AURALIAS

Intelsig

Room-acoustics predictions using a diffusion process - A state of the art

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Introduction

- Numerical tools are now widely used for buildings projects
- Most popular methods:
  - Ray-tracing method;
  - Statistical theory.

Quick ← **Intermediate models** → Slow

Statistical theory — Ray-tracing method

-

Rough results ← **Diffusion model** → Accurate results

Summary

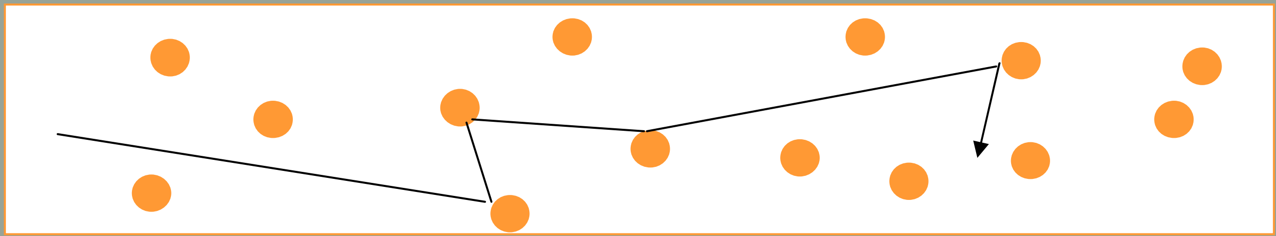
- Basic equations
- Mixed specular/diffuse reflections
- Numerical implementation
- Atmospheric attenuation
- Presence of fitting objects
- Rooms coupled through apertures
- Rooms coupled through partition walls
- Conclusions
- Application to a virtual factory

1. Basic equations

- Diffusion equation

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D\nabla^2 w(\mathbf{r},t) = P(\mathbf{r},t)$$

- Propagation of sound particles in a scattering medium



- Diffusion constant

$$D = \frac{\lambda c}{3}$$

w acoustic energy density

λ room mean free path ($4V/S$)

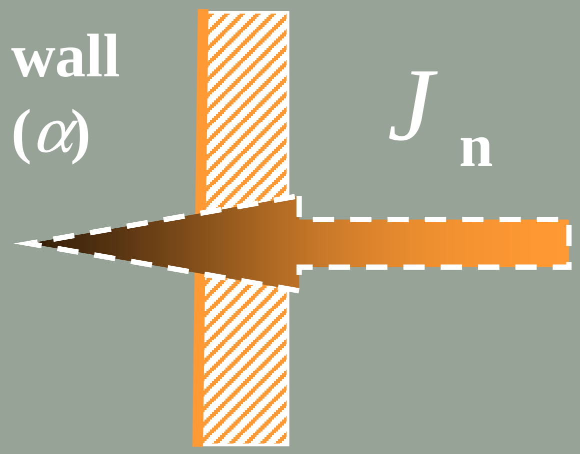
c sound speed

Morse and Feshbach (1953)
Picaut *et al.*, Acustica **83** (1997)
Valeau *et al.*, JASA **119** (2006)
Ollendorff , Acustica **21** (1969)
Picaut *et al.*, Applied Acoustics **56** (1999)

2. Boundary conditions

- Absorption at walls

$$J_{\mathbf{n}} = -D\frac{\partial w}{\partial \mathbf{n}} = h\,w$$



h exchange coefficient

$\mathbf{n}$ wall normal

- Expressions of the exchange coefficient

$$h = \frac{c\,\alpha}{4}$$

$$h = -\frac{c\ln(1-\alpha)}{4}$$

$$h = -\frac{c\alpha}{2(2-\alpha)}$$

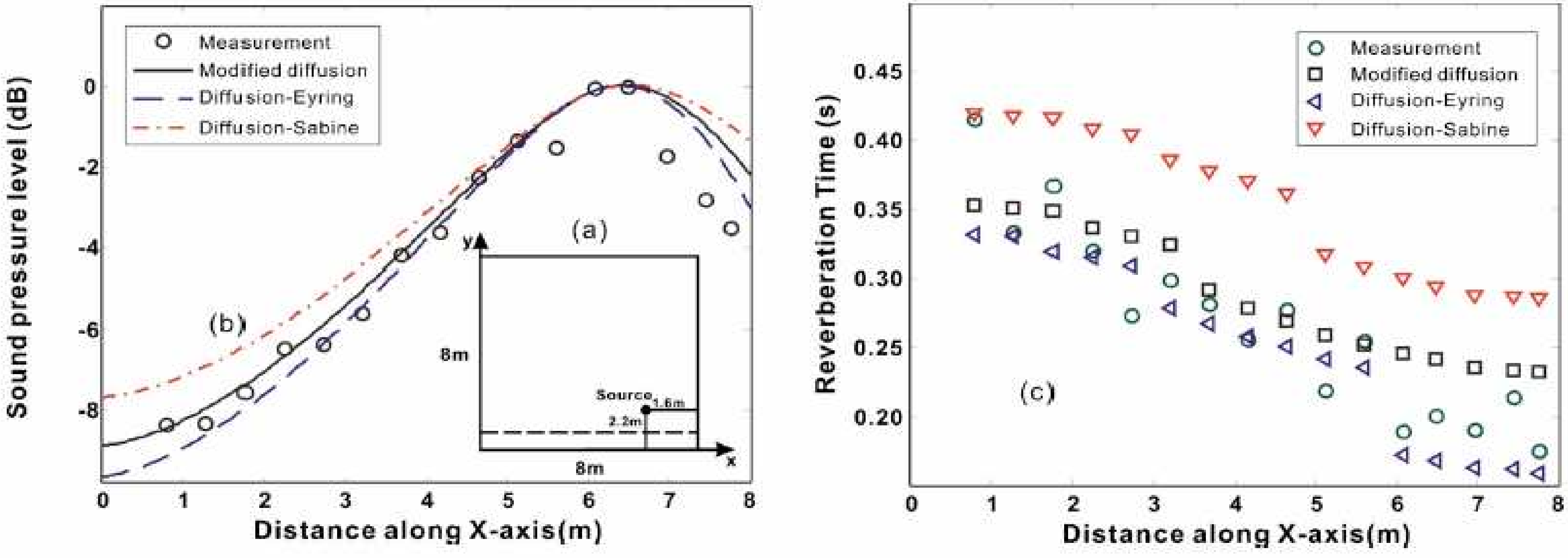
Picaut *et al.*, Applied Acoustics **56** (1999)

Billon *et al.*, Applied Acoustics **69** (2008)

Jing and Xiang, JASA **123** (2008)

2. Boundary conditions

Absorption at walls



Comparison of different boubary conditions with experiments (Jing and Xiang, 2008).

Picaut *et al.*, Applied Acoustics **56** (1999)

Billon *et al.*, Applied Acoustics **69** (2008)

Jing and Xiang, JASA **123** (2008)

3. Numerical implementation

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D\nabla^2 w(\mathbf{r},t) = 0$$

Source

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D\nabla^2 w(\mathbf{r},t) = P(\mathbf{r},t)$$

Room boundary ∂V

$$-D\frac{\partial w}{\partial n} = hw$$

Simulations characteristics:

- Finite Element Model (FEM) solver (*Femlab);*
- Unstructured mesh;
- Stationary response → Sound Pressure Level = *10 seconds*
- Impulse response → Sound decay < 1minute

4. Mixed specular/diffuse reflections

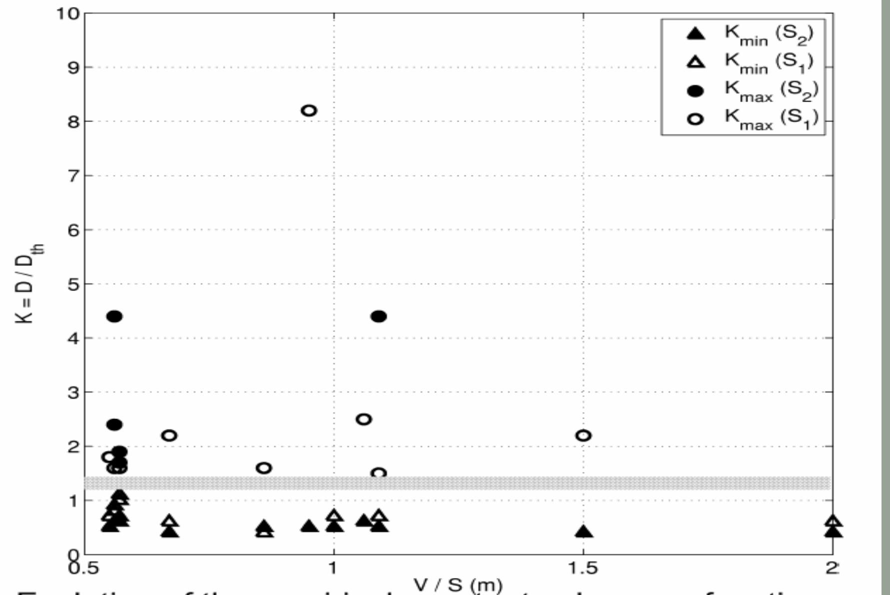
- Empirical diffusion constant

Valeau *et al.*, AAuA **93** (2007)

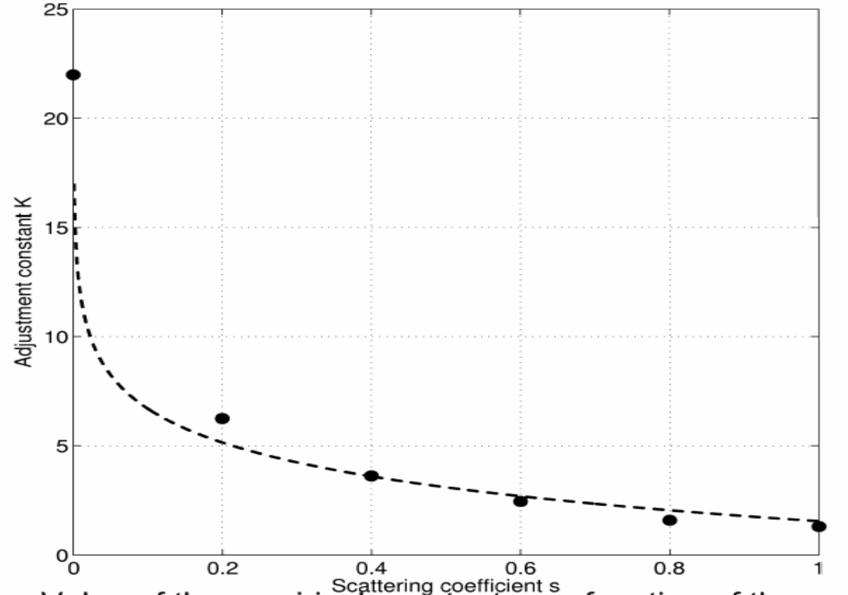
$$D(s) = k(s) \times D_{theorical}$$

- Generalization

Foy *et al.*, submitted to AAuA



Evolution of the empirical constant value as a function of the geometrical aspect ration for s=0.2 [Foy et al.]



Value of the empirical constant as a function of the scattering coefficient [Foy et al., submitted to AAuA]

The empirical model gives good predictions in terms of SPL, but not in terms of sound decay.

4. Mixed specular/diffuse reflections

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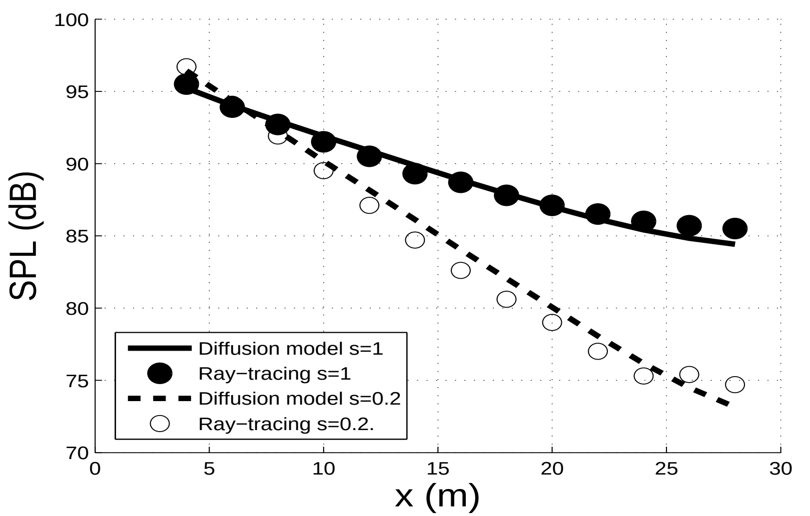
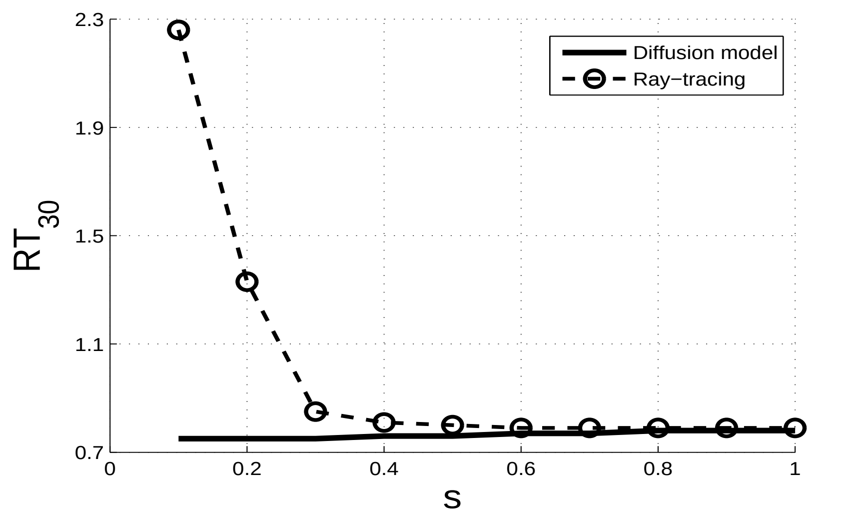


Evolution of the SPL in a long room for two scattering coefficient



Evolution of the reverberation time as a function of the scattering coefficient [Foy et al., submitted to AAuA]

The empirical model gives good predictions in terms of SPL, but not in terms of sound decay.

5. Atmospheric attenuation

- Diffusion constant

Billon *et al.*, JASA **123** (2008)

$$D' = D \times \frac{1}{1 + m\lambda}$$

- Absorption term

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D'\nabla^2 w(\mathbf{r},t) + mcw(\mathbf{r},t) = P(\mathbf{r},t)$$

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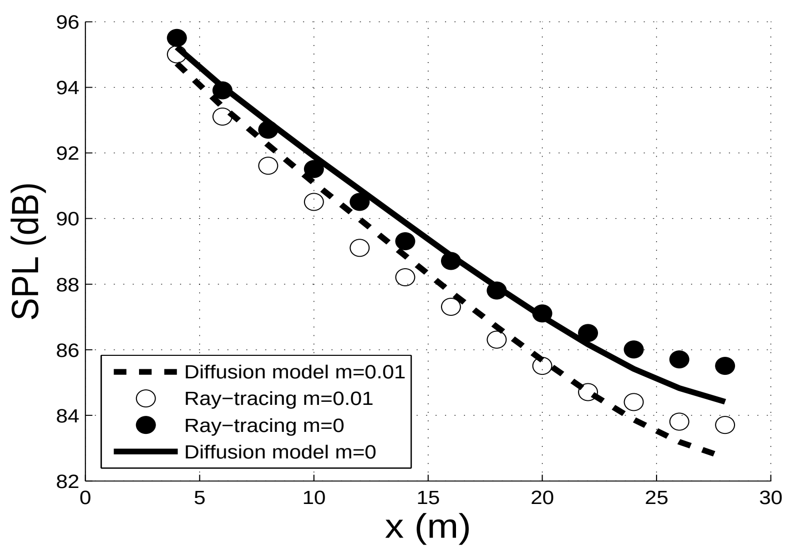
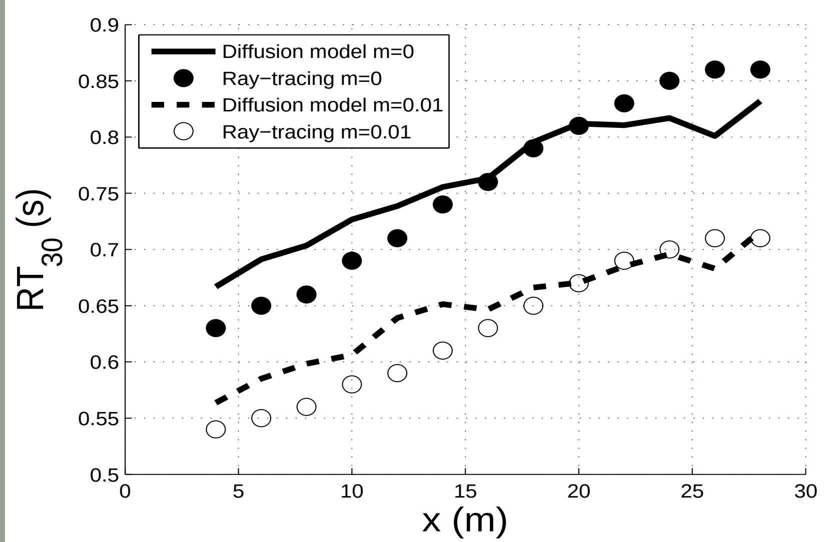


Evolution of the sound pressure level in a long room with and without atmospheric attenuation s=0.2



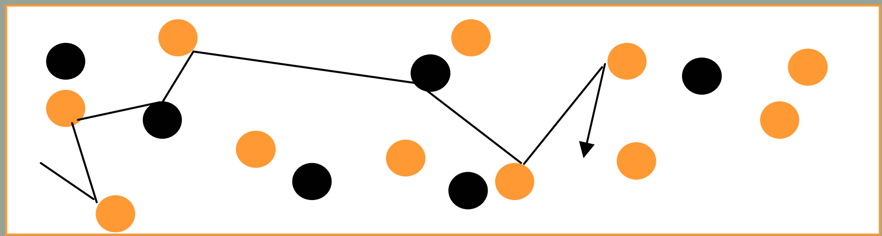
Evolution of the reverberation time in a long with and without atmospheric attenuation s=1

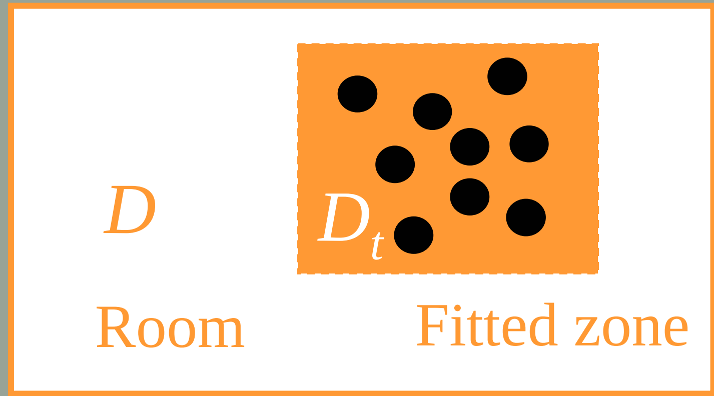
The diffusion model gives good predictions both in terms of SPL (for every s) and in termes of sound decay (for s=1).

6. Presence of fitting objects

- Diffusion constant

$(n_f, Q_f, \alpha_f) \longrightarrow D_f$





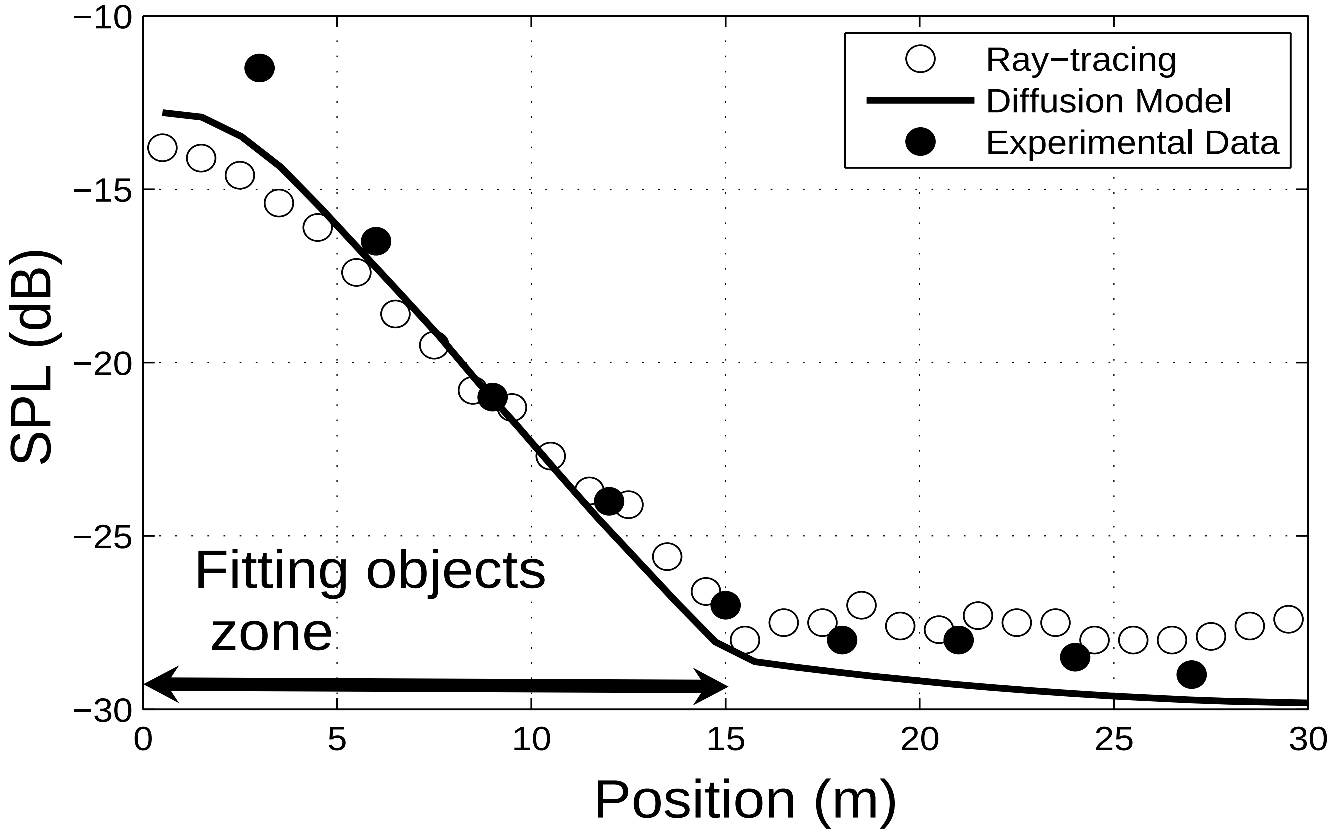
$$D_t = \frac{D_f D}{D_f + D}$$

V. Valeau *et al.*, AAuA **93** (2007)

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D_t \Delta w(\mathbf{r},t) + \frac{c\alpha_f}{\lambda_f} w(\mathbf{r},t) = P(\mathbf{r},t)$$

6. Presence of fitting objects

- Diffusion constant



Evolution of the SPL in a fitted room
[Valeau et al. 2007]

7. Rooms coupled through apertures

Billon *et al.*, JASA **120** (2006)

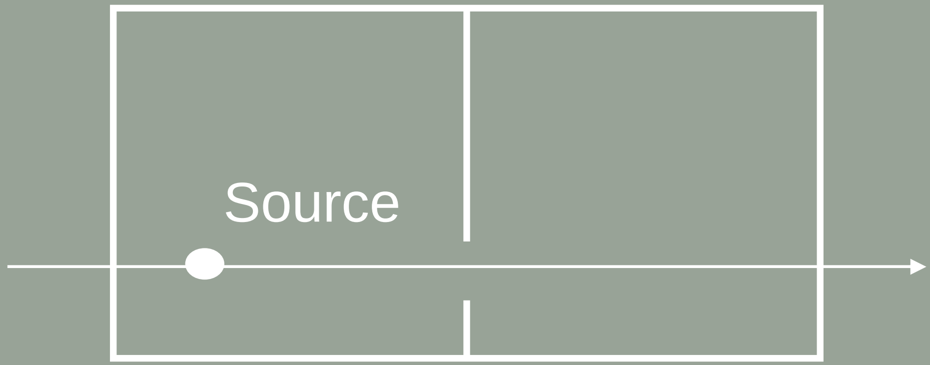
$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D_1 \nabla^2 w(\mathbf{r},t) = 0$$

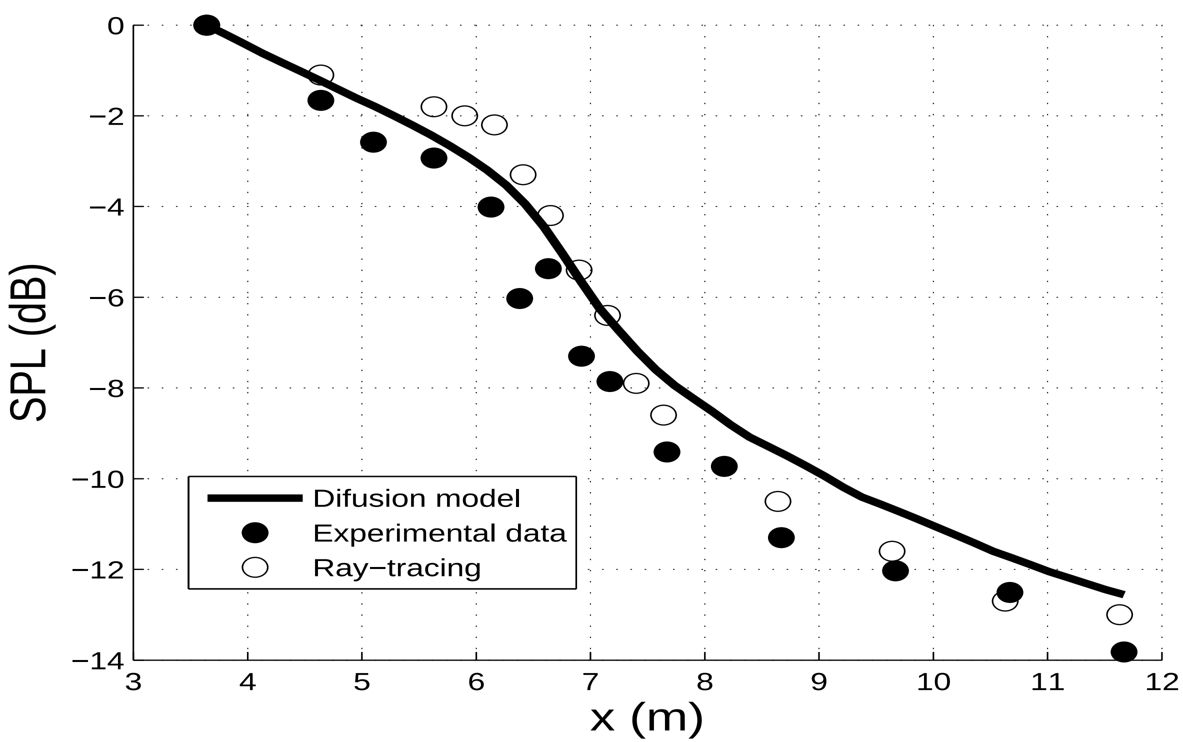
Source

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D_1 \nabla^2 w(\mathbf{r},t) = P(\mathbf{r},t)$$

$$\frac{\partial w(\mathbf{r},t)}{\partial t} - D_2 \nabla^2 w(\mathbf{r},t) = 0$$

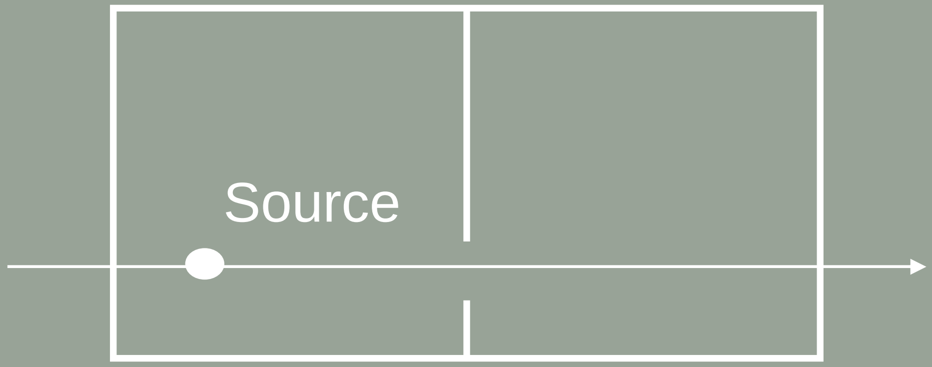
8. Rooms coupled through apertures

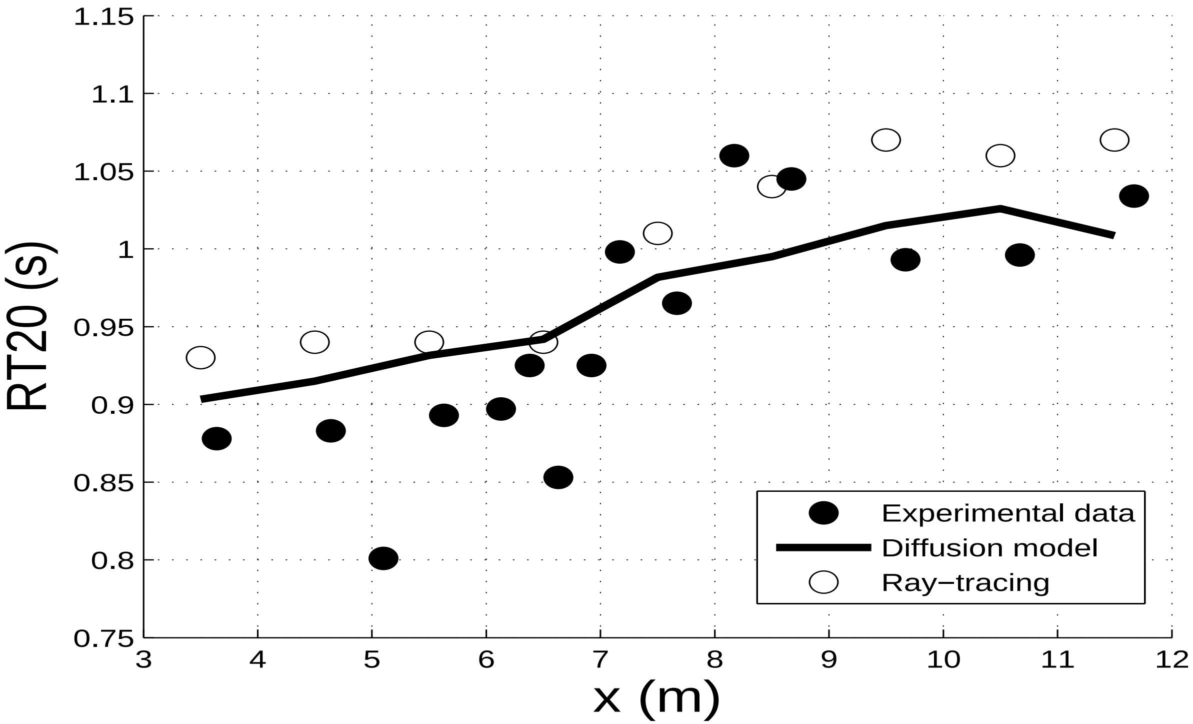




Evolution of the SPL through the coupling aperture

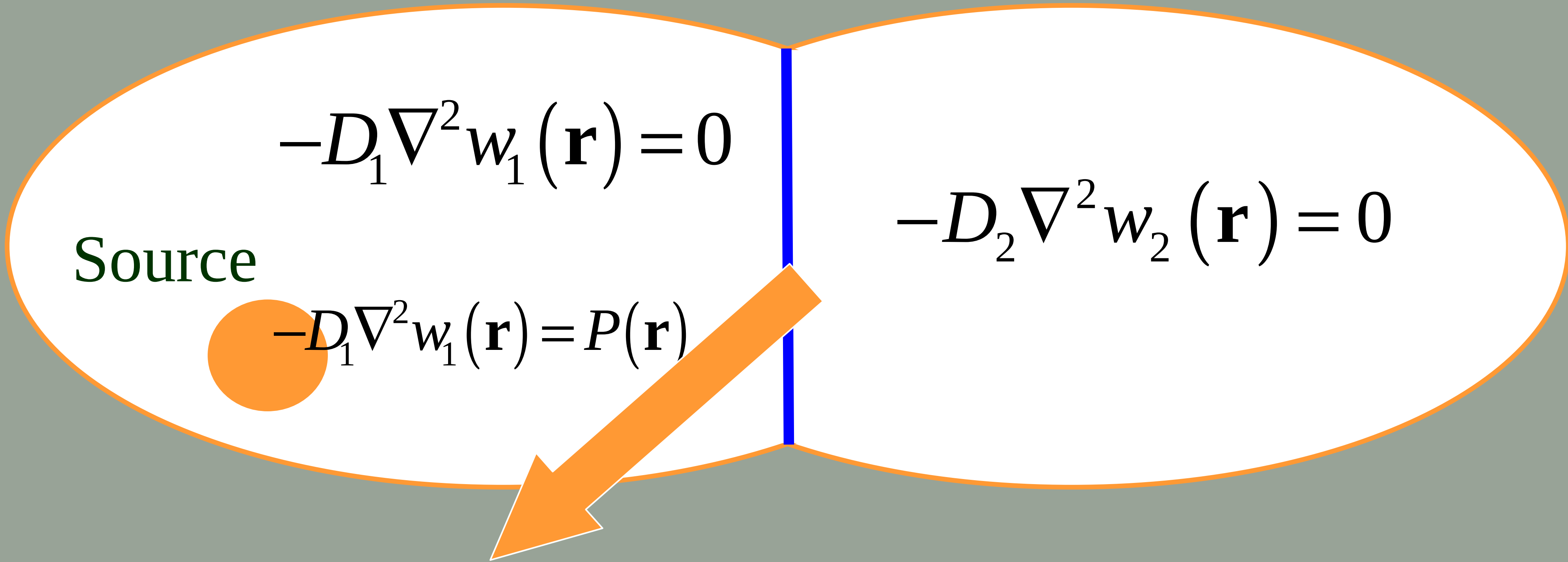
8. Rooms coupled through apertures





Evolution of the reverberation time through the coupling aperture

8. Rooms coupled through partition walls



- Coupling equations

Side V_1

$$\boxed{D_1 \frac{\partial w_1(\mathbf{r})}{\partial \mathbf{n}_1} + h_1 w_1(\mathbf{r}) = \frac{\tau c}{4} w_2}$$

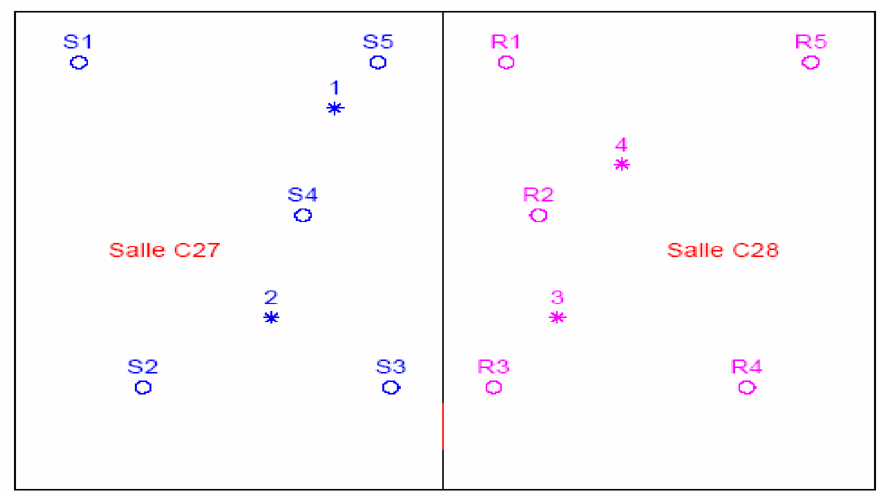
τ Transmission coefficient

Side V_2

$$\boxed{D_2 \frac{\partial w_2(\mathbf{r})}{\partial \mathbf{n}_2} + h_2 w_2(\mathbf{r}) = \frac{\tau c}{4} w_1}$$

Billon *et al.*, JASA **123** (2008)

8. Rooms coupled through partition walls

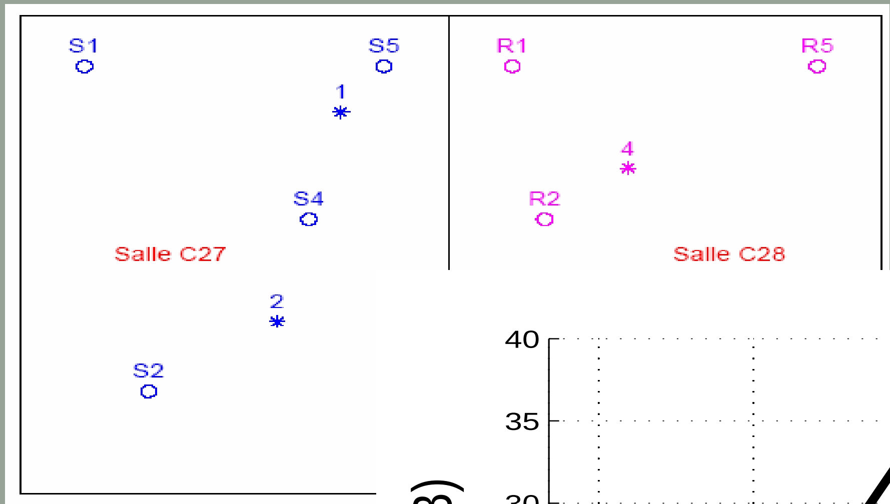


Norms 3382 and 140-4:

*: Sound source

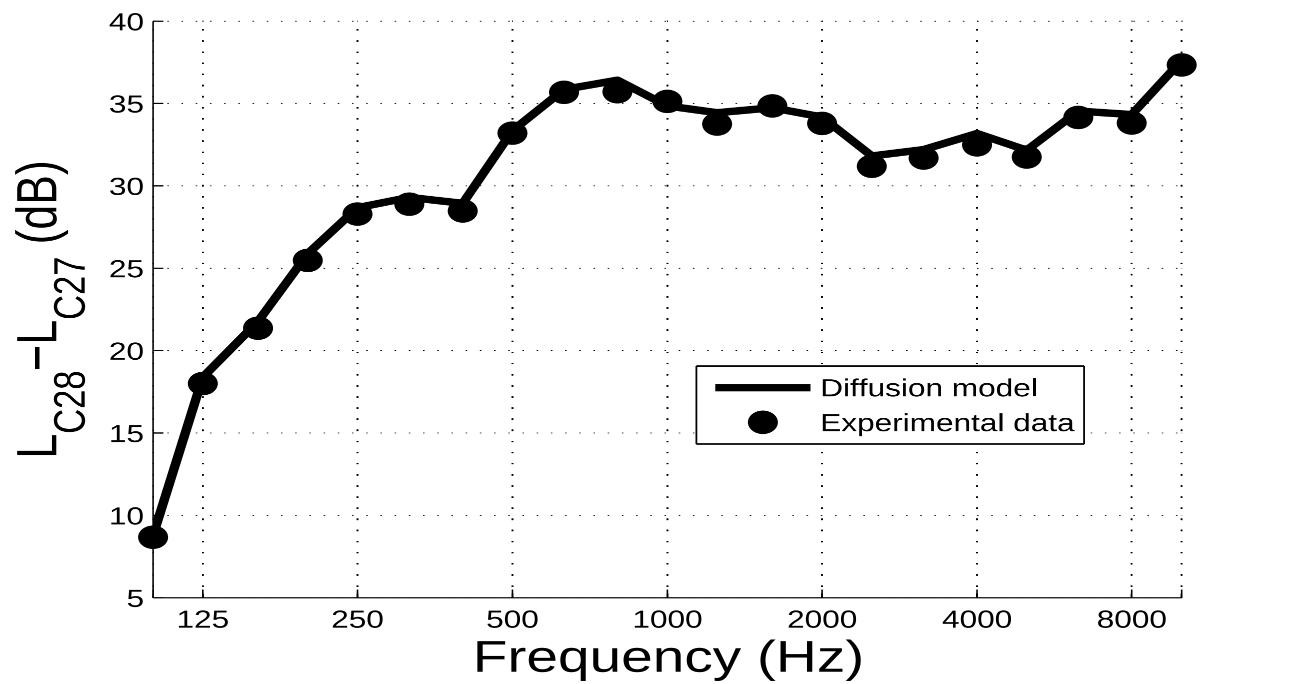
o: Microphones

8. Rooms coupled through partition walls



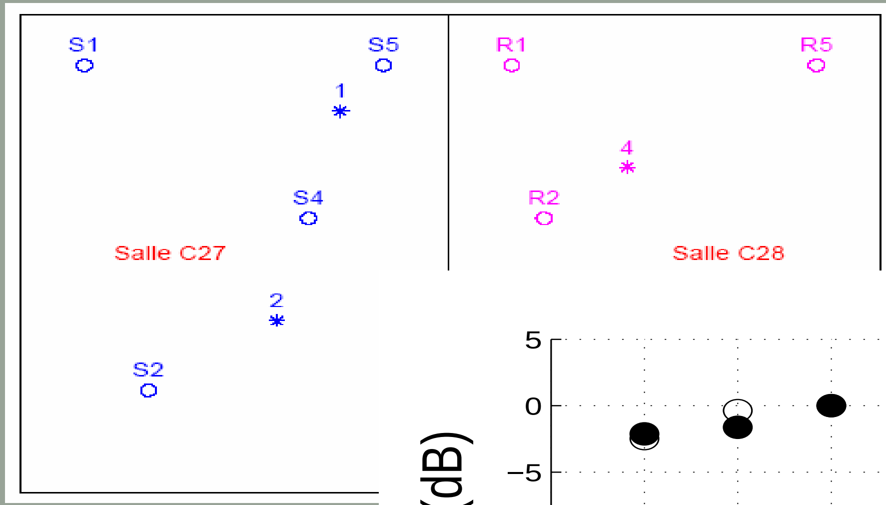
Norms 3382 and 140-4:

*: Sound source



Sound level diffrence between the room
as a function of the frequency

8. Rooms coupled through partition walls



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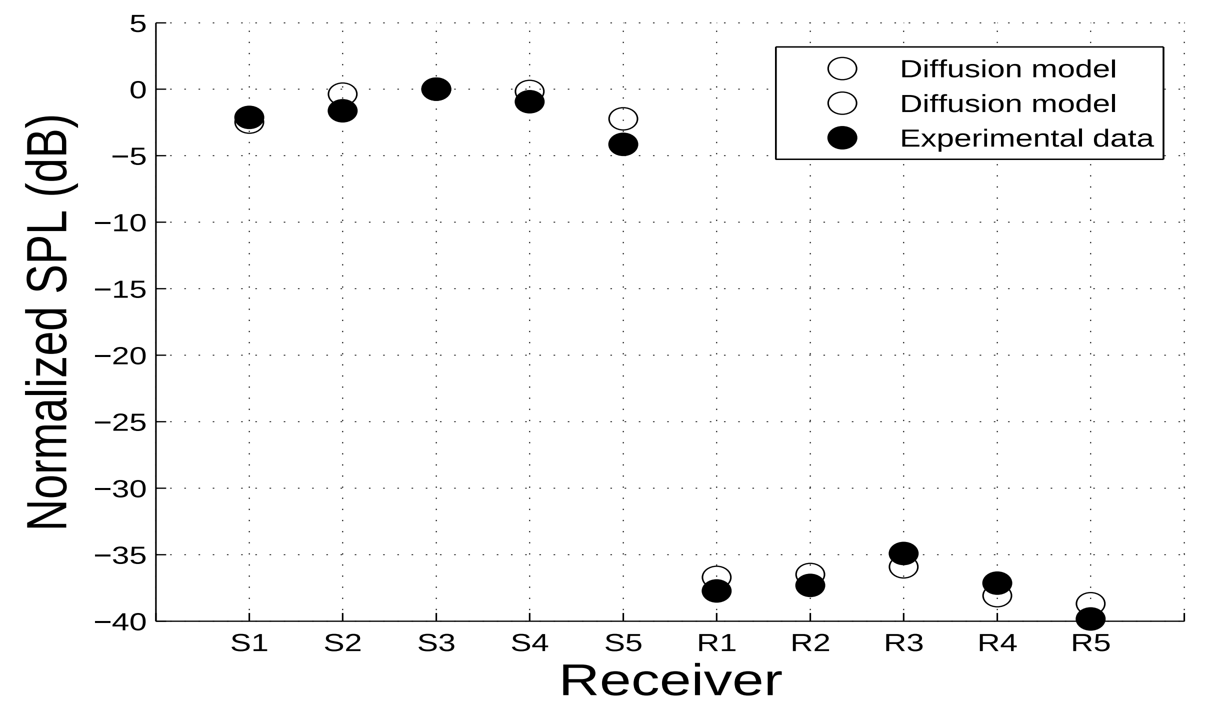


Normalized sound pressure level at the microphones locations

Conclusions

- Quick and flexible approach
- Handle main acoustic phenomena
- Adapted in networks of rooms

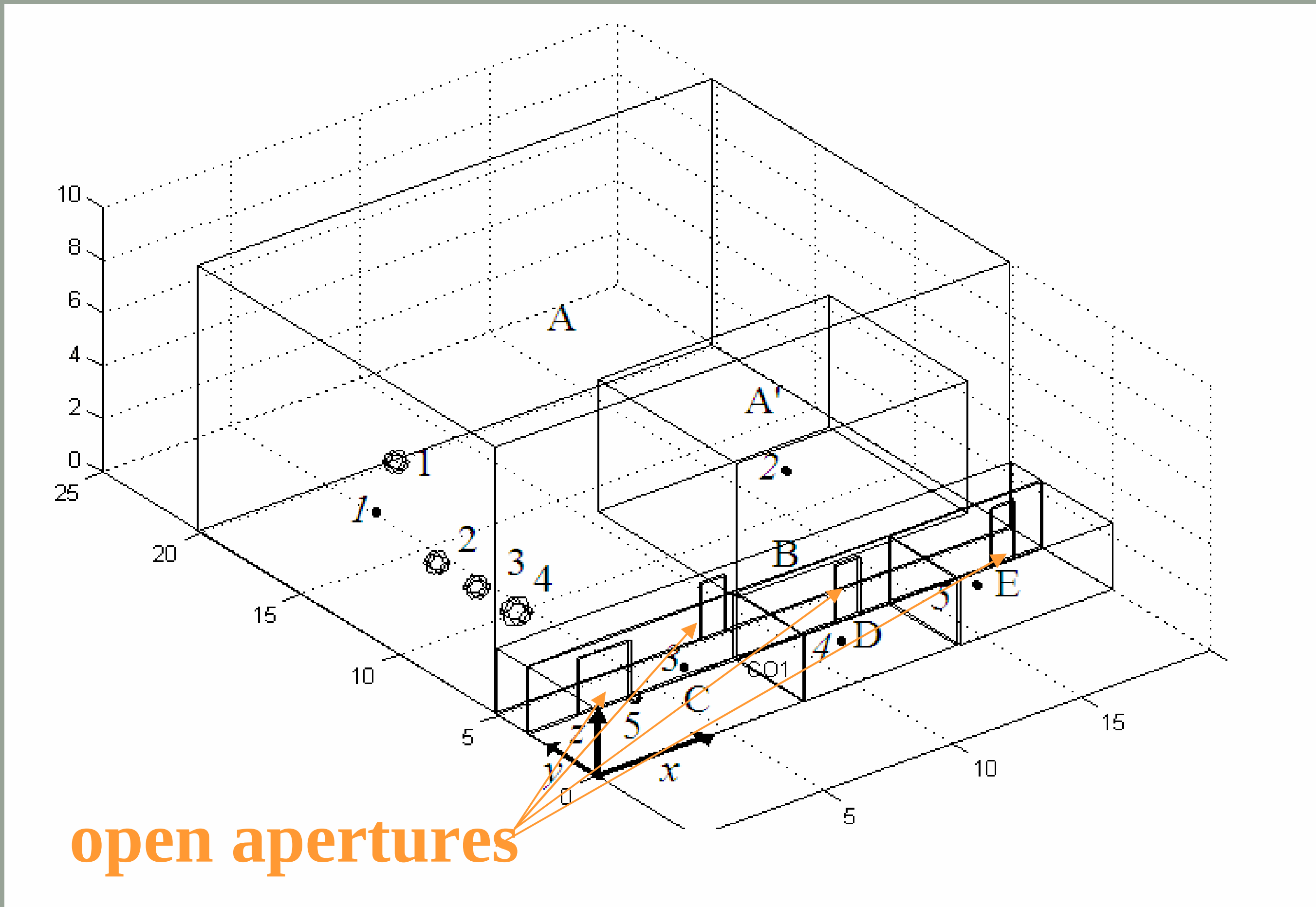
Future works

- Specular reflections in the sound decay
- Coupling with urban diffusion model

Acknowledgements:
The author would like to thank the ADEME (french agency for environmental studies) for supporting part of this work.

Application to a virtual factory

- Industrial hall coupled with offices



Hall A :

- 20m x 25m x 10m
- α=0.03
- source 1: 120dB

Fitted zone A':

- α=0.3
- λ_f=0.25m

Offices D, E:

- α=0.06

Workshop C:

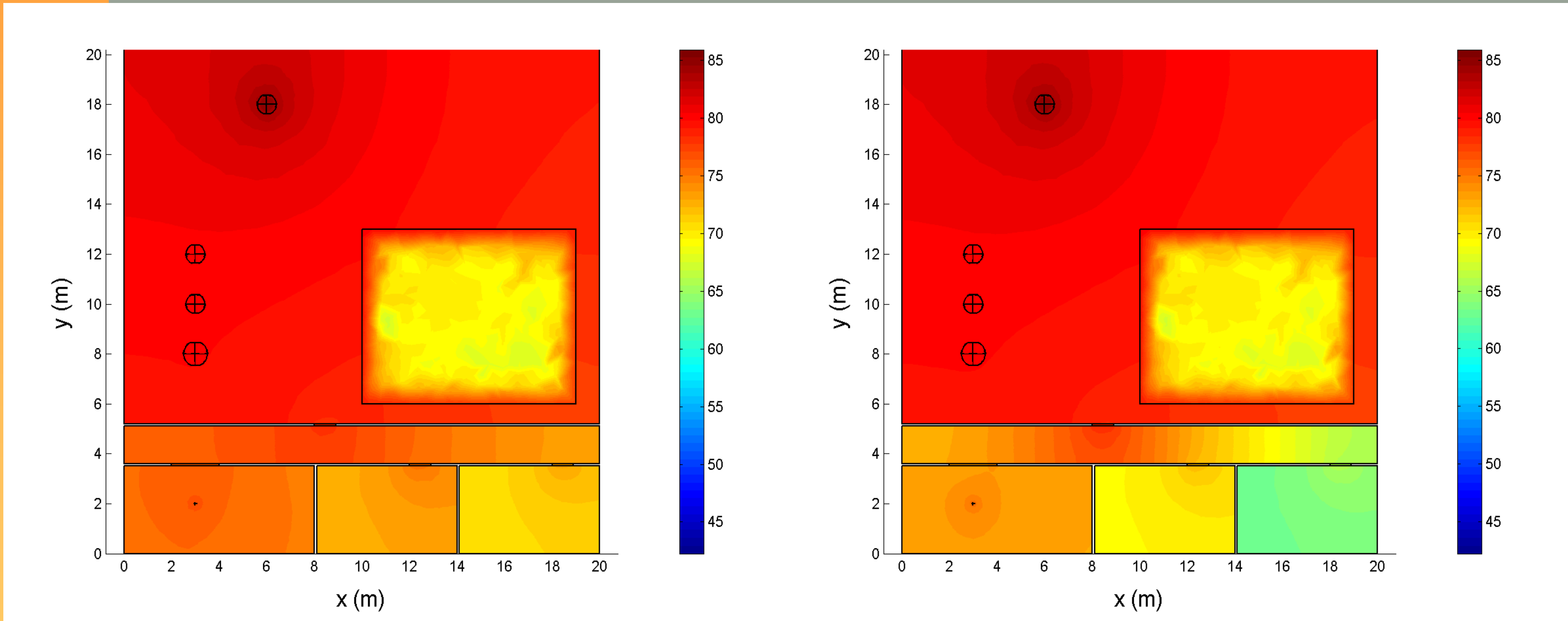
- α=0.03

Corridor B:

- **α = 0.06 or 0.6**

Application to a virtual factory

- Effect of the acoustic treatment



Before

After