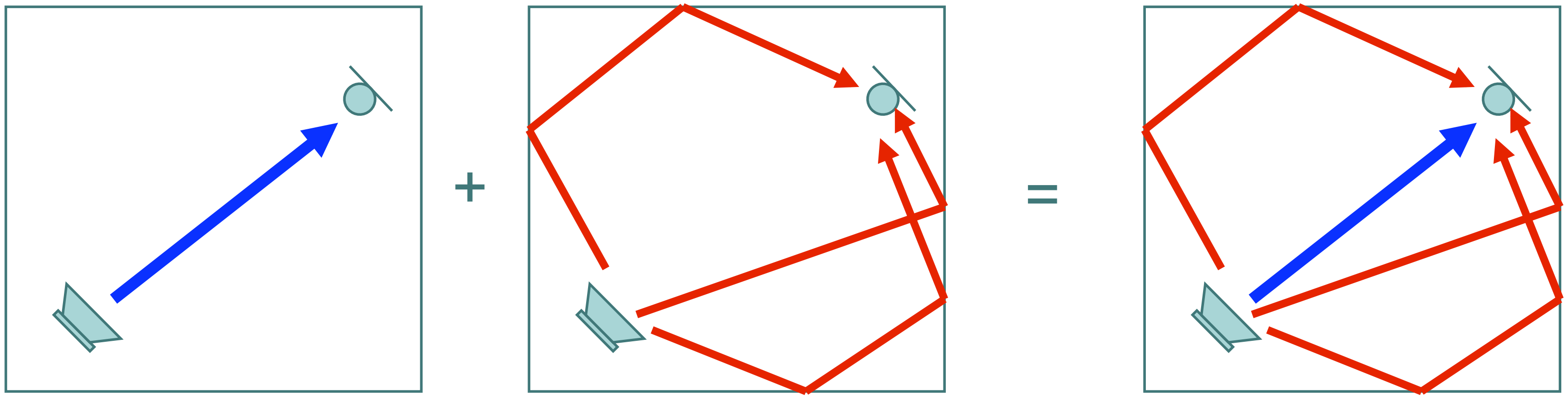
Room acoustics

Nicolas REMY

1-Positionnement du problème

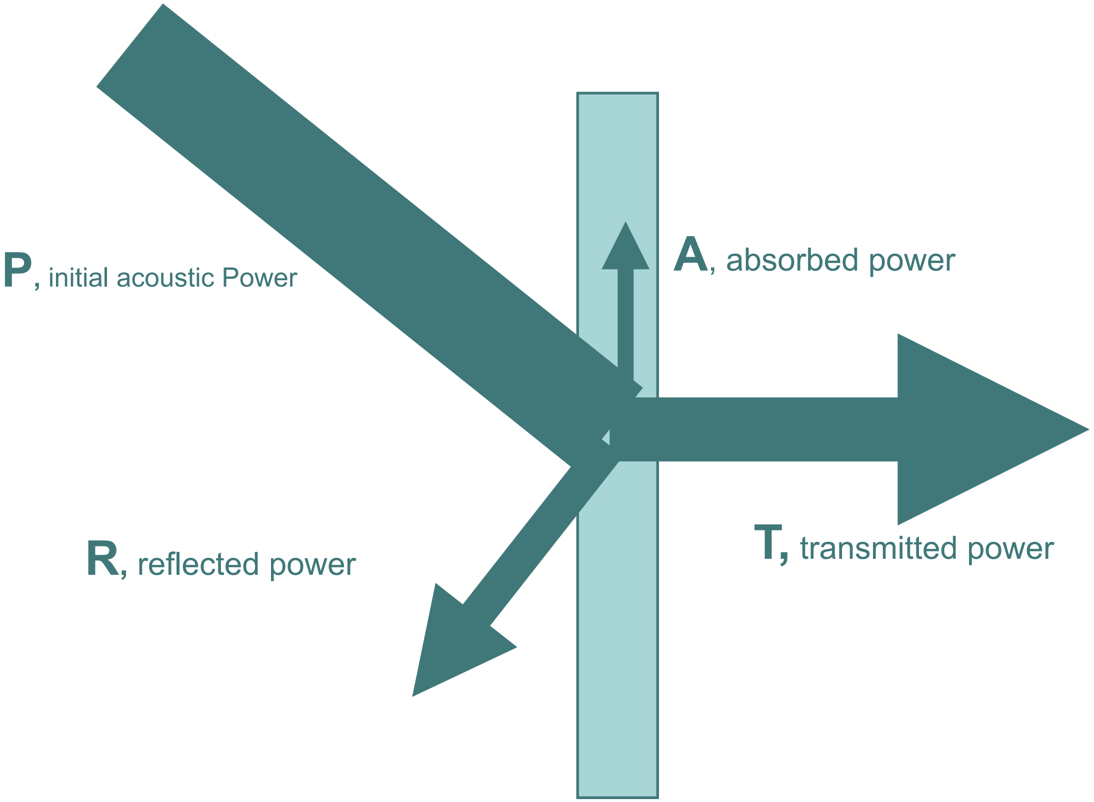
Room acoustic laws can be modelised easily : acoustic field in room is the sum a direct field and a diffuse field.



Direct field | **Diffuse field (reflexions)** | **Propagation in a room**

Free field propagation law → $Lp = Lw + 10\log\frac{Q}{4\pi d^2}$ en dB(A)

3- Acoustic behaviours of a panel in front an acoustic wave



$$P = A + T + R$$

$$\frac{P}{P} = \frac{A}{P} + \frac{T}{P} + \frac{R}{P}$$

$$1 = \alpha + \tau + \rho$$

avec :

. α, absorption factor or **alpha Sabine**

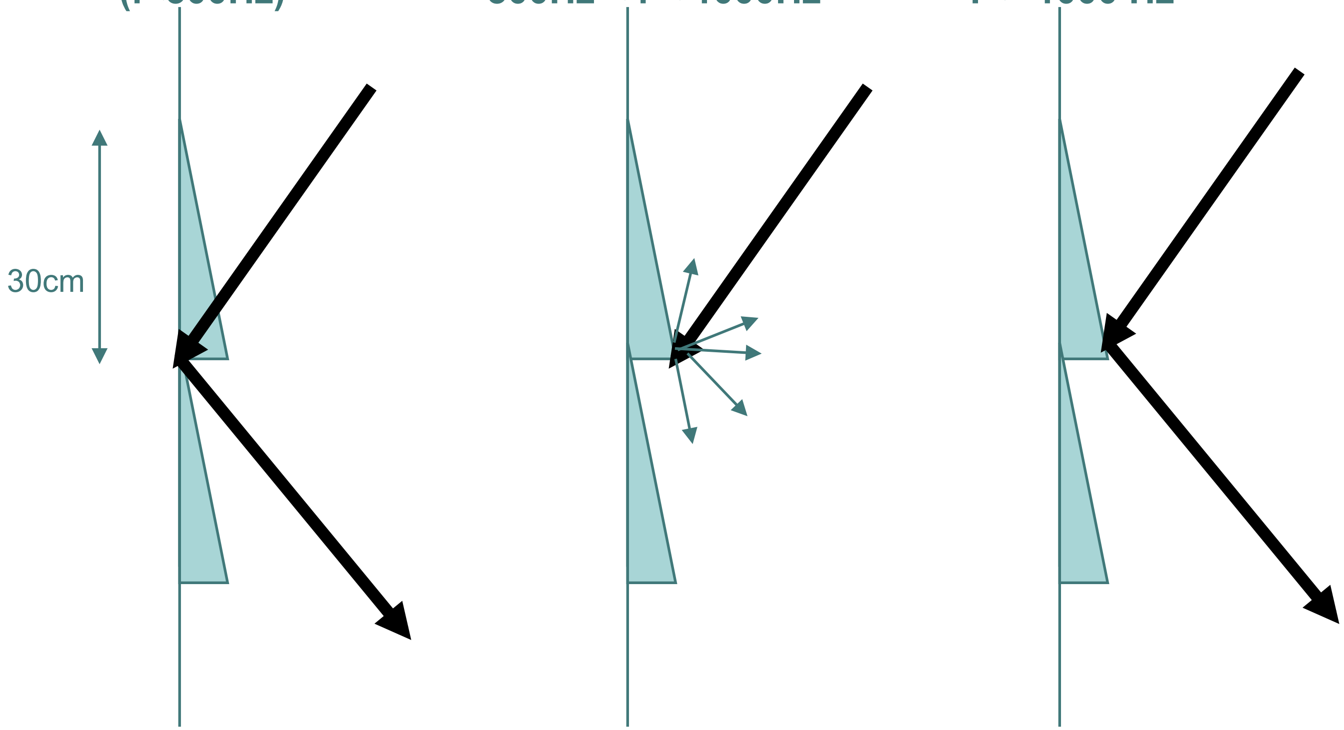
. τ, transmission factor

. ρ, reflexion factor

This equation is anycase the same but, depending of the wavelenght, the ratio between α, τ and ρ will change

3.1- Reflexion

BASS (f<300Hz) | **MEDIUM 300Hz < f < 1000Hz** | **TREBBLE F > 1000 Hz**



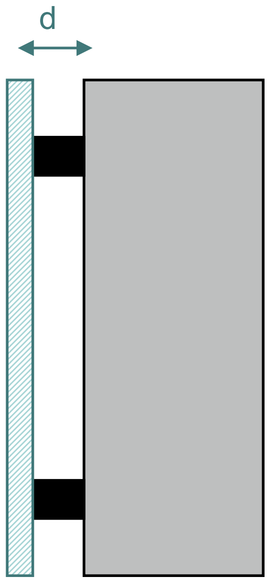
Specular reflexion
λ >>object dimension

Diffuse reflexion – Lamber Law
λ ≈ object dimension

Specular reflexion
λ << object dimension

3.2- Absorption

• ***Panel effect***: bass absorption(< 300Hz)
Panel and air mass behind the panel start to vibrate. Panel + air I enough heavy to transform acoustic power in oscillation of the panel (absorption)



The resonance frequency of a panel with mass expressed as ρ_s with kg/m^2 and located at the distance *d* from the the wall is:

$$f_0 = \frac{60}{\sqrt{\rho_s d}}$$

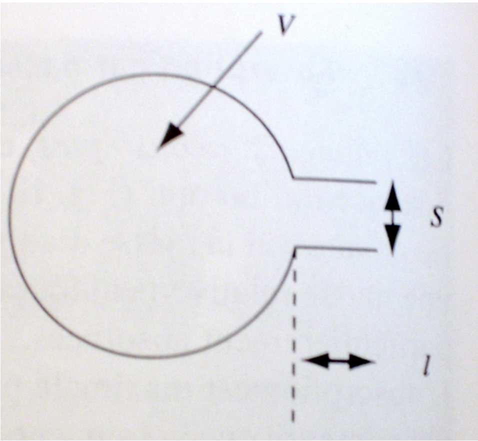
Exemple :
Wooden panel with ρ_s = 5kg/m^2 located at à 8cm from the wall
f_0 = 95 Hz

3.2- Absorption

•***Helmholtz's resonators*** : medium absorption (300Hz < f < 1000 Hz)
The resonator is made of a neck and a cavity. Acoustic energy makes vibrate the resonator (acoustic absorption). A fraction of acoustic energy is transformed in heat by dissipation on the walls of the neck

Resonance frequency can be found with :

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\gamma . P_0 . S}{\rho_0 . l . V}}$$

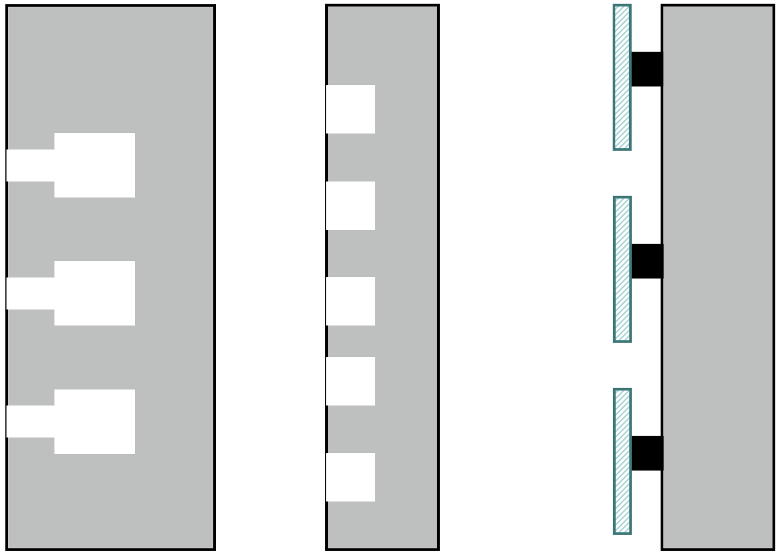


avec,
S, neck area,
l, neck lenght
P_0, atmospheric pression(P_0 = 1,013.105 Pa)
V, cavity volume(m^3)
ρ_0, volumic mass of the air (ρ_0 = 1,2 Kg/m3 at 20°C)
γ, thermodynanmic constant (γ = 1,4)

R- if the neck is short by its diameter (close dimensions), it is necessary to take into account the correction of end: one replaces in the preceding formula **l, by l+0,8d** (with **d**, diameter of the neck).

3.2- Absorption

•***Helmholtz's resonators*** : medium absorption (300Hz < f < 1000 Hz)
In practice
- the resonators can be constituted by cavities of various sizes (to absorb a larger frequency band).
- the neck (of the resonator) is not essential (hollow bricks for ex.)



3.2- Le cas de l’absorption

•***Helmholtz’s resonators*** : medium absorption (300Hz < f < 1000 Hz)
Acoustic vases in antic theaters

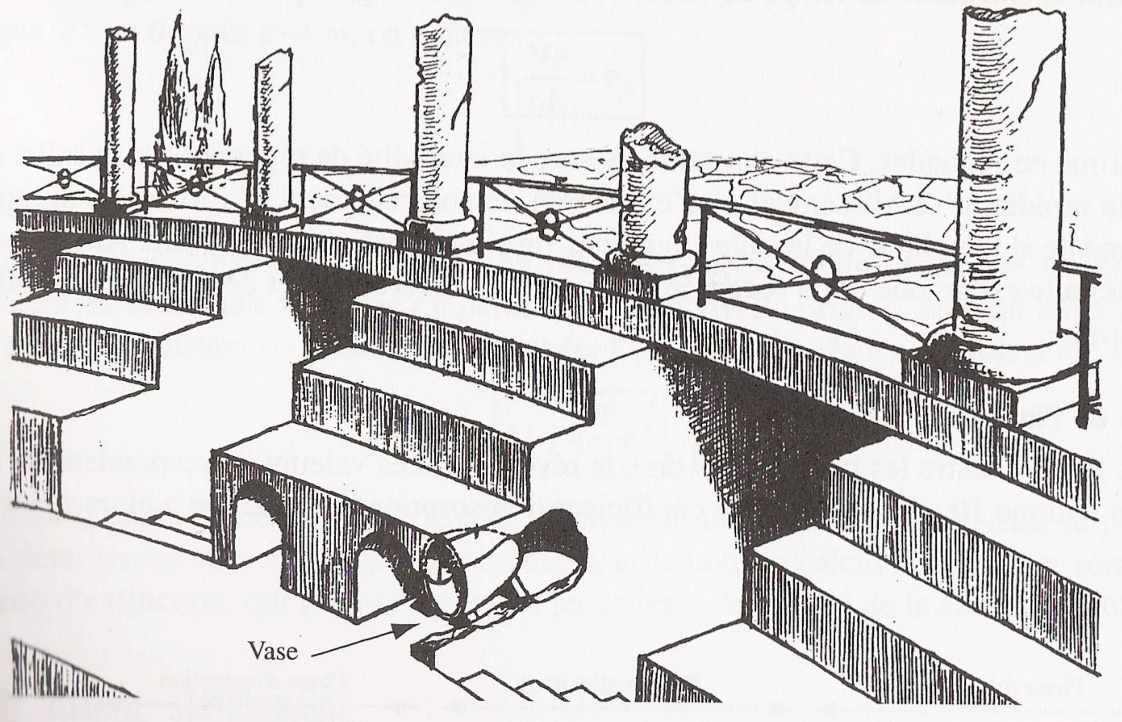
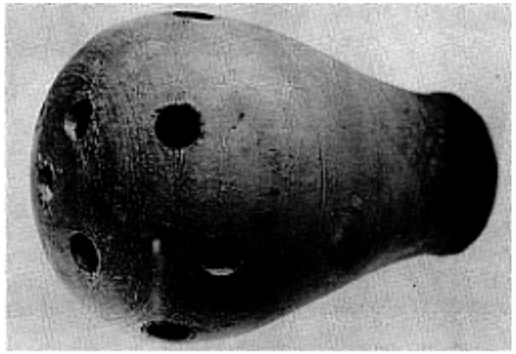


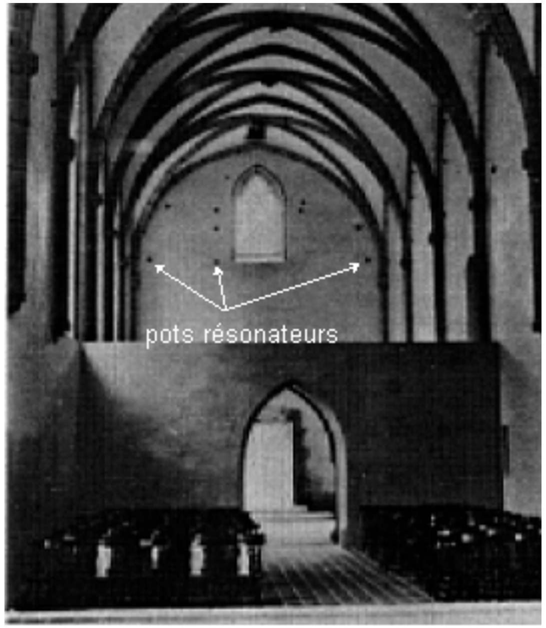
Fig. III.32. Vases acoustiques.

Cf. Antonio Fischetti, p.107

Résonateur en terre cuite du téâtre punico-romain de Nora, en Sardaigne.



Pot résonateur de la chapelle de Pleterje.



Chapelle de Pleterje, près de Ljubljana, construite en 1403.

ITALIE

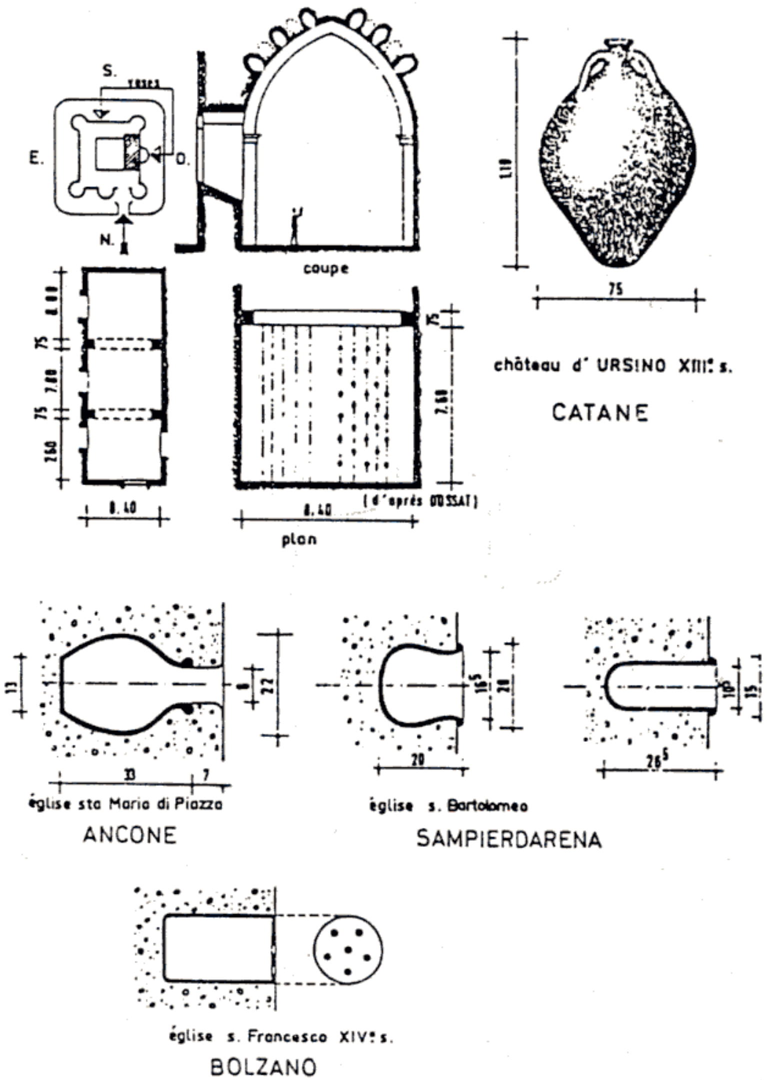
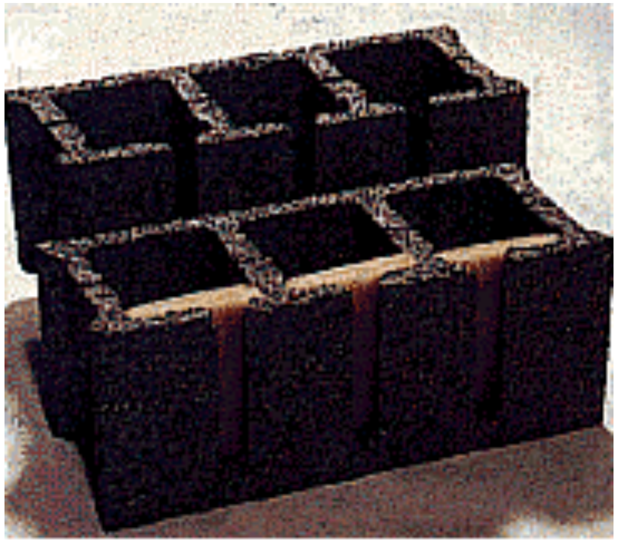


Fig. 3 - Exemples de vases acoustiques italiens

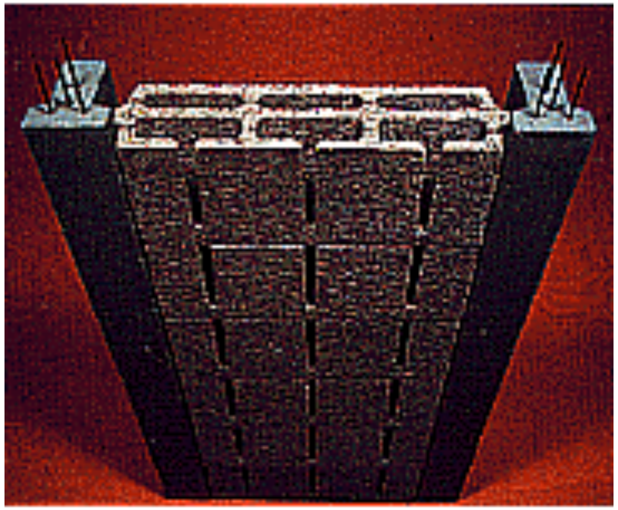
« les architectes de l 'Antiquité ne disposait que de deux moyens

la géométrie et l 'oreille »

F Canac



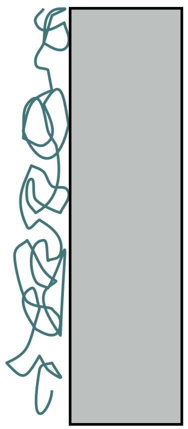
résonateur mural



résonateurs en plafond

3.2- Absorption

Friction effect: to absorb treble (F > 1000 Hz)
Acoustic energy is absorbed by frictions of the wave acoustics on fibres. The material will be all the more effective as it will be porous with the air.

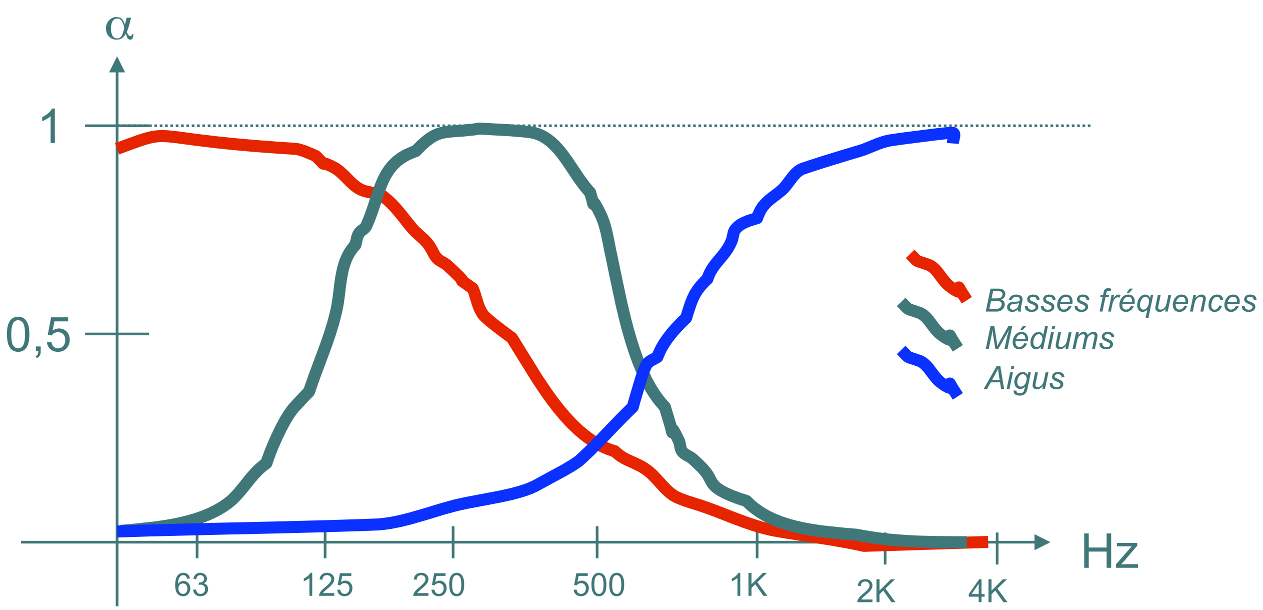


3.3- Alpha Sabine, Absorption acoustic factor

To describe how a material will absorb acoustic wave depending of the frequencies, we can read the Alpha Sabine factor (a, α or a_w)

Given by octave, the alpha Sabine factor value can be between 0 and 1.

* 0, means that it absorbs zero acoustic energy at this frequency
* 1, means that it absorbs all the acoustic energy at this frequency.
* if α> 0,5, we consider that the acoustic absorption stat to important.



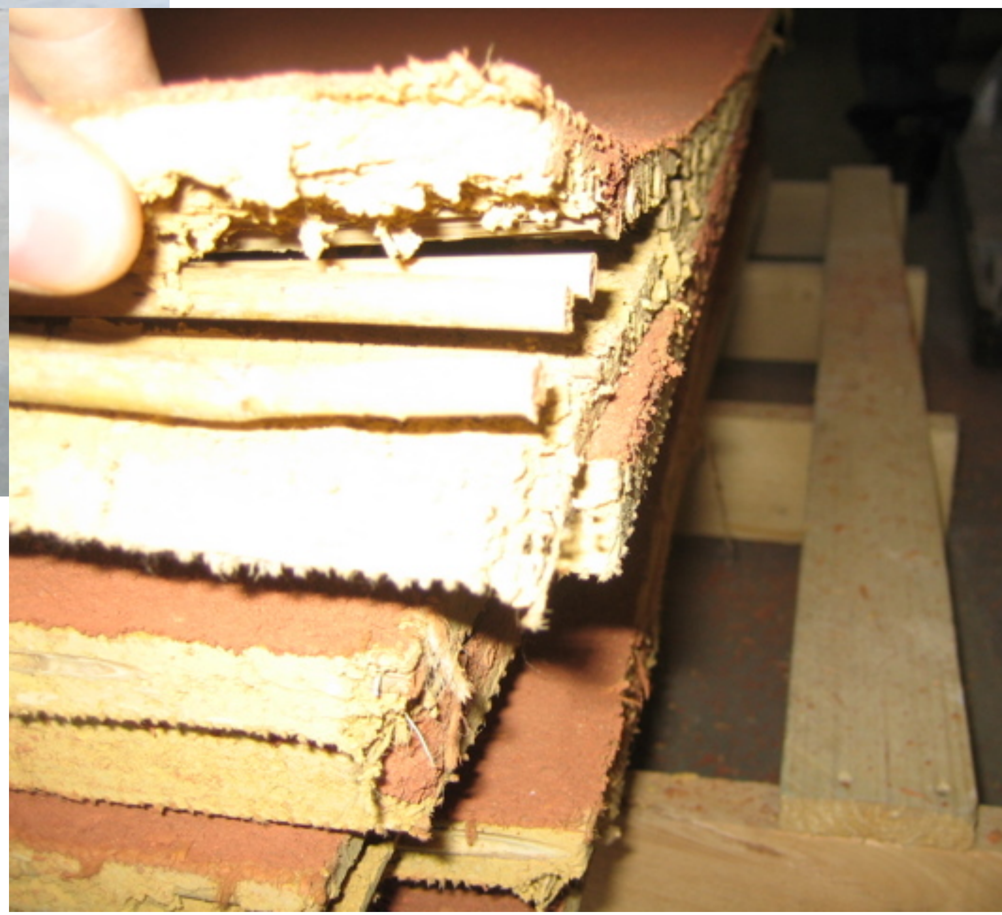
Classical curves of alpha sabine for3 different materials

3.3- Alpha Sabine, Absorption acoustic factor

Qualities of absorption of a material thus depend on:
- 1 of its matter
- 2 of its setting … the way it will be implemented

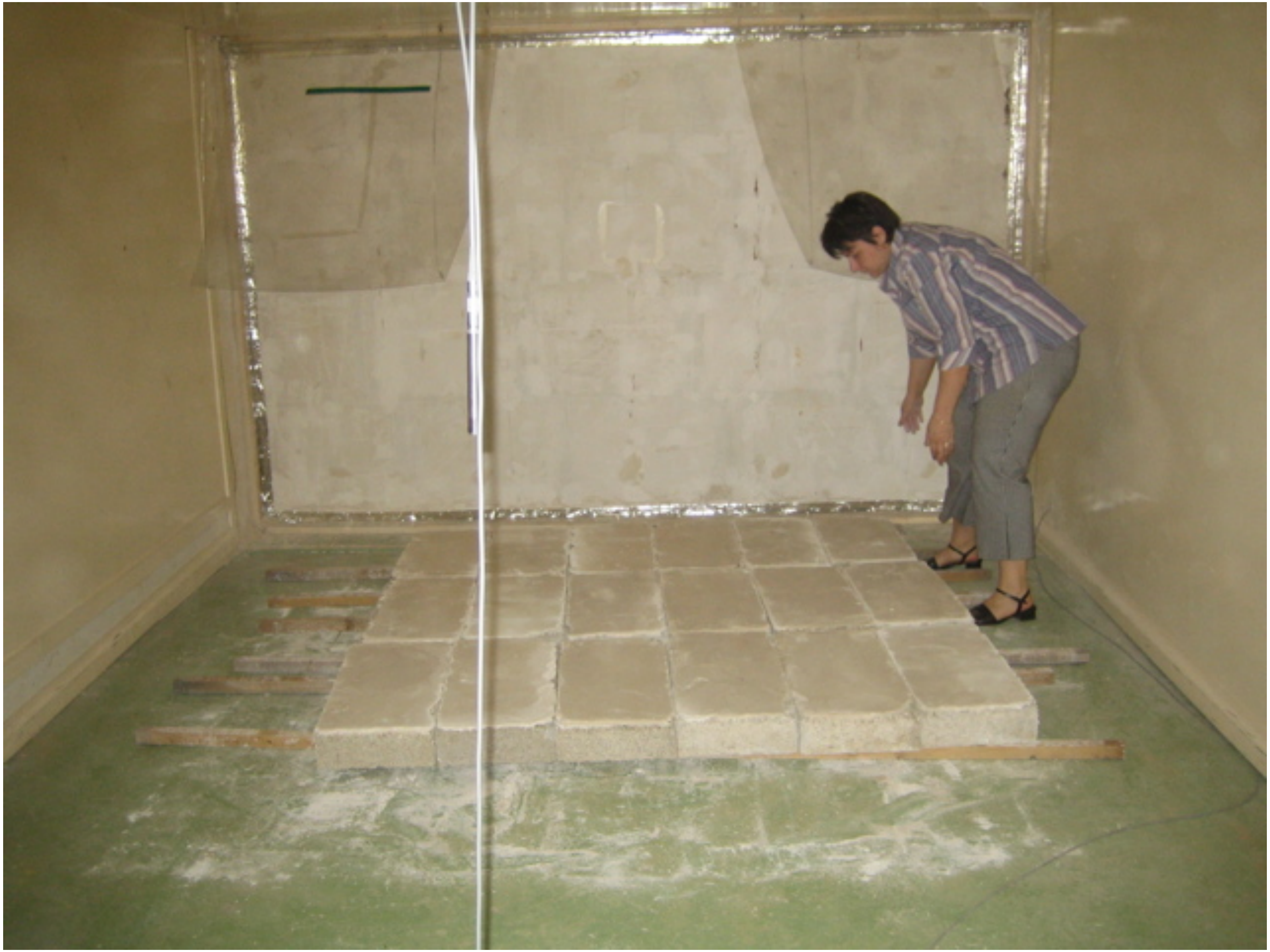
3.3- Alpha Sabine, Absorption acoustic factor

Alpha Sabine Measurments room



panels of straw and earth

Hemp bricks (+ciment)



4- The equivalent area of absorption

α, alpha Sabine

	125Hz	250Hz	500Hz	1kHz	2KHz	4KHz
Concrete rough	0,02	0,04	0,05	0,05	0,05	0,05
Foam 50mm	0,32	0,89	0,82	1,00	1,00	1,00

One can defines for a room **A, the equivalent area of absorption** by m^2 with:

$$A = \sum_{i=1}^{n} \alpha_i . S_i$$

α, alpha Sabine of the material surface
S, area in m^2 of the surface of the room

4- The equivalent area of absorption

Equivalent Area of absorption in m^2

$$A = \sum_{i=1}^{n} \alpha_i . S_i$$

So for example, for $20m^2$ of a ceiling

	125Hz	250Hz	500Hz	1kHz	2KHz	4KHz
. α rough concrete	0,02	0,04	0,05	0,05	0,05	0,05
. A (m2)	0,4	0,8	1	1	1	1
. α Foam 50mm	0,32	0,89	0,82	1,00	1,00	1,00
. A (m^2)	6,4	17,8	16,4	20	20	20

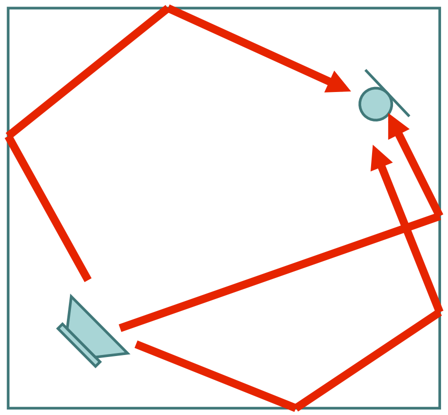
5- Sound level pressure in diffuse field

We can show that sound level pressure in diffuse field (reverberated field) is:

$$Lp = Lw + 6 - 10\log A$$ **in dB(A)**

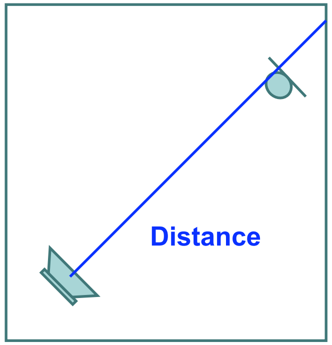
with :
Lp, sound level pressure in diffuse field
Lw, acoustic power level of the source
A, equivalent area of absorption

Consequences :
- Lp is constant what ever the position in the diffuse fiels)
- Lp depends only with A



Diffuse field

5- Sound level pressure in diffuse field



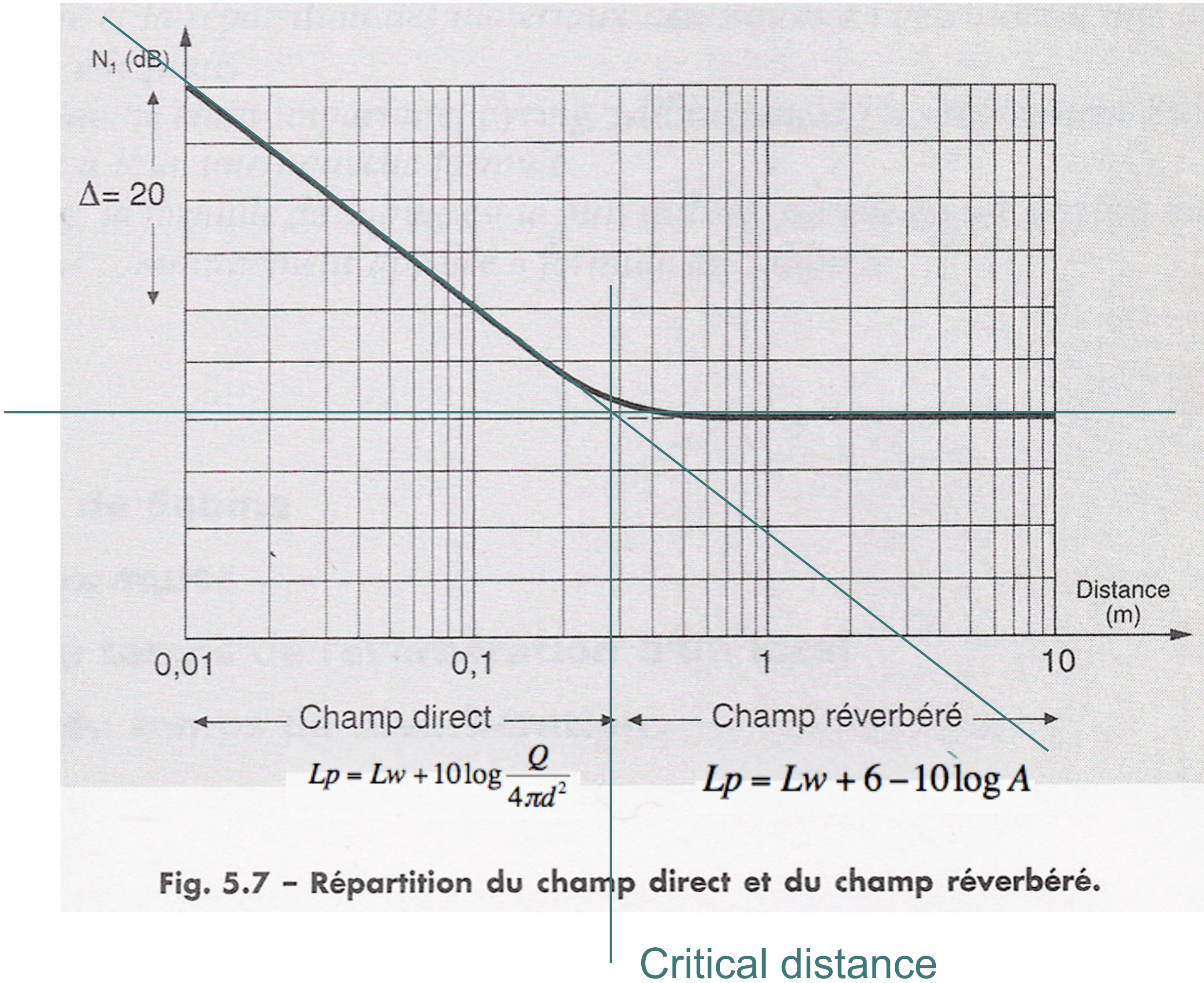


Fig. 5.7 – Répartition du champ direct et du champ réverbéré.

In free field,
We can reduce Lp in reducing Lw and in increasing d

In diffuse field,
We can reduce Lp with reducing Lw and increasing A

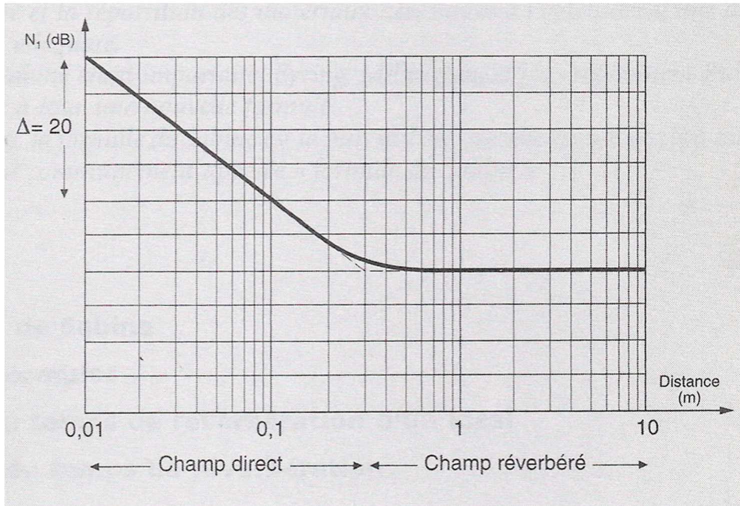
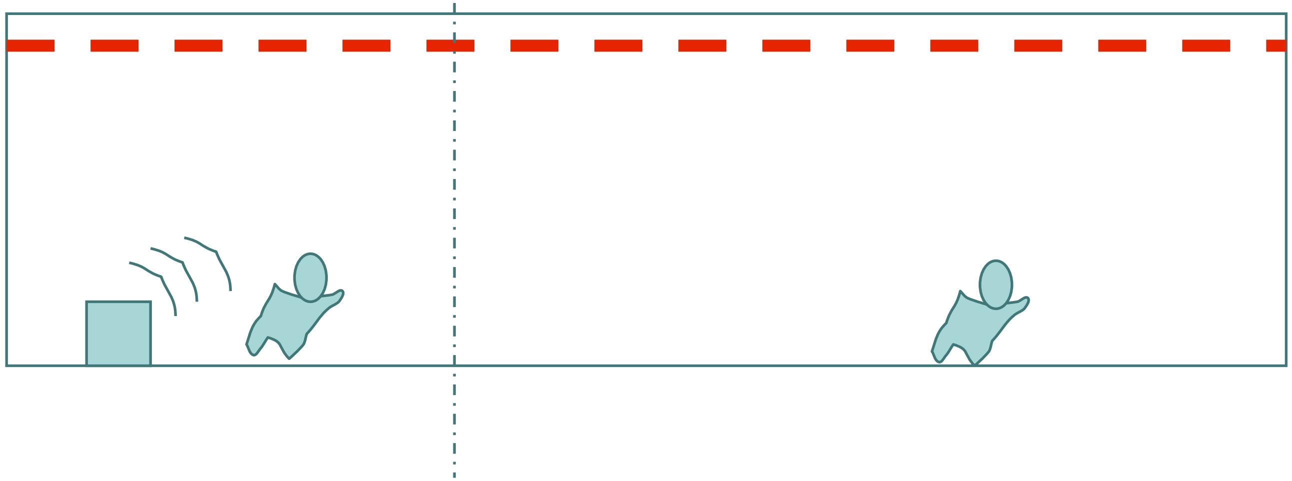


Fig. 5.7 – Répartition du champ direct et du champ réverbéré.

$$Lp = Lw + 10\log\frac{Q}{4\pi d^2}$$

$$Lp = Lw + 6 - 10\log A$$



7- Room reverberation

- Walter Sabine Formula

$$TR = 0{,}16 \frac{V}{A} \quad \text{en s}$$

with
A : equivalent area of absorption en m^2
α, Alpha Sabine factor

$$A = \sum_{i=1}^{n} \alpha_i . S_i$$

Definition : Reverberation time is the duration needed for a sound emitted in a room to decrease of 60dB(A).

7- Réverbération d’un local

- Formule de W.C. Sabine en seconde $$TR = 0{,}16\frac{V}{A}$$ en s

Alpha Sabine has different value for each octabe.
Alpha Sabine will have different value for each octave

To sum up it value, we give actually the arithmetic average of the reverberation time of the the following octves : 500Hz, 1k et 2kHz

Examples :

under Pyramide of Louvre	*10s environ*
Hall plateform in railway station	*1,5 à 3s*
Class room	*0,8s*
Gymnasium	*2 à 4s*
Concert hall	*1,8 à 2,5s*
Normaly furrnished house	*0,5s*
Normaly furrnished house	*0,2s*

7- Reverberation time values

The value of reverberation time for a room must be maintained in a range of values acceptable for its use.

A low value (acoustic too matt) as a large value (acoustic very reverberating) is not inevitably a comfortable value. It is necessary to adjust the reverberation with the uses.

la salle des Princes, Monaco - Système Carmen

Gymnase à Grenoble, Nicolas Michelin
www.cyberarchi.com

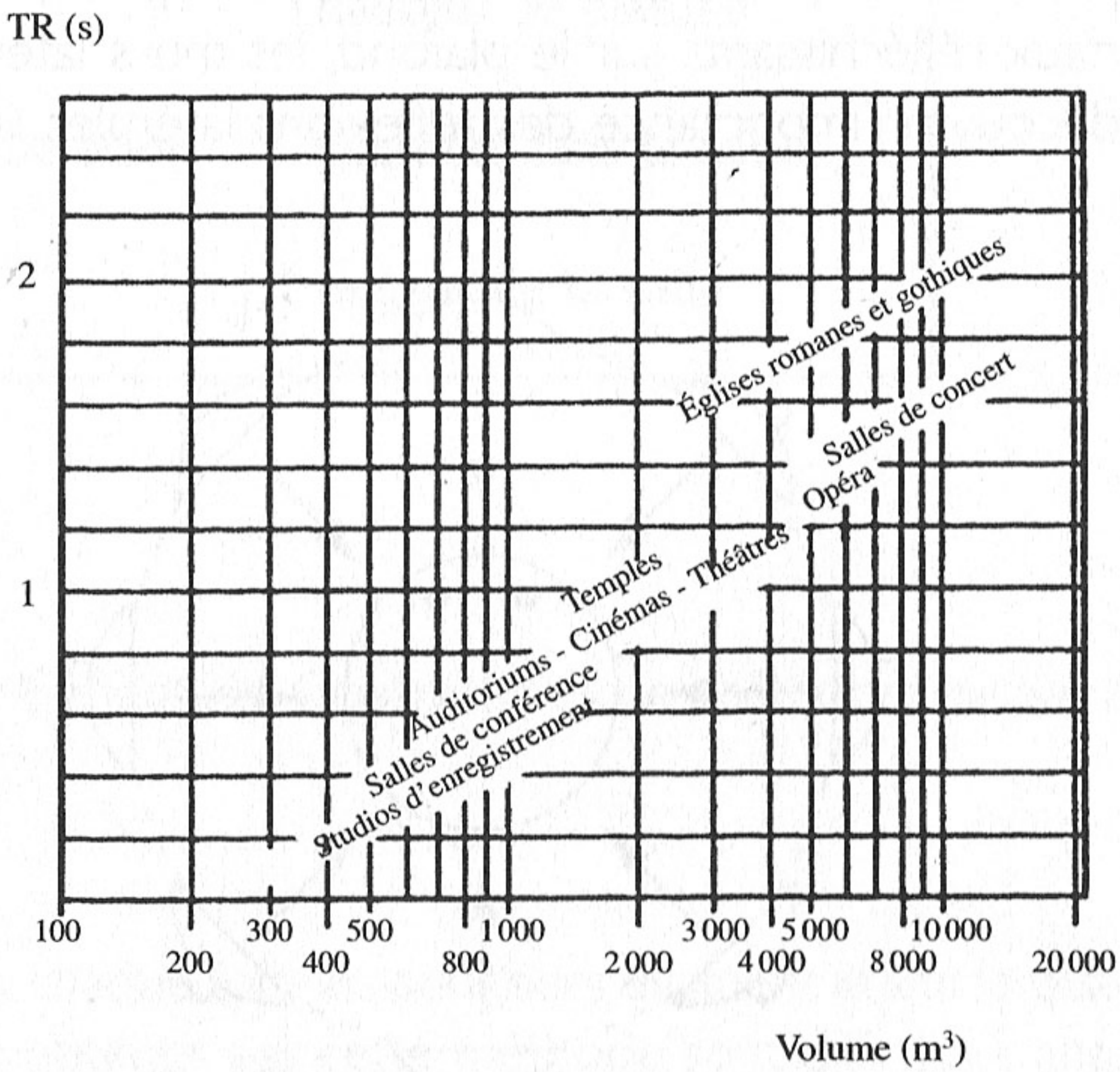
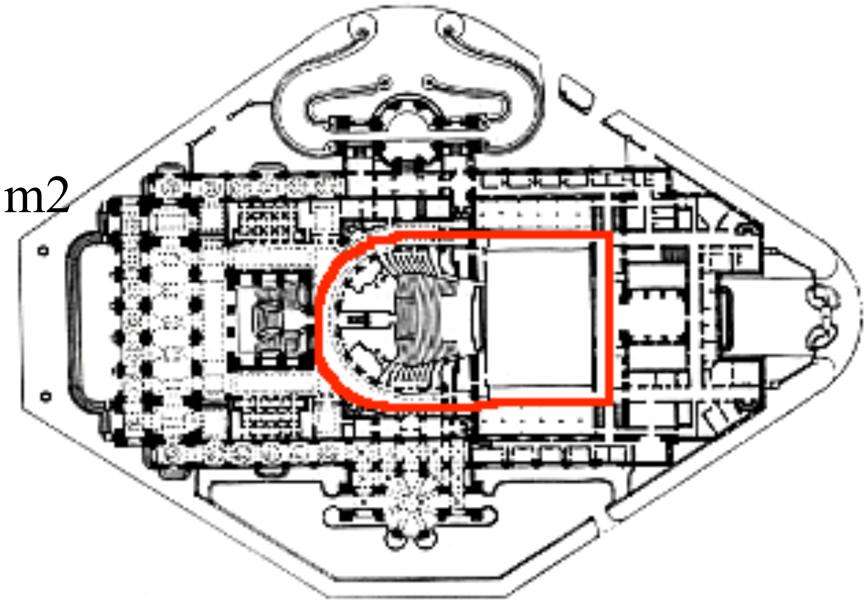


Fig. IV.2. Courbes usuelles du TR optimal.

Volume = 9 960 m3

Aire absorption équivalente = 1 448 m2

Tr = 1.2 s

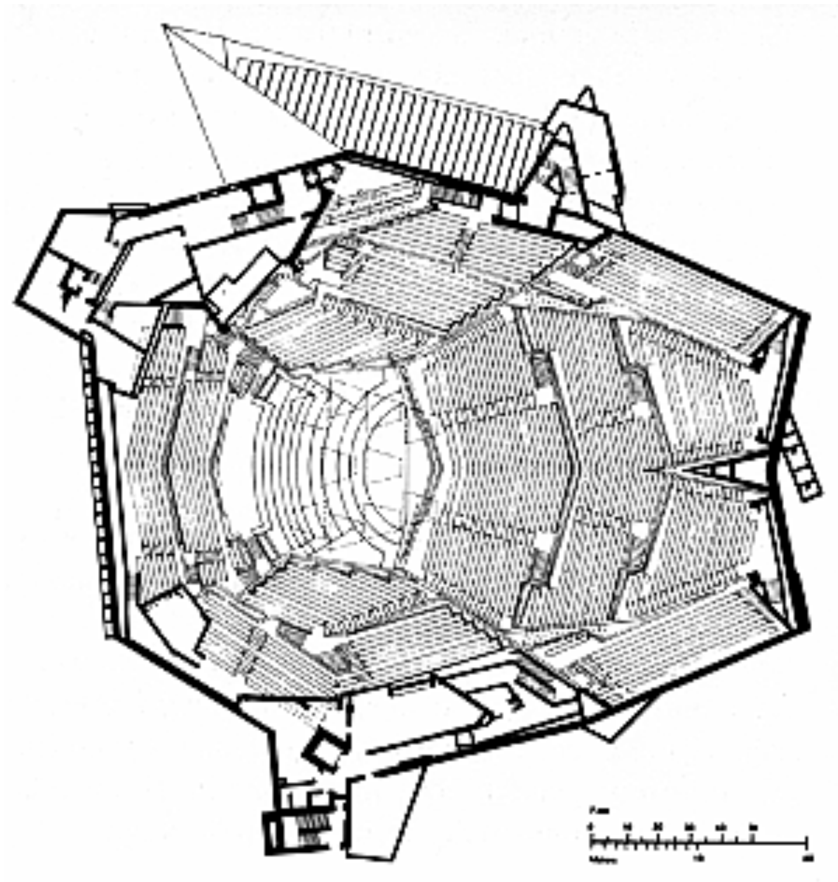


Salle de l ’Opéra de Paris 1875 Charles Garnier

Volume = 24 500 m3

Aire absorption équivalente = 2 010 m2

Tr = 1.95 s

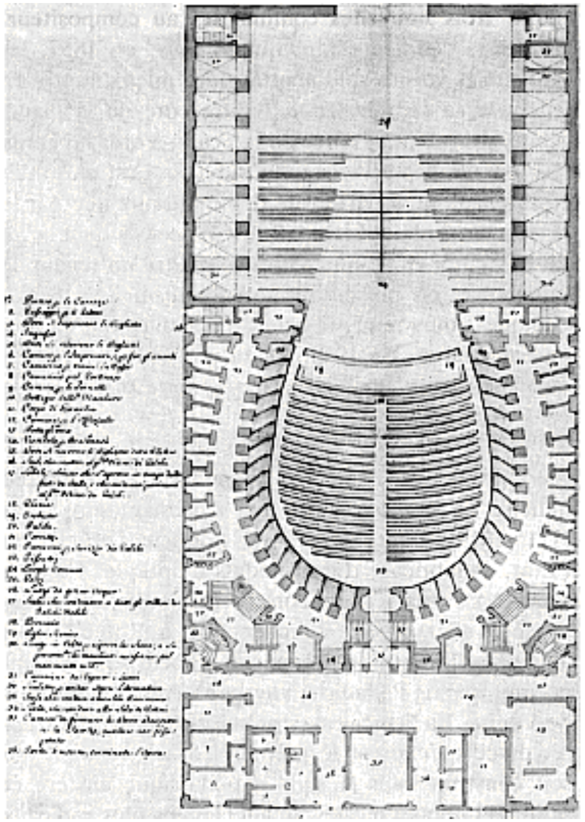


Philarmonie Berlin 1963 Hans SCHAROUN

Volume =11250 m3

Aire absorption équivalente = 1500 m2

Tr = 1.2 s



Theatro alla scala de Milan 1778

Giuseppe PIERMARINI

8- Measurments systems

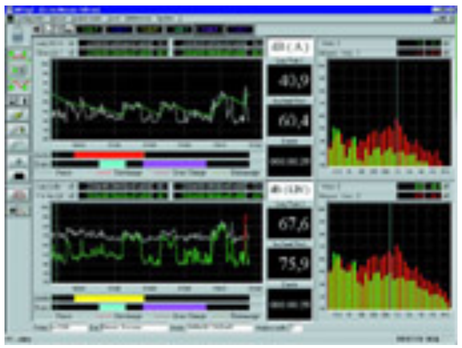
Mesures

Sonomètres des sociétes

Bruël et Kjaer — Brüel & Kjær — http://www.bksv.com/

01dB - Metravib — 01dB METRAVIB — http://www.01dB.com

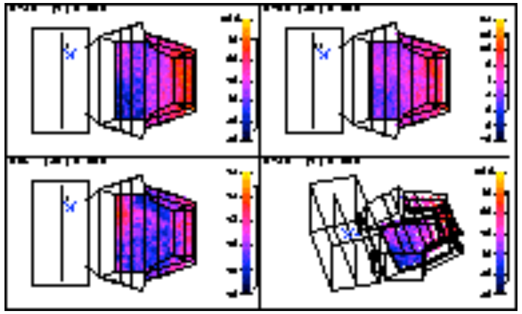
01dB : symphonie



01dB : dBEnv32

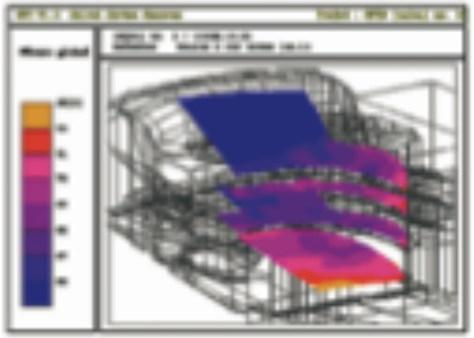
01dB : Solo

9- Outils modélisation



Catt Acoustic - acoustique des salles

CSTB - epidaurea



Prévision numérique du niveau sonore produit par un chanteur situé sur la scène de la grande salle d'opéra au moyen du programme Epidaure.

la salle des Princes, Monaco - Système Carmen

10- Bibliographie

Acoustique des salles :

- JOUHANEAU J. : *Acoustique des salles et sonorisation* - Paris - T1D - 1997 - 610p
- Collectif : *Theaters and halls.* Tokyo. Meisei. 1995. 224p
- BARRON M. : *Auditorium acoustics and architectural design*. Londres. E&FN SPON. 1993. 443p
_ Colllectif : *Rencontres architecture et musique* - Chateau de forges, Pesmes - 1992 78p
- EGAN David : *Architectural acoustics*. New York- Mac Graw Hill. 1992
- POUBEAU P, BARON C : *Produits pour la correction acoustique.* Paris. CATED. 1991. 72p
- FORSYTH M: *Architecture et musique:l'architecte,le musicien et l'auditeur du17ème siècle à nos jours.* Bruxelles-P.Mardaga. 1987,360p
- ADAM M. : *Acoustique architecturale et acoustique des salles*. Blauen (CH). Schweizer Baudokumentation. 1985. 68p
- LEIPP, E : *Acoustique et musique*. Paris. Masson. 1980
- IZENOUR : *Theater design*. New York : Mac Graw hill Cie, 1977, 630 p
- LAMORAL R : *Music et architecture*. Paris : Masson, 1975, 180 p.,
- RAES A.C. : *Isolation sonore et acoustique architecturale* - Paris - Chiron - 1964 - 383p
- BERANEK L : *Music, acoustic and architecture* . New York. J. WILEY,1962, 580 p
- KNUDSEN V.O. ET HARRIS C.M. : *Le projet acoustique en architecture* - Paris - Dunod - 1957