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REVERBERATION TIME STUDY OF AN AUDITORIUM

This paper is devoted to the solving problem of reverberation time prediction on the basis of analogical inference.
Keywords: reverberation time, room acoustic, Dirac impulse.

ДОСЛІДЖЕННЯ ЧАСУ РЕВЕРБЕРАЦІЇ ЛЕКЦІЙНОЇ АУДИТОРІЇ

Наведено результати експериментального дослідження часу реверберації лекційної аудиторії Національного університету “Львівська політехніка“.
Ключові слова: час реверберації, акустика приміщень, імпульс Дірака.

Introduction

Environmental sounds are important factors that determine the comfort of the building. The sound quality and noise level are frequently undervalued compared to lighting, interior design, control and display systems etc. Despite this, they have a huge impact on physiological conditions, psychological state, cognitive functions, behaviour and productivity of the people.

No matter what the type of the room is, the poor sound quality has a devastating effect on the communication, sales volume, customer satisfaction etc. Acoustics plays a special role in the theatre and concert halls. Good sound quality is essential for receiving unforgettable impressions on the concert. Providing good acoustics is also very important in the healthcare industry. The comfortable sound level and noise neutralization may facilitate the recovery of the patients and lead to more productive work of medical staff.

Speech intelligibility is the key to understanding the subject in the educational institutions. Students who take their place at the end of the auditorium often can hardly understand the teacher’s speech because of the bad acoustics. In addition, when working in the groups the noise level increases.

The acoustic properties of the lecture auditorium affect the quality of the communication between lecturers and students. There are a lot of acoustic field quality indicators. In terms of lecturer’s speech intelligibility, the most important one is the reverberation time. That is why investigation of the reverberation time of one of the Lviv Polytechnic National University auditorium has been conducted. The results are presented in the article.

Recent research and publications analysis

Nowadays, there are many scientific papers devoted to the investigations of the acoustic properties of the rooms. According to A. Vachko, who explores acoustic modernization of restored auditoriums, the excessive reverberation time is common thing in the buildings of that kind [1]. The different options of the Rybnik Silesian Polytechnic auditorium renovation are presented in the article by Professor Andrzej Kulovskoho and Professor Tadeusz Kamisinskoho [2] Similarly, there is a speech intelligibility problem in the audience due to the excessive reverberation time. M. Jedidi, A. Boulila [3] and Prodeus A.N. [4] have also conducted research in this field of study. Such active researches indicate that the problem of improving the acoustic climate is vital question.

Experimental study of the reverberation time

Object of study

The object of study is a lecture auditorium of Lviv Polytechnic National University that is found in the educational building number IV. Model of the room is presented in the Fig. 1. The auditorium has the following settings: the area is 66 m^2, the volume is 196 m^3, and ceiling height is 2.975 m.

The walls of the auditorium are made of brick. The following materials were used to equip the room: glass, plaster, parquet, metal doors and the wood-shaving plates the desks and benches are made of. There are 3 rows of desks in the auditorium which could accommodate up to 80 people. The are large windows without curtains that provide natural light during the daytime.

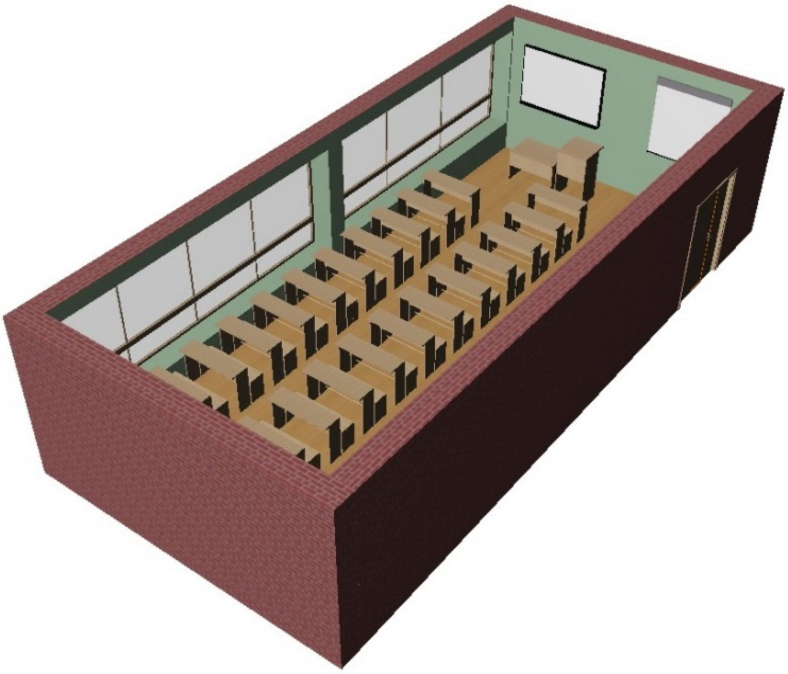

Fig. 1. Model of the auditorium

Measuring points location

Reverberation time is one of the important criteria that determines the acoustic quality of any building. Auditorium where the sound that reaches the listener is not distorted is suitable for being the lecture one [5]. Reverberation time measurements are made in octave bands. The arithmetically averaged result in the four octave bands in the range from 250 Hz to 2 000 Hz and in the three positions should be calculated as a single number result.

According to ISO 3741:2010 [6] reverberation time is the duration required for the space-averaged sound energy density in an enclosure to decrease by 60 dB after the source emission has stopped.

In obedience to ISO 3382-2 [7] reverberation time will be measured by using impulse response which is temporal evolution of the sound pressure observed at a point in a room as a result of the emission of a Dirac impulse at another point in the room [SOURCE: ISO 354:2003, 3.5] It is worth mentioning that it is impossible in practice to create and radiate true Dirac delta functions, but short transient sounds (e.g. from gunshots) can offer close enough approximations for practical measurement.

9 measuring points are selected in order to explore how reverberation time changes. There should be no sound sources near the measuring points in order to reduce the impact of the direct radiation. The minimum distance allowed between the sound source and the measurement point can be calculated by the formula [7]:

$$d_{\min} = 2\sqrt{\frac{V}{c \times T}} \tag{1}$$

де V – volume of the room [m^3]; c – speed of the sound [m/s]; T – expected reverberation time [sec.].

Performing calculations with the auditorium settings and taking the minimum and maximum reverberation time equals to 0.5 and 1.5 accordingly, the calculated distance is:

$$d_{\min} = 2\sqrt{\frac{196\left[\mathrm{m}^3\right]}{343.2\left[\mathrm{m/sen}\right]\times 1.5\left[\mathrm{sec}\right]}} = 1.23\left[m\right];\quad d_{\min} = 2\sqrt{\frac{196\left[\mathrm{m}^3\right]}{343.2\left[\mathrm{m/sen}\right]\times 0.5\left[\mathrm{sec}\right]}} = 2.14\left[\mathrm{m}\right].$$

Now we need to choose the greater distance which is 2.14 m. In this case, the closest distance from the sound source to the measuring point is 2.8 m, which meets the standard’s requirements.

Location scheme of measuring points and impulse noise sources is presented in Fig. 2. Maximum sound pressure level (dB) is specified at each measuring point. Firecrackers are used as a source of impulse noise. Shots are conducted in the place where the lector usually stands. The microphone is placed where the audience auditory sensory system is usually located, that is 1.2 m distance from the floor.

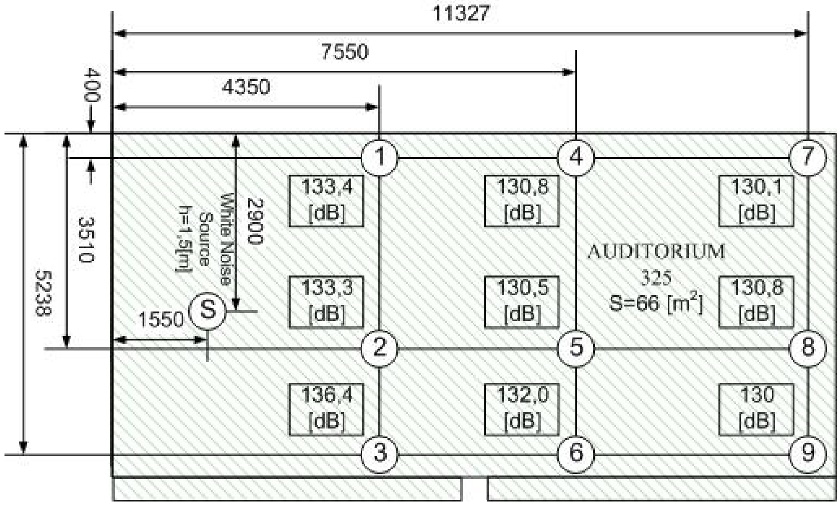

Fig. 2. Layout of measuring points

Excitation of the room

The impulse response can be measured directly using an impulse source such as a pistol shot. Impulse source should create a peak sound pressure level at which the initial level of the decline curve will be at least 35 dB greater than the level of background noise in the relevant frequency band. For instance, for the determination of T 30, the level of the background noise must be at least 45 dB below the maximum.

In this case, as shown on Fig. the maximum sound pressure level is 133.4 dB and the background sound pressure level equals 76.5. The difference 133.4–76.5 = 56.9 dB, which fully meets finding the reverberation time T 30 requirements.

The chart of the sound pressure level (Fig. 3) shows when the firecracker shot is made and how sound energy attenuates.

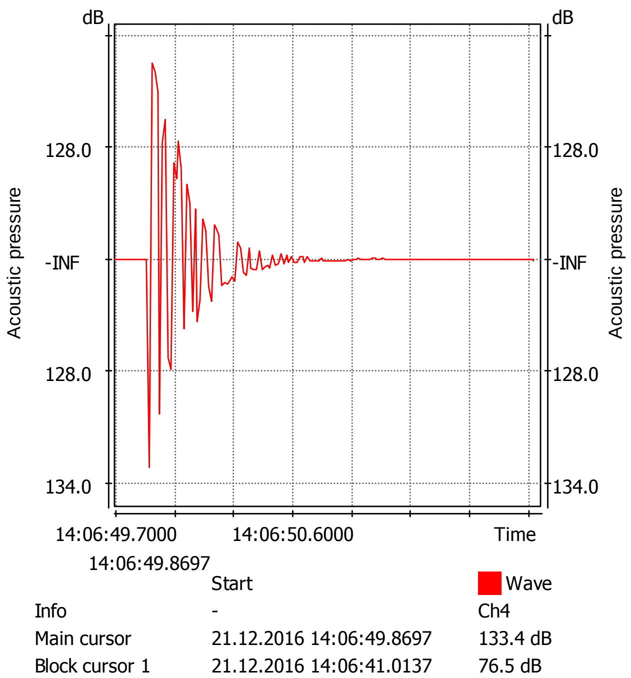

Fig. 3. Acoustic impulse used to estimate reverberation time

Measurements of reverberation time

The following equipment are used for the experiment:

- Precision sound level meter spectrum analyzer SVAN 958A;
- SV22 1/2" Omnidirectional Condenser Microphone, wide measurement range of 10 Гц to 16 кГц, sensitivity 25 mV/Pa. It makes the measurement of the high noise level possible;
- Firecrackers (impulse noise source);
- Bosch GLM30X – laser rangefinder.

All experiments are conducted at the temperature 22 °C and relative humidity of 45 %. The results of the reverberation time measurements for the seven octave bands in the range from 63 Hz to 4000 Hz taken at the nine points in the auditorium are presented in table 1.

Table 1

Reverberation time in seconds in octave bands of the auditorium

Measured point	Frequency, [Hz]							$RT_{Average}$
	63	125	250	500	1000	2000	4000	
1	1.56	1.38	1.44	1.28	1.17	1.20	1.15	1.23
2	1.85	1.66	1.28	1.05	0.98	1.28	1.17	1.02
3	1.74	1.58	1.22	1.19	0.94	1.21	1.01	1.07
4	2.00	1.32	1.51	1.14	1.22	1.34	1.21	1.18
5	2.23	1.35	1.43	1.39	1.34	1.35	1.15	1.37
6	2.06	2.07	1.51	1.47	1.16	1.28	1.15	1.32
7	1.80	1.21	1.05	1.21	1.21	1.24	1.19	1.21
8	1.71	1.43	1.26	1.28	1.33	1.39	1.21	1.31
9	1.97	1.56	1.68	1.25	1.30	1.32	1.16	1.28

The table 1 results for each octave frequency are shown below as a histogram (see. Fig 4–9). Measuring points numbers are on the right. Due to the fact that the histograms are designed to show the distribution of the reverberation time in lecture auditorium reverberation time on the histograms starts from 1 sec which allows to reflect the difference better.

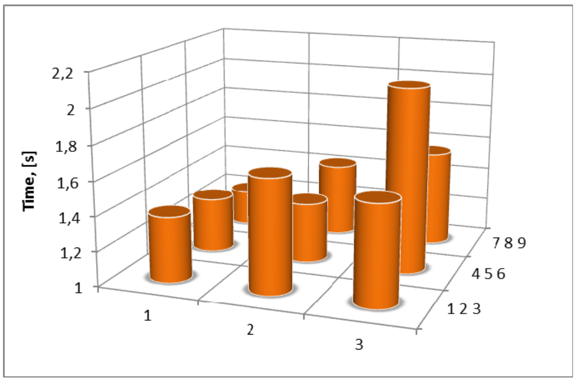

Fig. 4. Reverberation time for frequency f=125[Hz]

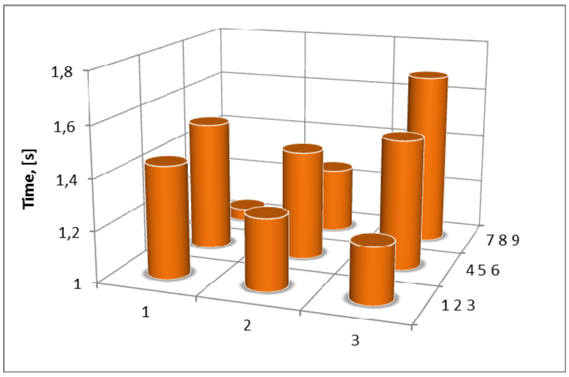

Fig. 5. Reverberation time for frequency f=250[Hz]

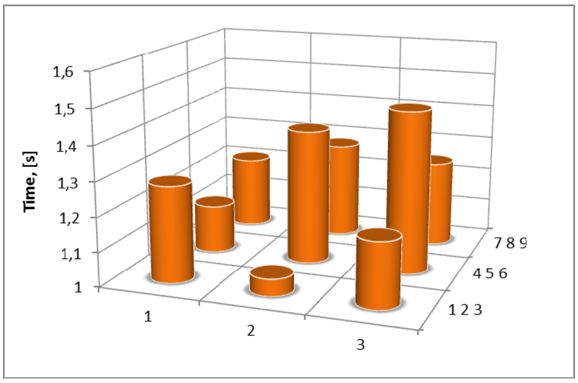

Fig. 6. Reverberation time for frequency f=500[Hz]

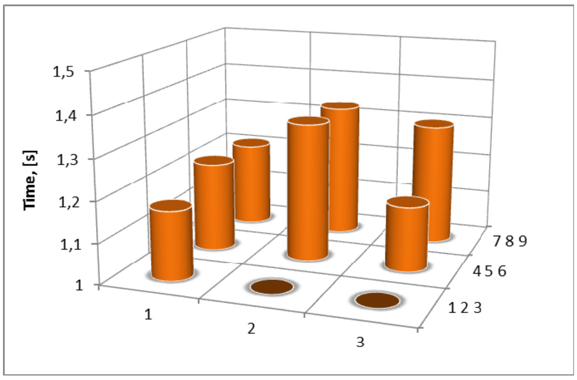

Fig. 7. Reverberation time for frequency f=1000[Hz]

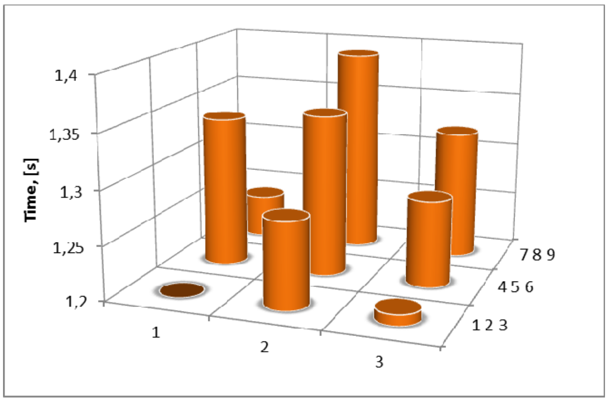

Fig. 8. Reverberation time for frequency f=2000[Hz]

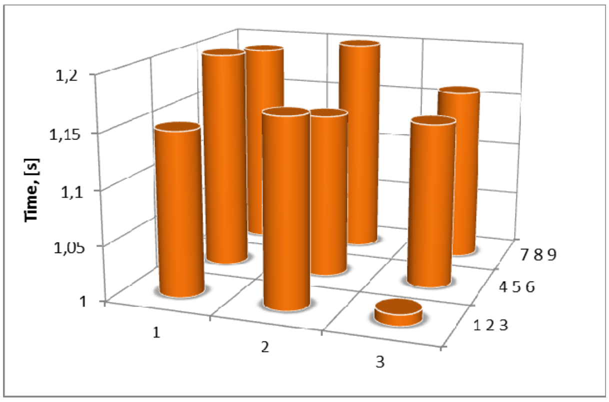

Fig. 9. Reverberation time for frequency f=4000[Hz]

As we can see from the results, reverberation time distribution is varied in different places of the auditorium. Especially it applies to low frequencies as each material has a different absorption coefficient for different frequencies.

Reverberation time of the room can be expressed as a single value by using the arithmetic mean of 500 Hz and 1000 Hz frequencies [8.9]. This values are presented in the last column of Table. 1 and in the Fig. 10.

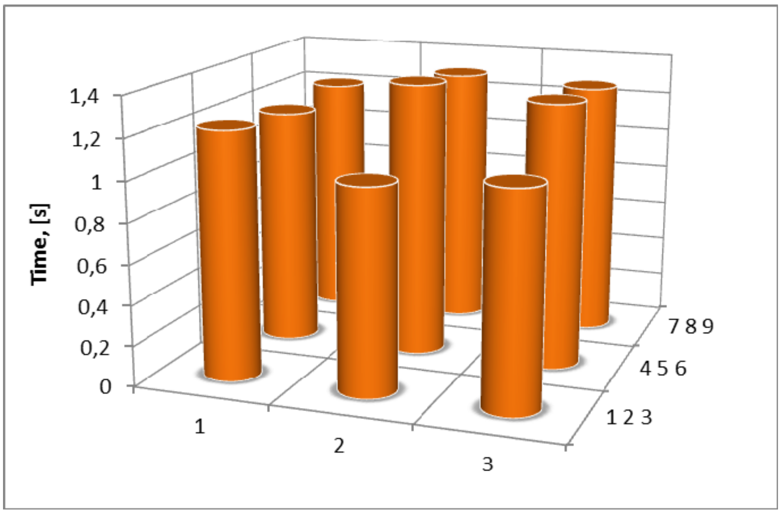

Fig. 10 Average reverberation time
for frequency f=(500+1000)/2 [Hz]

Analyzing that data we can see that reverberation time does not differ significantly, as location points of the experiment are chosen as close to the window and the wall as possible [9].

The lowest average value is 1.02 sec and appears in the measuring point that is closest to the source of the noise, which is expected. The biggest average value is 1.37 sec and is measured in the 5th point. The reason is that the item is in the middle of the room and could be reached by the reflections from many remote audience surfaces. So, the difference of 0.35 sec in different measuring points is not significant considering that there are no curtains on the windows, the presence of which would improve the distribution reverberation time situation. The presence of students also reduces reverberation. Therefore, we can assert that this is a comfortable auditorium for the lectures. However, the sound-absorbing curtains will reduce reverberation time even more, resulting in improved lecturer’s speech intelligibility.

Summary

The reverberation time research of the lecture auditorium of Lviv Polytechnic National University meets modern requirements for the acoustic comfort. However, using of the modern sound-absorbing materials can improve acoustics of the auditorium without any interior changes. Researches are carried out in 9 different location points using a precision sound level meter. It helps to establish equability of the

reverberation time distribution. Average reverberation time at the frequency of 500 Hz with no students in the auditorium is 1.23 which is within normal limits for the room of that type. The presence of the students leads to decreasing reverberation time value.

During the study the background noise presence in the lecture auditorium which causes the distortion of speech intelligibility is found. It's impact can be reduced by using doors with better insulation and applying more insulating and sound-absorbing materials. One of the most simple and low-cost way to increase the acoustic quality of the audience is to hang curtains of sound-absorbing fabric that reduces reverberation time and background noise, and does not require reconstruction of the room.

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