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VARIATION OF REVERBERATION TIME WITH QUANTITY OF ABSORBERS IN AN UNFURNISHED ROOM

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ABSTRACT

An experimental investigation of reverberation of sound at frequencies of 500 and 1000Hz in a room of 35.27m^3 has been carried out using B & K Type acoustic instruments. Varied amount of Celotex ceiling board was used as the sound absorber. The result showed that the reverberation time falls progressively with increasing number of the absorbers. This result was found consistent with those of other investigations measured under standard conditions. In this investigation, it was found that in small-sized rooms typical of those used for office accommodation, broadcasting and recording studios, reverberation time can be simply controlled to achieve desired results.

KEY WORDS: Reverberation time, Sound, Speech, Room, Absorber

1. INTRODUCTION

The quality of sound in any given enclosure is, to a major extent, determined by the reverberation time of the enclosure. Rooms used for different purposes have their desired reverberation times. In a room, the reverberant sound field tends to mask any subsequent sounds even after the source producing it has stopped (Gyang and Odoh, 2000). However, if the time between the first and second sound is long enough, the reverberant sound level decay by such an extent that no masking is observed.

The syllables of ordinary speech are a series of almost independent sources stopping and starting one after another. Where the reverberation time is long, the energy of one syllable can mask the direct energy of the next syllable sufficiently to interfere with intelligibility of the sound (McMillian, 1993, Urenyang, 2008).

Sounds generated in rooms like office accommodations, broadcasting and recording studios need be effectively controlled so that the desired intelligibility will be achieved. Since the reverberation time of any room among other factors depends much on the absorbent materials found in it, it becomes possible to enhance intelligibility by use of appropriate sound absorber. This work clearly presents a way of achieving the desired reverberant conditions required in certain rooms of interesting human activities particularly those specified above.

2. THEORY OF SOUND ABSORPTION IN ROOMS

In an enclosure - in a building say – the sound field produced by a source is not as simple as in the case of a source in a free- space. Wave theory, statistical and geometric (ray) methods are employed in the description of the resulting sound field (Meyer and Neumann, 1972). For an enclosure of finite dimension like a room, a radiated sound from a source is reflected whenever it strikes a bounding surface. The ray approach considers that the resulting sound field at any point is made up of partly sound radiated directly from the source and that partly arriving after many reflections (Purkis, 1966) from the bounding surfaces.

In rooms with walls or surfaces that are very reflecting and irregular in shape, reflection takes place in all directions thereby making the sound field effectively diffused. At any point there is no preferred direction in which sound is traveling (that is a homogeneous and isotropic field). The sound pressure level is therefore distributed uniformly throughout the volume of the room.

Reflection from each individual sound ray, no matter at which surface they take place, occur at an angle of incidence, which are uniformly distributed throughout all solid angles of the hemisphere. In a live room (a room where sound reflection can easily take place and persists for some time), the sound pressure and the corresponding intensity decrease with elapsed time at constant decay rate, D in decibel (db) per second (Kinsler and Frey, 1962) given by

$$D = \frac{1.087ac}{V} \qquad (1)$$

where a is the absorption power, c is the velocity of sound in air and V is the volume of the room. Using the definition of reverberation time, T, the time taken for the sound level in the room to decay to 60 dB, then

$$T = \frac{60}{D} = \frac{55.2V}{ac} \qquad (2)$$

If V is in cubic meter (m^3) and c = 343 ms^{-1} at a particular room temperature, then the reverberation time, T, is given by the Sabine formula (Sabine, 1964) as

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$$T = \frac{0.161V}{A} = \frac{KV}{A} \qquad (3)$$

where $A = \sum_{i=1}^{n} \alpha_i s_i$ is called the total absorption power of all surfaces in the room, α_i is the absorption coefficient of the *i*th surface, s_i is its area, *K* = 0.161, and *i* =1, 2,.., n, the total number of the exposed surfaces in the room. Equation (3) always gives a finite value of *T*.

Other reverberation time formulae are available in literature but one which considered in particular the cases of room geometry and amount of absorbent material in the room was that of (Arau-Puchades, 1988). His reverberation equation explained the result of sequential sound reflection occurring with preference to pairs of parallel walls and simultaneous sound reflections produced by adjacent walls. He gave his result of area weighted geometric mean T_w of the reverberation period in each of the directions considered (2) as

$$T_w = \frac{0.161V}{S\left[a_x^{(x/S)}.a_y^{(y/S)}.a_z^{(z/S)}\right]} \qquad (4)$$

where *S* and *V* are the total surface area and volume of the room respectively,

a_x = mean decay rate absorption coefficient in direction x:

$a_x = -\ln(1-\alpha_x)$;

a_y = mean decay rate absorption coefficient in direction y:

$a_y = -\ln(1-\alpha_y)$;

a_z = mean decay rate absorption coefficient in direction z:

$a_z = -\ln(1-\alpha_z)$.

α_x is the average energy absorptivity in x area; α_y is the average energy absorptivity in y area and α_z is the average energy absorptivity in z area. x = area of end walls, y = the area of side walls and z the area of ceiling and floor. Consequently, *S* = x + y + z.

Equation (4) above describes to a large extent the type of rooms found in broadcasting studios, recording studios and office apartment that this work focuses. Arau-Puchades equation along with that of Sabine was used to account for the reverberation time of the room size of interest.

As clearly seen from equations (3) and (4) the absorption of sound depends on the quantity of absorber and the area of its exposed surfaces. The effects of the edge and area of absorber on sound absorption have been shown by Chrisler (1934), Daniel (1963) and Bartel (1981). This explains that sharply defined edges along the length and breadth of the absorber contributes more to acoustic energy loss and consequently brings additional effect on the reverberation time of a room where they are found.

3. EXPERIMENTAL MEASUREMENTS

The experimental investigation was carried out in a rectangular room of volume 35.27 m^3; having two wooden doors and a louver – glass window. Both doors and window were shut when readings were being taken. This was to ensure that sound was not radiated outside the room. Open cell wood – fiber (celotex) ceiling board was used as the absorber material. This board is the same as soft particle board usually used as notice board in offices. It was made into sizes with each piece having an area of 7.07 m^2. The procedure of reading was done as explained by Kingsbury (1977), Gyang and Odoh (2000) in which sound was generated by a sound power source: B & K Type 4205. The sound was picked up by a B & K half – inch microphone placed about 1.5 m above the floor which was also connected to a measuring amplifier, B & K Type 2607. A level recorder, B & K Type 2307 connected to the amplifier received the sound decay and recorded it graphically after each sound was shut off. The reverberation time was then calculated from the decay curves obtained from the level recorder. This was done by first calculating the decay rate, D given by equations (1) and (2) which is actually the slope of the decay curve plotted by the level recorder. Accordingly, the reverberation time was calculated following equation (1).

The measurements were made in the room without any of the absorber specimen and then with increasing amounts of the absorber placed on the walls of the room. Table 1 shows the results of the measurements carried at frequencies of 500 and 1000 Hz respectively. These two frequencies were found to give good values that produced no resonances which could fraught the results. Apart from the absence of resonance, the choice of 500 Hz is for the reason of it been chosen as the optimum frequency for reverberation measurements, (BS. 3638 1987). It is expected that the result applies at other frequencies as the reverberation time of a room generally falls with increasing frequency of the sound.

The second part of the procedure involved the calculation of the reverberation time using the Sabine and Arau-Puchades formulae given in equations (3) and (4) respectively. The absorption coefficient, α of the specimen was calculated from the absorption power in equation (3). Spreadsheet software was used on a computer to facilitate the calculations. The values of the absorption coefficient α for the specimen and α_i for the various components of the room used were obtained from tables of standard measurement, (Blake and Mitchell, 1992).

4. RESULTS AND DISCUSSION

The results calculated at the two frequencies stated above for both Sabine and Arau-Puchades formulae respectively are given in Table 1. The measured reverberation times at the two frequencies are also presented in the same table. The plots of the reverberation time with quantity of absorber at frequency of 500Hz are given in Fig 1 for both the measured and calculated values while those at 1000Hz are given in Fig 2. In comparison, the reverberation times whether measured or calculated are lower at higher frequencies. This is consistent with theory that there is high acoustic energy loss due to the friction between the surface of the absorber and vibrating particles of the wave at higher frequencies (Kingsler and Frey, 1962).

Generally, the table and the plots in Figs 1 and 2 show that the reverberation times drop progressively with increasing amount of absorber (a result that had earlier been achieved by Chrisler, 1937; Daniel, 1963 - changing by about 29% and 25% (between Set-up 1 and 5) at 500 Hz and 1000 Hz respectively in the measured values - but to a non-zero value within the range of measurement. This shows an agreement between the measured values and calculated Sabine reverberation time as the Sabine formula always gives a finite reverberation time (Gyang and Odoh, 2000). At 500 Hz, the Sabine calculated reverberation time changed by 56%, while Arau-Puchades's calculated value changed by about 52% between when no absorber specimen was introduced into the room to when all the absorbers were placed on the walls. Under the same condition at 1000 Hz, the measured value changed by about 20%, the Sabine equation gave a change of about 61% while Arau-Puchades's equation changed by about 52%. Looking at the table it could be seen that depending on the amount of the absorber used in the room and the working frequency, the calculated reverberation times differed from the measured values reducing by about 9% to about 20% of the later.

From Table1, Set-up 4 and 5 in the Sabine formula gave the reverberation times as1.0 and 0.9 s respectively at 1 KHz. These values fall within recommended values of 0.75 to 1.0 s in speech rooms like law court, dramatic theatres, television studios and classrooms (Hall, 1987). The result also satisfied the recommended reverberation time of 1.0 s for living room and office accommodation. It was also observed that for a given absorber introduced into the room a far lower reverberation time was calculated for the Sabine formula than that of Arau-Purchades. This is in agreement with the fact that Sabine equation assumes a diffused field and not very applicable to a limiting case in which absorption coefficients of the surfaces boundaries of the room is unity (Kingsler and Frey, 1962; Gyang and Odoh, 2000) which logically will give a zero reverberation time.

Furthermore, the measured reverberation time was generally higher than the calculated. This should be expected as certain factors like improper excitation of acoustic modes in the room, the location of microphone and other factors of conditions which could not be avoided during reverberation measurement must certainly have contributed to the higher values.

CONCLUSION

The results showed that using certain quantity of absorbers in room used for certain purposes, the reverberation time could be closely monitored. Since the reverberation time falls with the quantity of absorber which agrees with literature given our earlier equations, acoustic problems like echoes, sound interference resulting from spherical surfaces and imbalance between direct and reverberant sound could be reduced drastically. Intelligibility and quality of sound desired in broadcast room, recording studio and office accommodation for certain purposes could be achieved using the appropriate absorbers in such places.

Table1: Measured and Calculated Reverberation Times using Celotex as Absorber

Set-up No.	Equivalent No of Absorbers Units used. Sizes 1.01m × 0.88 m	Positions and Actual sizes and Numbers of Absorbers Used	Measured Reverberation Times (s)		Calculated with Sabine Formula		Calculated with Arau-Puchades Formula	
			500 (Hz)	1000 (Hz)	500 (Hz)	1000 (Hz)	500 (Hz)	1000 (Hz)
1	0	None	2.1	2.0	2.5	2.3	2.5	2.3
2	4	1-Unit sizes 1 Unit on each wall	2.2	1.8	1.8	1.6	2.0	1.5
3	8	1-Units sizes 2 Units on each wall	1.9	1.6	1.5	1.3	1.8	1.6
4	12	1-Unit sizes 3 Units on each wall	1.7	1.5	1.2	1.0	1.6	1.4
5	16	1-Unit sizes 4 Units on each wall	1.5	1.5	1.1	0.9	1.2	1.1

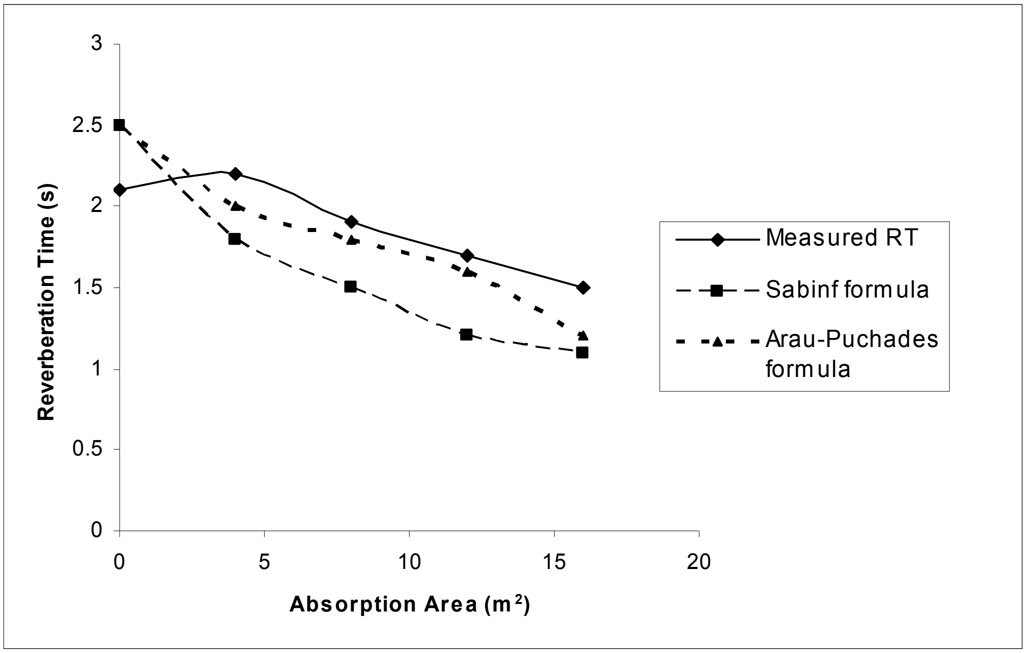

Fig. 1: The Variation of Reverberation Time with Absorption Area of Specimen at 500Hz. Measured reverberation time is given by the full curve, calculated reverberation time using Sabine formula is given by the broken curve while the dotted curve represents Arau-Puchades formula.

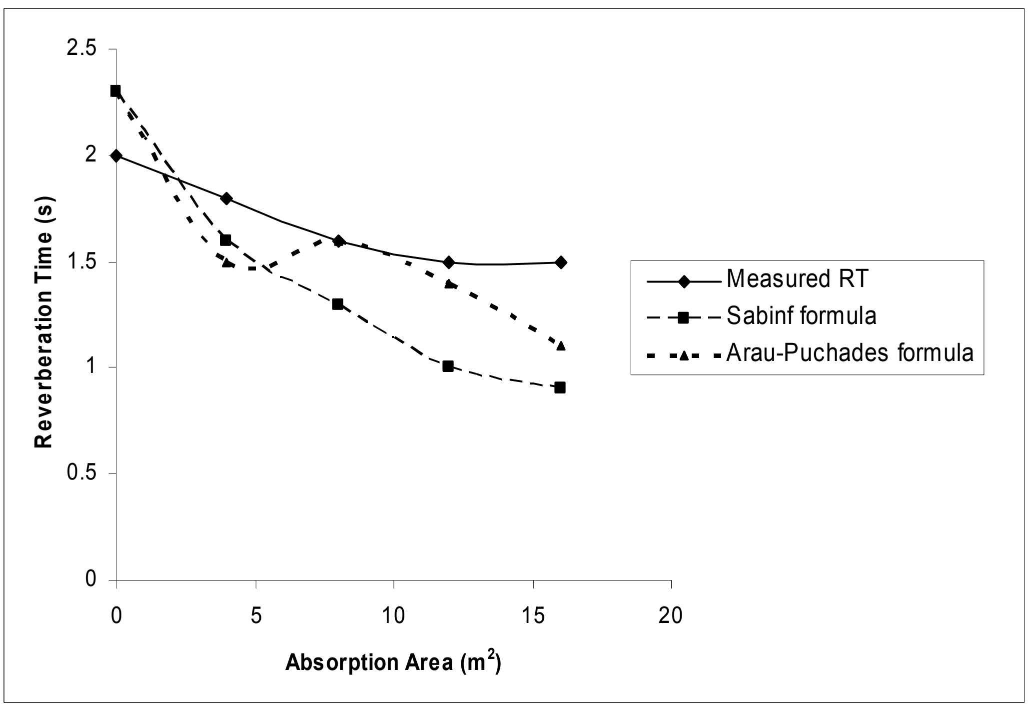

Fig. 2: The Variation of Reverberation Time with Absorption Area of Specimen at 1000Hz. Measured reverberation time is given by the full curve, calculated reverberation time using Sabine formula is given by the broken curve while the dotted curve represents Arau-Puchades formula.

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