AN ATTEMPT TO DETERMINE IMPACT OF A ROOM SHAPE ON THE REVERBERATION TIME

Artur NOWOŚWIAT [a], Marcelina OLECHOWSKA [b]

[a] Dr.; Faculty of Civil Engineering, The Silesian University of Technology, Akademicka 5, 44-100, Gliwice, Poland
E-mail address: *Artur.Nowoswiat@polsl.pl*

[b] MSc; Faculty of Civil Engineering, The Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland
E-mail address: *Marcelina.Olechowska@polsl.pl*

Abstract

One on the most important parameters defining acoustics of the interior is time of reverberation which determines all other parameters defining e.g. quality of speech, articulation, clarity of music, basses ratio, warmth of sound, etc. The authors of the paper made an attempt to determine impact of a room shape, length to height ratio on the reverberation time. After first simulations and studies it seams that not only room acoustic absorption and capacity influences reverberation time but also a room shape.

Streszczenie

Jednym z najważniejszych parametrów określających akustykę wnętrza jest czas pogłosu, który to determinuje wszystkie inne parametry określające choćby: zrozumiałość mowy, wyrazistość, klarowność muzyki, stosunek basów, ciepło brzmienia itp. Autorzy niniejszego opracowania podjęli próbę określenia wpływu kształtu pomieszczenia, stosunku długości do wysokości na czas pogłosu. Po pierwszych symulacjach i badaniach wydaje się, że czas pogłosu zależy nie tylko od chłonności akustycznej pomieszczenia i jego wielkości, ale również kształtu pomieszczenia.

Keywords: Reverberation time; Shape of room; Acoustics parameters; Acoustic absorption.

1. INTRODUCTION

Acoustics of interiors as well as research on the formation of acoustic climate in rooms have been subject of scientists' research for a long time. Essential parameter describing acoustic climate in the interior is reverberation time. Over 100 years ago an American acoustician Wallace Sabin defined reverberation time as the time after which sound intensity in the room would decrease million times from the moment of source disconnection. Sabin based his method of reverberation time determination on the assumption of isotropy of the acoustic field in the room. Development of computational and measurement methods of reverberation time determination is legitimate also today. An amendment to the decree regarding technical conditions buildings and their locations shall comply with, dated March 2009, supplemented required range of a building noise protection with protection against reverberation noise [1]. Reverberation sound is created as a result of repeated reflections from the partitions limiting room of a sound wave, reflections are the bigger the smaller is sound absorption coefficient. In such rooms human ear hears both direct sound as well as sound produced by reflected wave, which causes increase of noise in the room as well as deterioration of verbal or music sound reception conditions.

Today it is known that not only room acoustic absorption and its capacity influence reverberation time but also temperature in the room and in consequence speed of sound in the room. In order to illustrate the

dependence of the reverberation time as a function of not only the sound absorption, but also the speed of sound in the room we quote from the standard model [2].

$$T = \frac{55.3}{c_0} \cdot \frac{V(1-\psi)}{A} \quad [s], \qquad (1)$$

where:

V – room volume [m^3]

c_0 – speed of sound in the air [m/s]

ψ – fraction of objects determining volume of objects in the room

A – equivalent field of sound absorbing surface [m^2]

The authors of this paper make an attempt to show that apart from the listed factors also so called shape factor i.e. ratio of the room length or width to its height has got influence on the reverberation time. An attempt of determination has been presented by means of computational simulations. These simulations are treated as introduction to the laboratory research in doctor's thesis of this paper coauthor.

It also needs to be noted that other authors have already made an attempt to determine impact of the room shape on the reverberation time [3, 4, 5], or applications of geometrical relations to determine one-index evaluation of the sacral interiors acoustics [6].

2. PROPAGATION OF SOUND IN A CLOSED ROOM

Each closed room constitute a space limited by system of walls, floor and ceiling. For this reason acoustic quality of sound produced in the room is substantially influenced by the room own parameters such as volume, shape of the room, total volume of walls, used finishing materials. Moreover, each room is filled with air of specific temperature, relative humidity, with specific atmospheric pressure in it. These parameters also have specific influence on the process of sound propagation in the room.
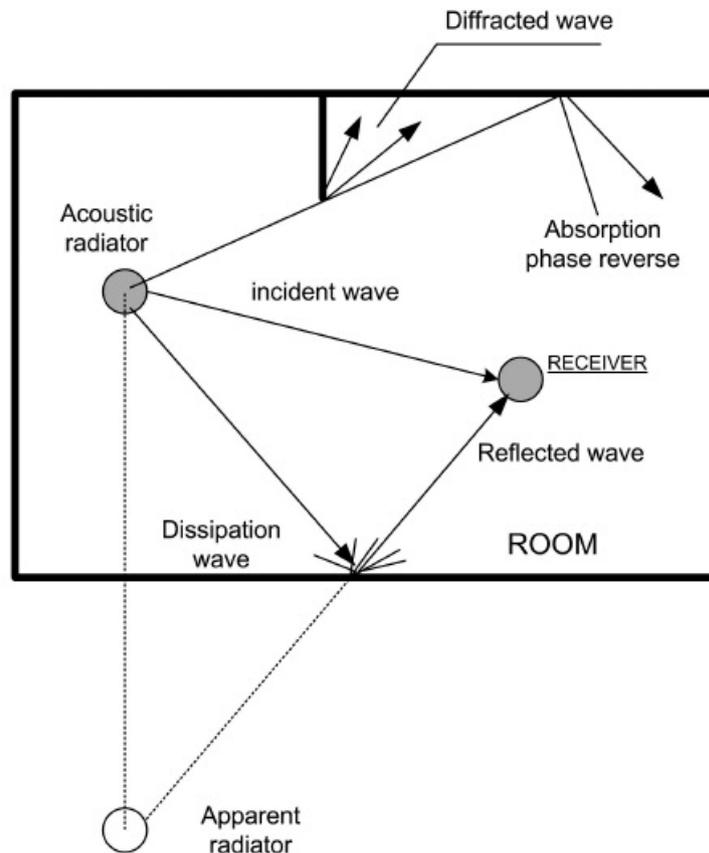

Figure 1.
Physical phenomena ensuing on the way of sound propagation between the source and point of record as a result of a sound wave interaction with elements of room itself [7]

Theoretically acoustic pressure of a sound emitted to the room or reaching the point of reception may take the value within the range from 20 μPa (threshold of audibility) to around 65 Pa (threshold of pain). In practice average range of acoustic pressure changes is usually considerably smaller and e.g. for medium loud speech sound, rms value of the acoustic pressure is equal around 0.1 Pa, therefore, it is million times smaller than atmospheric pressure. Due to small range of acoustic pressure changes for sounds produced in rooms, the rooms themselves may be treated as physical systems with constant parameters, for which impulse response is proportional to the size of produced simulation.

In each room there are at least two characteristic points i.e. point with the source of sound and point of the sound record (place of sound perception by the listener). In most of the cases usually there are many sources of sounds and many points of record in the room. Very often there are diversified sources of sound of various acoustic power in separated area of the room, however, in other area there are points of record located at different distances from the sound source. For this reason substantial complexity is characteristic for conditions of sound propagation in the room.

Only one source of sound and one point of record is enough to prepare approximate description of certain group of phenomena which occur in the room on the way of sound propagation between the source and point of record. However, it needs to be emphasized that on pair of characteristic points is not sufficient to evaluate acoustic quality of the whole room.

In the process of sound wave interaction with particular elements of the room there is a range of different physical phenomena disturbing process of sound propagation and indirectly having influence on the room acoustic quality. Fig. 1 shows some phenomena ensuing on the way of sound propagation between the source and point of record [7].

Sound reaching specific point of the room is a resultant of direct sound, diffuse sound as well as sound one-time and repeatedly reflected from the surfaces limiting the room.

During the sound wave reflection from the surfaces limiting the room partial absorption of its energy takes place as well as phase displacement resulting from the change of the acoustic impedance of medium. In case of non-uniform surfaces sound waves are additionally diffused and when the length of wave is comparable or smaller than linear dimensions of

obstacles sound waves reaching the point of record are moved in time and make a resultant of direct and secondary sound resulting from the described physical processes

It can be assumed that waves ensuing as a result of diffusion, deflection and repeated reflection are only a background for energy-wise substantial located on the sound propagation way, then sound waves undergo deflection. For this reason single reflections from planes limiting the room. Common feature of diffused, deflected and repeatedly reflected waves is their little energy and for this reason their influence on the intensity of a resultant sound reaching the point of record can be omitted.

3. STATISTICAL THEORY – DEFINITION OF REVERBERATION TIME

Statistical theory is based on the assumption that acoustic field inside the room is a perfectly dispersed field of exponential nature of the sound energy fading after disconnection of the sound source in the room. To describe sound propagation in the closed room the method uses basic notions used in the kinetic theory of gases. Based on the statistic theory dependences were introduced to determine mean length of free wave way, mean coefficient of sound absorption as well as dependencies known in the acoustics enabling calculation of the reverberation time. Statistic method can be applied only to rooms whose shapes ensure perfect diffusion of sound energy. Courses of sound increase and decay processes may be described approximately by means of time characteristics presented in Fig. 2.

Statistic theory is particularly useful for engineers as it allows to determine general acoustic properties of interiors with one number. Based on this theory Sabin's and Millington's dependencies were introduced in the acoustics enabling calculation of the reverberation time when the room volume and sound absorption capacity of all its surfaces is known.

Fig. 3 shows graphic form of definition of parameters characterizing speed of sound decay in the room. EDT (Early Decay Time) is determined based on the speed of sound decay for first 10 dB of the acoustic pressure level decrease after the sound source disconnection. Time Tr20 and Tr30 describe sound decay in the dynamic respect, corresponding to values 20 or 30 dB. In this case a reference point is the level of 5 dB below the agreed sound state. Provided definitions do not differ from the basic definition of the reverberation time. They only refer to different
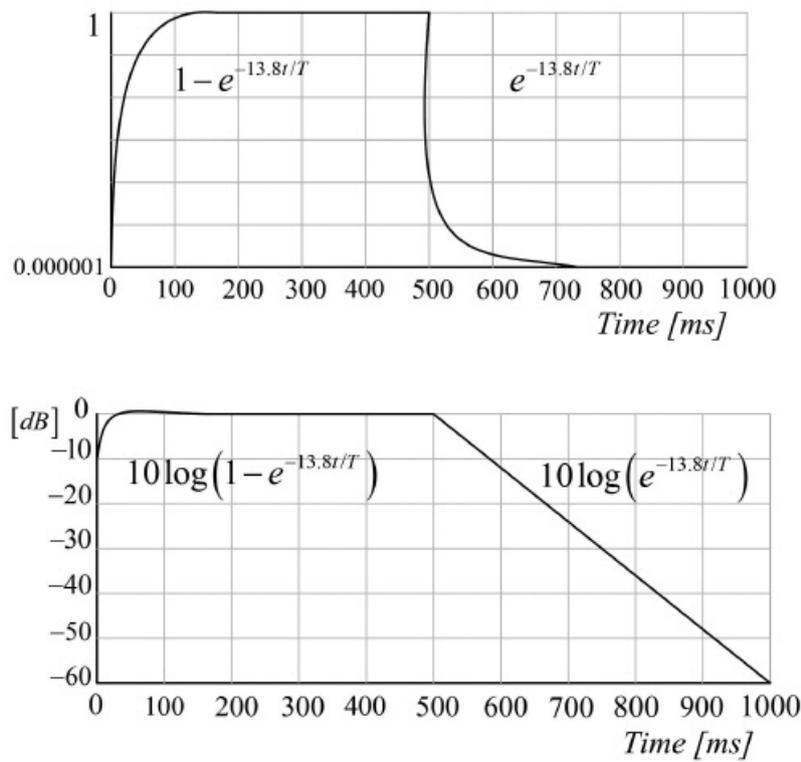
Figure 2.
Process of increase, agreed state and decay of sound in the room (reverberation time: *T = 0.5 s* (a) – linear scale – standard envelope *ne*, (b) – logarithmic scale [dB] [8]
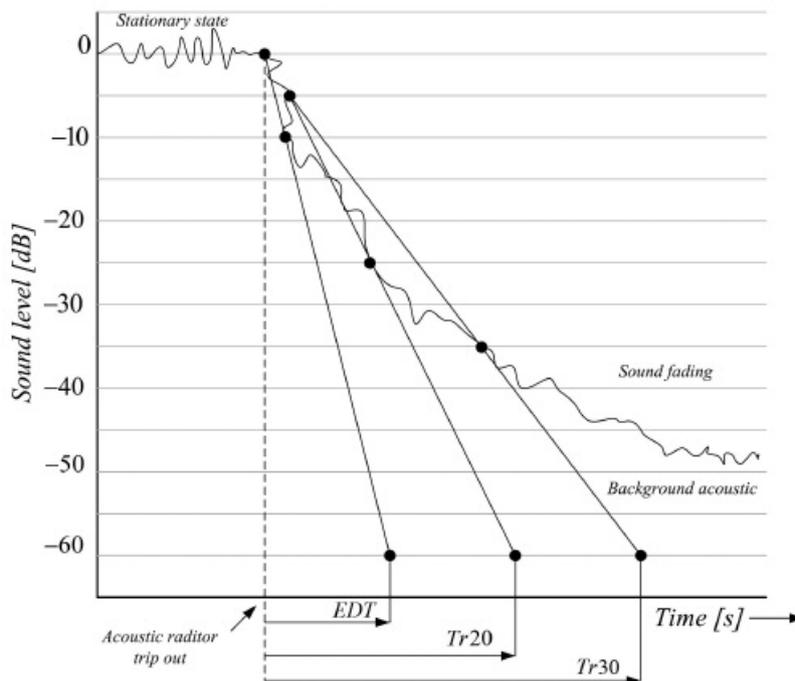

Figure 3.
EDT (Early Decay Time). Time Tr20 and Tr30 describing sound decay in the dynamic respect, 20 or 30 dB respectively

fragments of sound decay curve in the room. All listed parameters will be equal when basic assumptions of statistic theory are met.

Statistic theory refers exclusively to the rooms whose shapes ensure perfect diffusion of sound energy.

4. RESEARCH ON THE IMPACT OF ROOM SHAPE ON REVERBERATION TIME BY MEANS OF COMPUTER SIMULATIONS

4.1. Description of the experiment

Simulated room of the rectangular shape and changeable dimensions was employed in the research. Scheme of the analysed room has been presented in Fig. 4.

 The following dimensions were subject to changes:

– room height: **H** (2.5 m - 7.0 m);

– room width: **W** (3.0 m - 25.0 m);

– room length: **L** (1.5 m - 20.0 m).

– employed mean coefficient of sound absorption **α** (0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 0.99).

Simulation was made by means of very simple software CARA (Computer Aided Room Acoustics). The software uses algorithm based on the analysis of image sources and radial methods. CARA software is quite inaccurate software. However, accuracy of numerical calculations is not important in the exper-
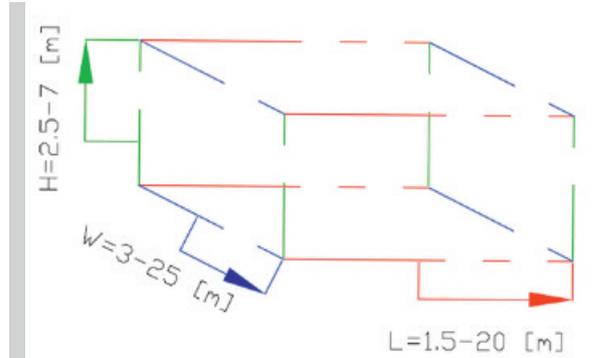

Figure 4.
Model of the room subject to analysis [9]

iment. The subject of interest here were quality changes rather then quantity changes and they were noticed. Isotropy of the acoustic field in simulated room was employed in the research. The room during the test was empty and all-directions sound source was assumed.

4.2 Results analysis

Preliminary analysis of the results shows that with the same volume V= 250 [m^3] and constant length of the room L=10 [m] it can be noticed that initial value increases along with the increase of height which is presented in Fig. 5.
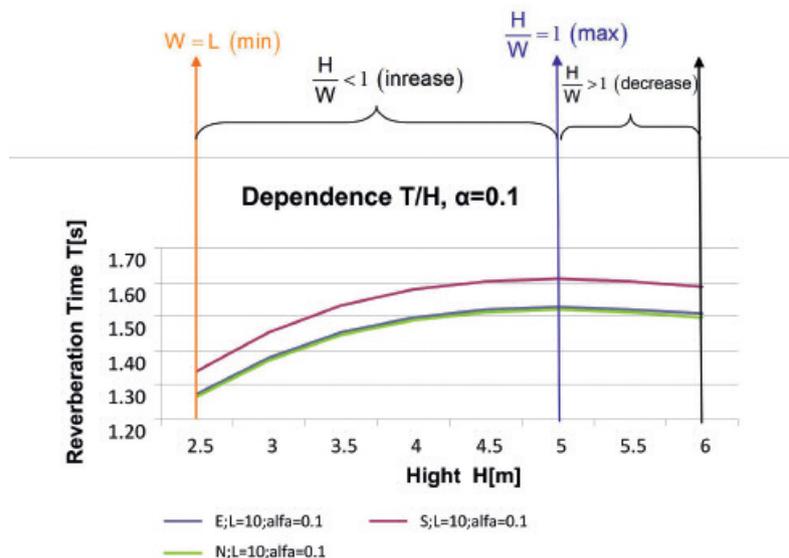

Figure 5.
Dependence of the reverberation time T on height H, at constants: V=250 [m^3] L=10 [m]; α=0.1
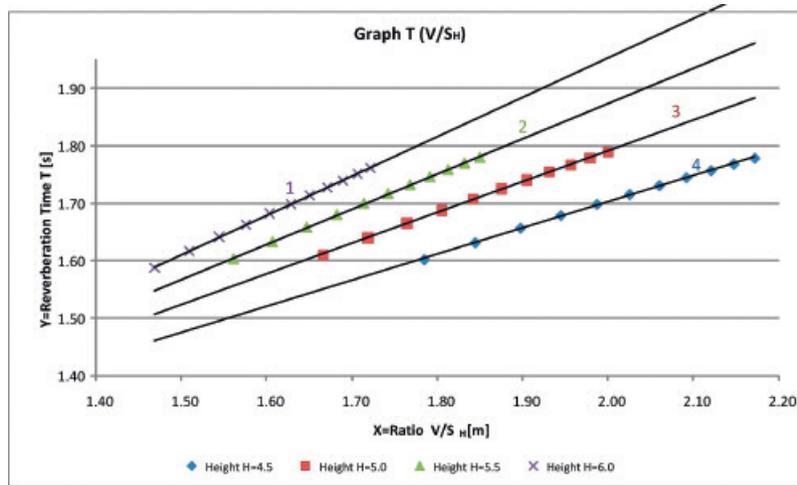
Figure 6.
Diagram of the reverberation time dependence on V/S_H ratio

Table 1.
Value of the reverberation time for ratio V/S_H for height H= (4.5 – 6 m) and mean sound absorption coefficient $\alpha=0.1$

4.50		5.00		5.50		6.00	
V/S_H	T	V/Sn	T	V/Sh	T	V/Sn	T
1.78	1.60	1.67	1.61	1.56	1.60	1.59	1.47
1.84	1.63	1.72	1.64	1.61	1.63	1.62	1.51
1.90	1.66	1.76	1.67	1.65	1.66	1.64	1.54
1.94	1.68	1.81	1.69	1.68	1.68	1.66	1.58
1.99	1.70	1.84	1.71	1.71	1.70	1.68	1.60
2.03	1.72	1.88	1.73	1.74	1.72	1.70	1.63
2.06	1.73	1.90	1.74	1.77	1.73	1.71	1.65
2.09	1.75	1.93	1.75	1.79	1.75	1.73	1.67
2.12	1.76	1.96	1.77	1.81	1.76	1.74	1.69
2.15	1.77	1.98	1.78	1.83	1.77	1.75	1.71
2.17	1.78	2.00	1.79	1.85	1.78	1.76	1.72

For each presented case it can be noted that a function graph changes from ascending to decreasing (between 5.5-6.0). Therefore, its shape reminds a parabola shape. Moreover, it can be concluded that if the height is different from the length and width (H≠L≠W) then the reverberation time increases. The value of the reverberation time will be smallest if the width equals length (W=L). If H/W ration is smaller or equal 1 then reverberation time increases too, but if H/W ratio is bigger than 1 then reverberation time decreases, which is shown in the above diagram.

The next examined relation is the room volume ratio to the surface area of vertical partitions limiting room. The results of these analyses have been pre-sented in Fig. 6.

Figure 6 presents curves of the trend of the equations and correlation coefficient r.

1 - y = 0.6853x+0.5826; r = 0.999

2 - y = 0.61253x+0.6491; r = 0.999

3 - y = 0.5351x+0.7204; r = 0.999

4 - y = 0.4552x+0.7926; r = 0.999

Based on the diagram presented in Fig. 6 it can be concluded that reverberation time increases along with the increase of V/S_H ratio. Naturally reverbera-tion time increases for greater heights as the volume is greater then. However, when analysisng reverbera-tion time for constant height, growth tendency of
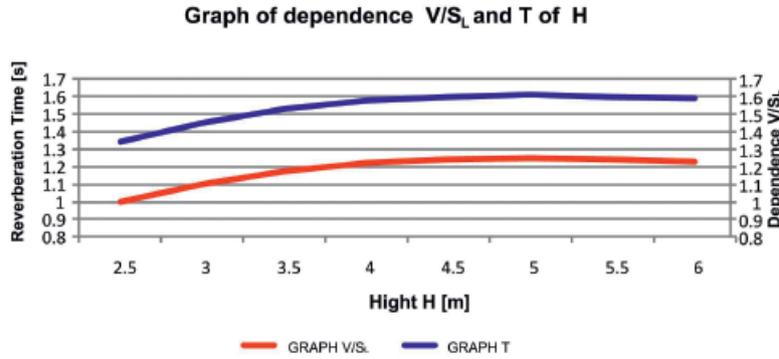
Figure 7.
Diagram of the dependence of V/S_L and T ratio on the room height H
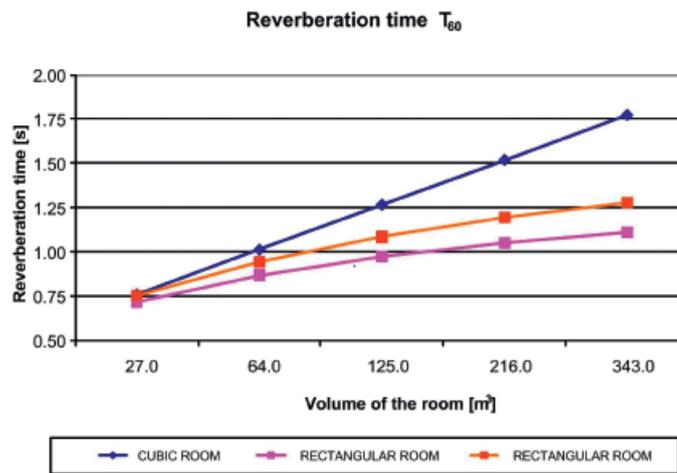

Figure 8.
Dependence of the reverberation time on the room volume

reverberation time can be easily noted with the increase of analysed ratio.

Moreover, V/S_H ratio decreases when the room height increases which is shown in the below presented Table 1. So if the room volume is biggest amongst the examined structures, then reverberation time for this room reaches maximal value.

The following diagram presents dependencies of V/S_L ratio on the height H as well as reverberation time on height H.

Function of the height impact on V/S_L ratio has got identical course. Looking at the course of functions presented in diagram 4 it can be noted that curve describing time of reverberation is a parallel displacement of a curve describing V/S_L ratio. This displacement may depend on the value of reverberation coefficient of sound absorption in the room. In this case values L=10 m and α=0.1 were employed. In the following works the authors will deal with

appointing strength of the correlation between the presented curves. It may occur that value of the reverberation time is determined, next to the sound absorption, by V/S_L ration.

It can also be proved that with constant volume also surfaces limiting room have got impact on the reverberation time. The scheme of the analysed room has been presented in Fig. 4, where:

– room height: $\mathbf{H} = H_i$ (i = 1,2,…,5);

– room width: $\mathbf{W} = W_i$ (i = 1,2,…,5);

– room length: $\mathbf{L} = L_i$ (i = 1,2,…,5).

Rooms of the same volume hale been employed for the analysis (two cuboidal rooms and one cube-shaped). For cuboidal room marked with red colour constant length was employed equal L = 2.5 m. The difference between the following approximations of room is:

$$H_1/L_1 - H_2/L_2 = H_2/L_2 - H_3/L_3 = … = H_4/L_4 - H_5/L_5 = 0.4$$

In Fig. 8 pink colour marks time of reverberation also for cuboidal room but of the side length equal L=2 m. However, the difference between the following approximations of the room is:

$$H_1/L_1 - H_2/L_2 = H_2/L_2 - H_3/L_3 = \ldots = H_4/L_4 - H_5/L_5 = 0.5$$

Obtained results show that if rooms volumes are the same for cuboidal room and cube-shaped one, then internal (limiting) surface area is decisive. Therefore it can be stated that if any of the analysed rooms has got smallest surface area then reverberation time is greatest for this room and the opposite for the room of the biggest surface area. Moreover, it turned out that the ratio of the longest side to the shortest one influences reverberation time. Therefore, it can be concluded that if the room sides are of the same length (L=W) i.e. their ratio equals 1 (W/L=1) then reverberation time reaches maximal value. Due to the above if sides ratio is bigger than 1 (W/L>1) then reverberation time will decrease.

5. CONCLUSIONS

Conclusions from this research confirm impact of the room shape on the acoustics in it. In cuboidal halls of similar capacity, acoustic absorptivity and acoustic field isotropy, proportions of the length to the projection width seem to be a substantial factor forming the acoustics of these rooms.

The analysis of obtained results shows that geometry of the room and shape coefficient influence time of reverberation. Fig. 5 already shows that depending on H/W, different values of reverberation time are obtained. Moreover, H/W coefficient indicates course of the reverberation time in the room height function. When H/W<1 then graph is increasing and in the opposite case i.e. H/W>1 graph is decreasing.

Also analysis of the remaining results shows impact of room geometry on reverberation time. Diagram 6 presents increase of reverberation time in V/S_H ratio function. During the further stage of works laboratory research is planned in non-reverberation chamber. Construction of the room whose all linear dimensions are going to be changeable is planned. Moreover, continuation of the research is planned with the use of computer simulations performer by means of Professional software such as e.g. ODEON.

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