Acoustical Evaluation for the Renovation of Multipurpose Performance Hall

Wei Lin[1(✉)], Hsuan Lin[2], Kung-Huang Huang[3], and Chung-Tsung Wu[4]

[1] Department of Interior Design, Hwa Hsia University of Technology, Taipei, Taiwan
weilin@cc.hwh.edu.tw
[2] Department of Product Design, Tainan University of Technology, Tainan, Taiwan
te0038@mail.tut.edu.tw
[3] Shang You Construction Co. Ltd., Kaohsiung, Taiwan
sf.land@msa.hinet.net
[4] Chung-Tsung Wu Architectural Firm, Taipei, Taiwan
archwu@seed.net.tw

Abstract. Taipei Arts Promotion Center Hall carried out renovation works and acoustical evaluation was conducted in 2003. In the past 15 years of use, due to air humidity and material aging and other factors, may affect the room acoustics. The assessments mainly focus on the setting of the space in theater mode, this is the most frequently used setting by the owner. Auditorium impressions of different audiences are different due to the different characteristics of the reverberation time. Different auditory impressions may also reflect time, space, intensity and frequency characteristics and other factors in sound field. In the survey and assessment, field measurement is taken as the basis for assessment, and the real field hall is measured, which includes in-site measurement and computer simulation evaluation for chamber music performance. Finally, the article finally presents the relevant improvement and description.

Keywords: Multipurpose performance hall · Room acoustics
Computer simulation · In-site measurement

1 Introduction

Taipei Arts Promotion Center Hall is multipurpose auditorium and normally used for theater. First, the single-channel sound measurement for indoor sound field performance which is carried out based on the sound field performance evaluation, and the reinforcement sound system measurement is conducted consequently. In order to consider the performance environment of music acoustic (natural sound), once again entered the venue for the two-channel spatial impression of the objective measurement which was evaluated. Some researches presented suitable mid-frequency depending on theater mode, room volume and seating capacity [1]. In the Meanwhile, the musicians can also hear their own sound with the monitoring system, which can improve performance communication among musical band at pit. In addition to creating a good theater environments, the sound reinforcement system is another major focus of this study, the role

J. Zhou and G. Salvendy (Eds.): ITAP 2018, LNCS 10926, pp. 297–306, 2018.
https://doi.org/10.1007/978-3-319-92034-4_22

and function of electro-acoustic system in hall, speakers deliver music to listeners by the PA sound system, known as PA (Public address), however, it is not satisfied to meet various performance status, the system of sound reinforcement (SR) is also introduced in 1965, SR demands not simply transmit the sound, but also receive the brilliant sound from the source, high-quality of sound speaker lead music effect clearly without distortion which could reach the ears of the listener's. This paper presents the in-site measurement, acoustical simulation for the live house which is verified at exited performance space. A number of major acoustical features have been employed in order to provide a hall which meets the various criteria for a venue designed to accommodate a multi-purpose repertoire of events [2]. Schroeder the basic principles of computer simulation into the room acoustics was since 1960 [3]. Room acoustic modeling technique and especially the room acoustic computer models have developed over the last decades [4] and highly accurate prediction models are available today.. Image Source Models method is based on the principle that a specular reflection can be constructed geometrically by mirroring the source in the plane of the reflecting surface. In a rectangular box-shaped room it is very simple to construct all image sources up to a certain order of reflection [5]. The first computer model that was used for practical design of auditoria was a ray tracing model which is proposed by Asbjørn Krokstad [6]. Numbers of sound rays are traced from a source point up to high order reflections following the geometrical and optical law of reflection. Although the room acoustic modeling technique has originally been devoted to the acoustic prediction and design of auditoria, the problems are equally challenging in practical projects, and to a great extent, the same methods can be adopted. One fundamental problem is that the rooms can be very irregular, the diffusion of sound can be uneven and very different from the simple assumption of a diffuse sound field, and the sound absorption is unevenly distributed over the surfaces [7]; all together this means that the reverberation time can be significantly different from that calculated by the classical equations of Sabine and Eyring [8]. Another situation is that even if the reverberation time can be measured and predicted, it may not be relevant parameters to describe the acoustical condition of a room. For the instance, stage support is evaluated for the musician communication and IACC and LF are for sound specialness. In auditoria and performance spaces the room acoustic parameters are laid down in ISO 3382-1 [9]. The paper begins with the in-site measurements, following sections are dedicated to detailed studies concentrating on the computer adjustable. The results presented here not only have been used to verify the design scheme concept, simple field verifications have also achieved in the future renovation in order to characterize information of room acoustic. A room form was developed as prototype that had overall proportion and volume similar to the rectangular, bilaterally symmetrical, the location of measuring points is taken unilateral planning, the average distribution in the auditorium on the right, 1002 seats are distributed in the three level of floors during all assessment. Compared to first renovated completion the planning of the reverberation time (RT), the chamber music mode at middle frequency band is 1.52 s, the theater mode is 1.28 s. The volume of the hall is 5614 m^3, and equipped the hall with acoustical curtains by modifying its acoustical characteristics.

2 In-Site Measurement

The main measurement is the theater mode, which is the most frequently used setting by the Taipei Arts Promotion Center Hall. The general design conditions of the auditorium which is included are shown in Table 1. All the curtains on the stage are open (Broadband frequency usage), including the backdrop, the curtain and screen cover, auditorium floor and the third floor of the sound-absorbing curtain fully expanded. The measurement was set unoccupied state, all entrances and exits are closed. When the background noise is measured, the air-conditioning system is normally set for theater performance, and the field lighting in the auditorium are turned on. In the measurement process, to be consistent with the consistency of the state of the environment, the hall lighting and equipment fully open and use air conditioning equipment to stabilize the temperature and humidity changes.

Table 1. List of general design conditions of the auditorium

Event	Theater mode
Room form	Rectangular hall
Seating capacity	1002 seats (Fist floor: 576 seats, second floor: 217 seat, third floor: 209 seats)
Hall dimensions	Width × Length × High: 32 m × 52 m × 15.6 m
Proscenium size	Width × Length: 14.8 M × 9.8 M
Stage size	Width × Length: 20.8 M × 24.4 M
Musical pit size	Width × Length: 16 M × 4 M
Auditorium volume	5614 M^3
Adjustable absorption	Heavy weight drapery

2.1 Measuring Equipment and Point Distribution Planning

Signal to noise ratio is sufficient and the frequency can reach more than 45 dB in the auditorium, the DIRAC was utilized for measurement as calculation station of the sound field measurement system. The sound source is set on the stage (S1), the receiving point is set to 10 points (M1-M10), the measurement points and instruments are located on the right side of the auditorium (See in Figs. 1 and 2). The omnidirectional sound source (S) is located 2-m above the center of the stage to the edge of the orchestra pit, 125-cm height above the ground, and the e-sweep signal is transmitted using a dodecahedron shape loudspeaker. The receiving points are distributed as a 0.5-in Microphone (B&K Type-2250), fixed with a microphone holder and 120-cm above the ground. The impulse response is calculated by the signals measured by a digital workstation (DIRAC) and filtered to obtain the decay curve by the inverse product. For the assessment of Spatial impression in the sound field, Inter-aural Cross Correlation (IACC) and early lateral energy fraction (LF) parameters were also evaluated, respectively. Sound reinforcement system are also conducted at the stage.

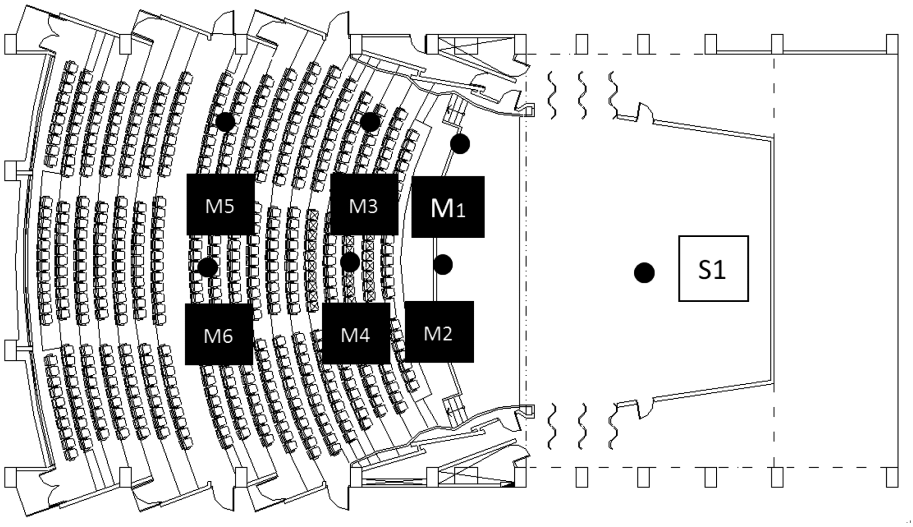

Fig. 1. Sound source and 6 receiving points are distributed in first floor of auditorium

Fig. 2. Photos of measurement instruments are illustrated

2.2 Results of Room Acoustic Measurement

In-site field measurement to the international standard ISO3382-1: 2009 (E) content and specifications described as the basis. In this field measurement, performance settings to the main theater mode, this is the most used frequency setting. Measurement parameters include the Reverberation time (T30), clarity (C80), Sound Strength (G), Stage support (ST), Inter-aural Cross Correlation (IACC) and early lateral energy fraction (LF). The results of in-site field measurement (theater mode), the reverberation time (RT) is 1.18 s at the middle frequency band (500 Hz, 1 kHz), and the recommended indoor performance of the theater is 1.05–1.35. The measured results are consistent with the sound field performance. In addition, the spatial image of music performance, IACC and LF two parameters were measured, results are indicated 0.73 and 0.18, respectively. The two parameters pointed out that may not meet the sense of subjective hearing specialness in auditorium. Preliminary measurements results and recommendation of acoustical parameters are summarized in Table 2.

Table 2. Acoustical parameters with live music performance are listed

Parameter	500 Hz	1000 Hz	Overall average	Recommendation
T_{30} (s)	1.25	1.11	1.18	1.05–1.35
C_{80} (dB)	5.4	6.6	6.0	4.0–6.0 dB
G (dB)	1.1	1.3	1.2	1.0–3.0 dB
Solo (ST)	–18.3	–16.8	–17.6	N/A
Brass (ST)	–16.3	–16.1	–16.2	N/A
String (ST)	–15.4	–16.3	–15.9	N/A
IACC	0.82	0.63	0.73	≦0.45
LF	0.16	0.20	0.18	≧0.20

Based on the usage of the sound reinforcement system in the theater mode, this hall is associated a line array system providing a very high performance of loudspeaker capability and a wide range of sound energy distribution for the sound field. Measurement indicators include array speaker electrical audio frequency response and acoustic gain. In the measurement of electrical audio frequency response, consider the sampling frequency of the speaker response to the scope of requirements, IEC268-5 provides in the frequency band within the scope of the electrical audio frequency response, the proposed tolerance difference for frequency of sound pressure within ±5 dB. Consideration all 1/3 octave band range, the difference of 50 Hz to 1.6 kHz in each frequency needs to be within 10 dB. Measurement results except for points M1 and M2 meet the recommended value, the remaining points are greater than the standard value (≦ ±5 dB). Transmission gain measurement results –18.3 dB, did not meet the recommended value (≧ –8 dB).

3 Computer Simulation for Chamber Music

In order to meet the future renovation, except the theater mode, chamber music mode is conducted by computer simulation. When the musical perform, in addition to facing architectural space design, the tone, volume, reverberation may have a influence musical performance, may also have an impact on the live sound effects. To further confirm the performance hall planning goals and acoustic parameters of the correlation between topography, assess technology includes the design stage through to computer simulation. Since the establishment of and modifications to establish a database of digital material model parameters through information operations, then check the status of the sound quality of the sound field. As shown in Fig. 3, the coverage of 1st order reflections can be evenly distributed to the stage and the frontal audience by only proposed upper reflectors.

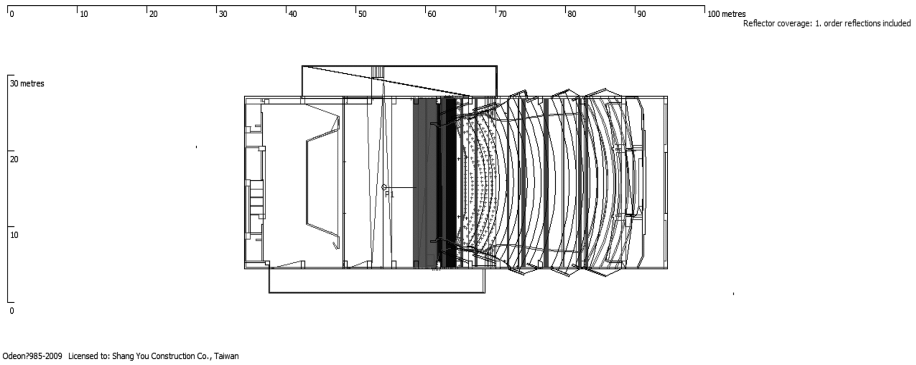

Fig. 3. Simulated 1st order reflection coverage from the upper reflectors

3.1 Computer Simulation Calculation

The simulation was performed by using the upgraded Odeon software package that can handle energy parameters of ray tracing calculation and was used to validate the schematic concept of using the curve reflectors. The number of rays was set to 10001 and the truncation time of calculation was set to 5000 ms. The source was on the central axis and 3-m from the front edge of the platform. Computer simulation of calculation is set as shown in Table 3.

Table 3. List of calculation for computer simulation

Scatter method	Lambert
Decimate late rays	ON
Transition order	1
Number of rays	10001
Max. reflection order	2000
Impulse response length	5000 ms
Angular absorption	All materials
Late reflection density	600/ms
Scatter method	Lambert

A diffusive bricks are attached and a 0.7 scattering factor are assigned to the side and rear walls. Occupied seating with medium upholstery was used for the audience and a 0.7 scattering factor was assigned. 650 m^2 heavy absorptive draperies for reinforcement music with a 0.4 scattering factor were introduced. Furthermore, acoustics parameters were proposed design target values by computer simulation for the energy parameters EDT, RT, C_{80}, D_{50} T_s and LF_{80}. Materials assignments in library of Computer simulation are as shown in Table 4.

Table 4. Materials assignments in library of computer simulation

Location	Materials	Frequency (Hz)							Scattering coefficient
		63	125	250	500	1 k	2 k	4 k	
Stage floor	Oregon Wood	0.15	0.15	0.2	0.1	0.1	0.1	0.1	0.1
Audience floor	Wood	0.15	0.15	0.11	0.1	0.07	0.06	0.07	0.1
Audience seat	Medium upholstered	0.24	0.25	0.47	0.63	0.75	0.78	0.83	0.7
Side wall	Diffusive Bricks	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.7
Reflector	Gypsum board	0.04	0.04	0.06	0.06	0.06	0.06	0.04	0.2
Stage opening	Drapery	0.28	0.28	0.26	0.46	0.71	0.75	0.7	0.3
Adjustable absorption	Heavy drapery	0.03	0.03	0.5	0.65	0.7	0.7	0.7	0.4

3.2 Results of Computer Simulation

A omni-directivity sound source provided by the software package and was used occasionally as references. The source was on the central axis and 1.5-m from the front edge of the platform. Due to the cross-shaped hall-room space and symmetry, averaging 8 measuring points are chosen one side of seating which were symmetrically distributed. Sound source in front of stage is set and simulated perspective and distribution of sound energy particles of schematic model is shown in Fig. 4. Preliminary obtain mono sound parameter, reverberation time (RT), early decay time (EDT) and music clarity (Clarity, C80) are discussed. Acoustical indices, such as RT30, C80, D50, Ts and EDT, are derived from the impulse response which is based on the International Standard ISO 3382 (Bradley 2004) [10]. Preliminary results of acoustical parameters were calculated by computer simulation were summarized in Table 5 when all the acoustical draperies are taken on. The reverberation time for the chamber music at mid-frequency is resulted about 1.42 s.

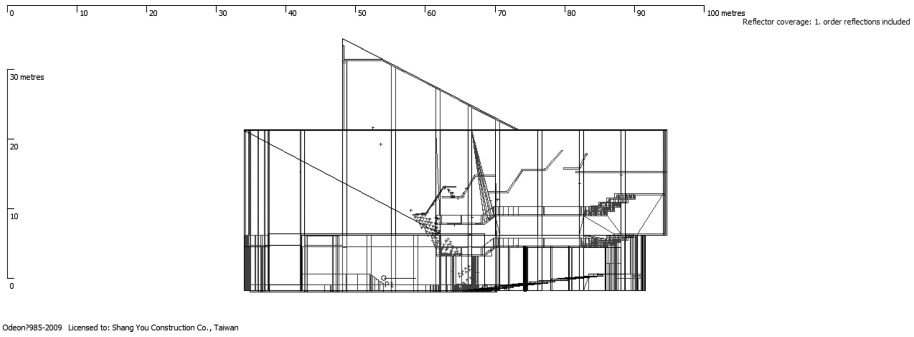

Fig. 4. Simulated perspective model and distribution of sound energy particles

Table 5. Acoustical parameters with music performance (Chamber music) are listed

Frequency	Parameter					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
EDT (s)	1.95	1.73	1.66	1.51	1.38	1.20
T_{30} (s)	1.35	1.59	1.45	1.38	1.28	1.15
C_{80} (dB)	5.4	3.1	3.4	3.7	4.2	5.0
D50	0.54	0.56	0.56	0.58	0.60	0.70
Ts (ms)	82	74	70	64	57	39
LF_{80}	0.056	0.064	0.060	0.067	0.065	0.073

4 Preliminary Results

The result of reverberation time measurement was 1.18 s at middle frequency of this investigation, compared with the renovation in 2003, reverberation time measurement was 1.28 s at middle frequency (Theater mode), sound amplitude is decreasing to 0.1 s, mainly due to the hall 15 years of sound-absorbing material effect results. Although the use of the theater mode is currently influential, considering the future use of music performances, it is suggested that the middle band reverberation time should be 1.52 s (Chamber music mode), and it is suggested that details be elaborated and explained in the future detailed construction design. It is recommended that the amplitude range of the reverberation time range from 16% to 30%. The comparison of reverberation times (T30) among the different period derived from the measurement and simulation for the theater and chamber music mode are shown in Fig. 5.

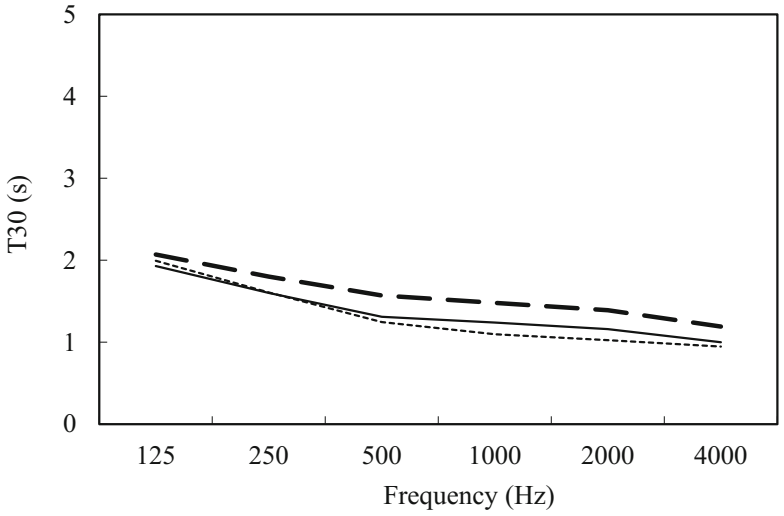

Fig. 5. Comparison of reverberation times (T30) at 1/1 octave frequency band among the different period time, year 2003 (Solid line) and year 2017 (Dotted line) derived from the measurement, respectively and simulation for the chamber music mode (Dashed line) are illustrated.

5 Discussion

The main assessments in Taipei Arts Promotion Center Hall carried out renovation works and acoustical evaluation was conducted in 2003 and 2017, respectively. In the past 15 years of use, due to air humidity and material aging and other factors, may affect the room acoustics. Theater mode is the most frequently used setting for the owner utilized. The auditorium impressions of different audiences are different due to the different characteristics of the reverberation time. In the survey and assessment, field measurement is taken as the basis for assessment, which includes in-site measurement and computer simulation for chamber music performance. Some preliminary results are abstracted as followed:

1. The result of reverberation time measurement was 1.18 s at middle frequency of this investigation, compared with the renovation in 2003, reverberation time measurement was 1.28 s at middle frequency (Theater mode), sound amplitude is decreasing to 0.1 s, mainly due to the hall 15 years of sound-absorbing material effect results.
2. Measurement results except for points M1 and M2 meet the recommended value, the remaining points are greater than the standard value ($\leqq \pm 5$ dB). Transmission gain measurement results –18.3 dB, did not meet the recommended value ($\geqq -8$ dB).
3. For Spatial image of music performance, IACC and LF two parameters results in 0.73 and 0.18, respectively. The two parameters pointed out that may not meet the sense of subjective specialness in auditorium. Upper divided reflector of the hall can compensate the insufficient of sense of hearing in specialness.
4. Although the use of the theater mode is currently influential, considering the future use of music performances, it is suggested that the middle band reverberation time should be 1.52 s (Chamber music mode), and it is suggested that details be elaborated and explained in the future detailed construction design.

Acknowledgements. The authors wish to thank Huang Kung Huang, Shang You Construction Co. Ltd. for the assistant of filed measurements and simulation, Professor Wei-Hwa Chiang, Dep. of Architecture, National Taiwan University of Science and Technology the kindly assistances during the measurement phase.

References

1. Barron, M.: Auditorium Acoustics and Architectural Design, 2nd edn. E & FN Spon, London (1993)
2. Chiang, W., Lin, W., Chen, Y.-R., Hu, H.-Y.: Variable acoustics design of a small proscenium concert Hall. J. Asian Archit. Build. Eng. (2008)
3. Schroeder, M.R., Atal, B.S., Bird, C.M.: Digital computers in room acoustics. In: 4th International Congress on Acoustics (ICA 4), Kopenhagen, Vortrag M21 (1962)
4. Rindel, J.H.: Modelling in auditorium acoustics. From ripple tank and scale models to computer simulations. Revista de Acústica **XXXIII**(3–4), 31–35 (2002)
5. Allen, J., Berkley, D.A.: Image method for efficiently simulating small-room acoustics. J. Acoust. Soc. Am. **65**, 943–950 (1979)

6. Krokstad, A., Strom, S., Sorsdal, S.: Calculating the acoustical room response by the use of a ray tracing technique. J. Sound Vib. **8**(1), 118–125 (1968)
7. Christensen, C.L., Rindel, J.H.: A new scattering method that combines roughness and diffraction effects. In: Proceedings of Forum Acusticum, Budapest, Hungary, pp. 2159–2164 (2005)
8. Siebein, G.W., et al.: Project Design Phase Analysis Techniques For Predicting the Acoustical Qualities of Buildings. University of Florida (1986)
9. ISO 3382-1:2009: Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces (1986)
10. Bradley, J.S.: Using ISO 3382 measures to evaluate acoustical condition in concert halls. In: International Symposium on Room Acoustics: Design and Science 2004, Kyoto, Japan (2004)