UNIVERSITI MALAYA

Journal of Design and Built Environment
E-ISSN: 2232-1500 |Print ISSN: 1823-4208
https://ejournal.um.edu.my/index.php/jdbe
Vol. 24, Issue 2, 2024, 19-30

Assessment of Acoustic Conditions in Worship Spaces Adjacent to Urban Noise: A Simulation Case Study of St. Thomas Garrison Church, Chennai

Beryl Raja Divya Mahimairaj[1], Pradeepa Chandramouli[1], Abdul Wafi Razali [2,3], Nazli Bin Che Din[2*]

[1]School of Architecture and Interior Design, SRM University, Kattankulathur, Tamil Nadu 603203, India.

[2]Faculty of Built Environment, Universiti Malaya Malaysia, 50603 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur.

[3]Faculty of Built Environment, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak.

*Corresponding author: nazlichedin@um.edu.my

Article Info
Submission date: 21st May 2024
Acceptance date: 5th June 2024

Keywords:
Urban Noise, Church, Acoustics, Reverberation Time, Speech Intelligibility, Sound Pressure Level Distribution

ABSTRACT

According to its cultural and spiritual importance, church acoustics are intensively investigated. These architectural marvels serve religious worship, community events, and cultural preservation. Preserving these sites' historical importance and acoustic comfort requires understanding their complex sound transmission dynamics. However, urban noise severely reduces sacred sites acoustically. In view of their proximity to airports, highways, and Metro, this study explores the acoustics of Chennai's medieval St Thomas Garrison Church. Reverberation times (RT) at 500 and 1000 Hz exceed the optimum value, especially for speech purposes. Day and night background noises over 60 dBA affect speech transmission index (STI) and sound pressure level (SPL) distribution. These findings are also examined in relation to potential service interventions, such as amplification systems, in places of worship. This study suggests that urban planners, architects, and others can help preserve and improve religious experiences by addressing urban noise and improving church acoustics.

1.0 INTRODUCTION

Within the domain of modern architecture and acoustic research, the examination of sound properties in religious spaces and churches is gaining significance as an area of study. The analysis of churches and worship places' acoustics is gaining significance in recent studies and research. These marvels of architecture with cultural heritage are to be explored to understand their sound propagation (Klepper, 1971). These sacred sites, steeped in millennia of cultural heritage and religious importance, function as central locations for religious worship, community gatherings, and the manifestation of traditional customs. The intricate process of sound transmission plays a crucial role in shaping the worship experience and fostering a profound sense of connection and transcendence among the members of the congregation within the context of these remarkable architectural structures (Boren, 2021). Therefore, it is crucial to understand the acoustical dynamics present in these places to maintain their historical importance and ensure that religious messages and musical performances are conveyed optimally.

The Thomistic Christians, who pioneered Indian Christian theology in the 19th century, are renowned for their doctrinal convictions (Beaver, 1958). By incorporating elements of Western culture, it reconstructs Christianity within the context of Indian culture (Doss, 2018). With its Indian lineage, this entity has focused its efforts on the attainment of divine enlightenment. The study of Christian theology involves an examination of the sociopolitical conditions and human life situations that are present in the respective nation (Bretherton, 2011). It has endeavoured to tackle the problems in our society in a pertinent manner.

Churches have always been revered for their capacity to create immersive auditory environments that enhance the worship experience through the use of reverberant soundscapes and resonant harmonies. The acoustics of a place of worship have an important effect on the communication, including verbal, musical, and emotional aspects, during worship. Speech intelligibility, music clarity, and overall comfort in acoustical environments are all aspects that are addressed in this context. The primary factors influencing this include the building's architectural design, geometric shape, choice of materials, and the number of people present at any particular time (Algargoosh, 2022). It is not possible to solely manipulate the auditory field using only electro-acoustic methods. The responsibility of the individual controlling sound amplification during sermons in churches is demanding (Djupe, 2002).

Investigating the acoustic properties of churches presents numerous obstacles, with urban noise being a particularly significant problem. This consciousness has escalated as urban areas persistently expand and evolve. Consequently, there have been appeals for implementing laws and regulations aimed at mitigating the adverse effects of noise pollution while safeguarding the sacredness of religious sites and respecting the rights of individuals residing nearby (Kumar, 2004). Hence, it is imperative to thoroughly understand how architectural characteristics, building materials, and external noise impact the level of sound transmission in these areas.

Given the fact that industrial and commercial zones produce excessive noise levels, the institutional buildings built in that zone, such as churches, schools, etc., which are sensitive to the acoustic environment, should be considered in the early design stage and require appropriate control and corrective actions. Considering this context, our research aims to examine the acoustic characteristics of historically ancient churches in Chennai, India. Chennai, located in the cultural hub of Tamil Nadu, boasts a varied architectural heritage marked by a blend of colonial, indigenous, and religious influences. By analyzing essential factors such as reverberation time, speech intelligibility, and sound distribution, our goal is to clarify the elements that influence the overall acoustical excellence particularly on speech delivery. In addition, it will examine the possible consequences of our discoveries for future design interventions and acoustic restrictions in places of worship.

1.1. Case Study

Chennai, distinguished by its vibrant urban environment and extensive historical heritage, symbolizes cultural and economic importance in the southern region of India. Social, cultural, and economic progress have been reflected for centuries in the city's transformation from its colonial beginnings to its current status as a hubbub. Throughout the period of British colonial rule, Chennai experienced substantial changes that propelled it to the forefront of architectural, administrative, and economic progress (Lewandowski, 1975). It was during the 1644 construction of Fort St. George that the city's trajectory shifted significantly, as It established a foundation for deliberate urban expansion and provided a blueprint for subsequent expansion.

Chennai’s architectural landscape is distinguished by a distinctive amalgamation of British architectural elements and regional influences (Kennedy, 2014). An illustration of this eclectic fusion of architectural traditions is the Indo-Saracenic style, which arose from the fusion of European, Indian, and Islamic design elements. This architectural diversity is exemplified by notable structures including chapels, commercial and government buildings, which serve as tangible reminders of the city’s abundant historical and cultural legacy.

Despite its rich historical background, Chennai is currently confronted with a multitude of pressing issues such as inadequate infrastructure, urban expansion, climate change, and the lack of access to digital resources. These obstacles highlight the criticality of effective governance and sustainable urban planning in order to guarantee the city’s ongoing development and prosperity (Rasoolimanesh et al., 2011). Furthermore, the increasing visibility of noise pollution as a critical environmental concern underscores the necessity for regulatory structures to alleviate its detrimental impacts on the health and welfare of the general public. An effective approach to enhancing the quality of life in relation to noise pollution is diminishing the number of private vehicles while improving the public transportation system in urban areas (Othman & Ali, 2020).

According to the Ministry of Environment and Forests (2000), the enactment of the Noise Pollution (Regulation and Control) Rules, 2000, signifies a substantial advancement in tackling the noise pollution problem in Chennai and similar metropolitan areas throughout India. The objective of these regulations is to oversee and manage noise-generating and producing sources to uphold standards for ambient air quality with respect to noise. Establishing noise pollution regulations - which delineate undesirable sounds as intrusive, irritating, or loud - furnishes a structure for recognizing and mitigating noise pollution at its origin. Furthermore, the regulations establish precise thresholds for noise levels across various land uses, including residential, commercial, industrial, and silence zones, as shown in Table 1.

Table 1. Noise level regulations of different category of area in India.

Category of Area / Zone	Limits in dB(A) L_{eq}*	
	Day Time	Night-time
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silence Zone	50	40

St. Thomas Garrison Church, alternatively referred to as St. Thomas English Garrison Church is situated in Chennai, the capital of Tamil Nadu, a state in South India. It is unique among the churches in the St. Thomas Mount region and the earliest. 1830 saw the church’s construction in this vicinity at the direction of the Director of the East India Company and in response to a request from army officers. The majority of this church’s materials were imported from the United Kingdom, and it was constructed with a bomb-resistant roof and rust-resistant iron handrails on all sides. The church is situated at the base of St. Thomas Mount, after St. Thomas, one of the twelve apostles who spent his final years in this area, was called (Jayewardene-Pillai, 2007). This historical church, designated a heritage monument by the Chennai Circle of the Archaeological Survey of India, is under the administration of the Church of South India's Diocese of Madras.

Table 2. Detailed summary of St. Thomas building description.

Year	Church Name	Location	Seating Capacity	Volume (m^3)	Area (m^2)	Width (m)	Length (m)	Height (m)
1827	CSI St. Thomas (Garrison) Church	St. Thomas Mount	600	8221.9	814.1	20.1	40.5	10.1

Figure 1. Location of St. Thomas Garrison. (Source: Google Maps)

This church is considered an unmistakable representation of the London-based St. Clement Danes (Bond, 2004). The enormous church in question has architectural dimensions of 133 feet (41 metres) in length and 66 feet (20 metres) in width as tabled in Table 2 in detail. Bricks, mortar, and limestone were utilised in the construction of the compound. Additionally, the rust-resistant iron railings are repurposed from discarded weaponry, muskets, barrels, and pikes belonging to the defeated Tippu Sultan. Situated at No. 1 Grand South Trunk Road, Chennai as shown in Figure 1, this ecclesiastical structure serves as an extraordinary juncture for the southern districts of Tamil Nadu. Each chair made of cast iron was imported from England, and the altar features traditional images of the Methodist faith. The space designated for the congregation and devotees is known as the prayer hall.

The entrance portico of this church features twenty windows, five doors, and Roman emblematic pillars; the prayer hall features a false ceiling crafted from teak wood, a Bible, and a pipe organ. To comply with the regulations set forth by the Airport Authority of India (AAI) and facilitate air traffic access to the adjacent Chennai International Airport, a foot was removed from the three-tiered multilevel church steeple, reducing its height to a single spire.

The unique architectural styles of the churches have also positioned them as focal points of communal influence in urban and rural areas. These structures are deliberately built with the specific purpose of serving as places for prayer and worship. Churches are inherently unsuited for complex requirements related to speech and music. The diverse services offered in modern churches vary in their requirements (Arnoult, 2007), as can be seen in the comparison between traditional European and modern American churches. To achieve optimal acoustics, it is recommended to avoid having parallel surfaces and dimensions that are multiples of each other. According to Zosim (2020), European repositories and Gregorian enchantments are appropriate for churches that have a Gothic architectural design, but they are not successful for Gospel and contemporary Christian music.

For optimal appreciation of music and voice, a place of worship must be devoid of higher background noise and have appropriate acoustics. Constantly, the acoustical demands of discourse differ from those of music and song. Vocal and instrumental music are subject to additional criteria beyond speech, which are generally accepted in places of worship. Additionally, sound sources can have a variety of characteristics, necessitating distinct forms of acoustics to function optimally (Elicio & Martellotta, 2015). The congregation, consisting of numerous unique individuals, will have diverse expectations regarding the quality of their listening experience, including but not limited to language proficiency, age, and other comparable attributes.

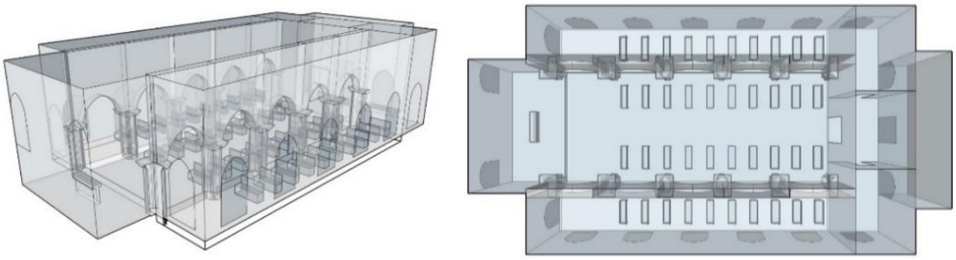
2.0 METHOD

2.1. Background Noise Measurement

To assess the ambient noise level, the continuous equivalent sound levels (LAeq) in unoccupied conditions were recorded during the day and night. The noise level was measured in two separate areas, namely the interior and the surrounding compound as shown in Figure 2. The background noise level was measured using a NOR132 sound level meter placed at 1.2 m from the ground level for a duration of two (2) minutes at each receiver position during day and nighttime, with data being recorded at one-second intervals. The mean sound pressure level was computed, spanning from 63 Hz to 8000 Hz.

Figure 2. Location of background noise measurement (a) site plan 1:10, (b) interior, and (c) exterior.

2.2. 3D Modelling and Simulation



(a) (b)

Figure 3. St. Thomas' Garrison Church 3D model and layout perspectives.

As illustrated in Figure 3, the St. Thomas' Garrison Church 3D model was generated utilising Sketch up Pro® software. The models were produced using dimensions that were directly measured on-site. Precise delineation of surface area is essential to mitigate model inaccuracies throughout the verification phase. According to Jalil et al. (2019), the highest permissible decrease in surface material for room models used in verification is 80%. The extent of reduction can fluctuate and is impacted by factors such as modelling techniques, model configurations in simulation software, and the precision of materials' scattering and absorption coefficients.

The simulation was conducted using ODEON Room Acoustic Software version 17. Prior to the commencement of the simulation, the 3D model needs to be accurately set up in accordance with the ODEON features. Adequate allocation of the number and positioning of the sound source and receivers is essential. 12 receivers were placed within the church area at a height of 1.2 m from the floor, corresponding to sitting ear level. An ISO 3382-3_OMNI.SO8 directivity pattern was chosen as the sound source for assessing reverberation time, positioned at a set distance of 1.65 m from the altar floor level.

Two separate sound source directivity patterns were used for STI measurement:

- ANSI_RAISED_SPEECH_ NATURAL.SO8 for unamplified room settings and Bose Corporation-DS 40SE_8Ohm.CF2 for amplified room conditions. The sound source was positioned 1.65 m from the altar floor level in unamplified room conditions, replicating RT measurements. Two different speakers' configurations, namely Speaker A and Speaker B, were positioned in specific locations for amplified room settings at 2 m above floor level. Eight (8) speakers were utilized for the Speaker A configuration and 12 speakers for the Speaker B arrangement. The detailed coordinates of sound sources and receivers are displayed in Table 3. The positions of the sound source and receivers for both unamplified and amplified room settings are shown in Figure 4.

Table 3. Sound sources and receivers' coordinates for simulation

Room settings	**Sound source coordinates**				**Receiver's coordinates**			
	Ref	**x**	**y**	**z**	**Ref**	**x**	**y**	**z**
Unamplified	1	-0.40	9.00	2.25	1	6.40	16.20	1.75
Speaker A	1	0.90	13.50	2.00				
	2	1.60	17.70	2.55	2	14.00	16.20	1.75
	3	14.00	17.70	2.55				
	4	23.60	15.00	2.55	3	21.60	16.20	1.75
	5	0.90	5.10	2.00				
	6	1.60	0.40	2.55	4	6.40	12.00	1.20
	7	14.00	0.40	2.55				
	8	23.60	3.30	2.55	5	14.00	12.00	2.20
Speaker B	1	4.80	14.80	2.55				
	2	9.50	14.80	2.55	6	21.60	12.00	3.20
	3	14.20	14.80	2.55				
	4	19.00	14.80	2.55	7	6.40	6.50	4.20
	5	4.80	13.35	2.00				
	6	9.50	13.35	2.00	8	14.00	6.50	5.20
	7	14.20	13.35	2.00				
	8	19.00	13.35	2.00	9	21.60	6.50	6.20
	9	4.80	5.20	2.00				
	10	9.50	5.20	2.00	10	6.40	1.80	1.75
	11	14.20	5.20	2.00				
	12	19.00	5.20	2.00	11	14.00	1.80	1.75
	13	4.80	3.65	2.55				
	14	9.50	3.65	2.55	12	21.60	1.80	1.75
	15	14.20	3.65	2.55				
	16	19.00	3.65	2.55				

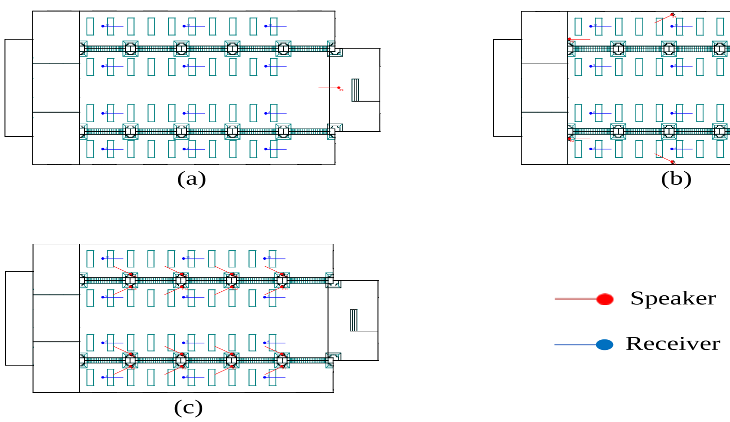


Figure 4. Sound sources and receivers' locations of (a) unamplified, (b) Speakers A (existing), and (c) Speakers B settings (proposed).

Additionally, the surface material for each room component must be precisely configured based on real-world conditions. Incorrect assignment of materials to surface components might lead to erroneous simulation results. The surface materials designated for the church model are listed in Table 4. After setting up the two rooms, the 3D Investigate Rays feature should be used to do a water tightness test on the model to make sure there is no model leakage, which could cause more ray loss during the simulation phase. One of the purposes of the simulation is to analyze how varying background noise levels in amplified and unamplified room environments affect the STI. According to Beranek (1997), the lowest recommended NC rating for small churches ranges from 30 -35. However, based on the Ministry of Environment and Forests (2000), the Noise Pollution (Regulation and Control) Rules 2000, India, the highest noise limit in industrial area is 75 dBA. Hence, four different noise criteria (NC) and the total level (dBA) were utilized in the simulation: NC-35 (44.2 dBA), NC-45 (53.4 dBA), NC-55 (62.5 dBA), and NC-65 (72.2 dBA), representing the background noise level within the church interior space. The settings were carried out in fully enclosed conditions. Thus, the simulation seeks to analyse the impact of different levels of background noise and sound amplification arrangements on the STI performance in the church.

Table 4. Detailed surface materials assignment. (Source: Odeon, 2021)

Building elements	ODEON surface material	Sound absorption coefficient (α)	Surface area (m^2)
Floor	Stone floor, plain/tooled granolithic finish	0.05	595.9
Wall	Lime cement plaster on masonry wall	0.05	989.7
Column	Lime cement plaster	0.05	219.1
Beam	Lime cement plaster	0.05	524.1
Ceiling	8 mm wood veneer on 50mm studs	0.1	545.5
Door	Solid wooden door	0.1	10.2
Window	Glass, ordinary window glass	0.1	144.8
Pew	Plywood paneling, 1 cm thick	0.1	172.8

3.0 RESULTS AND DISCUSSIONS

3.1. Background Noise Measurement

Table 5 shows the on-site background noise level measurement results for interior and exterior spaces approximately at 4 pm (daytime) and 10 pm (nighttime). The findings expose that the interior background noise level during the night is higher than during the day, with noise levels of 66 dBA and 63 dBA, respectively, due to the higher number of heavy vehicles passing on the adjacent highway. None of the measured results comply with the Indian noise pollution regulation. The simulation process utilized the actual conditions of the background noise level measured and compared with lower noise criteria to evaluate the impact on STI performance.

Table 5. St. Thomas Garrison background noise level, LAeq.

Conditions	Interior (dBA)			Exterior (dBA)		
	Min	Max	Average	Min	Max	Average
Daytime	52	81	63	65	85	74
Nighttime	57	76	66	69	82	74

Although the church was built prior to urban development, the recorded level of background noise is unreasonably high considering the significant expansion of the surrounding area over time. Hence, it is imperative to consider implementing corrective measures in order to maintain the church's fundamental purpose and ensure optimal acoustic comfort.

3.2. Simulation of Reverberation time (RT)

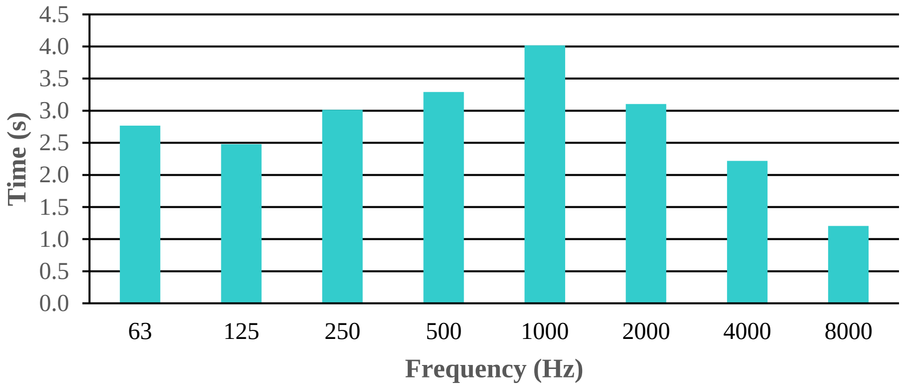


Figure 5. Average reverberation time across 1/1 octave frequency band.

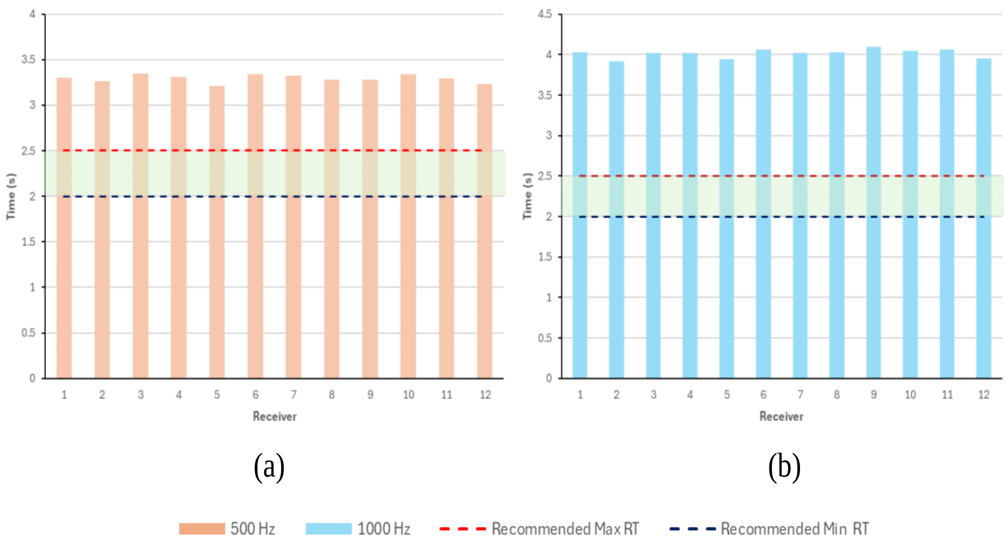


Figure 6. Reverberation time over receivers' positions at a) 500 and b) 1000 Hz

Figure 5 displays the average RT results for St. Thomas' Garrison Church. These results were obtained in a completely enclosed room setting and covered the 1/1 octave band. As a whole, the simulated RT was 2.76 seconds on average. The results indicate that the RT of St. Thomas Garrison Church is slightly higher than the recommended maximum RT value of 2.5 seconds, especially in the mid-frequency region. Mike Sorensen (2012) has indicated that the ideal RT range for church spaces is between 2 and 2.5 seconds, focusing on the mid-frequency region of 500 and 1000 Hz. Based on Figure 6a, the RT for a frequency of 500 Hz differs among different receivers, with values ranging from 3.21 to 3.35 seconds. For the 1000 Hz frequency, the measured RT at all receivers varies between 3.92 and 4.1 seconds, as depicted in Figure 6b.

The RT conditions surpassed the recommended levels by 34% and 64% at frequencies of 500 Hz and 1000 Hz, respectively. The primary determinant of the adverse RT circumstances is the design with a high ceiling. The ceiling height was 9.38 meters, measured from the lowest floor level. In addition, nearly all the surface materials employed in the building have a low absorption coefficient, enabling them to reflect sound energy to a greater extent, and so creating a reverberant environment. According to Gramez and Boubenider (2017), the primary cause of high reverberation time is the use of inappropriate finishing materials for the floor and walls, as well as an excessive number of reflective materials employed (Eldakdoky, 2017). Although longer

RT may apply to music activities that include choir, it is essential to consider interventions for speech intelligibility, which requires shorter RT.

3.3. Simulation of Speech Transmission Index (STI)

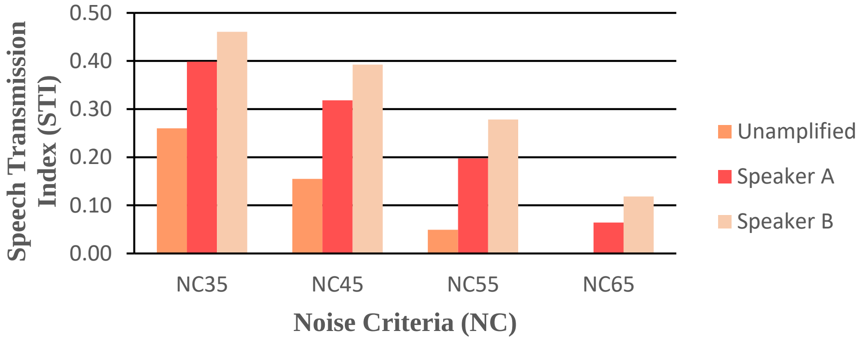


Figure 7. STI results of unamplified and amplified settings under different NC ratings.

Figure 7 depicts the comparison of STI values between unamplified and amplified room conditions at various background noise levels (NC35, NC45, NC55, and NC65). The results indicate that the STI decreased gradually as the NC ratings increased. The maximum average STI measured for unamplified, Speaker A, and Speaker B setups was 0.26, 0.4, and 0.46, correspondingly, at a Noise Criteria (NC) level of 35. The STI value had a decline of 40.4%, 68.3%, and 96.6% in NC45, NC55, and NC65, respectively for unamplified conditions. However, Speaker A and Speaker B configurations experienced a smaller decrease in the percentage of STI over higher NC ratings. In addition, the incorporation of a sound amplification system enhances the STI rating.

The STI of Speaker A and Speaker B configurations showed substantial enhancements of 53% and 77%, respectively, compared to the unamplified room conditions at NC35. Nevertheless, when the background noise level escalated to NC65, there was no discernible improvement in STI. The relationship between the background noise level and the sound amplification factor has a notable influence on the Speech Transmission Index (STI) value within a specific confined area. According to previous findings by Razali et al. (2023), the STI rating improved from poor to good when sound amplification systems were employed in classrooms with ideal reverberation time conditions. However, achieving NC35 is quite difficult in normal conditions due to the heavy traffic volume. Some interventions, such as the implementation of a noise barrier or traffic control, can be considered. This suggests that merely performing corrective actions within the church building, such as reducing the ambient noise and using sound amplification systems, may not resolve this issue. It is necessary to incorporate environmental factors, such as urban noises, in order to implement appropriate corrective measures and attain a ‘good’ STI rating. Therefore, in these circumstances, it is necessary to take into account external as well as internal factors simultaneously.

3.4. Simulation of Sound Pressure Distribution

In this section, the simulation of sound pressure distribution only emphasises NC-35 settings based on the recommendation by Beranek (1997) and the results analysed in the previous section, which have achieved a ‘fair’ STI rating. Table 6 displays the distribution of sound pressure in the NC35 environment for three different configurations: unamplified, Speaker A, and Speaker B. The table includes data taken at various locations where receivers were placed. The sound pressure distribution in the room, without any amplification, was measured to range from 57.6 to 61.2 dB over 12 different receiver locations. The sound pressure distribution for Speaker A and Speaker B designs varies between 67.9 and 70.1 dB and between 72.0 and 73.0 dB, respectively. This indicates that Speaker B configurations produce a greater sound pressure level distribution in comparison to both unamplified and Speaker A configurations. The findings indicate that the positioning of the speaker enhances the listeners' perception of the sound pressure level. Speaker B configurations can enhance the sound pressure level by up to 20% compared to unamplified situations. By placing the appropriate directivity of speakers closer to the listeners' area, it may be possible to obtain optimal sound pressure distribution.

Table 6. Mean and standard deviation of sound pressure distribution of unamplified and amplified room conditions at NC35.

Receivers' Location	Room condition	Frequency (Hz)								Mean $\bar{x}$
		63	125	250	500	1000	2000	4000	8000	
1	Unamplified	27.6	38.1	49.8	55.9	53.9	44.5	36.5	24.3	58.9
	Speaker A	38	48.6	60.1	66.3	64.5	55.8	48.9	38.8	69.4
	Speaker B	41.6	52.2	63.5	69.6	67.6	58.9	52.3	43.3	72.6
	Std Dev	5.4	5.5	5.3	5.4	5.4	5.7	6.3	7.4	5.4
2	Unamplified	26.6	37.1	49	55.4	53.8	44.5	36.3	23.6	58.5
	Speaker A	40	50.7	61.9	67.7	65.7	56.9	49.2	38.8	70.7
	Speaker B	42.2	52.9	64.1	70	67.9	59	51.6	41.8	73
	Std Dev	6.4	6.5	6.2	6.0	5.8	6.0	6.3	7.4	5.9
3	Unamplified	26.2	36.6	48.6	54.9	53.1	43.7	35.1	21.6	57.9
	Speaker A	38.9	49.6	61	67	65.3	56.7	49.5	38.4	70.1
	Speaker B	40.6	51.2	62.7	69	67.5	59.1	52.8	44.2	72.2
	Std Dev	6.0	6.1	5.9	5.8	5.9	6.3	7.1	8.8	5.9
4	Unamplified	29.9	40.6	52.2	58.1	56.1	47.3	39.5	28.2	61.2
	Speaker A	37	47.6	59.2	65.4	63.7	54.6	47	36	68.5
	Speaker B	41.5	52.1	63.4	69.5	67.7	59	52.4	43.4	72.6
	Std Dev	4.2	4.1	4.0	4.2	4.3	4.2	4.5	5.1	4.2
5	Unamplified	28.3	38.9	50.6	56.7	55.2	45.9	37.6	25	59.8
	Speaker A	36.4	46.9	58.7	64.9	63.5	54.2	46.3	34.6	68.1
	Speaker B	42.1	52.8	64	69.9	67.9	58.8	51.3	41.1	72.9
	Std Dev	4.9	4.9	4.8	4.8	4.7	4.7	5.0	5.7	4.8
6	Unamplified	27.5	37.9	49.7	55.7	54	44.6	36.3	23.4	58.8
	Speaker A	37.2	47.8	59.4	65.5	63.8	54.7	47	36.2	68.6
	Speaker B	40.6	51.3	62.7	68.9	67.5	58.9	52.4	43.7	72.1
	Std Dev	5.1	5.2	5.0	5.1	5.2	5.4	6.0	7.4	5.1
7	Unamplified	29.8	40.5	52.1	58.1	56	47.5	39.9	28.8	61.1
	Speaker A	37.2	47.7	59.4	65.5	63.8	54.6	47.1	36.2	68.6
	Speaker B	41.5	52.1	63.4	69.5	67.6	58.8	52.2	43.4	72.5
	Std Dev	4.2	4.2	4.1	4.2	4.3	4.1	4.3	4.9	4.2
8	Unamplified	27.8	38.3	50	56	54.5	45.1	36.8	24.2	59.2
	Speaker A	36.4	46.9	58.6	64.8	63.3	53.9	45.9	34.2	67.9
	Speaker B	42.2	52.9	64.1	70	68	58.9	51.2	41.1	73
	Std Dev	5.1	5.2	5.0	5.1	5.0	5.0	5.2	6.0	5.0
9	Unamplified	27.3	37.7	49.5	55.6	54.2	44.7	36.5	23.6	58.8
	Speaker A	37.3	47.8	59.4	65.5	63.8	54.7	47.1	36.5	68.6
	Speaker B	40.5	51.1	62.5	68.8	67.3	58.7	52.2	43.6	72
	Std Dev	5.2	5.2	5.1	5.1	5.0	5.3	5.8	7.3	5.1
10	Unamplified	28	38.5	50.3	56.5	54.2	45.2	37.2	25	59.4
	Speaker A	38.1	48.7	60.3	66.4	64.6	55.8	48.8	38.4	69.4
	Speaker B	41.2	51.9	63.2	69.2	67.3	58.4	51.6	41.2	72.3
	Std Dev	5.2	5.2	5.1	5.0	5.2	5.3	5.8	6.6	5.1
11	Unamplified	26.3	36.8	48.5	54.9	52.9	43.3	34.9	21.4	57.8
	Speaker A	40.1	50.8	62	67.9	65.9	57.1	49.3	38.9	70.9
	Speaker B	41.9	52.5	63.7	69.6	67.7	58.7	51.4	41.6	72.7
	Std Dev	6.5	6.6	6.4	6.2	6.2	6.5	6.9	8.4	6.2
12	Unamplified	26.1	36.4	48.3	54.6	52.9	43.4	34.9	21.4	57.6
	Speaker A	38.7	49.3	60.7	66.8	65.1	56.4	48.9	37.2	69.9
	Speaker B	40.5	51.1	62.6	68.9	67.4	58.9	52.5	43.9	72.1
	Std Dev	6.0	6.1	5.9	5.9	5.9	6.3	7.0	8.5	6.0

4.0 CONCLUSION

This study has performed an extensive acoustical simulation for St. Thomas Garrison Church on parameters. A series of background noise measurements during the day and night revealed that the existing urban noises exceeded the recommended and impacted the STI and SPL distribution simulated values. This study recommends remedies, such as amplification systems, for conserving and enriching religious experiences in communities by identifying the issues that urban planners, architects, and other stakeholders should consider. Further numerical and experimental investigations on the potential implementation of noise barriers surrounding and increasing absorption characteristics are being conducted intensively.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to the Deacons and St. Thomas Garrison Church staff for allowing measurements to be carried out and for the facilities provided. The authors extend gratefulness for the collaboration between SRMIST and UM in the current research under the UM International Collaboration Grant ST038-2022.

5.0 REFERENCES

Algargoosh, A., Soleimani, B., O'Modhrain, S., & Navvab, M. (2022). The impact of the acoustic environment on human emotion and experience: A case study of worship spaces. Building Acoustics, 29(1), 85-106. https://doi.org/10.1177/1351 010X211068850.

Arnoult, S. L. (2007). Worship in Medieval and Early Modern Europe: Change and Continuity in Religious Practice. Anglican and Episcopal History, 76(1), 124-125. http://ezproxy.um.edu.my:2048/login?url=https://www.proquest.com/scholarly-journals/worship-medieval-early-modern-europe-change/docview/211090461/se-2.

Beaver, R. P. (1958). The Indian Christians of St. Thomas. An Account of the Ancient Church of Malabar. By LW Brown. New York: Cambridge University Press, 1956. xii, 315 pp. Church History, 27(1), 80-81.

Beranek, L. L. (1997). Applications of NCB and RC noise criterion curves for specification and evaluation of noise in buildings. Noise Control Engineering Journal, 45(5), 209-216. https://doi.org/10.3397/1.2828442.

Boren, B. (2021). Word and mystery: The acoustics of cultural transmission during the Protestant Reformation. Frontiers in Psychology, 12, 564542. https://doi.org/10 .3389/fpsyg.2021.564542.

Bond, J. W., & Wright, A. (Eds.). (2004). Southern India: its history, people, commerce, and industrial resources. Asian Educational Services.

Bretherton, L. (2011). Christianity and contemporary politics: The conditions and possibilities of faithful witness. John Wiley & Sons.

Djupe, P. A., & Gilbert, C. P. (2002). The political voice of clergy. Journal of Politics, 64(2), 596-609. https://doi.org/10.1111/1468-2508.00142.

Doss, M. C. (2018). Indian Christians and the making of composite culture in South India. South Asia Research, 38(3), 247-267. https://doi.org/10.1177/02627280 18798982.

Eldakdoky, S. (2017). Optimizing acoustic conditions for two lecture rooms in Faculty of Agriculture, Cairo University. Ain Shams Engineering Journal, 8(4), 481–490. https://doi.org/http://dx.doi.org/10.1016/j.asej.2016.08.013

Gramez, A., & Boubenider, F. (2017). Acoustic comfort evaluation for a conference room: A case study. Applied Acoustics, 118, 39–49. https://doi.org/http://dx.doi. org /10.1016/j.apacoust.2016.11.014

Jalil, N. A. A., Din, N. B. C., Keumala, N., & Razak, A. S. (2019). Effect of model simplification through manual reduction in number of surfaces on room acoustics simulation. Journal of Design and Built Environment, 19(3), 31–41. https://doi. org/http://dx.doi.org/10.22452/jdbe.vol19no3.4

Jayewardene-Pillai, S. (2007). Imperial conversations: Indo-Britons and the architecture of South India. Yoda Press.

Kennedy, L., Varrel, A., Denis, E., Dupont, V., Dhanalakshmi, R., Roumeau, S., Baud, I., Pfeffer, K., Sridharan, N., Vijayabaskar, M., Babu, M.S., Seifelislam, A., Rouanet, H., & Saharan, T. (2014). Engaging with Sustainability Issues in Metropolitan Chennai. City Report Chance2Sustain, ISSN: 2309-8198.

Klepper, D. L. (1971). Acoustics of Worship Spaces. The Journal of the Acoustical Society of America, 49, 126-126. https://doi.org/10.1121/1.1975778.

Lewandowski, S. J. (1975). Urban growth and municipal development in the colonial city of Madras, 1860–1900. The Journal of Asian Studies, 34(2), 341-360. doi:10.2307/2052752.

Odeon. (2021). ODEON Room Acoustics Program User's Manual. Version 17.0. Available online: https://odeon.dk/download/Version17/OdeonManual.pdf.

Othman, A. G., & Ali, K. (2020). Transportation and Quality of Life. Journal of the Malaysian Institute of Planners, 18(3), 35–50. https://doi.org/10.21837 /pm. v18i13 .774

Razali, A. W., Din, N. C., & Hamdan, S. (2023). Investigation of the Acoustics Performance of the University's Lecture Rooms by using Economical and Feasible Design Improvement Strategies. Journal of Design and Built Environment, 23(3), 1–25.

Rasoolimanesh, S. M., Badarulzaman, N., & Jaafar, M. (2011). City development strategies (CDS) contribution toward sustainable urban development in developing countries. Journal of the Malaysian Institute of Planners, 9(2). https://doi.org/10.21837/pm.v9i2.82

Sorensen, M. (2012, October 28). Church Acoustical Measurements. https://www.acousticfields.com/church-acoustical-measurements.

Ministry of Environment and Forests. (2000). The Noise Pollution (Regulation and Control) Rules 2000, India. Available online: https://www.elaw.in/air/noise /rules.htm.

Zosim, O. (2020). Popular Music in Contemporary Church Chants. Journal of History Culture and Art Research, 9(2), 227-235. https://doi.org/10.7596/taksad.v9i2. 2508.