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# Average Sound Absorption per Person at Octave Band Frequencies Between 125Hz And 4000Hz in an Enclosure

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**Abstract**

The audience constitutes the major sound absorbent materials in most church auditoria and, non-inclusion of the sound absorbed by the audience in the determination of the optimum reverberation time from the design stage accounts for the problem of poor sound quality in such church auditoria. To address this problem, this research was carried out to provide designers with data on sound absorption by an individual at some octave band frequencies important for understanding speech. The work utilized the Sabine's formula for Reverberation Time to determine the sound absorption per person at Octave band frequencies of 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz. Data which included the volume, sitting capacity of persons and reverberation time of eight (8) churches were obtained when the churches were occupied and when unoccupied. These data gave the calculated average sound absorption per person of 0.29, 0.43, 0.51, 0.68, 0.71 and 0.73 at these octave band frequencies respectively, all showing that the average sound absorption by an individual increases with frequency within this octave band frequency range.

**Key Words**: Reverberation Time, Sound Absorption, Octave Band Frequency.

## 1. Introduction

Speech intelligibility in an enclosure is influenced by many parameters reasonably well accountable in terms of objective descriptors. Among these parameters, the most significant are the signal-to-noise ratio (S/N) that represents the emergence of speech level over the background noise (Reich and Bradley, 1998) and the reverberation time (RT) which suffers reduction as a result of additional sound absorption brought by the audience (Doelle, 1972).

The acoustics of enclosed spaces has been of obvious importance ever since people began to gather in large auditoriums and churches, however, there were a lot of misunderstandings and superstitions concerning the subject. These practices without scientific basis lingered until 1895 when Wallace Clement Sabine was able to establish a firm foundation of scientific knowledge about the subject. Through extensive experimental studies of acoustical properties of a room, Sabine arrived at an empirical relation between reverberation characteristics of an enclosure, its size and the amount of sound absorption (Kinsler et al., 1982).

At the dawn of the 21$^{st}$ Century, there is presently an on-going revolution in the sizes of auditoria and churches all over the world (www.africanloop.com, 2009). We are witnessing a paradigm shift from small church enclosure to very large church auditorium. Most of these auditoriums fall short of providing good sound quality and often the problem starts from either an attempt to avoid the cost of consulting an acoustician or lack of adequate knowledge as to the graveness of not taking into consideration the issue of sound quality. Whichever way, sooner or later it becomes a very serious problem because such buildings are basically places for communication to an audience and hence the issue of speech intelligibility cannot be dismissed. It has been observed that when these auditoria are constructed, obtaining good sound becomes a huge problem due to the fact that there was a negligence of acoustical implementation at the onset (www.churchacoustics.com, 2008) and in particular sound absorption by people is often ignored when estimates of the values of reverberation time are determined. For high intelligibility of sound in church enclosures, the acoustical environment must be placed among the higher priority concern during the design process. To achieve this, sound absorption by people at octave band frequencies should be included in the estimation of total sound absorption which in turn would give better estimate of the reverberation time of the enclosure in order to fulfill the main functions of a worship space.

The reverberation time (RT) is defined as the time required for the absolute intensity to drop by a factor of $10^6$ or equivalently, the time for the intensity level to drop by 60 decibels after the source is switched off. The loudest crescendo for most orchestral music is about 100dB and a typical room background level for a good music-making area is about 40dB. Thus the standard reverberation time is seen to be about the time for the loudest crescendo of the orchestra to die away to the level of the room background. Therefore the 60dB range is about the range of dynamic levels for orchestral music. It is an important parameter in calculating the objective descriptors of room acoustics. Since such parameters are well related to subjective assessment of room acoustics, it is most important for the acoustical design process to provide a general design tool which enables prediction of relevant sensations in auditorium (Beranek, 1992).

The first and most remarkable approach to describe the reverberation characteristics of an enclosure was found by Wallace Clement Sabine. Sabine established his theory on the basis of practical results. To find a theoretical basis for calculating reverberation time, many researchers contributed new theories. Since Sabine published his results, several different approaches have been adopted to obtain equations that describe the reverberation characteristics (Franklin, 1903; Eyring, 1930; Millington, 1932; Sette, 1933; Fitzroy, 1959; Kosten, 1965; Tohyama and Suzuki, 1995; Arau-Purchades,1988; Bistafa and Bradley, 2000). However, the general description of the reverberation time based on Sabine's reverberation theory is still in common use and is used in this work.

**2. Theoretical Consideration**

The reverberation time, RT, given by Sabine is

$$RT = \frac{0.161V}{A} \quad (1)$$

where V is volume of the enclosure and

A is the total sound absorption

The reverberation time of an unoccupied enclosure is therefore given as

$$RT_{unoccupied} = \frac{0.161V}{A} \quad (2)$$

The reverberation time for the occupied enclosure is therefore given by

$$RT_{occupied} = \frac{0.161V}{A+A_{persons}} \quad (3)$$

where $A_{persons}$ is the additional sound absorption due to enclosure occupants

From Equation (2)

$$A = \frac{0.161V}{RT_{unoccupied}} \quad (4)$$

Also, from Equation (3)

$$A + A_{persons} = \frac{0.161V}{RT_{occupied}}$$

$$A_{persoms} = \frac{0.161V}{RT_{occupied}} - A$$

$$= \frac{0.161V}{RT_{occupied}} - \frac{0.161V}{RT_{unoccupied}}$$

$$= 0.161V\left(\frac{1}{RT_{occupied}} - \frac{1}{RT_{unoccupied}}\right) \quad (5)$$

Thus, the absorption per person is therefore given as

$$A_{person} = \frac{A_{persons}}{N}$$

$$= \frac{0.161V}{N}\left(\frac{1}{RT_{occupied}} - \frac{1}{RT_{unoccupied}}\right) \quad (6)$$

 

(Note that N is the number of members of the audience in the enclosure).

## 3. Materials and Methods

The equipment used in this work included a sound source type HP 1001, Power source Type 4205, Measuring Amplifier Brüel & Kjaer Type 2607, Graphic level Recorder Brüel & Kjaer Type 2307, microphone Brüel & Kjaer Type 4166, measuring Tape 100mm and a ladder.

A power source (Type 4205) which was switched on was connected to a sound source (Type HP 1001) which was used to generate sounds of different frequency between 125Hz and 4000Hz depending on the settings. The sound that was generated by the sound source was picked or sensed by the microphone (Brüel & Kjaer Type 4166). The microphone was fixed on a stand 1.5 meters above the ground level and was connected to the amplifier (Brüel & Kjaer Type 2607). The amplifier was used to boost the sound picked or sensed by the microphone from the sound source which was then passed to the connected Graphic level recorder (Brüel & Kjaer Type 2307). When the pen drive and the paper drive of the Graphic Sound level recorder were switched on, loud sounds at octave band frequencies were obtained from the sound source. Also, the rectifier response for the writing speed and the paper speed were adjusted to values that would enable stable and smooth pen functioning.

Immediately the sound source was switched off, the decay level of the sound was recorded by the graphic level recorder. From the slope of this decay rate graph, the decay rate and the reverberation time at the different frequencies of the different enclosures were obtained when the enclosures were unoccupied. The experiment was repeated when the enclosures were occupied.

## 4. Results and Discussion

Reverberation time at octave band frequencies (125-4000Hz) of eight churches (all in Jos-South Local Government Area of Plateau State) of volume ranging from 1840 – 6718m3 and church occupation ranging from 113-388 people were determined when the churches were occupied and unoccupied. Table 1 shows the church's volume, occupation and reverberation time when the enclosures were occupied and unoccupied and Table 2 shows the calculated values of the average sound absorbed per person (using equation 6) at these octave band frequencies.

In all cases and for each enclosure, the reverberation time for all the occupied enclosure is shorter than the reverberation time for the unoccupied enclosure. Essentially, the reverberation time of an unoccupied enclosure increases with volume as is seen in the cases of church G, D, E, F, B,A, H and C. However, the trend becomes discontinuous because of the non-proportionality of the absorption in the enclosures. The additional absorption of sound by people in the church auditorium lowers the reverberation time in the otherwise empty or unoccupied church auditoria.

The average sound absorption per person at octave band frequencies of 125, 250, 500, 100, 2000 and 4000Hz were 0.29, 0.43, 0.51, 0.68, 071 and 0.73 respectively. This shows that the sound absorption per person within this frequency range increases with frequency. Obviously, the absorption per person obtained depends on the types of clothing worn by the people in the church auditoria. It is believed that the absorption per person would be influenced by spacing between people and temperature.

## 5. Conclusion

This study has been able to qualitatively and quantitatively determine sound absorption by an individual at octave band frequencies between 125-4000Hz by the use of Sabine's equation of reverberation time. These values could be used by architects, building engineers, room designers and acousticians in the determination of optimum reverberation time (from the design stage) for effective communication in enclosures of any type. However, this is an exploratory study and the values of the average sound absorption by an individual depend on the clothing of the members of the audience. It is believed that such values also depend on the spacing between the members of the audience and upon temperature.

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**Table 1: Reverberation Times of the Churches when occupied and when unoccupied**

| | | | | Reverberation Time at Octave Band frequencies when occupied and unoccupied | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Church** | **Situation** | **Volume** | **Occupation** | **125** | **250** | **500** | **1000** | **2000** | **4000** |
| **A** | Occupied | | | 1.70 | 1.74 | 1.84 | 1.72 | 1.50 | 1.34 |
| | Unoccupied | 5354.65 | 324 | 1.93 | 2.41 | 2.83 | 3.07 | 2.51 | 2.12 |
| **B** | Occupied | | | 1.13 | 1.84 | 1.92 | 1.75 | 1.63 | 1.35 |
| | Unoccupied | 4538.83 | 225 | 1.74 | 2.43 | 2.74 | 2.77 | 2.53 | 2.93 |
| **C** | Occupied | | | 2.59 | 2.62 | 2.51 | 2.07 | 1.64 | 1.55 |
| | Unoccupied | 6718.35 | 388 | 3.15 | 4.40 | 4.65 | 4.20 | 2.81 | 2.60 |
| **D** | Occupied | | | 2.31 | 2.02 | 2.18 | 2.09 | 1.93 | 1.64 |
| | Unoccupied | 2834.75 | 124 | 2.62 | 2.64 | 3.13 | 3.40 | 3.08 | 2.42 |
| **E** | Occupied | | | 2.40 | 2.02 | 1.99 | 1.79 | 1.75 | 1.68 |
| | Unoccupied | 3293.42 | 186 | 2.81 | 2.91 | 3.08 | 3.13 | 3.11 | 2.95 |
| **F** | Occupied | | | 2.82 | 2.77 | 2.74 | 2.54 | 2.36 | 2.15 |
| | Unoccupied | 4184.34 | 207 | 3.38 | 4.36 | 4.79 | 5.42 | 4.87 | 4.17 |
| **G** | Occupied | | | 1.73 | 1.80 | 1.83 | 1.82 | 1.57 | 1.38 |
| | Unoccupied | 1839.82 | 113 | 1.98 | 2.56 | 2.84 | 3.46 | 2.73 | 2.23 |
| **H** | Occupied | | | 2.60 | 2.26 | 2.22 | 1.99 | 2.04 | 1.45 |
| | Unoccupied | 5604.21 | 381 | 3.28 | 3.83 | 4.25 | 4.62 | 2.96 | 2.62 |

**Table 2: Average sound Absorption per person at Octave Band Frequencies**

| Frequency (Hz) | Average Sound Absorption per person |
|---|---|
| 125 | 0.29 |
| 250 | 0.43 |
| 500 | 0.51 |
| 1000 | 0.68 |
| 2000 | 0.71 |
| 4000 | 0.73 |