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The average absorption coefficient for enclosed spaces with non uniformly distributed absorption

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Abstract

This study concerns the determination of an equivalent acoustic absorption model of the flat heterogeneous walls present in industrial rooms. Numerous measurements of the reverberation time in reverberant room were carried out for several facings with different distributed spatial absorption. Experimental results were compared to classical reverberation time models. The measurements showed that the change in average acoustic absorption depends on the relative distance between the sound source and the absorbent panels, as it is this which creates heterogeneity. Therefore, taking into consideration, in the theoretical models of average acoustic absorption studied, the solid angles representing the equivalent area of the panels as viewed by the source, improved the accuracy of the calculated reverberation time compared to the measurements. This equivalent acoustic absorption model, based on Sabine's absorption coefficient and employing the solid angle ratio, was used to calculate the reverberation time of several industrial rooms. The results obtained are better than those obtained with the standard formula.

Keywords: Acoustic adsorption; Reverberation time

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1. Introduction

This study concerns the acoustic characterization of industrial rooms. The National Institute of Research and Security (INRS) employs the *RAY+* software [1]

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to predict the sound levels in industrial rooms. This uses coefficients of acoustic absorption associated to every wall (or obstacle) of the rooms to determine exactly the degree of acoustic damping of the sound waves in a closed space. Industrial rooms often have heterogeneous walls (made up of several areas with different acoustic absorption capacities) with area irregularities. This study primarily concerns the acoustic characterization of the flat heterogenous walls present in workplaces. A geometric description of heterogeneity in the acoustic software is indeed often difficult to achieve because it requires a fine discretization of the walls, which in turn requires numerous measurements of the dimensions of the room. One way to solve this problem is to replace the heterogeneous wall by an equivalent homogeneous wall to which an average absorption coefficient is associated. The difficulty then lies in determining the acoustic absorption of the equivalent wall. The work presented here concerns the study and the improvement of techniques for determining an equivalent acoustic absorption of a heterogeneous facing.

This can be determined from the arithmetic average of the elementary absorption coefficients α_i of every elementary area S_i (Sabine's formula). To study the Sabine's formula validity, the influence of several heterogeneous areas on the reverberation time of several rooms was studied. The different theoretical reverberation time models, which depend on the average acoustic absorption of the room estimated by Sabine's formula, were compared with the measurements. Some of these models take into account the spatial distribution of the acoustic absorption in rooms by distinguishing the average acoustic absorption of the walls parallel to three principal axes of the room.

This article firstly reviews the principal theoretical reverberation time models, then goes on to compare these with measurements taken in a reverberant room for various wall area configurations. The variations in reverberation time observed experimentally led us to modify the average acoustic absorption calculation method. The variations in the reverberation times obtained with the new expression of the average acoustic absorption were compared with the experimental results measured in industrial rooms.

2. Reverberation time formulae

The reverberation is formed by a multitude of reflected sounds superposed without discontinuity that add to the direct sound and prolong it. The reverberation time (T_r) is defined as time required for the sound energy density to decay 60 dB after the source has stopped emitting. It depends on the acoustic and geometric characteristics of the walls which bound the space. There are methods to determine reverberation time based on the wave or geometrical theory [2]. This paragraph reviews the models based on statistical theory used in industry. For each formula, air absorption is ignored.

2.1. Sabine's formula

In diffuse sound field conditions, for a reverberant room with walls of a homogeneous geometrical and acoustic nature and for an omnidirectional source, Sabine

[3] defines the reverberation time according to the average absorption coefficient of the walls $\bar{\alpha}$ as :

$$T_{\mathrm{r}} = \frac{0.16.V}{S\bar{\alpha}} \tag{1}$$

V and S are the volume of the room and the total wall area, respectively.

$\bar{\alpha}$ is the arithmetic average of the area elements S_{i} associated with the absorption coefficient α_{i}:

$$\bar{\alpha} = \frac{1}{S}\sum_i S_i\alpha_i \tag{2}$$

$\bar{\alpha}$ is the absorption coefficient normally used by professionals. It is usual to find $\bar{\alpha}$ higher than 1 for certain absorbent materials.

2.2. Eyring's formula

The Eyring's formula [4,5] takes into account relatively high absorption coefficients, the reverberation time expression remains unchanged:

$$T_{\mathrm{r}} = \frac{0,16.V}{S\alpha_{\mathrm{Ey}}} \tag{3}$$

$$\alpha_{\mathrm{Ey}} = -\ln(1-\bar{\alpha}) \tag{4}$$

The limited development shows that for low absorptions, the Eyring's absorption coefficient is similar to that of Sabine:

$$\alpha_{\mathrm{Ey}} = -\ln(1-\bar{\alpha}) = \bar{\alpha} + \frac{\bar{\alpha}^2}{2} + \ldots + \frac{\bar{\alpha}^n}{n} \tag{5}$$

if $\bar{\alpha}$ is low then

$$\alpha_{\mathrm{Ey}} \approx \bar{\alpha} \tag{6}$$

2.3. Millington's formula

To treat the problem of $\bar{\alpha}$ higher than 1, Millington [6] suggests replacing $\bar{\alpha}$ by:

$$\alpha_{\mathrm{Mil}} = -\frac{1}{S}\sum_i S_i\ln(1-\alpha_i) \tag{7}$$

The reverberation time formula according to Millington becomes:

$$T_r = \frac{0.16.V}{S\alpha_{\mathrm{Mil}}} = \frac{0.16.V}{\sum_i S_i\ln\left(\frac{1}{1-\alpha_i}\right)} \tag{8}$$

This model presents a drawback when one of the areas is very absorbent because, in this case, the reverberation time is close to 0. To allow the Millington's formula to be used, Dance and Shield [7,8] propose a conversion graph decreasing the high values of the Sabine's absorption coefficient (Fig. 1).

2.4. Kuttruff's formula

Kuttruff [9,10] established a reverberation time formula for rooms with diffuse walls and for non-uniformly distributed absorption. He assumes that, for diffuse reflections, the walls of the room reflect the sound according to Lambert's law. He suggests correcting the Eyring's formula by introducing the variance γ^2 of the mean free path :

$$\alpha_{\mathrm{Kut}} = \alpha_{\mathrm{Ey}}.\left(1 - \frac{\gamma^2}{2}\alpha_{\mathrm{Ey}}\right) + \frac{\sum_i (1-\alpha_i).(\bar{\alpha}-\alpha_i).S_i^2}{S^2.(1-\bar{\alpha})^2} \tag{9}$$

$\gamma^2 \approx 0,4$ for rectangular rooms.

2.5. Arau-Puchades's formula

For rectangular rooms, Arau-Puchades [11] defines an average acoustic absorption based on the Eyring's model for every wall parallel to every direction of the space:

$$\alpha_{\mathrm{ArP}} = [-\ln(1-\alpha_x)]^{S_x/S} \times [-\ln(1-\alpha_y)]^{S_y/S} \times [-\ln(1-\alpha_z)]^{S_z/S} \tag{10}$$

$$\alpha_{\mathrm{ArP}} = [a_x]^{S_x/S} \times [a_y]^{S_y/S} \times [a_z]^{S_z/S} \tag{11}$$

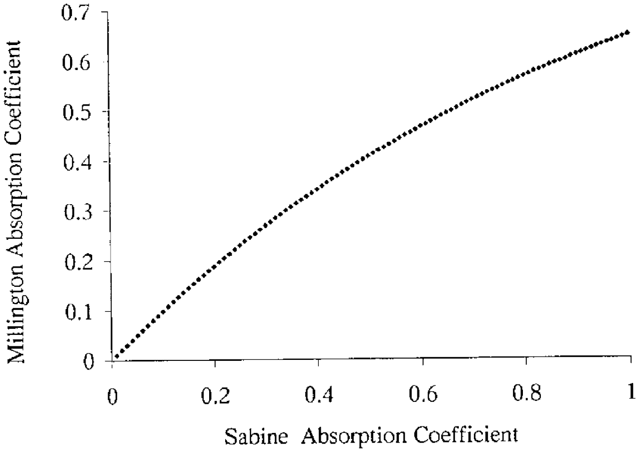


Fig. 1. The standard Millington absorption coefficient conversion graph.

where S_x, S_y, S_z are respectively, the areas of walls normal to the coordinate system x, y, and z. α_x, α_y, α_z are the average acoustic absorption coefficients of these walls.

The expression of the global acoustic absorption being the product of three terms representing the acoustic absorption for every direction, Arau-Puchades defines the reverberation time as follows:

$$T_r = \left[\frac{0.16.V}{-S\ln(1-\alpha_x)}\right]^{S_x/S} \times \left[\frac{0.16.V}{-S\ln(1-\alpha_y)}\right]^{S_y/S} \times \left[\frac{0,16.V}{-S\ln(1-\alpha_z)}\right]^{S_z/S} \tag{12}$$

$$T_r = \frac{0.16.V}{S[a_x]^{S_x/S}.\left[a_y\right]^{S_y/S}.[a_z]^{S_z/S}} \tag{13}$$

Hence, the total acoustic energy decreases according to three exponential functions:

$$E(t) = E_o \times e^{-N_x a_x.t} \times e^{-N_y a_y.t} \times \mathrm{e}^{-N_z a_z.t} \tag{14}$$

N_x, N_y and N_z are the probability of having a sound reflection on walls parallel to direction x, y or z respectively.

2.6. Fitzroy's formula

This is used for rectangular rooms whose opposite walls have similar absorption coefficients [12]:

$$T_r = 0.16\frac{V}{S^2}\left[\frac{-S_x}{\ln(1-\alpha_x)} + \frac{-S_y}{\ln(1-\alpha_y)} + \frac{-S_z}{\ln(1-\alpha_z)}\right] \tag{15}$$

The acoustic absorption model used in this formula is the Eyring's model, as for the Arau-Puchades's formula. Recently, R.O. Neubauer [13] proposed a modified Fitzroy's formula that takes into account the non-uniformity of the absorption of parallel walls. The absorption model used in this new formula is based on Kuttruff's model :

$$\alpha^* \approx \alpha_{Ey}. + \frac{\sum_i (1-\alpha_i).(\bar{\alpha}-\alpha_i).S_i^2}{S^2.(1-\bar{\alpha})^2} \tag{16}$$

The reverberation time expression becomes:

$$T_\mathrm{r} = 0.16\frac{V}{S^2}\left[\frac{S_x}{\alpha_x^*} + \frac{S_y + S_z}{\alpha_{y,z}^*}\right] \tag{17}$$

α_x^* represents the acoustic absorption of walls parallel to the x axis and $\alpha_{y,z}^*$ that of walls parallel to the y and z axes.

2.7. Pujolle's formula

The mean free path l_{m} which represents the average distance crossed by a wave between two reflections, appears in most of the reverberation time models:

$$l_{\mathrm{m}} = \frac{4V}{S} \tag{18}$$

All the previously mentioned models can be expressed in terms of mean free path [Eq. (18)] and of their respective average acoustic absorption coefficient α:

$$T_r = \frac{0,04.l_m}{\alpha} \tag{19}$$

Pujolle [14–16] introduced a new formula for l_{m} that takes into account the dimensions of the rooms. Pujolle firstly proposes:

$$l_{\mathrm{m}} = \frac{1}{6} \times \left(\sqrt{L^2 + l^2} + \sqrt{L^2 + h^2} + \sqrt{h^2 + l^2} \right) \tag{20}$$

and,

$$l_{\mathrm{m}} = \frac{1}{\sqrt{\pi}} \times \left(L^2.l^2 + L^2.h^2 + h^2.l^2 \right)^{1/4} \tag{21}$$

where L, h and l are respectively, the length, the height and the width of the rooms.

The relation (21) seems appropriate because it results directly from the guided propagation in rectangular ducts.

The reverberation time according to Pujolle is:

$$T_{\mathrm{r}} = \frac{0.04.l_{\mathrm{m}}}{\alpha_{\mathrm{Ey}}} = \frac{0.04.l_{\mathrm{m}}}{-\ln(1 - \bar{\alpha})} \tag{22}$$

3. Study of the average absorption coefficient of diverse facings in reverberant room

To study the influence of heterogeneous areas on the average acoustic absorption, the reverberation times were measured in a reverberant room for several heterogeneous areas. The experimental results were compared with the theoretical reverberation time calculated using the models decribed in the previous paragraph.

The absorbent panels used to create heterogeneous facings are the following:

- glass wool panels, 100 mm thick and 1.26 m×1 m in size.
- glass wool panels, 100 mm thick and 1.95 m×0.65 m in size.

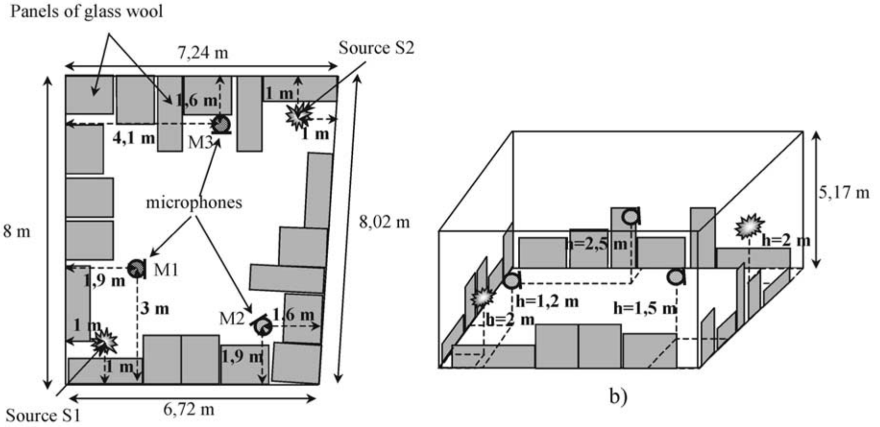
The acoustic absorption coefficients of these panels were measured independently with an experimental system using the free field method developped by Allard [17].

This technique allows to determine the acoustic impedance of a porous material using the transfert function between two microphones placed above the studied sample of several square meters. The acoustic absorption coefficient is deduced from the measured acoustic impedance. These panels have coeffcients relatively constant and close to 0.9 in the frequency range 500–4000 Hz. In the reverberant room, the concrete walls were very reflective, the difference between both absorption coefficients creates the heterogeneity.

Both facings studied were made up of 19 glass wool panels, placed flat on the floor around the walls (facing no. 1, see Fig. 2a) or up in periphery on the four walls of the reverberant room (facing no. 2, see Fig. 2b). For these two facings, the same panels area (24 m^2) is arranged differently in relation to the position of both sources to vary the spatial acoustic absorption distribution.

Sources S1 and S2 are explosions emitted successively by a 9 mm blank pistol. The dimensions of the reverberant room, the position of both sources and three receivers (see Fig. 2) verify the requirements fixed by the referenced norm [18]. First, reverberation time was estimated from the decay of the acoustic energy obtained at every measurement point (at the three omnidirectional microphones M1, M2 and M3). It was accurately determinated from the linear decay included 10 dB below the maximal sound level and 10 dB above background noise. The dynamic of this linear decay was about 30 dB. The measured reverberation times reported finally here are given as the three positions averaged values.

For both sources, the relative sound source—absorbent panels position varies for the same facing. The experimental results obtained for the two source positions and the two facing configurations are presented in third octave bands in Fig. 3. The experimental values of T_r vary according to the relative sound source–panels position and according to the position of panels on walls. It can therefore be seen that the acoustic attenuation provided by a heterogenous area varies according to its position in the room in relation to the source [19].



a) b)

Fig. 2. Glass wool panels arranged in the reverberant room: (a) Facing no. 1, (b) Facing no. 2.

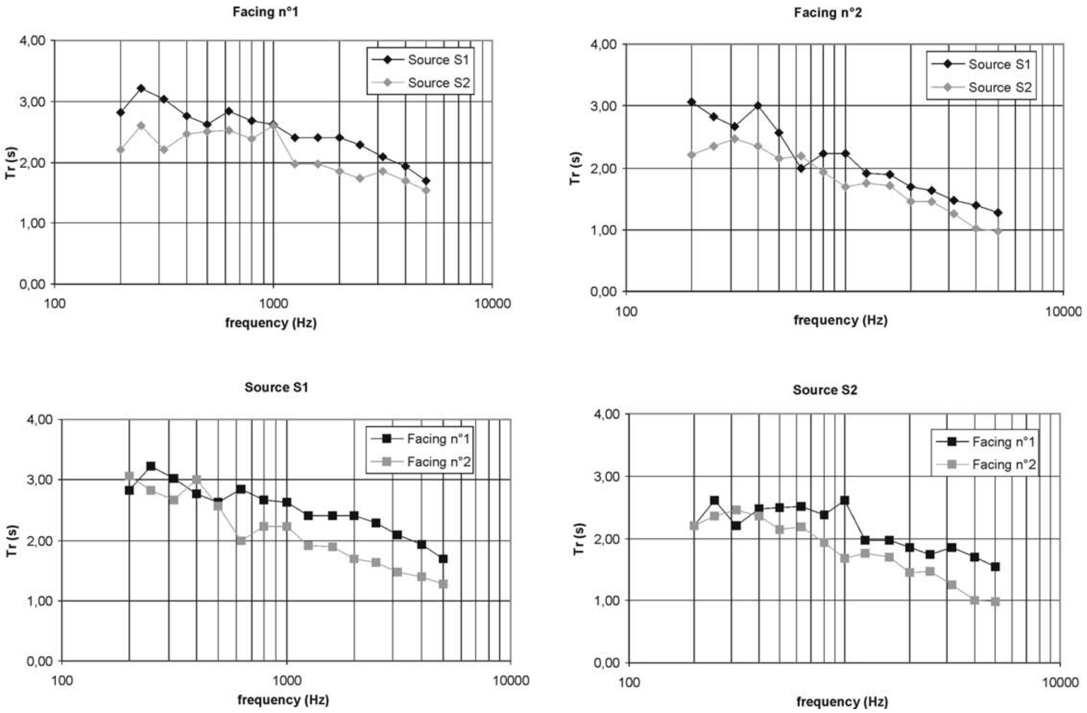


Fig. 3. Experimental reverberation time for the facings nos. 1 and 2 and for each source.

The reverberation times determined by the theoretical models were compared with those obtained experimentally. Fig. 4 presents the reverberation times relative error between the experiment and the theory for the two sources and the two facings configurations:

$$E(\%) = \frac{|T_{\mathrm{exp}} - T_{\mathrm{théo}}|}{T_{\mathrm{exp}}} \times 100 \tag{23}$$

It would appear from Fig. 4 that the theoretical T_{r} models are different from the experimental values. The maximal relative error is between 40 and 60%. Globally, the theoretical change in T_{r} with frequency is respected. The Arau-Puchades's model, which is adapted to non-uniformly distributed absorption, is the closest to the experimental results (maximal relative error $<20\%$). The other theoretical T_{r} models depend on the average acoustic absorption coefficient of the room which does not take into account the distribution of the absorbent panels on the walls and the source positions S1 and S2. For these models, the area acoustic absorption is constant for the facings no. 1 and no. 2. So, these models do not predict the reverberation time variation observed between the two different facings and the two source positions. The predicted reverberation time obtained with classical models are always lower than experiment. When absorbent panels are placed in the reverberant room, the diffuse sound field conditions are not respected and the average acoustic absorption coefficient is not correctly estimated by the standard models. The average acoustic absorption formula which uses area ratio must be improved.

Fig. 3 shows that the position of both the source and the panels has an impact on reverbation time. The relative position of the sound source and absorbent panels must therefore be taken into account in the theoretical T_{r} model.

4. New formula of the average acoustic absorption

A geometric parameter which can take into account the position of every absorbent panel referred to the source position, is the solid angle Ω. It is defined at the point source and contains all the sound beams coming from the source and directly absorbed by the panel. It represents the equivalent area of absorbent panels covered by the sound source (Fig. 5).

The solid angle is defined as follows:

$$\Omega = \iint_S \frac{\vec{\mathrm{OM}}}{\mathrm{OM}^3}.d\vec{\sigma} = \iint_S \frac{\cos\theta.d\sigma}{r^2} \tag{24}$$

$d\sigma$ is the area element around the point M, O the source position and θ the angle between the normal to the area S and the vector $\vec{\mathrm{OM}}$. The integral applies to the entire area S of the material to determine the solid angle Ω.

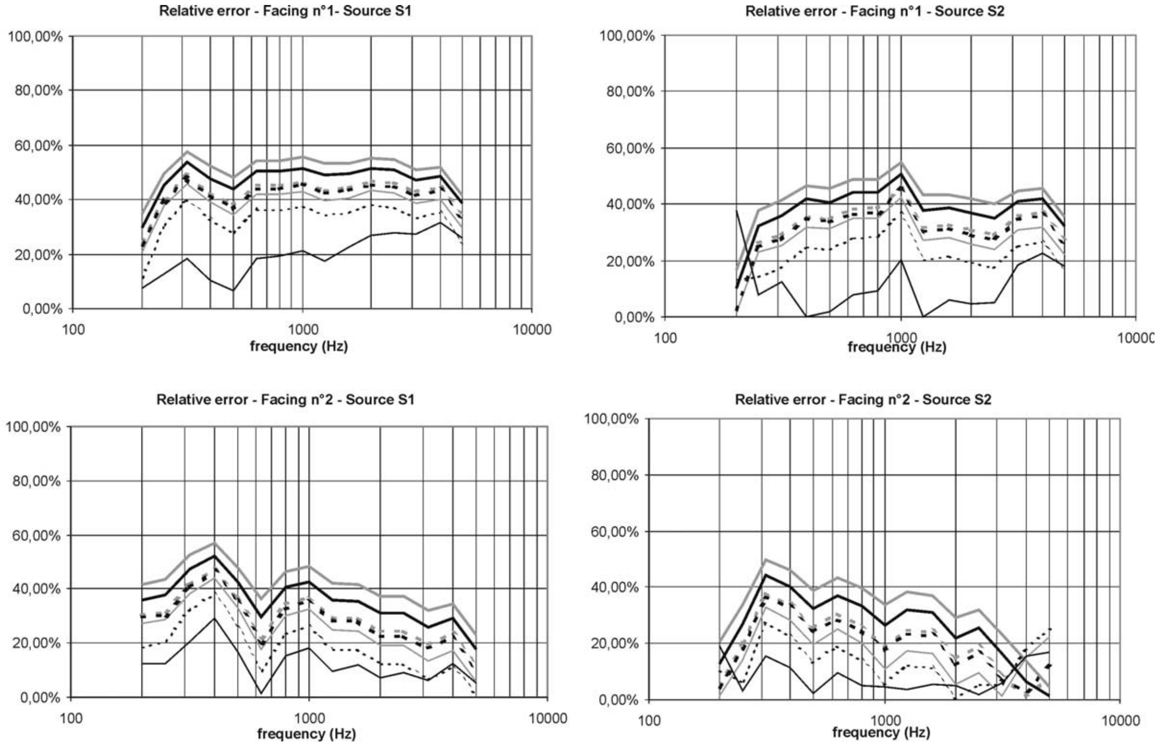


Fig. 4. Reverberation time relative error between the experiments and analytical predictions for facings nos. 1 and 2 and for each source: — Sabine's model; ▬ ▬ Eyring's model; ▬ ▬ Millington's model ; - - Pujolle's model; ▬ Kuttruff's model; — Arau Puchades's model; ▬ Fitzroy's model.

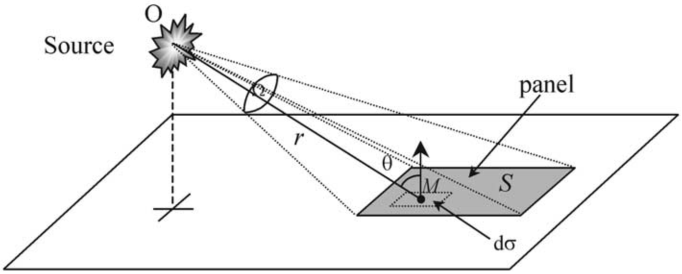


Fig. 5. Illustration of the solid angle.

Let us now replace the area ratio by the solid angle ratio in the theoretical standard acoustic absorption formulae (Fig. 6). By taking into account the solid angle ratio, the models of Sabine, Eyring, Millington, Kuttruff, Pujolle, Arau-Puchades and Fitzroy become:

Sabine:

$$\bar{\alpha}' = \frac{1}{\Omega_{\text{tot}}} \sum_i \Omega_i \alpha_i \tag{25}$$

Eyring:

$$\bar{\alpha}'_{\text{Ey}} = -\ln(1 - \bar{\alpha}') \tag{26}$$

Millington:

$$\bar{\alpha}'_{\text{Mil}} = -\frac{1}{\Omega_{\text{tot}}} \sum_i \Omega_i \ln(1 - \alpha_i) \tag{27}$$

Kuttruff:

$$\bar{\alpha}'_{\text{Kut}} = \bar{\alpha}'_{\text{Ey}} \left(1 - \frac{\gamma^2}{2} \bar{\alpha}'_{\text{Ey}}.\right) + \frac{\sum_i (1 - \alpha_i).(\bar{\alpha}' - \alpha_i)\Omega_i^2}{\Omega_{\text{tot}}^2.(1 - \bar{\alpha}')^2} \tag{28}$$

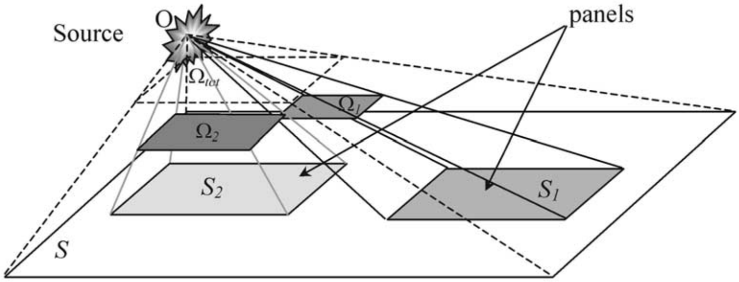


Fig. 6. Illustration of the solid angles ratio.

Pujolle:

$$\bar{\alpha}'_{\mathrm{Puj}} = \bar{\alpha}'_{\mathrm{Ey}} = -\ln(1 - \bar{\alpha}') \tag{29}$$

Arau-Puchades:

$$\bar{\alpha}'_{\mathrm{ArP}} = \left[-\ln\left(1 - \bar{\alpha}'_x\right)\right]^{S_x/S_{\mathrm{tot}}} \times \left[-\ln\left(1 - \bar{\alpha}'_y\right)\right]^{S_y/S_{\mathrm{tot}}} \times \left[-\ln\left(1 - \bar{\alpha}'_z\right)\right]^{S_z/S_{\mathrm{tot}}} \tag{30}$$

with

$$\bar{\alpha}'_x = \frac{1}{\Omega_x}\sum_i \Omega_i \alpha_i,$$

$$\bar{\alpha}'_y = \frac{1}{\Omega_y}\sum_i \Omega_i \alpha_i,$$

$$\bar{\alpha}'_z = \frac{1}{\Omega_z}\sum_i \Omega_i \alpha_i$$

Fitzroy:

$$\bar{\alpha}'^{*} \approx \bar{\alpha}'_{\mathrm{Ey}}. + \frac{\sum_i (1 - \alpha_i).(\bar{\alpha}' - \alpha_i).\Omega_i^2}{\Omega_{\mathrm{tot}}^2.(1 - \bar{\alpha}')^2} \tag{31}$$

where Ω_i is the ist area solid angle, Ω_{tot} is the room total solid angle, and Ω_x, Ω_{y} and Ω_z, are the solid angles of the walls parallel to axes x, y and z respectively.

Fig. 7 shows the relative errors [Eq. (23)] obtained for the facing configurations no. 1 and no. 2 and for both sources between the experiment and the theoretical reverberation time models. These theoretical models are all improved by taking the solid angle ratio into consideration. The maximal relative error is now about 40% over the entire spectrum examined. It is lower than the maximal relative error obtained with the unmodified theoretical T_{r} models (see Fig. 4).

For the facings studied, taking the solid angle ratio into account in the different acoustic absorption expressions contained in every model improved the accuracy of the theoretical reverberation time compared to the experiment.

In the examples chosen, the absorbent panels are placed close to the source. The sound field is highly influenced by the first reflections on these panels. The solid angle, which represents the total equivalent area of panels covered by the source, also becomes higher. The hypothesis of spatial homogeneity of absorption is no longer respected, and the standard reverberation time model of Sabine no longer valid. Taking into consideration the solid angle ratio therefore allows correction of the acoustic average absorption of the room and improvement of the reverberation time prediction.

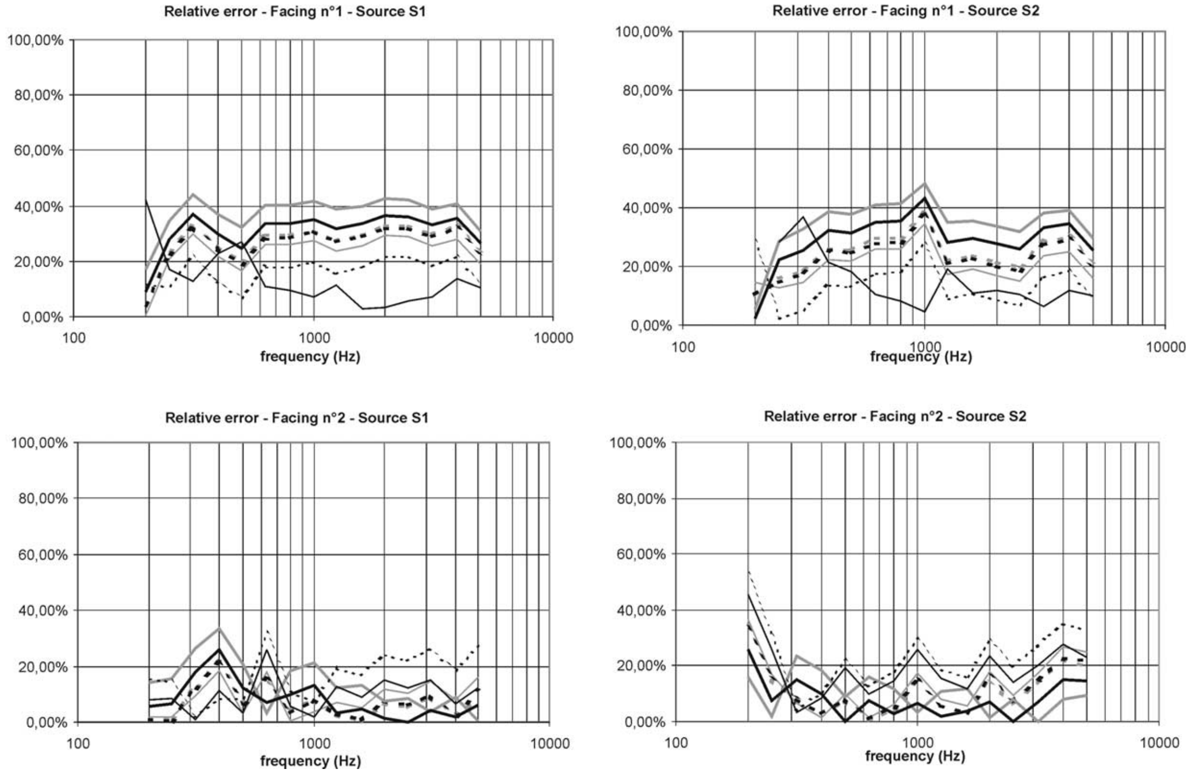


Fig. 7. Reverberation time relative error between the experiments and analytical predictions for facings nos. 1 and 2 and for each source: — Sabine's model; ‒ ‒ Eyring's model; ▬ ▬ Millington's model ; - - Pujolle's model; ▬ Kuttruff's model; — Arau Puchades's model; ▬▬ Fitzroy's model.

5. Validation in two industrial rooms of the reverberation time models modified by including the solid angles

One of the rooms studied was a large-size industrial workplace, and the other was a small, furnished conference room. The geometric characteristics of these rooms are provided in Figs. 8 and 9, respectively.

- Room no. 1: the four facades were built of painted bricks with partitions of sheet metal placed above. The windows panes, wooden doors, both sliding doors as well as a door opening towards the outside, constituted four heterogeneous facades. The floor was made of concrete and the

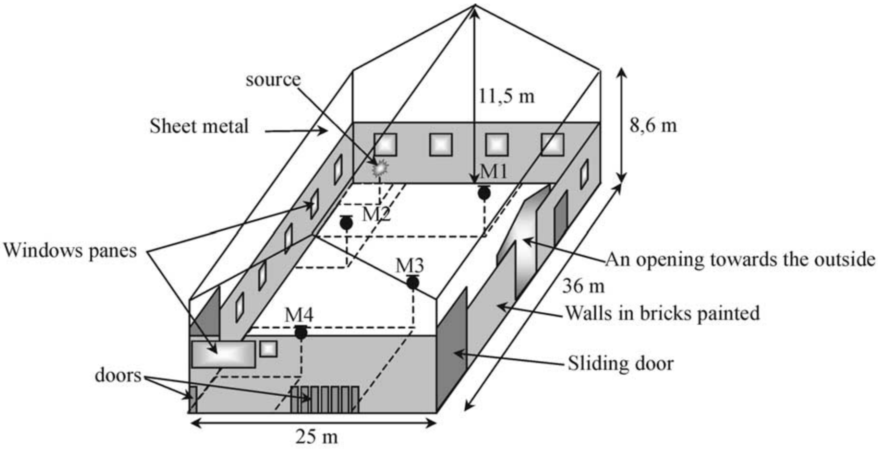


Fig. 8. Room no. 1.

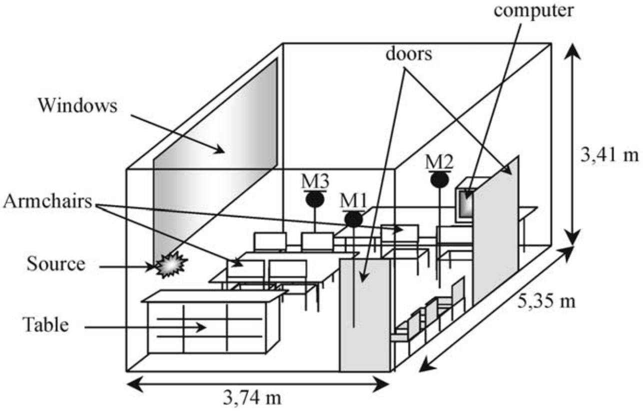


Fig. 9. Room no. 2.

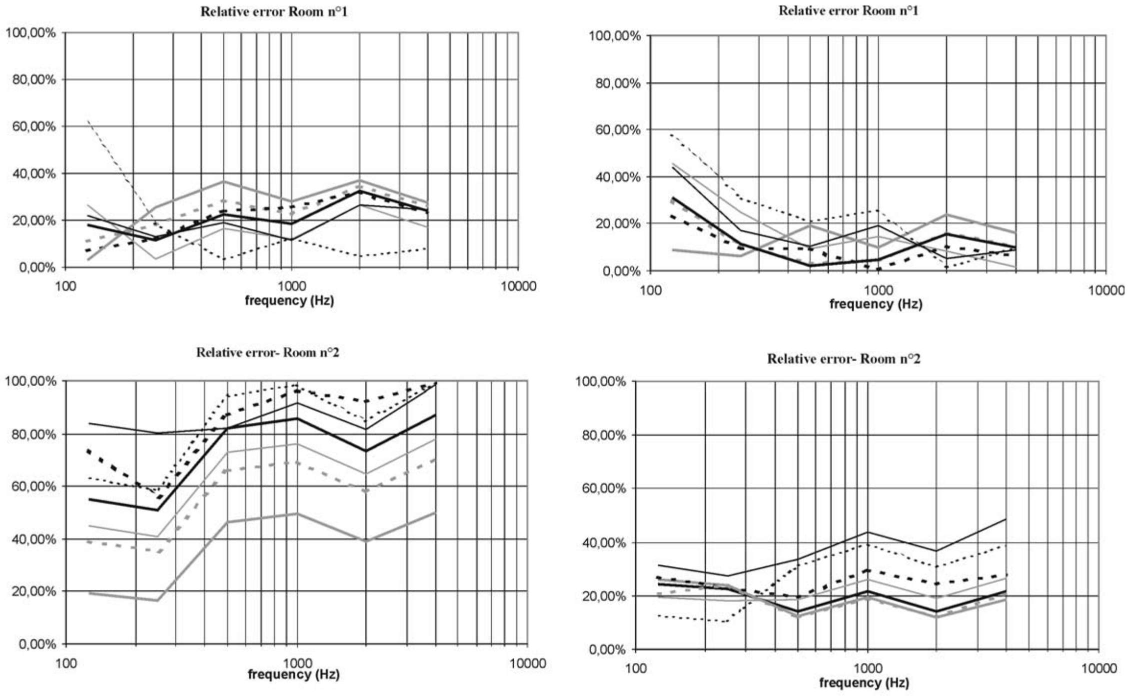
ceiling was composed of absorbent panels of glass wool covered with a protection film of aluminium. The source was an explosion emitted by a 9 mm blank pistol at a height of 2 m. Four microphones M1, M2, M3 and M4 placed along the entire length of the room were situated at a height of 1.2 m.

- Room no. 2: Three of the four wall facades were constructed of painted bricks and the fourth concrete. The big window as well as both doors give the heterogeneity of these facades. The room was furnished with three tables, several armchairs and a computer. The floor was covered with a plastic cover whereas the ceiling comprised a layer of plaster.

The source was an explosion emitted by a 9 mm blank pistol a height of 1.4 m. Three microphones M1, M2 and M3 were located at a height of 1.7 m, 1.7 m and 1.25 m respectively.

The graphs of Fig. 10 show the reverberation time relative error between the experiment and theoretical predictions for the two rooms in octave bands. The theoretical models are at first, unchanged then, modified and by considering solid angle.

- Concerning room no. 1, unmodified models originally gave theoretical reverberation times close to those obtained experimentally. This was a relatively large room and most of the facade walls were reflective (concrete, brick-built wall, sheet metal, etc.), with the exception of the ceiling which was covered with panels of glass wool. This made room no. 1 sufficiently reverberating, and in these conditions, the Sabine's model and the other models deriving from it could be applied and gave good results. The Pujolle's model adapted to industrial buildings, without modification, also gave acceptable reverberation times compared to the experiment. The calculation of the mean free path was approximate because the room was not a parallelepiped. Taking the solid angle into account in every model gave a better calculation accuracy. The relative error defined by Eq. (23) decreased about 10%.
- Room no. 2 was small and in spite of the presence of reflective walls, the reverberation time was short. However, it should be noted that the furniture influenced the sound field and reduced T_r considerably. Reverberation time models based on the assumption of diffuse field are less applicable here, the theoretical results obtained without modification by the solid angles being very different from the experimental results (relative error contained between 20 and 100%). Taking into consideration the solid angles in these models gave a better prediction of T_r, the relative error is contained between 10 and 45%. The sound field was strongly influenced by the first reflections on the walls. The representative solid angle of the zone directly covered by the source improves the time reverberation prediction as it takes into account the first echoes, especially if the room is small, as is the case with room no. 2.



Results with unmodified models

Results with modified models

Fig. 10. Reverberation time relative error between the experiments and analytical predictions for rooms nos. 1 and 2: — Sabine's model; ▬ ▬ Eyring's model; ▬ ▬ Millington's model ; - - Pujolle's model; ▬ Kuttruff's model; — Arau Puchades's model; ▬▬ Fitzroy's model.

6. Conclusion

This work concerns the acoustic characterization of the flat heterogenous walls present in workplaces. More particulary, it has allowed to study and to improve the techniques for determining an equivalent acoustic absorption of a heterogeneous facing. First, this study allowed us to quantify the influence on reverberation time of spatial non-uniformity of acoustic absorption in an industrial room. To achieve this, many measurements of the reverberation time in a reverberant room were carried out. Absorbent panels were placed in different positions in the reverberant room to create heterogeneity. In theory, T_r is related to the equivalent acoustic absorption, and the different existing theoretical models were studied and compared. A difference in experimental reverberation time due to the spatial non-uniformity of absorption, and to the relative position of the sound source and panels, was observed. Hence, taking into consideration the source position in relation to the position of the absorbent panels in the calculation of the average absorption of the room seemed necessary to us. A geometric variable answering this requirement is the solid angle. We thus replaced the area ratio by the solid angle ratio in all the standard average acoustic absorption formulae. The reverberation time obtained with the analyticals modified formulae were closer to the experiment than those given by the standard formulae.

The study showed that the sound field is always influenced by the relative positions of the sound source and panels. As the reverberation time is conditioned by the first reflections on the walls, if the absorbant material is close to the source, the standard Sabine's model can no longer be used, and it must be modified by taking into account the solid angles. During a study carried out by INRS in 2001, it was demonstrated that when the material is placed far from the source, models including the solid angle are no longer appropriate:the area ratio must be again considered [19].

The possibility of replacing a heterogeneous facing by an equivalent homogeneous one was also studied during the study conducted by INRS [19]. The solid angles were therefore taken into consideration in the equivalent acoustic absorption model. We simulated the acoustic pressure field with the $RAY+$ software for an industrial room in the case where one of the walls was heterogeneous, and then in the case where the heterogeneous wall was replaced by an equivalent homogeneous wall. The results showed that the simulated acoustic pressure fields are similar especially if the heterogeneity is close to source position.

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