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Article

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Influence of Source Room Sound Power and type of noise on Acoustic Performance of Building Elements

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Abstract. The sound reduction index (SRI) is considered the most important factor for knowing the properties of Building elements, while electrical equipment are characterized by their sound power. In our research here, we examined the effects of the sound power in receiving room and the noise type of the sound source on Performance of building elements. Validity was tested on several doors and rooms of varied sizes in order to compare the differences between sound reduction (SRI), which is assessed using ISO 140-3, and that which is determined by the sound power technique ISO 3741, using two sound transmission rooms method. When the source room has a small volume, the sound power method produced SRI values that are higher than the SRI values established by ISO140-3, whether or not flanking transmission is present. The findings showed how the source room's volume and total surface area affected the SRI. The two approaches stated produced good results at a specified frequency bands (630:1250Hz) for SRI of doors with a source room with a volume of 160 m³ and a receiving room with a volume of 100m³. Furthermore, levels emitted from reference sound source (L2R) values cannot be replaced by levels of receiving room (L2) values, this cause a decrease in the sound reduction values of Building elements.

Keywords; Sound power, sound reduction, doors, omnidirectional and reference sound sources

1-Introduction

To improve human life and preserve the surrounding environment, interest came in acoustics, as the noise of air conditioners and electrical appliances is measured by knowing their sound power. From the standard specifications, the sound power is measured using the reference sound source, as stated in specification 3741.
The transmission of sound inside buildings to partitions and structural elements of doors and windows depends on the method of measuring sound insulation in buildings using air borne sound transmission according to the iso140 series. The measurement depends on the use of omnidirectional sound source. A significant number of on-site measurements were conducted to assess the ceramic walls in Brazil, using a single, comprehensive sound source [1]. There are many studies that use the airborne sound method to measure sound insulation, as in the following references, and they did not use the reference sound source, which contributed to conducting a comparative study between the two methods.
Through numerical simulations and experimental validations, the proposed adjustment has demonstrated improved accuracy compared to the standardised method, particularly when the noise barrier provides low sound insulation. The acoustic performance of windows plays a significant role in the assessment of buildings; however, the configuration of the window frame, including factors like the type of threshold and mullion, has a negligible effect on sound insulation. [2].

The refined formula also addresses overestimations typically observed at low frequencies where sound insulation tends to be weaker [3]. The term ‘scaled-down’ stands for measuring the airborne sound insulation using scaled-down specimens and sound transmission rooms. It represents areal dimensions of two rooms. The stand validation results were presented in the context of the reliability and repeatability of measurement results [4].

Pink and white noise were utilised in the source room for sound experiments. Several insights examined how frequency impacts the sound reduction index. It was determined that frequencies above 120 Hz had no significant influence on the results. After examining the effects of noise type, frequency, and excitation interval on the apparent sound reduction index, the findings showed that the results were not dependent on the noise type across two frequency intervals [5]. Nonetheless, some measurement conditions—especially in the low-frequency spectrum—impacted the results, with the type of excitation noise being one of the critical factors. This type of noise, when evaluated in the source room, stimulates the diffuse sound field, and its transmission through the partition structure is gauged. Developing new and more precise models to evaluate the acoustic quality of interiors

has become necessary, considering the properties of partition structures. This presents a promising avenue for future developments [6]. Certain measurement methods in building acoustics tend to be applied in an extended frequency range, reaching as low frequency of 50 Hz. Within this broader frequency range, refining the Waterhouse correction significantly impacts the results. However, this correction is often not implemented, leading to exaggerated values at lower frequencies. It's important to note that the Waterhouse correction is not required for the source room. Additionally, when measuring sound insulation using the intensity technique, applying Waterhouse corrections is unnecessary [7]. These were analysed under varying source room geometries. The findings reveal that variations in sound insulation in the low-frequency range were influenced by the incident sound field, indicating that the sound insulation rating based on JIS standards could be affected by incident characteristics, particularly for composite walls. The sound field analysis, conducted using the proposed method, showed the impact of mode matching between the source and receiving rooms on low-frequency sound transmission for RC single walls. Specifically, the alignment of room modes with sound propagation directions near-normal to the separating wall had a substantial effect on the transmitted sound [8]. A novel methodology utilising laser Doppler vibrometry to evaluate two types of panels, a lightweight wall and a gypsum block wall—were tested through standardised measurements, as well as laser Doppler vibrometry experiments and computations. This approach demonstrates its suitability for assessing the acoustic insulation of building elements at low frequencies [9]. The theoretical study analysed the noise reduction performance within the impulse response it achieved using different impulse response measurement signals. These findings confirm that the MN signal, with a power spectrum matching the square root of the noise power spectrum, is the most effective approach for reducing noise impact on measured impulse responses [10]. In this work, it was verified how the sound diffusers—their number and manner of distribution in the reverberation room—affect the results of sound insulation measurements in laboratory conditions. It can therefore be concluded that the acoustic adaptation of the receiving room did not affect the measurement results of the basic acoustic insulation indicators, but rather improved the uniformity of the frequency domain of both the reverberation time and sound pressure level [11]. Mainly, the calibration of sound sources and the determination of their acoustic power depends on using the reference sound source as a method within the methods of calibrating sound sources [12]. The use of sound power is also one of the methods for determining the sound insulation of building partitions [13].

The success of architectural design is connected to obtaining the necessary benefit from the place being designed. There are acoustic criteria and specifications for enclosed places [14], and these criteria and specifications must be met to attain the intended objective of the location. The most important of these criteria and specifications in enclosed places is a standard for the reverberation time for each place, and also determining a specific level of noise permitted in this place. To achieve and preserve these criteria, attention is paid to the specifications of the structural components used in building the location. Amongst these structural elements are the doors used for these places, as well as the capacity and specifications of these doors to diminish sound, in order to attain and uphold the required sound reduction levels. There are many sound sources inside or outside buildings, such as air conditioners or generators, as sources of noise, which are talked about by their acoustic power ability. Hence, the idea of this research arose by trying to use the reference sound source (RSS) and an omnidirectional sound source to study the effect of source sound power on the sound reduction index of building elements in source and receiving rooms.

That to study the difference in sound reduction index, which is determined using ISO 140-3, and that which is determined by using the sound power method.

2.Test Facility and Samples

2.1 Test Facility

The measurements were carried out at Al Azhar University, Egypt. The facility consists of two sound transmission rooms, a source room and a receiver room, separated by an opening into which a test sample was inserted for sound reduction test.

To determine the sound attenuation performance of building elements, sound transmission rooms are the most common method for testing. The utilization of transmission rooms is regarded as a main technique for assessing the sound insulation of construction components and has been employed to verify enhancements in window characteristics. Glass sheets evaluated by employing the transmission rooms method showed that the unequal mass of the glass sheets provide superior sound isolation figures for multi-layered windows [15]. Transmission rooms, as shown in Figure 1, are required to conduct this testing

[16,17]. The transmission rooms consist of a source room (S.Room) and a receiving room (R.Room). The two rooms are separated by a partition between them with a test aperture into which test samples (door) are installed.

The transmission rooms consist of two adjacent rooms with a door between them (100,160m^3). Another test design is formed from a corridor as source room with two different receiving office rooms (80, 90m^3), with a door between them, which details the geometry of the source and the receiving rooms in Figure 1a and 1b.

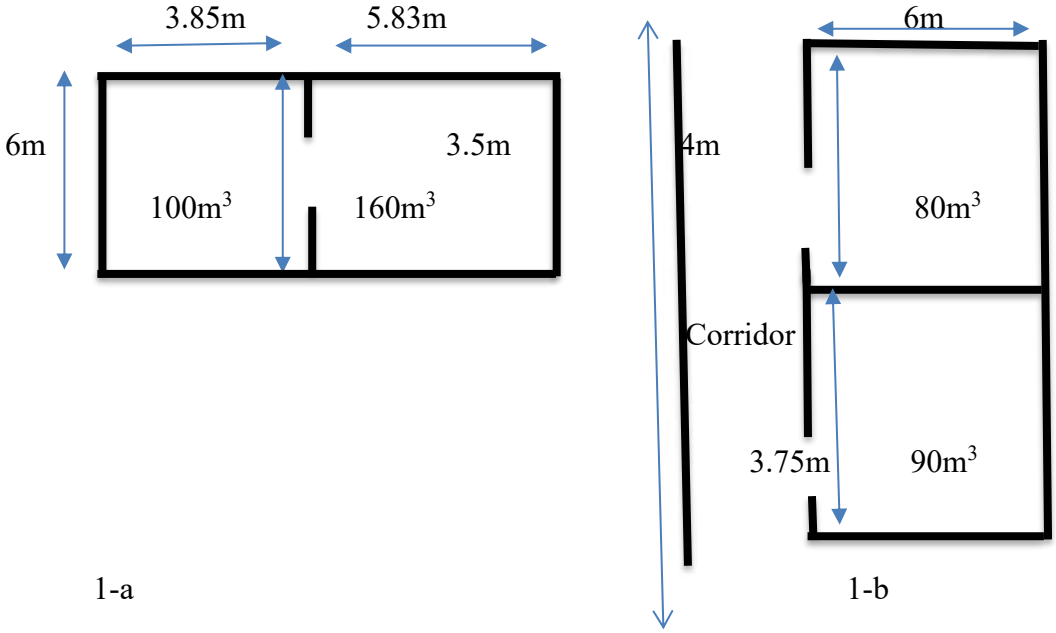


Figure 1: a) transmission rooms, 100m^3 and 160m^3; b) corridor with separate rooms, 80m^3 and 90m^3

2.2.Test Samples

As mentioned above, the aim of the research is to obtain sound insulation values with higher accuracy by improving the measurement method itself, as well as the sound source, and also calculating the sound reduction index itself. The study is based on comparing different measurements and equations to calculate the SRI for the same sample. It is not through improvement in the components of the sample that we are led to install and describe the door. Figure 2 (a and b) shows two photos of door sample, one of them inside the source and the receiving rooms (100m^3 and 160m^3), and the other photo inside the receiving rooms (80m^3 and 90m^3). The dimensions of the doors are 0.98m wide and 2.07m high. with a thickness of 0.06m and an area of 1.94m^2



Figure 2 - a)





Figure 2 - b)

a) the door between two transmission rooms (100m^3 and 160m^3)
b) the door between corridor and 80m^3 or 90m^3 room

3.Standards and Equations

3.1.Reverberation Time According to ISO Standards 354 [18]

$$T=\left(\frac{0.16\ V}{A}\right) \quad (1)$$

T:Reverberation time in sec.
A,V: equivalent absorption area of the room, and the room volume (m^3).
Because it distinguishes the room, its characteristics, and its size, it is referred to as 'the rooms used' in this research, namely T160, T100, T90, T80.

3.2.The Sound Reduction Index Calculated (R') Using Equation(2) from ISO:12354-1 and ISO140-3 [19,20].

R: sound reduction index is calculated for the sample under test without flanking transmission
R': sound reduction index is calculated for the sample under test with flanking transmission
Rf: sound reduction index for special structure to measure flanking transmission

$$R' = L1 - L2 + 10\lg\left(\frac{Ss}{A}\right) \quad (2)$$

$$R = -10\lg(10^{\frac{-R's}{10}} - 10^{\frac{-R't}{10}}) \quad (3)$$

L1, L2: Average sound pressure level in the source and receiving room
Ss: test sample area in m^2
Rs: denotes the adjusted sound reduction index of the test specimen in decibels.
R's: is measured, in decibels, with the test specimen in the test opening;
R't: is measured, in decibels, with the special construction (for flanking measurements) in the test opening

3.3.The Sound Power Calculated (L_{wR}) using Equation(4) from ISO 3741 [21].

L_W: the sound power of the sound source in the receiving room calculated from the following formula:

$$L_W = \overline{L_{p(ST)}} + 10\lg\frac{A}{A_0} + 4.34\ \frac{A}{S}dB + 10\lg\left(1 + \frac{SC}{8Vf}dB\right) + C_1 + C_2 - 6dB \quad (4)$$

where;
$\overline{L_{p(ST)}}$: the average sound pressure level one-third-octave band time averaging over all source and microphone positions, in dB.
A: equivalent sound absorption area of the test room, in m^2
A_0=1m^2 : reference value. S: the total surface area of the reverberation room, in m^2
f: mid-band frequency, Hz, c: speed of sound, in m/s
for constant temperature t ^{0}c then C1 = C2 = C
C = (331+0.6 t) m/s
where c, represents speed of sound at constant temperature *t*

3.4.The Sound Reduction Index Calculated (R') Using Equation (5) [22]

Reverberation time is an indirect indication of the sound power inside the receiving room, but cannot be measured accurately at low frequencies. Sound reduction index can instead be measured by determining the sound power emitted by the wall into the receiving room by comparing it with a reference sound source. Transmission loss is expressed under the assumption that the sound field is diffused in the source room and in the receiving room, [22,23].

$$R = L1 + 10\lg\left(1 + \frac{\lambda_i Ss}{8V}dB\right) + 10\lg\left(\frac{S}{S_0}\right) - 6 - (L2 + L_{wR} - L_{2R}dB) \quad (5)$$

L_{WR}: the power level, in the receiving room when the reference sound source is switched on,
L_{2R}: the sound level, in the receiving room when the reference sound source is switched on
Ss,: is the surface area of the source room, λ_i: is the wave length and S:sample area levels

3.5. Uncertainty of Measurements

The uncertainty due to measurement repeatability, $U_{L'p(ST)}$, is the closeness of agreement between results of successive measurements; it may be obtained from the standard deviation of measured levels *[21].*

$$U_{UL'PsT} = \frac{1}{\sqrt{N_M N_S}} \sqrt{\sum_{j=1}^{N_S} \sum_{i=1}^{N_M} \frac{\{[L'_{PiST}]j - L'_{PmST}\}^2}{N_M N_S - 1}} \quad (6)$$

$L'_{p(ST)}$: is the arithmetic mean value of the uncorrected time-averaged sound pressure levels in decibels

N_M,N_S: number of microphone and source positions

$[L'_{PiST}]j$: sound level at microphone position (i), and for source number (j)

4.Measurement Methods and Instrumentation

4.1. Methods of Measurements

4.1.1. Firstly, reverberation time measurements were carried out in the four rooms used in this research, as detailed in Table1, with the omnidirectional sound source (Type 4295) in the receiving room according to ISO354, 2003, [18].

4.1.2. Sound transmissions were determined from L1 and L2 measurements, to determine the sound reduction index for a door sample with the omnidirectional source placed in the source room, in the four rooms as shown in Table 1, [19].

4.1.3. Sound power measurements in the four rooms using the reference sound source (RSS Type 4204) in the receiving room only, as shown in Table 2, [21].

4.1.4. Sound transmissions were determined from L1 and L2 measurements, to calculate the sound reduction index for a door sample with the RSS in the source room in the four rooms, as shown in Table 3, [19].

3.1.5. Sound power measurements in the four rooms using the reference sound source (RSS) in the receiving room only, as shown in Table 3, [21].

4.1.6. Measurements of the sound reduction index for the special structure were used to determine its sound reduction coefficient, in order to calculate the flanking transmission from the source room to the receiving room, for the different rooms used in this research, [20].

4.2. Steps of Measurements

4.2.1. Noise Emitted from Omnidirectional Sound Source in Source Room to Receiving

- Sound reduction calculated using equation (2), (R')

After turning on the omnidirectional sound source in the source room and taking the average of the sound pressure levels in the source and receiving room (as L1, L2), then substituting them in Equation 2), the sound reduction index was obtained (R'), as R'160, R'100, R'80, R'90.

- Sound reduction from equation (5),(R'w)

average sound pressure level in the source and receiving room (L1, L2) were measured, assuming that L_{2R}=L2, and using L2 in Equation 4. We can obtain L_{wR}.

Using the L_{wR} and L2 to substitute in Equation 5, we can obtain the different values of R' as R'w160, R'w100, R'w80, R'w90.

4.2.2. Noise Emitted from Omnidirectional Source in Source to Receiving Room and RSS in Receiving Room

- Sound reduction calculated using equation (2), (R')

with using the calculated values of R'160, R'100, R'80, R'90 in (3-2-1).

- Sound reduction from Equation 5 (R'w's)

By using the average sound pressure level of RSS measurements in the receiving rooms only, represented as (L_{2R}=$\overline{L_{p(ST)}}$), and the sound power from Equation 4 of the RSS (L_w=L_{WR}).

With substitute in Equation 5, we can obtain the different values of (R'w) as, R'w's160, R'w's100, R'w'161, R'w's80, R'w's90.

3.2.3. Noise Emitted from RSS in Source Room to Receiving

- Sound reduction calculated using Equation 2 (R'ss)

The measured values of the RSS in the source room and take the average sound pressure level in the source and receiving room as (L1,L2), substitute in Equation 2, we obtain (R'ss), as R'ss160, R'ss100, R'ss161

- Sound reduction from Equation 5, (R'wss)

With the average sound pressure level in the source and receiving room as (L1, L2), assuming that L_{2R}= L2, and using L2 in Equation 4 to obtain L_{WR}.

- With substitute in Equation 5, we can obtain the different values of R' as R'wss160, R'wss100, R'wss161

4.2.4. Noise Emitted from RSS in Source to Receiving Room and RSS in Receiving Room

- Sound reduction calculated using Equation 2 (R')

using the calculated values of R'ss160, R'ss100, R'ss161, as in 3-2-3.

- sound reduction from Equation 5 (R'w'ss)

Using the average level of RSS measurements in the receiving rooms only, which represented as ($L_{2R} = \overline{L_{p(ST)}}$), and the sound power from Equation 4 of the RSS (L_w=L_{WR}).

With the substitute in Equation 5, we can obtain the different values of (R') as, R'w'ss160, R'w'ss100, R'w'ss161.

4.3. Measurements and Instrumentation

4.3.1. Reverberation Time (T) Measurements

Before starting measurements, the sound level meter was calibrated before and after each measurement using the sound calibrator. To measure the reverberation time in the four rooms, with two source positions were chosen, where the B&K type 4295 omnidirectional sound source is located at a distance of 1m from the walls, (ISO354, 2003). The microphone of the 2260 sound meter is placed at six positions with a distance of more than 1m from the walls and at a height of 1.5m from the floor. The measurements were performed using the interrupted noise method according to ISO-3382 (ISO 2008) standard. The measurements were collected at a range from 125 to 5000 Hz. The reverberation time measurements were carried out to four receiving rooms, as shown in Figure 3.

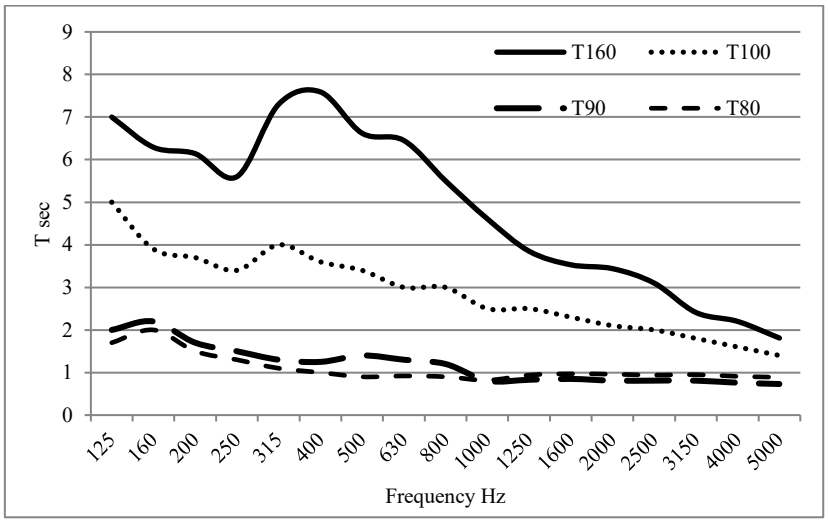


Figure 3: Measured reverberation time of the four receiving rooms

Reverberation time (T) was measured as the most important quantity for any reverberation room. T can be determined from the general form of Sabine's reverberation time equation. The sound analyser B&K 2260, with sound analysis software, was used in the receiving room, with the average reverberation time T recorded. The measured T is shown in Figure 3 as T160, T100, T80 and T90, which are the measured reverberation times T of the four receiving rooms of different volumes, respectively.

4.3.2. Sound Reduction Index Measurements (R') using Equation 2

Sound transmission measurements were carried out using Table 1. Two locations for the sound source were selected in the source room with two metre spacing between them. B&K type 4295 omnidirectional sound source

was used to introduce white noise in the source room. The excited noise (L1) in the source room was recorded and analysed using the sound analyser B&K 2260 at five microphone positions for each sound source location. The microphone positions were far from any boundaries of the room at more than 0.8m, from the source at more than 1.7m, and from the floor at 1.5m. The sound field was measured inside the receiving room (L2) at five microphone positions for each sound source location.
Using the averaging of (L2) and (L1) according to EN-ISO:12354-1 with Equation 2 to calculate and obtain the R'160, R'100, R'80 and R'90, as shown in Table 1.

table 1. calculated parameters using equations 2,3 and 5 with description of testing rooms

Eq(5) & L_{2R}=L2	Eq(2)	Eq(3)	R.Room		S.Room
R'=R'w	R'	R	Surf. area	Vm^3	Vm^3
R'w160	R'160	R160	180	160	100
R'w100	R'100	R100	138	100	160
R'w80	R'80	R80	115	80	Corridor
R'w90	R'90	R90	120	90	corridor
R'w161	R'161	R161	180	160	100
Vm^3	Rooms Descriptions				
160	4.12:4.26m height Rev.Room With diffusers 5.87:6.3m width and length				
100	3.85w×6L×4.3h Empty Room				
80	3.35w×6L×4h office room				
90	3.75w×6L×4h office room				

4.3.3. Sound Power Measurements in the Four Rooms (Table 1) using the RSS

The reference sound source (B&K Type 4204) is placed at the same position of the sound source type 4295, as well as the microphones, which are used to measure the noise levels, as shown in Table 2. It also verified that the SPL ($\overline{L_{p(ST)}}$) measured in the receiving room is 10 dB higher than background noise level. Using Equation 4 to calculate the sound power (L_w) of RSS in the four receiving rooms.

Table 2. Contains the calculated parameters using equations 2,3 and 5 with RSS in R. Room only

Eq(5) & $L_{2R}=\overline{L_{p(ST)}}$		Eq(2)	Eq(3)	R.Room		S. Room
R'=R'w's	R.Room	R'	R	Sur. area	Vm^3	Vm^3
R'w's160	RSS	R'160	R160	180	160	100
R'w's100	RSS	R'100	R100	138	100	160
R'w's161	RSS	R'161	R161	180	160	100
R'w's80	RSS	R'80	R80	115	80	corridor
R'w's90	RSS	R'90	R90	120	90	corridor

4.3.4. The Sound Transmission was Determined from L1 and L2 Measurements Using the Reference Sound Source (Type 4204, as shown in Table 3).

Using RSS to determine the sound Reduction index (R') from Equation 5, (Maluski, S. 1999), repeating Step 2, but using the RSS instead of B&K type 4295 omnidirectional sound source, with the same sound source and microphone positions, as shown in Table 3.
Using RSS to (L1, L2) measurements for determining the sound Reduction index (R'ss) from Equation 2. Using the RSS in the receiving room to determine the L_{2R} to calculate the L_{WR} from Equation 4 and with substitute in Equation 5, we can obtain the sound Reduction index (R') for receiving rooms $160m^3$ and $100m^3$ as (R'wss160 and R'wss100).
Here, the sound Reduction measurements were carried out using the RSS in the source and receiving rooms (as shown in Table 3).

Table 3. This is a table **for** calculations using equations 2,3 and 5 with RSS in source and R.Room

2 sound transmission rooms						
Eq(5)		Eq(2)	Eq(3)	R. Room	S.Room	
R'	R.Room	R'	R	Vm^3	S.Room	Vm^3
R'wss160 (L_{2R}=L2)	-----	R'ss160	Rss160	160	RSS	100

R'wss100 (L_{2R}=L2)	-----	R'ss100	Rss100	100	RSS	160
R'w'ss160 L_{2R}	RSS	R'ss160	Rss160	160	RSS	100
R'w'ss100 L_{2R}	RSS	R'ss100	Rss100	100	RSS	160

4.3.5. The Sound Reduction Index Measurements (R't) for Special Structure with Flanking Transmission

The sound Reduction index measurements (R't) for special structure with flanking transmission can be calculated using Equation 2 and the data of Table 1.
To measure the flanking transmission from the source to receiving room, a special structure was put in place. Accordingly, a special structure was put over the under test sample according to ISO 140-3. The first face of the door was covered with an 18mm thick gypsum board, which was placed directly on the first face of the door. Then from the second face of the door, rock wool was placed until it filled the space behind the door, and a 5mm thick sheet metal board was placed on it. Subsequently, an 18mm thick gypsum board was placed directly on this face to cover the entire area of the door, [20].

5. Results and Discussion

5.1. SRI for Door Measured in 100m^3 Source Room and 160m^3 Receiving Room

Figure 4a depicts the comparison between the sound reduction index (SRI) without flanking sound transmission (R160), which was determined using Equation 3. It achieved just 31dB at 1000Hz. Additionally, when the SRI contains flanking transmission as R'160, obtained from Equation 2, it is equal to the R'w160, which is obtained based on the sound power method for SRI when substituted with (L_{2R}=L2) in Equation 5. There is an increase in the R160 value of the tested door in a frequency range from 250–1000Hz; however, R'160 decreased due to flanking transmission to the receiving room, which caused an increase in L2 values.

Figure 4b shows the comparison between the values of the sound reduction index SRI of R160 and R'160 for the door sample. While the variance arises in R'ws160 from Equation 5 after turning on the RSS in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ which was emitted in the receiving room, the SRI value of R'ws160 is a greater value than other remaining factors, as shown in Figure 4b) in the range from 315–1000Hz. This was seen as a result of the sound power in the receiving room. This therefore means a divergence in results between R'160 and R'ws160.

With the RSS in the source room, Figure 5a depicts the comparison between the values of the SRI without flanking sound transmission Rss160 from Equation 3, and also with flanking sound transmission R'ss160 from Equation 2. The R'wss160 derived from Equation 5, assuming that (L_{2R}=L2) where the source room contains the RSS. The figure indicates that the value of Rss160 increased when compared with the amount of R'ss160 for the door under test. Whereas the amount R'wss160 derived from Equation 5 increased to reach 30dB, where its values were higher than the other factors in Figure 5a in the range from 400–800Hz. This means that there is a divergence in results between R'160 and R'wss160.

Figure 5b illustrates the comparison between the SRI values for the door sample, of Rss160 and R'ss160. From Equation 5, the R'w'ss160 values were obtained; however, after the RSS turned on in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ emitted from it, the R'w'ss160 values were found to be higher than other factors within the frequency range 400–800Hz, signifying that the L2 amount is below the measured value, which produces improved isolation values for the sample (door). In general, there is a divergence in results between R'ss160 and R'w'ss160.

As observed in Figure 6a, the curves for R'ss160 and Rss160 are a higher value than others in two of the frequency ranges: one is lower than 250Hz and the other is upwards of 1600Hz. For the middle band frequency, from 250Hz to 1600Hz, the values of R'160 and R160 start to rise up to 1600Hz. The values then decreased again to lower than R'ss160 and Rss160. In general, there is a divergence in results between R'160 and R'ss160.

As shown in Figure 6b, the R'ws160 begin to be higher than R'160 through all the frequency bands by about 2dB, except at 315–1000Hz, when it reached approximately 4dB. Increasing in R'ws160 and R'w'ss160 values, referring to the emitted sound power when the RSS turned on in the receiving room and measure the level $L_{2R}=\overline{L_{p(ST)}}$. Also, it is observed that the values of R'ws160 ranged between 18dB and 32dB, and the R'w'ss160 values ranged between 25dB and 30dB. It is also the highest values at all the frequency bands except at the frequency from 400–1600Hz, at which point it drops down lower than R'ws160.

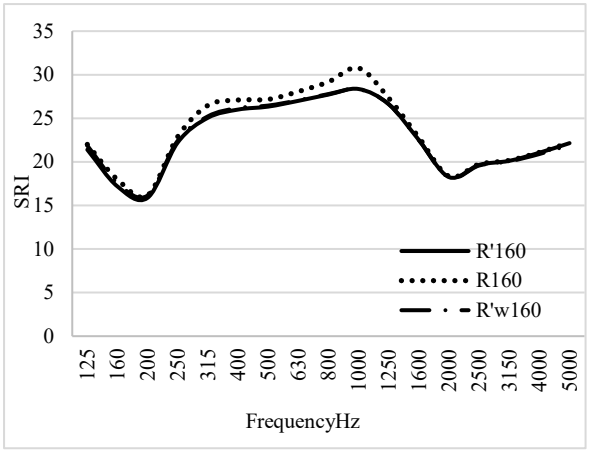


Figure 4-a)

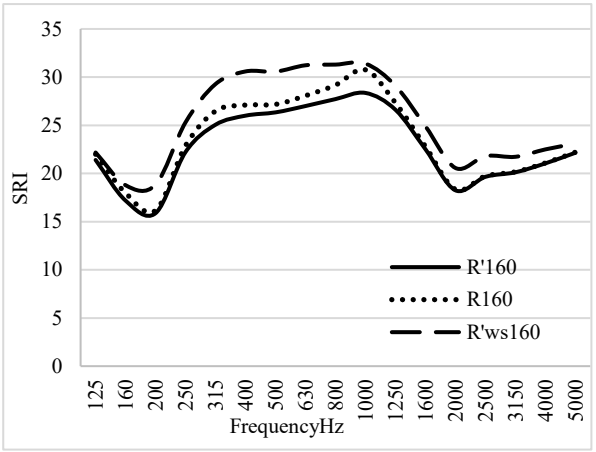


Figure 4-b)

Figure 4: SRI using: a) omni in source room and L_{2R}=L2, and b) omni in source room and RSS in receiving room, $L_{2R}=\overline{L_{p(ST)}}$

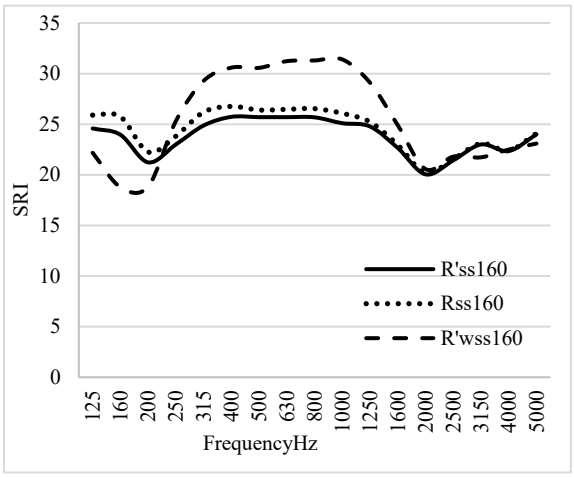


Figure 5-a)

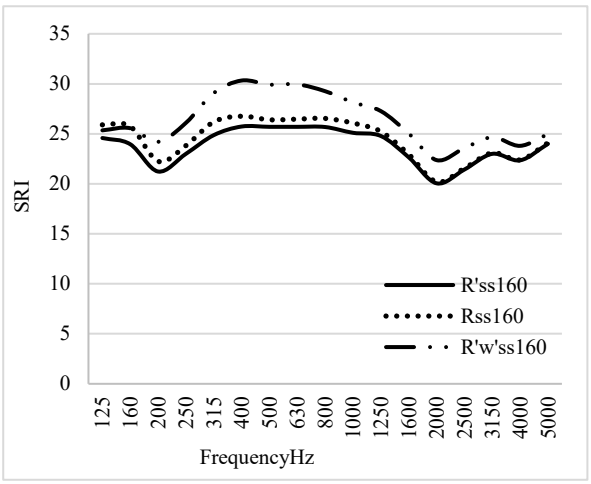


Figure 5-b)

Figure 5: SRI using: a) RSS in source room and L_{2R}=L2, and b) RSS in source room and RSS in receiving room, $L_{2R}=\overline{L_{p(ST)}}$

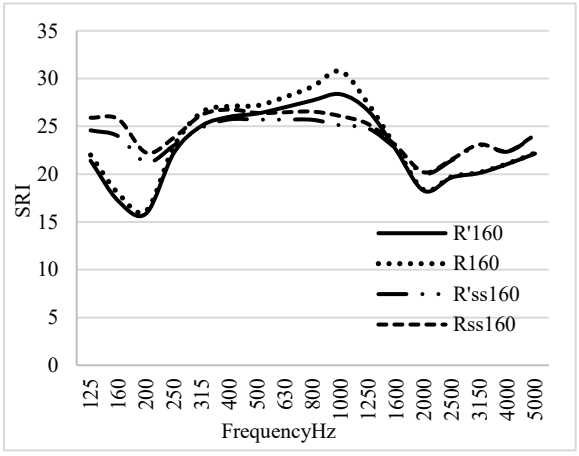


Figure 6-a)

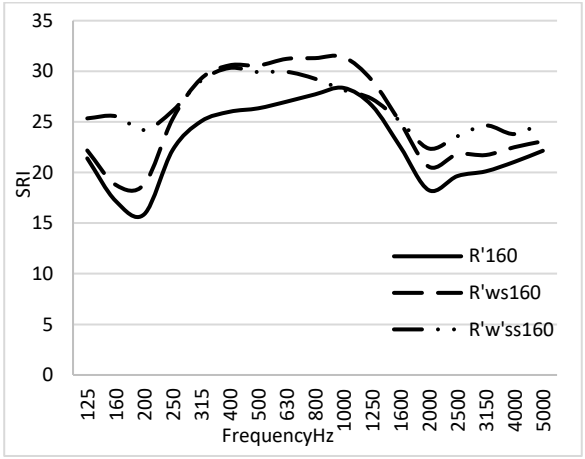


Figure 6-b)

Figure 6: a) comparison between omni and RSS in source room, and b) effect of RSS in receiving room

5.2. SRI for Door Measured in160m^3 Source Room and 100m^3 Receiving Room

Figure 7a shows the comparison between the values of the SRI without flanking sound transmission R100, obtained through Equation 3, reaching 32dB at 1000Hz, and with flanking sound transmission R'100 obtained from Equation 2, as well as R'w100 from Equation 5, assuming (L_{2R}=L2), based on the sound power method for SRI. The figure indicated an increment in the value of R100 for the door under test, where the SRI values resulting from equations 1 and 5 by means R'100 were almost equal with R'w100.

Figure 7b displays the comparison of the SRI values for the door sample of R100 and R'100, where the difference comes from Equation 5. However, after turning on the RSS in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ emitted from it, SRI yields R'ws100 were almost equal to R'100, with both smaller than R100 throughout the frequency range from 125-5000Hz.

Figure 8a depicts the comparison between the values of the SRI without flanking sound transmission Rss100 from Equation 3, and also with flanking sound transmission R'ss100 from Equation 2. The R'wss100 derived from Equation 5 assumes that (L_{2R}=L2), where the source room contains the RSS. The figure indicates that the value of Rss100 increased compared to the amount of R'ss100 for the door under test. Moreover, the value of R'ss100 was equal to R'wss100 for the door under test resulting from Equation 5, attaining 30dB at 400Hz, where the value declined to 20dB at 2000Hz, whilst Rss100 and its values were greater than the remaining factors in the figure throughout the range 400–2000Hz and decreased from 32.5 to 20dB.

Figure 8b depicts the comparison between the SRI values for the door sample, of Rss100 and R'ss100, whilst the disparity stems from Equation 5. After running the RSS in the receiving room and evaluating the $L_{2R}=\overline{L_{p(ST)}}$ from it in the room, the SRI produced a value of R'w'ss100, equalised with R'ss100 for the door under test. An increase from Equation 5, the value reached 30dB at 400Hz, then dropped to 20dB at 2000Hz, whilst Rss100 and its value were higher than the other curves, demonstrating a range of 400–2000Hz, which declined from 32.5 to 20dB.

As noted in Figure 9a, the values of R'ss100 throughout the examined frequency range surpassed R'100 by an amount spanning 1dB to 4dB. Lower than 250 it rised by 3dB and from 250Hz to 400Hz, and from 1600Hz to 5000Hz it increased by 1dB. The region between 400Hz to 1600Hz showed unstable behaviour, it is changed from positive to negative dB. Generally, the upper values related to the Rss100 curve with the exception of 800Hz to 1600Hz.

In Figure 9b, it can be observed that the values of R'w'ss160 and R'ws160 start to escalate, beginning at frequency 250 by 3dB from R'160 up to 800, with a decline following after. It is noted that the values of R'wss160 are equal to the values of R'w'ss160. The R'wss160 was greater than R'160 up to 800, with a change in dB witnessed from positive to negative dB at the range from 800Hz to 1600Hz. In the frequency range above 1600Hz, the curve results are comparable with each other. The R'w'ss160 was also seen to be in the upper most part concerning the increase when using RSS in the source room and also when using it in the receiving room to gauge L_{2R},

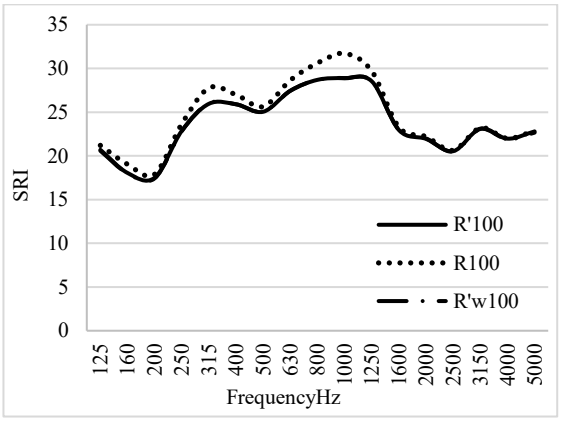


Figure 7-a)

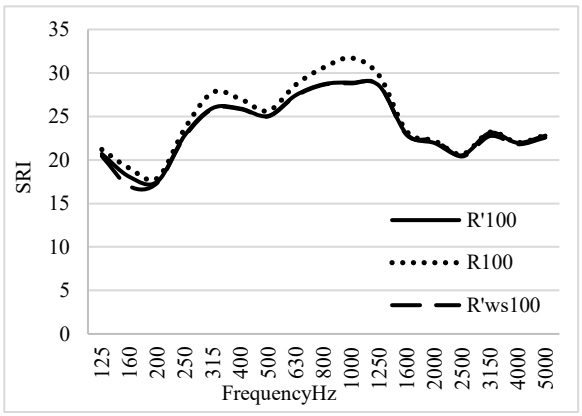


Figure 7-b)

Figure 7: SRI measurements using a) omni in source room and L_{2R}=L2 b) omni in source room and RSS in receiving room, $L_{2R}=\overline{L_{p(ST)}}$

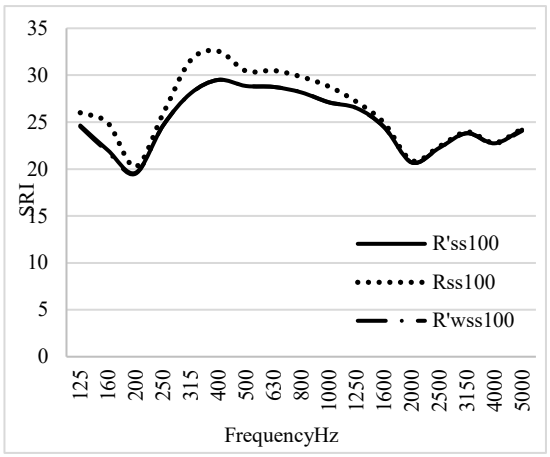


Figure 8-a)

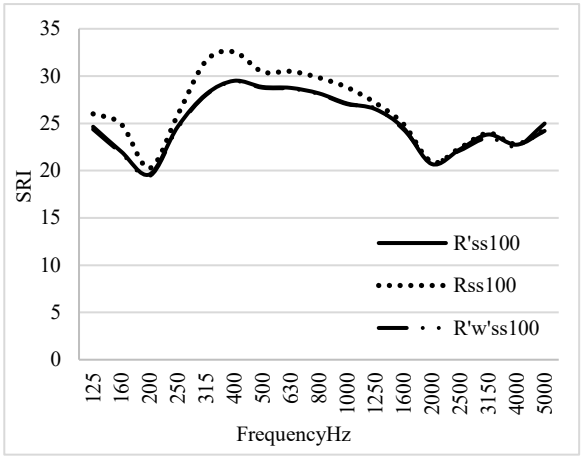


Figure 8-b)

Figure 8: SRI measurements using a) RSS in source room and L_{2R}=L2 b) RSS in source room and RSS in receiving room, $L_{2R}=\overline{L_{p(ST)}}$

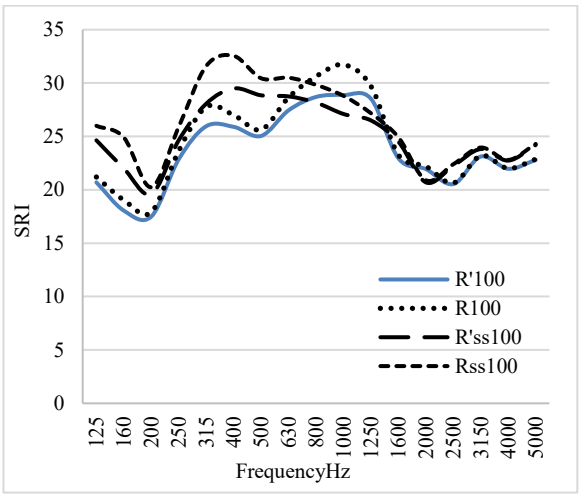


Figure 9-a)

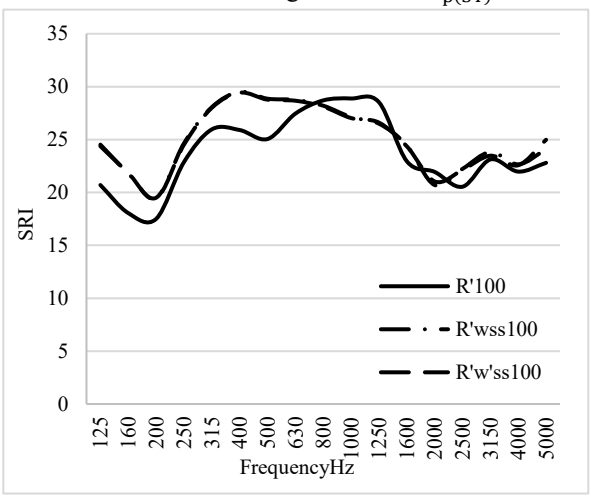


Figure 9-b)

Figure 9: a) comparison between omni and RSS in source room, and b) effect of RSS in receiving room

In Figure 10, it can be observed that the values of R'ss100 in the examined frequency span surpass R'100 by an amount varying from 1 to 4dB, aside from at 1200, 1600 and 2000Hz, R'100 increases by 2dB over the values of R'ss100. In the frequency spectrum from 315Hz to 1600Hz, and also in the frequency region from 1600Hz to 5000Hz and the values of R'160, values start to increase beginning at the frequency of 250Hz, with an increase of 3dB from each of R'160 and R160 to 800Hz. A decrease then occurs after. It is noted that the values of R's160 were greater than R160 throughout the investigated frequency range, and R'ss160 was also the highest, except at 1000Hz.

5.3. SRI for a New Door (161) Measured in 100m^3 Source Room and 160m^3 Receiving Room

Figure 11 illustrates the measurements of another door sample, but under identical conditions a side from the door components; however, the same installation technique was implemented, as it was mounted on the same hinges. The comparison was made between the values of the sound reduction index SRI without flanking sound transmission R161 from Equation 3 and also with flanking sound transmission R'161 from Equation 2, where R'w161 derived from Equation 5 with the assumption (L_{2R}=L2). The figure indicated that the SRI value R'w161 for the door tested increased the R161, then came the amount R'w161, where the calculation was carried out with Equation 5 by setting (L_{2R}=L2). The maximum amount derived from Equation 5 after; however, after turning on RSS in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ coming from it in the room, the SRI produced the amount R'ws161. This amount was higher than the other factors.

5.4. SRI for a Door Measured in a Corridor as a Source Room and 80m^3/90m^3 Receiving Rooms

Figure 12 depicts the comparison between the SRI and without flanking sound transmission R80 from Equation 3, as well as with flanking sound transmission from Equation (2) R'80, in addition to R'w80 ensuing from Equation 5, under the supposition (L_{2R}=L2), with the omnidirectional sound source in a corridor with 4m width and up to 150m length, and a receiving chamber of 80m^3. The figure indicated that the value of R80 increased to the highest value and R80 augmented by up to 3dB over all curves across the frequency range from 125 to 1600Hz, and all factors are equal from 1600Hz to 5000Hz, while the lowest coefficient is R'ws80 for the door under test as derived from Equation 5; however, when turning on the RSS in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ emitted from it in the room, across the whole frequency range.

Figure 13 shows the comparison between the values of the SRI and R90, which do not include flanking transmission (from Equation 3), and the values of R'90, which do include flanking transmission (from Equation 2). The R′w90 value was obtained from Equation 5, assuming (L_{2R}=L2), with the omnidirectional sound source acting as a source in a corridor 4 m wide and up to 150 m long. The R90 values represent the highest values in the figure, with R90 increasing by up to 1.5 dB over the other curves in the frequency range from 125 Hz to 1600 Hz. The varied factors converge together above 1600Hz, encompassing R'ws90 for the door under test, where we result from Equation 5; however, after running the RSS in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ from it in the room, the values of the different SRI factors ranged between 24dB as the minimum value and 31dB as the maximum value.

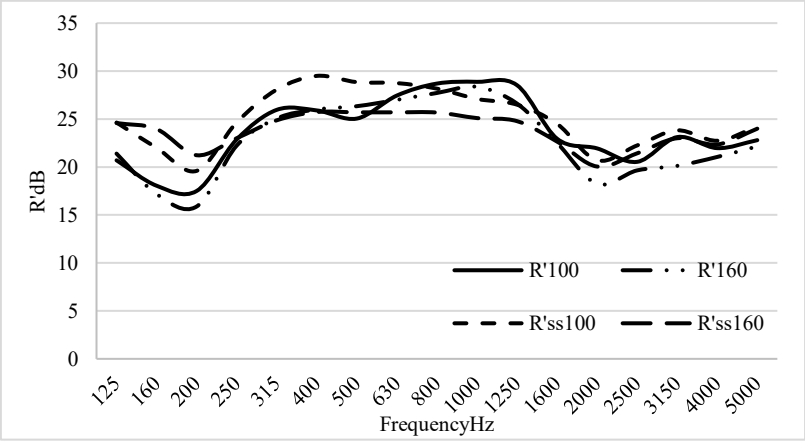


Figure 10: the omni source in a source room of 100m^3 and when 160m^3

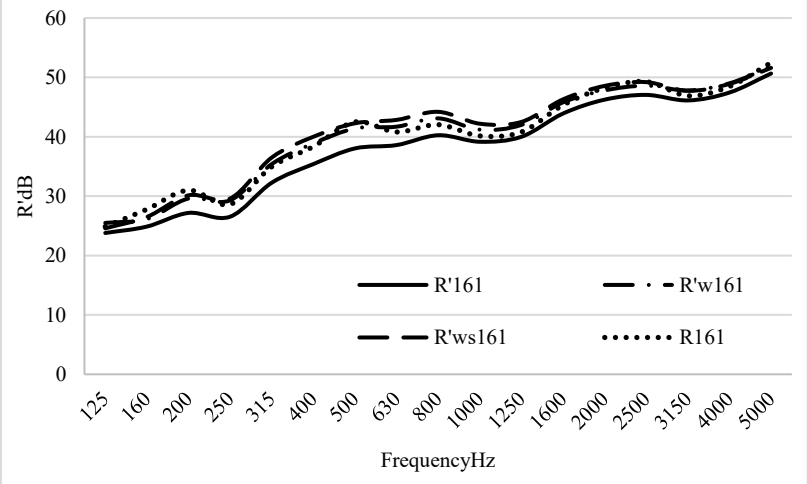


Figure 11: the omni source in a source room of 100 m^3

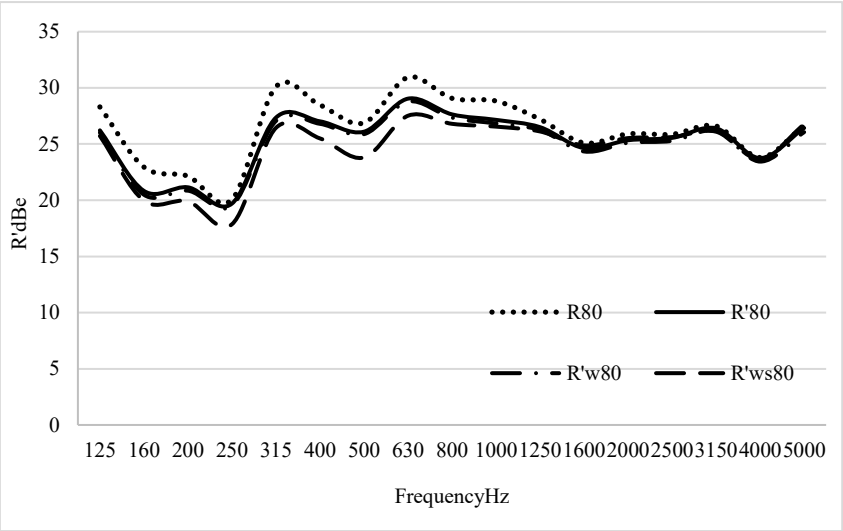


Figure 12: the RSS source only in a receiving room of 80m^3

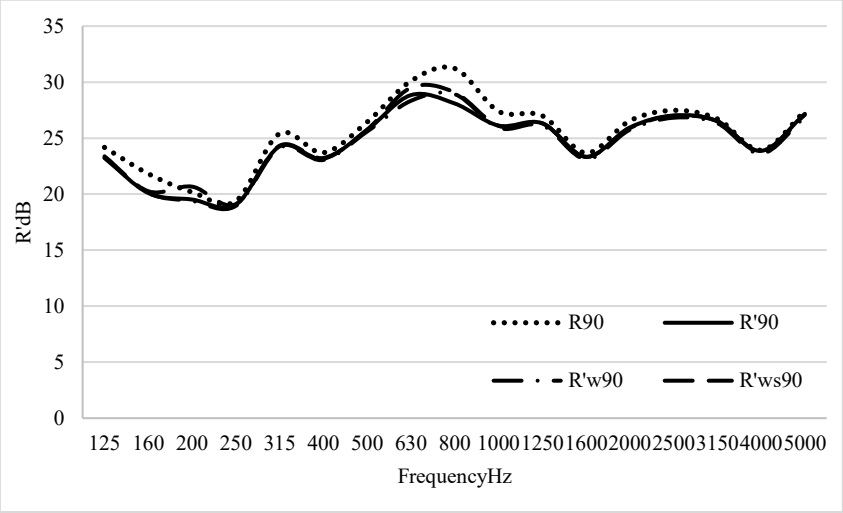


Figure 13: the RSS source only in a receiving room of 90m^3

5.5.Uncertainity Calculations

The uncertainty due to measurement repeatability is very small for large source room (160m^3) than other volumes for source room (100m^3 and corridor); it is approximately 0.1dB for a frequency above 400Hz as a result from equation 6, [21]. appear in figure 14.

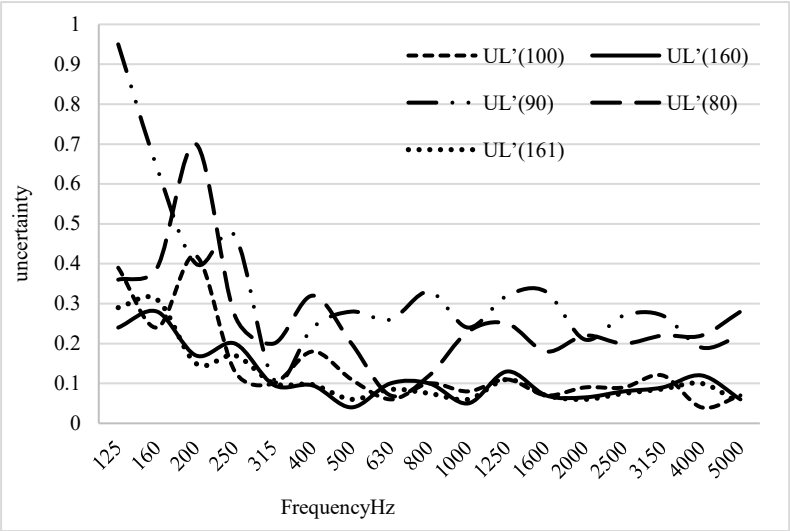


Figure 14: The uncertainty due to measurement repeatability in different rooms

5.6. Effect of L2 and $\overline{L_{p(ST)}}$ in Sound Power Calculations4As stated in Table 4,

Regarding the comparison between the sound level measured in the receiving room, whether L2 or $\overline{L_{p(ST)}}$, and the sound power Lw calculated for:

- **First Case: Use a 100 m^3 Source Room and a 160 m^3 Receiving Room:**

When the omnidirectional sound source in the source room and using the measured L2 in the receiving room, as L_{2R}=L2 and compensating with Equation 4, the difference between L2 and L_w ranges from 0.5dB to 8.1dB within the frequency range from 125Hz to 10000Hz. When using the RSS as a sound source in the source room and using the measured L2 in the receiving room, however, as L_{2R}=L2 and compensating with Equation 4, the difference between L2 and L_w ranges from 0.5 to 8.1dB in the frequency range from 125Hz to 10000Hz.

When using RSS as a sound source in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ and compensating for it in Equation 4, the difference between L_{2R} and L_w ranges from 0.5dB to 8.1dB in the frequency range from 125Hz to 10000Hz.

- **Second Case: Use a 160m^3 Source Room and a 100m^3 Receiving Room:**

When using the omnidirectional sound source in the source room and using measured L2 in the receiving room, as L_{2R}=L2 and compensating with Equation 4, the difference between L2 and L_w ranges from 0.5dB to 8.1dB within the frequency range from 125Hz to 10000Hz. When using the RSS as a sound source in the source room and using the measured L2 in the receiving room, however, as L_{2R}=L2 and compensating with Equation 4, the difference between L2 and L_w ranges from 0.5dB to 8.1dB in the frequency range from 125Hz to 10000Hz.

When using RSS as a sound source in the receiving room and measuring the $L_{2R}=\overline{L_{p(ST)}}$ and compensating for it in Equation 4, the difference between L_{2R} and L_w ranges from 0.5dB to 8.1dB in the frequency range from 125Hz to 10000Hz.

Table 4: the comparison between the sound level measured in the receiving room, whether L2 or the $\overline{L_{p(ST)}}$ and the sound power Lw calculated from equation(4).

Source R.160m^3 /Receiving R.100 m^3					Source R.100m^3 /Receiving R.160 m^3			
F	omni	RSSon	RSSs		F	omnis	RSSs	RSSon
125	0.5	0.64	0.49		125	1.3	1.32	0.98
160	0.54	1.55	0.52		160	2.31	2.32	1.06
200	1.37	1.44	1.37		200	3.66	3.66	0.96
250	1.4	1.5	1.38		250	4.07	3.07	1.19
315	0.6	0.72	0.65		315	3.9	3.9	-0.16
400	0.97	1.03	0.97		400	4.0	4.05	-0.42
500	1.12	1.2	1.11		500	4.2	4.22	0.09
630	1.44	1.52	1.44		630	4.3	4.31	0.13
800	1.5	1.59	1.51		800	4.3	4.31	0.78
1000	2.1	2.18	2.09		1000	4.6	4.54	1.52
1250	2.24	2.31	2.41		1250	4.76	4.77	2.28
1600	2.5	2.65	2.56		1600	5.05	5.04	2.64
2000	3.1	2.82	3.17		2000	5.1	5.1	2.73
2500	3.15	3.24	3.15		2500	5.4	5.4	3.17
3150	3.36	3.7	3.36		3150	6	6.04	4.32
4000	4.1	4.23	4.14		4000	6.34	6.34	4.73
5000	4.76	4.85	4.76		5000	6.77	6.77	5.63
6000	5.1	6	5.1		6000	7.6	7.61	6.84
8000	6.8	6.96	6.87		8000	9	9.03	8.47
10000	8.1	8.21	8.12		10000	10.24	10.24	10

5.7. Effect of Source and Receiving Room Data (V and S) in Equation 5

In terms of $(\frac{\lambda_i Ss}{8V}\text{dB})$ in Equation 5 for sound power method, the compensation in this term with the values of volume and total surface area for the source room (100m^3& 137m^2), or the values for receiving room (160m^3& 178m^2), there is a small difference in R'w.

As stated in Table 5, an increase in SRI will be obtained from the sound power method R'w. Here, an increase in the values of SRI can be seen by 0.2dB in a frequency range starting from 125Hz to 1250Hz. Outside, this range increased by less than 0.1dB until it reached zero. When comparing both cases as stated in Table 5, we notice that there is a single absolute values for different cases.

Table 5: The results obtained from Equation 5 when substitute with the values of (V and S) source or receiving room, in Equation 5.

Using V=100m^3&S=138m^2				Using V=160m^3&S=180m^2		
F	R'w100	R'ws100		F	R'ws160	R'w160
125	0.28	0.28		125	- 0.28	- 0.28
160	0.24	0.24		160	-0.24	-0.24
200	0.18	0.18		200	-0.18	-0.18
250	0.17	0.17		250	-0.17	-0.17
315	0.13	0.13		315	-0.13	-0.13
400	0.11	0.11		400	-0.11	-0.11
500	0.0	0.0		500	0.0	0.0
630	0.07	0.07		630	-0.07	-0.07
800	0.0	0.0		800	0.0	0.0
1000	0.0	0.0		1000	0.0	0.0
1250	0.02	0.02		1250	-0.02	-0.02
1600	0.03	0.03		1600	-0.03	-0.03
2000	0.0	0.0		2000	0.0	0.0
2500	0.0	0.0		2500	0.0	0.0
3150	0.0	0.0		3150	0.0	0.0
4000	0.0	0.0		4000	0.0	0.0
5000	0.0	0.0		5000	0.0	0.0
6000	0.0	0.0		6000	0.0	0.0
8000	0.0	0.0		8000	0.0	0.0
10000	0.0	0.0		10000	0.0	0.0

Conclusion

As a result of various measurements and comparisons, the results indicated that, in the sound power method for SRI measurements, it is absolutely not permissible to utilise L2 values as a substitute for L2R values, as this causes the values of the SRI to decrease, and that the reason for the increase in the value of R'w is due to the increase in sound power. When the source room is a large area than receiving room, the variation between the sound level and sound power is small, due to the sound is more dispersed in the room, and the difference between sound pressure levels and their corresponding sound power is smaller compared to higher levels and their power. However, the variation between the level and its power remains almost constant and does not change with increases or decreases in the level. For a small source room, the difference and disparity were large between sound levels and the sound power, and not constant across differing levels. However, the results indicated that the source room must be large and the receiving room must be small in order to obtain equality between the two methods results. The uncertainty due to measurement repeatability is very small for a large source room compared to other source room volumes; it is about 0.1 dB for frequencies above 400 Hz.

The measurements and estimations of sound insulation using the sound power approach in both the source and receiving rooms showed better sound reduction values. This indicates that the sample's sound reduction index improved more than when using the sound levels method in these rooms, if we take into consideration the loss of power in the receiving room, this is true whether a reference sound source or an omnidirectional sound source that spreads in all directions is used. If the receiving room is smaller than the source room, the sound insulation value, or sound reduction index, goes down.

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Data Availability Statement: all results and the data of experimental methods generated or used during the study appear in the submitted article

Conflicts of Interest: The authors declare no conflict of interest.

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