehta, M., Johnson, J. & Rocafort, J. (1998) *Architectural Acoustics Principles and Design*. Prentice Hall.

Sadowski, J. (1976) *Akustyka architektoniczna*. Warszawa, PWN.

Sadowski, J. & Wodziński, L. (1959) *Akustyka pomieszczeń*. Warszawa, WK.

Templeton, D. (ed.) (1997) *Acoustics in the built environment*. Oxford, Architectural Press.

Żyszkowski, Z. (1966) *Podstawy elektroakustyki*. Warszawa, PWN.