Acoustics of the new Opera Houses in Moscow **4936 (N1)**

Michael Lannie [1] and Vadim Souchov [2] ,

[1] Research Institute for TV and Radio, Moscow, Russia

[2] Research and Design Institute for Culture, Leisure, Sports & Public Health Constructions, Moscow, Russia

Presented at the 106th Convention 1999 May 8–11 Munich, Germany

This preprint has been reproduced from the author's advance manuscript, without editing, corrections or consideration by the Review Board. The AES takes no responsibility for the contents.

Additional preprints may be obtained by sending request and remittance to the Audio Engineering Society, 60 East 42nd St., New York, New York 10165-2520, USA.

All rights reserved. Reproduction of this preprint, or any portion thereof, is not permitted without direct permission from the Journal of the Audio Engineering Society.

AN AUDIO ENGINEERING SOCIETY PREPRINT

ACOUSTICS OF THE NEW OPERA HOUSES IN MOSCOW

Michael Lannie and Vadim Soukchov

Research Institute for TV and Radio,
12, 3-rd Khorochevskaja st., Moscow, 123298, Russia

Reseach & Design Institute for Culture, Leisure, Sports &
Public Health Constructions
29-A, 2-nd Brestskaja st., Moscow, 123065, Russia

ABSTRACT

The new opera house "Novaja Opera" with a theatre hall for 790 seats was open in Moscow in 1998. Three other theatres are under a construction. They are: the Sister Stage of the Bolshoj Theatre (hall for 970 seats); the State Ballet Theatre (2 halls for 1000 and 300 seats) and Galina Vishnevskaja's Theatre-Studio (hall for 250 seats). The description of all the theatres and the results of the acoustic design are presented. In the completed hall of "Novaja Opera" acoustic measurements according to ISO 3382-1997 were made and the results have been analysed.

O. INTRODUCTION

From 1917 till the crash of the USSR only one special building for a music theatre was built in Moscow - the State Musical Theatre for Children. The acoustic solution of that theatre hall was rather successful [1]. There were not enough music theatres in such a large city as Moscow. For that reason in the middle of the 90-th the design of the new four opera houses was started. They are (1) Galina Vishnevskaja's Theatre - Studio (GVTS) - a new building with a small hall for 250 seats; (2) The State Ballet Theatre (SBT) - a fully renovated building, 2 halls for 1000 and 300 seats; (3) The Sister Stage of the Bolshoj Theatre (SSBT) - a new building, hall for 970 seats; (4) The theatre "Moscow Novaja Opera" (MNO) that is located in fully renovated old building. Nowadays the first three theatres are under a construction and the last is mainly ready. The main acoustic design of these opera houses was made by the authors of this paper under the head of prof. L. Makrinenko. The leading part in the design belongs to prof. L. Makrinenko who died on 18.08.1997. The authors dedicate this publication to the memory of their friend prof. L. Makrinenko with whom they have worked together for many years. Below in sections 1-4 the acoustic solutions of the mentioned theatre halls will be presented. The problems of sound insulation and acoustics of the rehearsal halls that were solved for all the theatre buildings are out of the topic of this article.

1. GALINA VISHNEVSKAJA'S THEATRE - STUDIO (GVTS)

The hall in GVTS (arhitect A. Velikanov) was designed as a small copy of a classical opera house. The theatre building now is under a construction. There are N=250 seats in common that are located in the stalls, the dress-circle and two circles. The view of the hall made by acoustic computer model is shown In fig. 1. The dimensions of the hall are very small. The length from the footlights to the back wall is equal to 9.5 m; the maximum width -14 m; the height in average - 8.5 m.

The main problem of the acoustic design deals with a small volume of the hall that in the prior architectural design was only V=868 m^3 (without the stage volume). In this case the volume for 1 seat V/N=3.5 m^3. It's a very small value, and for opera houses V/N=6-7 m^3 is usually recommended [2,3]. It was estimated that in fully occupied hall the reverberation time will be $RT60_{occ,0.5\text{-}2kHz} \sim$ (0.7-0.8) s. The required value for the halls of the corresponding volume is much larger (1.1-1.2) s [3]. The dimensions of the hall's plan could not be changed. The investor also refused to reduce the number of seats. So there were two main ways for the estimation of the recommended values of RT60: (1) to enlarge the volume of the hall by the design of more high ceiling; (2) to use in interior the materials with a low sound absorption. The estimated form of the ceiling is shown in fig.2. This decision enlarged the hall's volume to ~1000 m^3. The convex form of the ceiling near the portal provided the appearance of the early sound reflections. Two measures were proposed for reducing the concentration of sound due to the concave form of the rear walls: (1) the slope (see fig. 2) between the ceiling and the upper part of the walls; (2) niches in the walls behind the circles for better scattering of sound. There were proposed: plaster for the ceiling and walls; parquet for the floor; hard wooden chairs both for the stalls and the circles.

It was estimated that all these measures can provide the values of RT60 (shown in the table 1) that are close to the recommended optimum.

Table 1.

f, Hz	125	250	500	1000	2000	4000
RT60, s	1.20	1.10	1.05	1.00	0.95	0.95

The structure of sound reflections was calculated and analysed in details for all areas of the seats. The form of the impulse response was rather good. No high - level sound reflections with large time delay were estimated. The clarity was equal to +(7-10)dB in the first half of the stalls and +(3-4)dB in the rear part and in the circles (for the sound source on the stage near the footlights). The large values of C80 in the first rows are due to the small distance to the sound source. When the latter moved to the centre of the stage the clarity became smaller C80 = +(4-6)dB. Such values of C80 seem to be acceptable for the music hall of the corresponding volume.

Good intelligibility of the singing voices is important for the opera houses. The RASTI values may be used for it's approximate estimation. The calculations showed that RASTI $\geq$ 0.5 for all areas of the seats. The tempo of the singing voice is more slow than that of the common speech. So such a result seems to be acceptable for an opera house.

2. THE STATE BALLET THEATRE (SBT)

This theatre now is under a construction. It is located in fully renovated old historical building in Begovaja street. The building includes two main halls - the Large hall for 1000 seats and the Small hall for 300 seats (architect A. Anisimov). Ballet show is the main purpose for the both halls. Opera performance may take place as well.

2.1. Large hall

The plan of the hall is shown in fig. 3. The hall's volume V=10500 m^3 and the volume for 1 seat V/N= 10.5 m^3. The length of the hall from the portal to the back wall - 25 m: the width between the lateral walls - 36 m; the height in the middle part - 13 m. The demand to remain the historical walls and to include them into the interior influenced greatly upon the plan of the hall. For that reason the plan is mainly rectangular (not to take into account the shoe - like form of the barrier between the stalls and the gallery/boxes). For the same demand the large foyer coincides with the back part of the hall through the big arch openings.

For the opera houses of the given volume the values $RT60_{occ} \sim 1.5$ s at the middle frequencies and RT60=1.8-1.9 s at the low frequencies are recommended [2,3]. The following materials were proposed: walls - plaster on the brick; ceiling - wooden panels in the plane surfaces and plaster in the curved surfaces; floor in the stalls, galleries and boxes - parquet; floor in the pit - boards (40 mm thick) over a airspace of 500 mm; chairs - upholstered with cloth covering. It was proposed to place the sound absorbing panels on the ceiling and partly on the walls of the foyer. This decision will decrease the influence of the foyer on the hall's acoustics. As a result the values of RT60 that are shown in table 2 were estimated.

Table 2.

f, Hz	125	250	500	1000	2000	4000
RT60, s	1.90	1.85	1.60	1.45	1.40	1.35

It was not possible to provide the seating area with the early lateral reflections from the very wide historical wall. So it was proposed to use these walls for enlarging the diffusion of the sound field. Various convex architectural elements were used on these walls. The problem of the early high - level lateral reflections was partly solved due to the barriers of the galleries and boxes. Their height from the floor of the stalls to the upper level of the barriers was large enough to provide geometrical sound reflections at the middle and high frequencies. The time delay of these reflections was not more than 50 ms.

In the given situation it was very important to design the optimal form of the ceiling. The proposed form of the ceiling is shown in fig. 4. A large horizontal section was used in it's central part. It provides the early sound reflection to the main part of the stalls. The rise of the ceiling in it's back part was mainly to the architectural demand. The latter was caused by the need to remain the historical walls of the hall. The slope of the ceiling in this part was proposed in order to eliminate the sound reflections with large delay at the stage and in the first rows of the stalls. All early reflections from this part of the ceiling are directed to the rear and partly central rows of the chairs. For the same reason a slope of the ceiling above the central box was proposed.

The ceiling between the portal and the lighting gallery has a form of three convex sections. This part is especially important for the ballet because it's located above the pit. For the sound source in the pit the reflections from these sections are directed on the stage and back to the pit. Their time delay is not more than 75 ms. For a singer on the stage the time delay of the first reflections from the mentioned three ceiling sections will be less than 55 ms in the pit and 45 ms in the first rows of the stalls. Such values are acceptable for classic music, so these reflections seem to improve the contact between the orchestra and the performers.

Computer model was used for the estimation of optimal hall's form. The main acoustic parameters were calculated and analysed as well. For example, C80=+(3-5) dB in the first rows and C80= -1 dB in the rear rows. These values correspond to the middle frequencies and for the sound source located in the central part of the pit. In the common RT60, EDT, C80, RASTI are rather close to the recommended values. The structures of sound reflections that were calculated up to the time delay of 125 ms also lead to the conclusion that good acoustic conditions may be expected in the hall.

2.2. Small hall

The plan of the hall is shown in fig. 3. The hall is not symmetric. Seats are located in the stalls and in a small balcony with only two rows of chairs. The hall's volume V=1700 m^3 and the volume for 1 seat V/N= 5.6 m^3. The length of the hall from the portal to the back wall - 13 m: the width in the central part of the stalls - 18 m; the height in the middle part - 7.8 m. The optimal values of RT60 for such halls are close to 1.2 s at the middle frequencies with a rise up to 1.5-1.6 s at the octave band 125 Hz. It was proposed according to the acoustic calculations to use plaster on the walls and the ceiling, parquet floor in the stalls and the balcony, and upholstered chairs with cloth covering. Such solution was mainly the same as for the Large hall. The facing of the pit was the same as well. In table 3 the calculated values of $RT60_{occ}$ are shown.

Table 3.

f, Hz	125	250	500	1000	2000	4000
RT60, s	1.50	1.40	1.30	1.20	1.15	1.10

The lateral reflections from the walls will cover all the seat's area. Their delay will be less than 50 ms. Some convex architectural elements were proposed for the walls in order to enlarge the diffusion of the sound field. Several forms of the ceiling were proposed and discussed with the architect. The final solution is shown in fig. 5. The ceiling consists of 4 convex sections and a slope in its back part. The calculated impulse responses had a good form in all areas of the seats. It was enough early sound reflections for the location of the sound source both in the pit and at the stage.

3. THE SISTER STAGE OF THE BOLSHOJ THEATRE (SSBT)

The new theatre hall is located near the main historical building of the Bolshoj Theatre and should be open at the end of this year. The volume of SSBT is equal to V=7900 m^3. In the hall there will be 970 seats (V/N=8.1 m^3). The computer acoustic model was used to predict the sound quality in the hall. This first stage of the acoustic design was briefly mentioned in the AES preprint 4427 [4]. There will be a lot of decorations and curved constructions in the hall's interior. For that reason it was considered to be useful to provide acoustic scale measurements as well. The results of this research will be presented below.

SSTD was designed as a classical theatre hall with a shoe-like form of the plan and a flat ceiling (architect A.Maslov). The seats are located in the stalls, the dress - circle and two rows of circles. The plan and the section of SSBT are shown in fig. 6,7. The scale n=25 was used. The model was made from 4 mm polystyrene. This material was widely used by the authors for the models in scale 1:20 - 1:25. It was estimated that the values of sound absorption coefficient α of polystyrene are close to α of plaster (at the corresponding frequencies). It was difficult and expensive to construct every chair of the hall. It was proposed to make models of every row of chairs as a vertical surface made of polystyrene. The position of such surfaces corresponds to the back of the chair. It was important to model properly the absorption of the occupied chairs. Strips of felt were used. The thickness of every strip was equal to 4 mm. Several methods to place the felt were tested. They are shown in fig. 8. The measurements were made in a model of reverberation chamber. It was estimated that case №5 (see fig. 8) with one strip of felt on the upper part of the vertical surface is the best choice for modeling the occupied seats. The measured values of α for this case are shown in fig. 9. It should be noted that all the frequencies and other measured values in this section correspond to the case of a real hall; i.e. the frequencies that were used in the model are divided by n; time intervals are multiplied by n; the absorption in the air at high frequencies is also taken into account. The measured values of α in fig. 9 are compared with the recently published data [5] on medium upholstered chairs that are recommended for SSBT. The measured and published values are rather similar. For that reason the location of the felt according to the case №5 was used in the model of the hall. The samples of different curtains were also tested in the model of reverberation chamber. It was made for the estimation of the sample that may be used for the model of the main curtain for the hall's proscenium. The best result is shown in fig.10 and it is compared with the published data [6].

The placement of the sound source and the receiver is shown in fig. 6,7. Two types of spark discharge were used as a sound source. One of them (omnidirectional) was used in the pit, and the other (with the directivity similar to the human voice) was located at the stage. The power of the discharge may be controlled in several steps. The maximum of the sound spectrum was chosen to 600-700 Hz. The spectrum had a wide band form, and it was possible to measured the acoustic parameters in the interval of 4 octaves. A small omnidirectional condenser microphone was used as a sound receiver.

The hall should have the reverberation time ~(1.45-1.50) s at the middle frequencies with a ruse up to 1.8-1.9 s at the low end of the frequency band. The measured in the model values of $RT60_{occ}$ are presented in table 4. The results of acoustic calculation made on the previous stage of acoustic design are shown as well.

Table 4.

		Frequencies of the octave bands, Hz					
		125	250	500	1000	2000	4000
The curtain in proscenium is put down	$RT60_{occ}$,s (measured in the model)	1.75	1.55	1.45	1.35	1.3	-
	$RT60_{occ}$, s (calculated)	1.70	1.65	1.45	1.30	1.20	1.10
The stage is open	$RT60_{occ}$,s (measured in the model)	1.80	1.60	1.50	1.45	1.35	-
	$RT60_{occ}$, s (calculated)	1.70	1.65	1.55	1.40	1.30	1.20
The fire curtain is put down	$RT60_{occ}$,s (measured in the model)	1.85	1.75	1.65	1.60	1.55	-
	$RT60_{occ}$, s (calculated)	1.75	1.75	1.65	1.50	1.40	1.35

The structure of sound reflections was analysed in details. The impulse responses were measured in the form of ETC. About 90 ETC were measured for various combinations of the source-receiver positions. The values of C80, C50 and G were calculated from the measured ETC for a wide frequency band (no digital octave filters were used). It was estimated that mainly in all areas of the seats: -2 dB $< C80 < 2$ dB; $C50 \geq -0.9$ dB and 3 dB $< G < 7$ dB. These results lead to the conclusion that in the hall rather good acoustic conditions may be expected.

Only in one case a non optimal form of ETC was estimated. It corresponds to the position of the microphone in point 6' and the sound source at the centre of the stage near the footlights (see fig. 11). A group of reflections with a delay ~ 50 ms and a level close to the direct sound can be seen. These reflections are caused by a concentration of sound from the curved back wall behind the stalls. Additional architectural elements were proposed to enlarge the scattering of sound by that wall and the walls behind the circles as well. They were installed into the model and after that the measurements were repeated. The results are shown in fig. 12. The level of the most intensive reflections became ~ 5 dB smaller. The form of ETC is more "smooth" now in the part of the early reflections. After the discussions with the architect it was proposed to include the these additional architectural elements in the hall's interior. The model measurements were useful for checking the primary project. They also allow to make some corrections of the hall's acoustic design.

4. "MOSCOW NOVAJA OPERA" (MNO)

The theatre is located in the Hermitage Garden in the very centre of Moscow. The existing old building was fully renovated (architect V. Kotelnikov). The theatre hall includes N=790 seats that are located in the stalls and in the balcony. The volume of the hall $V=5500$ m^3 ($V/N=7$ m^3). The view of the hall according to the computer model is shown in fig. 13. The plan is rectangular due to existing walls of the old building. The walls and the ceiling are covered with plaster. The wooden panels were used as well. The level of the pit's floor may be changed up to the level of the stage. So the concerts with the orchestra on the stage may be provided as well. The prior acoustic solution developed by prof. L.Makrinenko and the authors was checked by the scale model measurements. The large scale (1:10) was used. The model was built abroad and the measurements were provided by the German company ADA. Their results showed that in general the prior acoustic solution of the hall was made correctly.

The measurements were made in an empty hall with MLSSA DRA Laboratories system. The values of RT60 were measured in an occupied hall as well. In table 5 the results of RT60 and EDT measurements are shown.

Table 4.

		Frequencies of the octave bands, Hz					
		125	250	500	1000	2000	4000
The hall is empty; the stage is fully open and without any decorations and curtains; the floor of the pit is raised up to the level of the stage.	$RT60_{emp}$, s (measured)	2.10	1.70	1.65	1.70	1.45	1.25
	EDT_{emp}, s (measured)	1.70	1.55	1.40	1.40	1.35	0.95
The hall is 100% occupied; orchestra in the pit; decorations and about 20 actors on the stage.	$RT60_{occ}$, s (measured)	1.70	1.45	1.40	1.30	1.20	1.1

The impulse responses of the hall were measured for 3 positions of the omnidirectional sound source on the stage. The acceptable structure of the sound reflections was estimated in all cases. Two examples are shown in fig.14,15. The first corresponds to the source position near the footlights and the microphone in the middle of the stalls. The second corresponds to the sound source in the centre of the stage (5 m from the footlights) and the microphone in the balcony. In both cases a monotonous decay form of ETC with high - level early reflection can be seen. The similar situation was noticed for the other source - receiver positions. The values of C80=2-5 dB for the sound source near the footlights (at the middle frequencies 500-1000 Hz). When the sound source moves to the centre of the stage these values become a little bit smaller C80=0-4 dB. The values of D50=62% in average were estimated. This result corresponds to good speech intelligibility.

The hall was opened not long ago. So it seems premature to make the final conclusion on the sound quality. However some prior conclusions can be done. The hall's acoustics is good in general. The voices are clearly heard in all the seat's area. The balance between the orchestra and the singers is good. The musicians feel comfortable in the pit.

At the final part of the construction it was decided by the investor to divide one rehearsal hall into two parts and to organise sound recording studio with a control room for 5.1 format. This decision leads to a lot of difficulties. The rehearsal hall was completely ready at that period, and of course no special measures for sound insulation that are necessary for professional studio were done. Nowadays the control room is completed. It's view according to the computer model is shown in fig. 16. The form of the control room and the placement of acoustic materials had been chosen in order to eliminate the early reflections that are coming to the position of the sound master just after the direct sound. MLS measurements showed that this problem was successfully solved. The optimal values of RT60 and other requirements of [7] were provided as well.

REFERENCES

[1] Makrinenko L., Smirnova T., Krainova A. and Lannie M. Acoustic Measurements in the Scale Model of Moscow Musical Theatre for Children. Stzenicheskaja Technika i Technologia (The Stage Technics and Technology), 1977, No 4, p. 24-27.
[2] Beranek L.L. Concert and Opera Halls. How They Sound. Published for ASA through the American Institute of Physics, 1996.
[3] Acoustics of Auditoriums in Public Buildings. Published for ASA through the American Institute of Physics, 1994.
[4] Makrinenko L. Acoustics of the Russian Classical Opera Houses. AES preprint 4427. Presented at the 102nd Convention 1997 March 22-25, Munich, Germany.
[5]Beranek L.L., Hidaka T. Sound Absorption in Concert Halls by Seats, Occupied and Unoccupied, and by the Hall's Interior Surfaces // J.Acoust.Soc.Amer., 1998, v.104, No. 6, p. 3169-3177.
[6]Fasold W. Raumakustik. Berlin. 1975.
[7] Rec. ITU-R BS.775-1.Multichannel stereophonic sound system with and without accompanying picture.

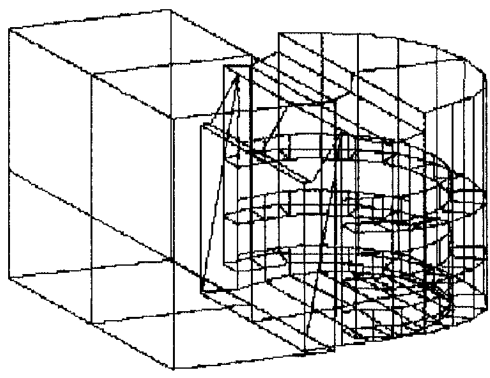

Fig. 1. GVTS. The view of the hall (computer model, one of the primary versions).

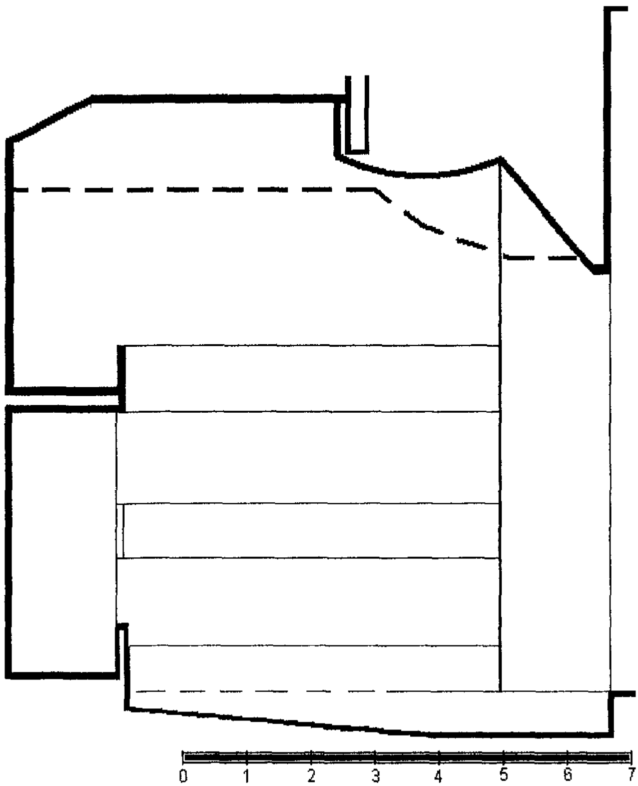

Fig. 2. GVTS. The section of the hall. Dashed line - the primary form of the ceiling.

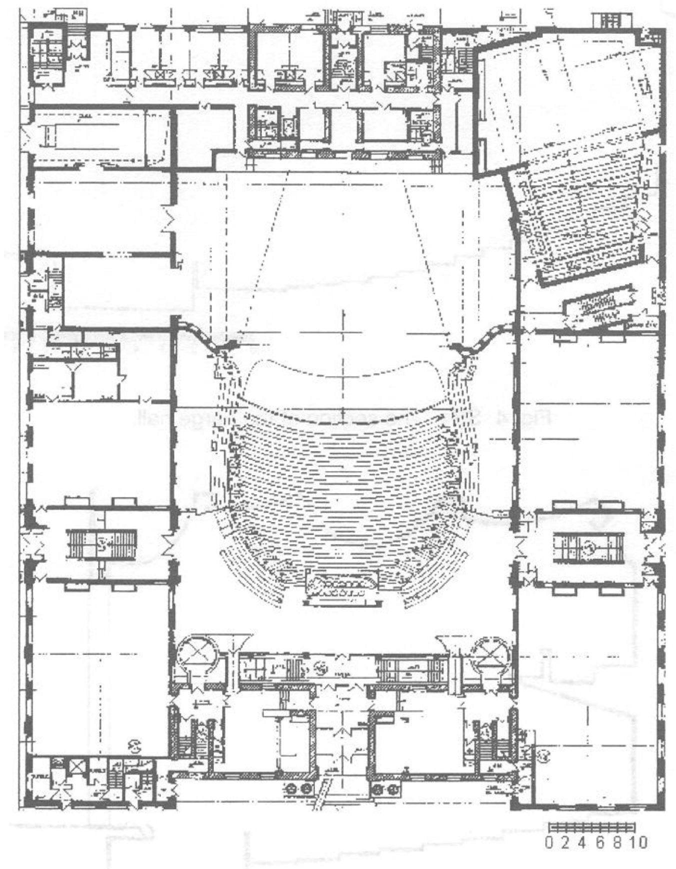

Fig. 3. SBT. The plan of the halls.

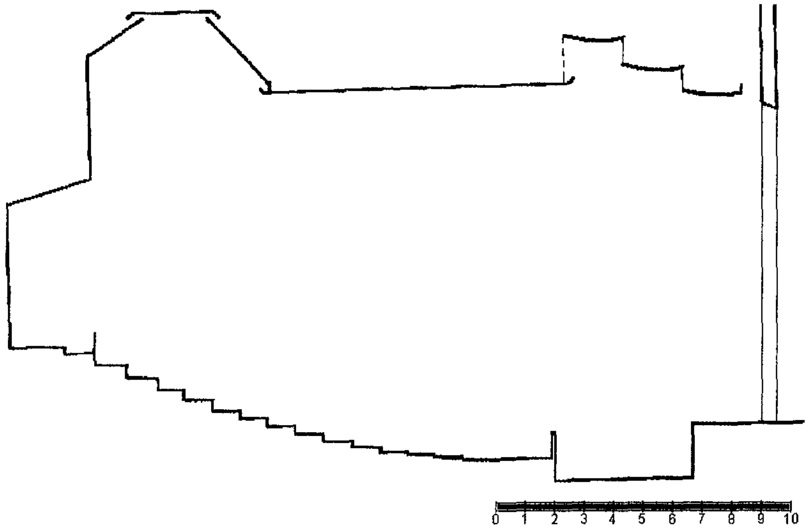

Fig. 4. SBT. The section of the Large hall.

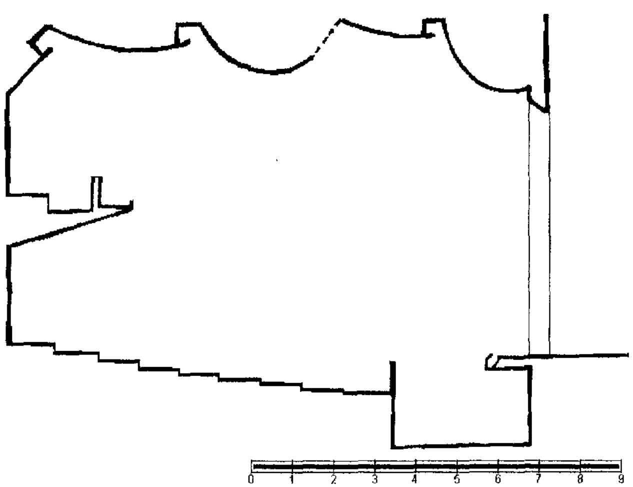

Fig. 5. SBT. The section of the Small hall.

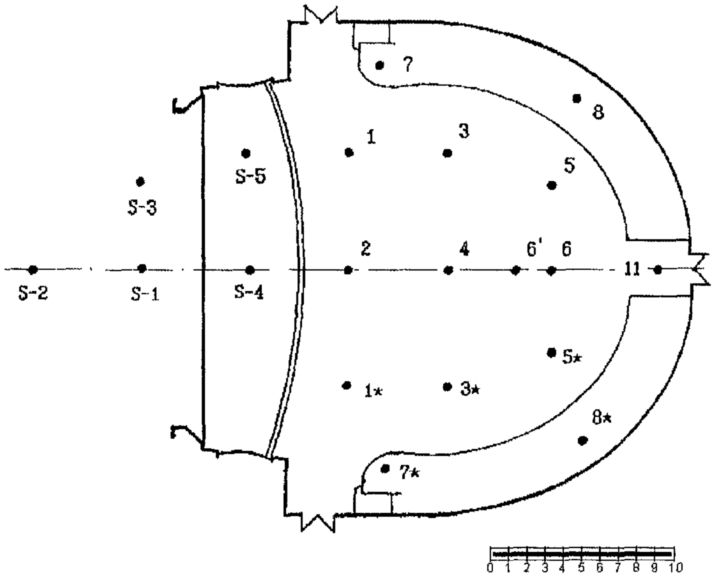

Fig. 6. SSBT. The plan of the hall. Positions of the sound source (S1...5) and the microphone in the stalls and dress-circle (1...11) are shown

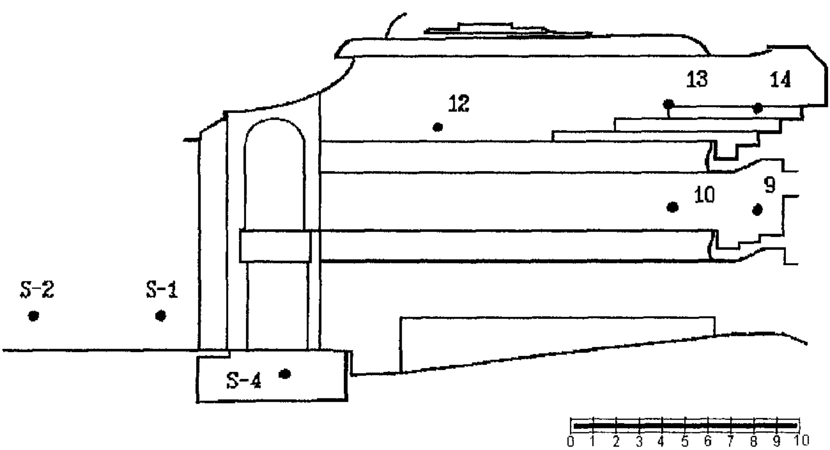

Fig. 7. SSBT. The section of the hall. Positions of the sound source (S1...4) and the microphone in the circles (9...14) are shown.

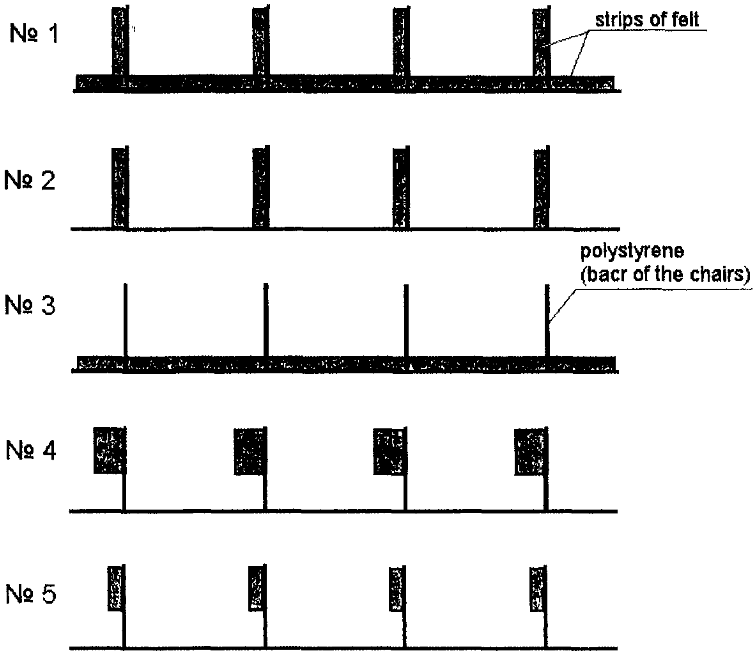

Fig. 8. SSBT. The placement of the felt in the model of the reverberation chamber.

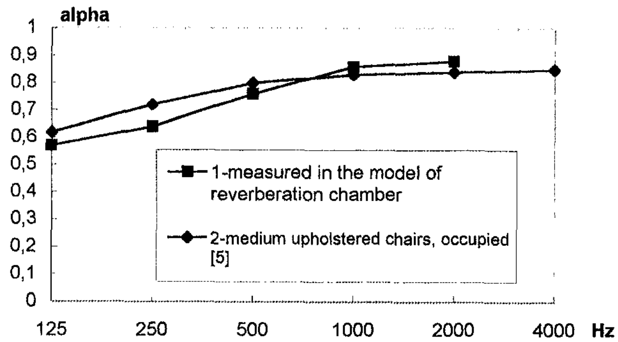

Fig. 9. SSBT. Sound absorption coefficient of the occupied chairs.

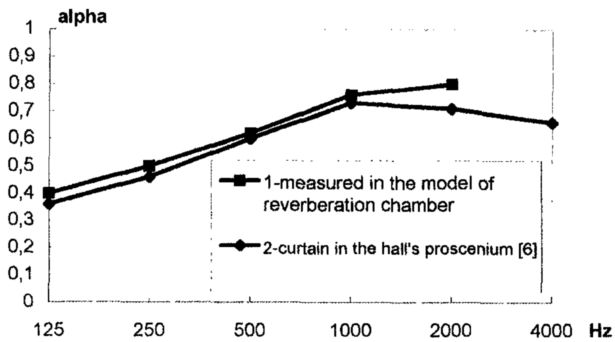

Fig. 10. SSBT. Sound absorption coefficient of the curtain.

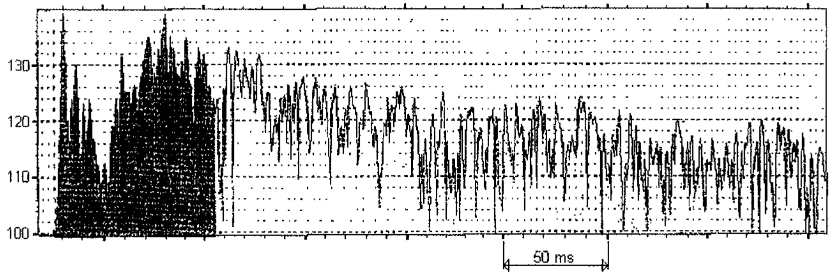

Fig. 11. SSTB. ETC for the microphone in point 6'. The shaded area corresponds to the first 80 ms after the direct sound.

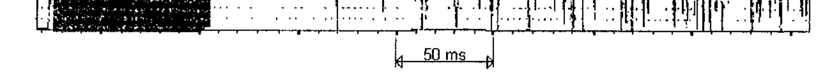

Fig. 12. SSTB. ETC for the microphone in point 6'. Additional architectural elements are installed at the walls. The shaded area corresponds to the first 80 ms after the direct sound.

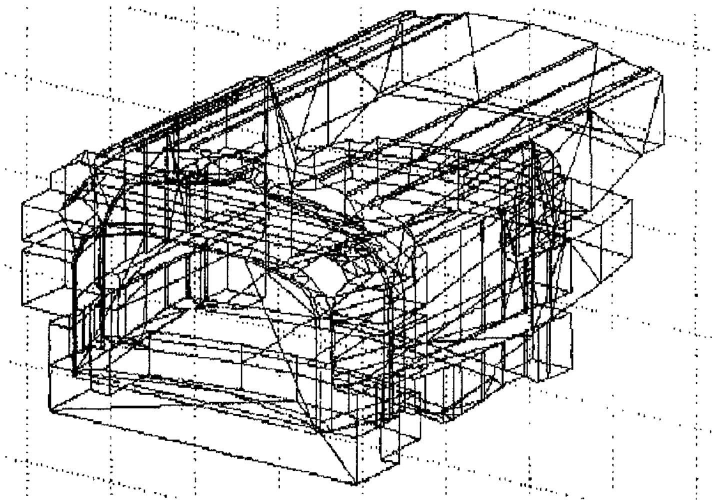

Fig. 13. MNO. The view of the hall (computer model).

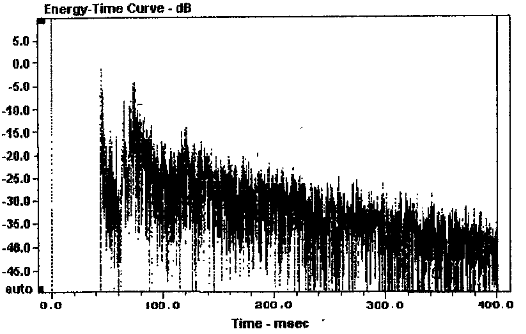

Fig.14.MNO. ETC measured in the central part of the stalls.The sound source is near the footlights.

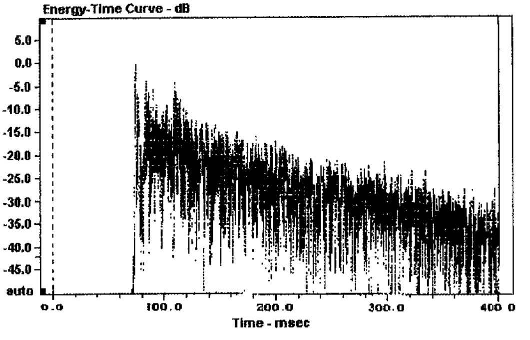

Fig.15.MNO. ETC measured in the balcony. The sound source is at the centre of the stage.

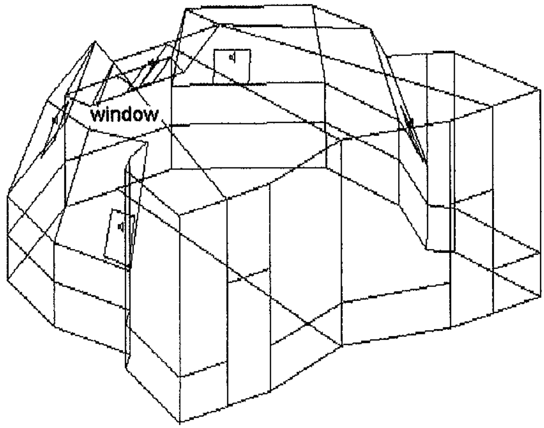

Fig. 16. MNO. The view of the control room (computer model).