LCPC Laboratoire Central des Ponts et Chaussées

Réseau Scientifique et Technique de l'Equipement

1949 • 2009 LCPC 60 ans d'innovation

LES PLÉNIÈRES 2010 DU LCPC

Sciences et techniques du **Génie Civil**

JOURNÉES ACOUSTIQUE

Wissembourg – 2 et 3 JUIN 2010

Diffuseur urbain : un dispositif pour la réduction des nuisances sonores en milieu urbain

J. Picaut (LCPC)

D. Scouarnec[#], H. Hossam Eldien[µ] (LCPC)

A. Billon (Université de Liège)

[#]Valeo Engine Cooling (France)

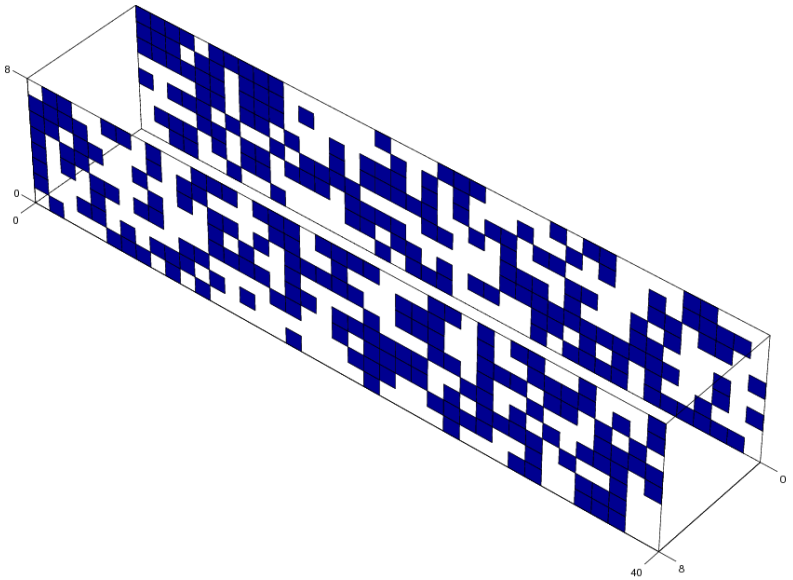
[µ]Dammam University (Kingdom of Saudi Arabia)

- Réduction du bruit en milieu urbain
  - **Réduction des émissions**
  - **Revêtements de chaussée peu bruyants**
  - **Écrans acoustiques**
  - **Dispositifs spécifiques pour le milieu urbain**
    - **Panneaux absorbants** [Kang]
    - **Panneaux réfléchissants orientés** [Hornikx et Forssén]
    - **Diffuseurs urbains** [Picaut et Scouarnec]

- Étude numérique
  - **Lois de réflexion**
  - **Surface relative**
  - **Disposition sur les façades**
  - **Taille**
  - **Absorption**
- Prototype
  - **QRD**
  - **Caractérisation expérimentale**
- Validation expérimentale
  - **Mesures sur maquettte**

Diffuseur urbain

- Géométrie
  - Rue rectangulaire
    - *8m x 40m x 8m*
  - Source omnidirectionnelle
    - *(6.5,30.5,1.5)*
  - Chaussée
    - *Parfaitement réfléchissante (spéculaire)*
  - Façades
    - *Parfaitement réfléchissantes (spéculaires)*
  - Diffuseurs
    - *Carré*
    - *Réflexion non spéculaire*
    - *Avec/sans absorption*



- Code de calcul
  - SPPS
  - Durée de simulation : 1s [2ms]
  - 10^6 particules
  - Indicateurs : SPL, RT30, EDT

Diffuseur urbain

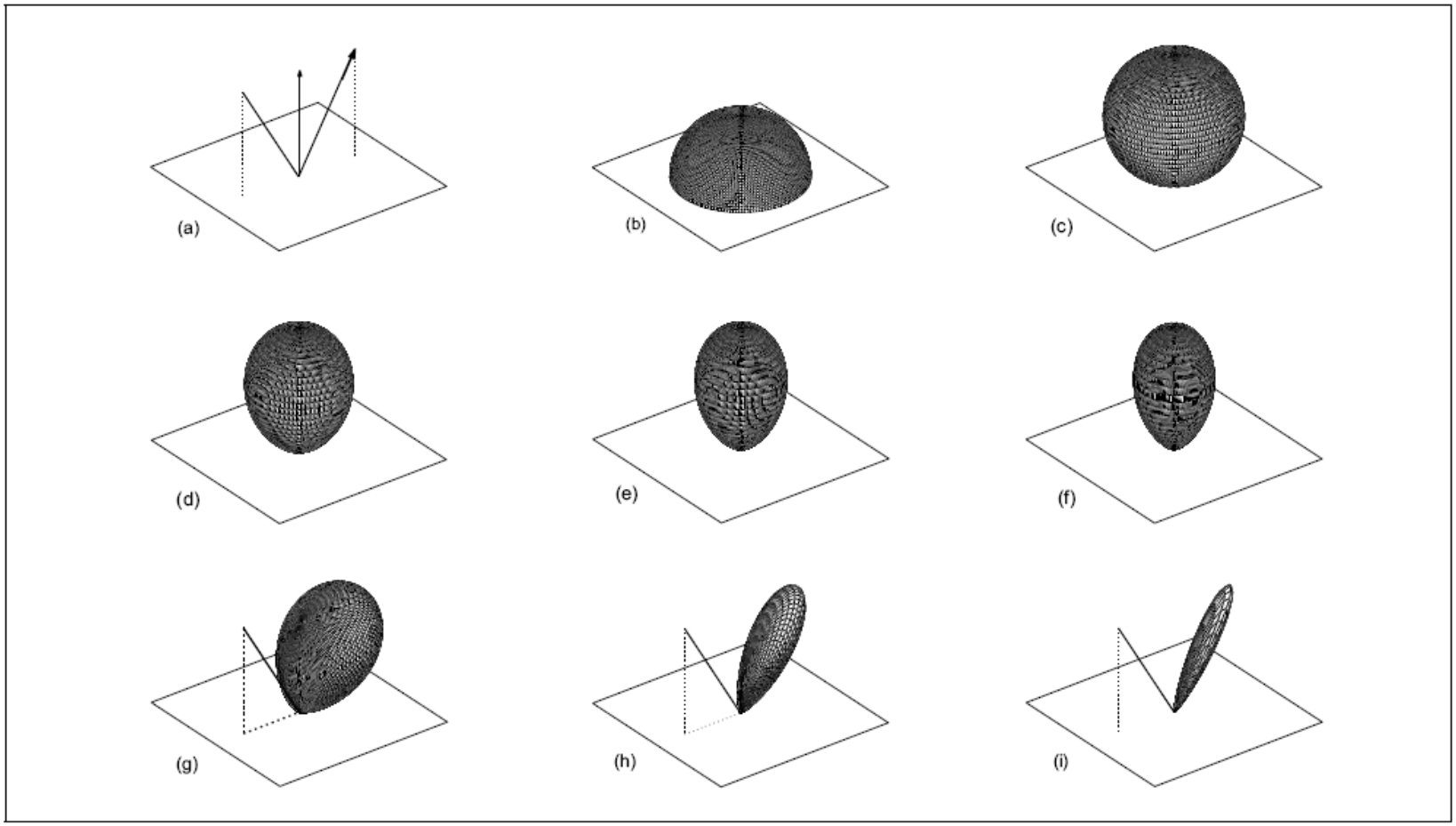


Figure 1. Building façades and diffusors reflection laws. Reference configuration: (a) specular (SP). Normal laws w^n: (b) Uniform (UN, $n = 0$), (c) Lambert (LA, $n = 1$), (d) w^2 (W2), (e) w^3 (W3), (f) w^4 (W4), (g) Semi-diffuse reflection laws with $T/\sigma = 5$ (SD5), (h) $T/\sigma = 10$ (SD10), (i) with $T/\sigma = 20$ (SD20).

Diffuseur urbain

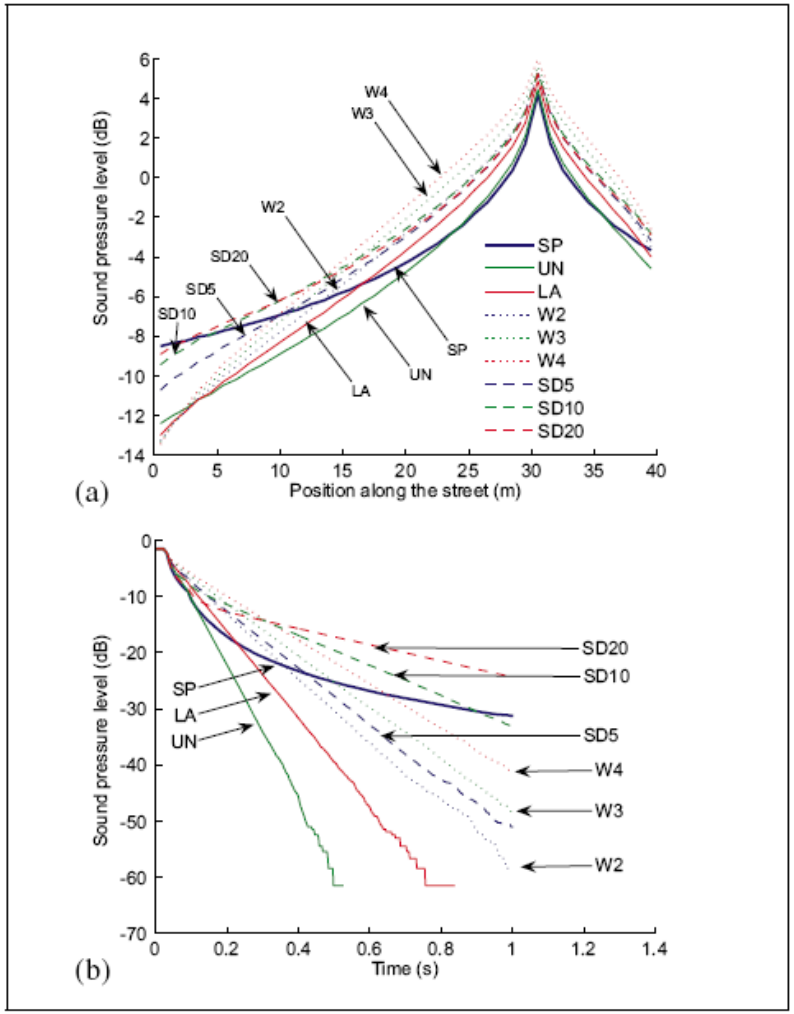


Figure 2. Effect of the façade reflection laws on the sound propagation along the street: (a) sound attenuation and (b) sound decay in the street.

Table II. Effect of diffusor reflection law on the sound propagation in a street, in terms of global sound decay (RT30, EDT) and sound attenuation (m, $\overline{\Delta L}$). Symbol * mentions configurations that have a significant effect of the noise reduction in the street. The relative deviation σ_m and σ_{RT} (in %) by comparison with the reference configuration SP is also given in parenthesis.

Reflection laws	RT30 (s)	EDT (s)
SP	2.81	0.54
UN*	0.51 (82%)	0.53 (2%)
LA	0.77 (73%)	0.72 (−33%)
W2	1.04 (63%)	0.93 (−72%)
W3	1.31 (53%)	1.16 (−115%)
W4	1.53 (46%)	1.39 (−157%)
SD5	1.18 (58%)	1.00 (−85%)
SD10	2.19 (22%)	1.15 (−113%)
SD20	3.82 (−36%)	0.76 (−41%)
Reflection laws	**m (dB/m)**	**$\overline{\Delta L}$ (dB)**
SP	0.25	—
UN*	0.41 (−64%)	1.03
LA	0.47 (−88%)	0.35
W2	0.51 (−104%)	−0.25
W3	0.55 (−120%)	−0.79
W4	0.57 (−128%)	−1.26
SD5	0.40 (−60%)	−0.65
SD10	0.36 (−44%)	−1.17
SD20	0.33 (−32%)	−1.11

Diffuseur urbain

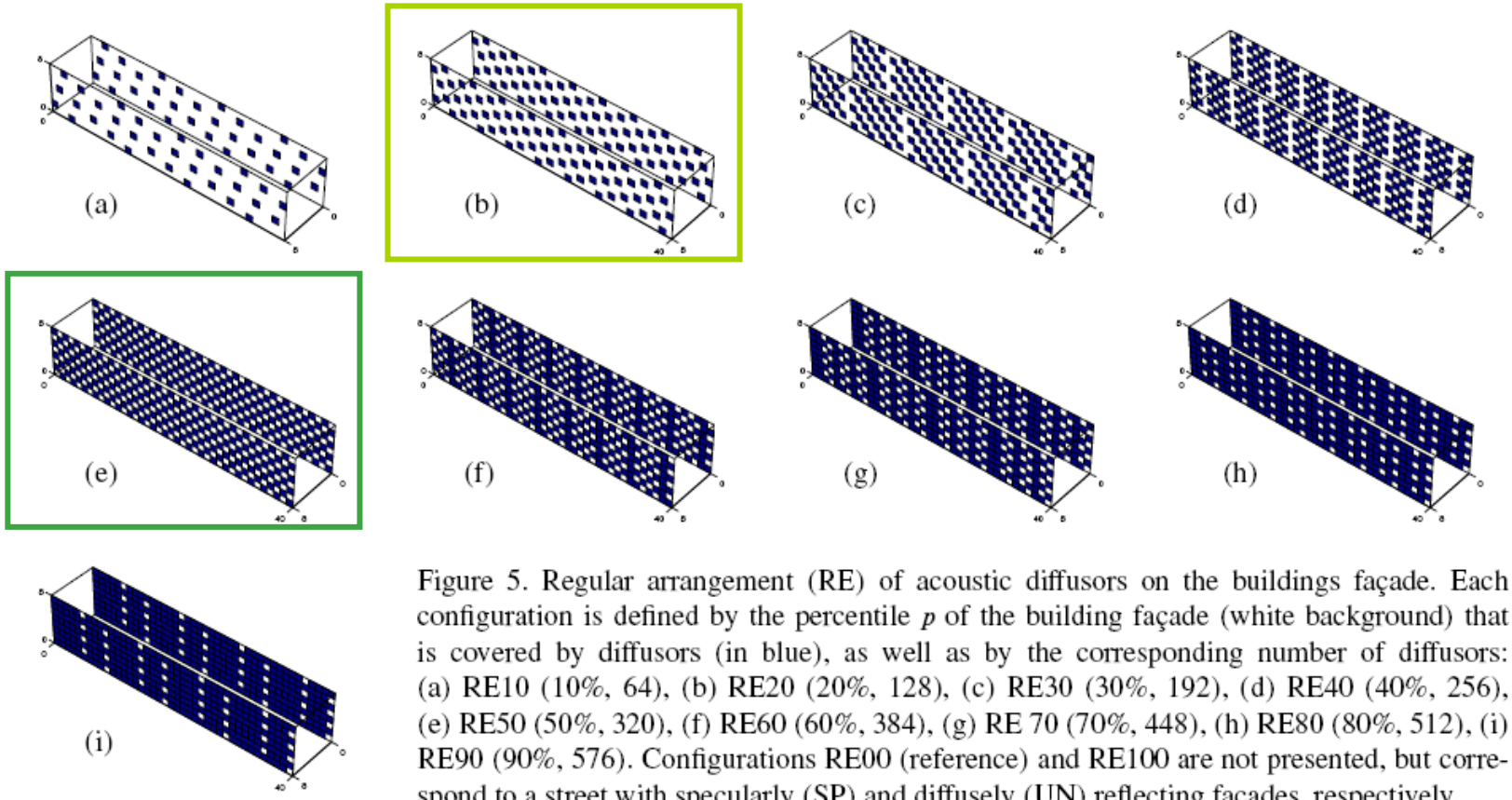


Figure 5. Regular arrangement (RE) of acoustic diffusors on the buildings façade. Each configuration is defined by the percentile p of the building façade (white background) that is covered by diffusors (in blue), as well as by the corresponding number of diffusors: (a) RE10 (10%, 64), (b) RE20 (20%, 128), (c) RE30 (30%, 192), (d) RE40 (40%, 256), (e) RE50 (50%, 320), (f) RE60 (60%, 384), (g) RE 70 (70%, 448), (h) RE80 (80%, 512), (i) RE90 (90%, 576). Configurations RE00 (reference) and RE100 are not presented, but correspond to a street with specularly (SP) and diffusely (UN) reflecting façades, respectively.

Diffuseur urbain

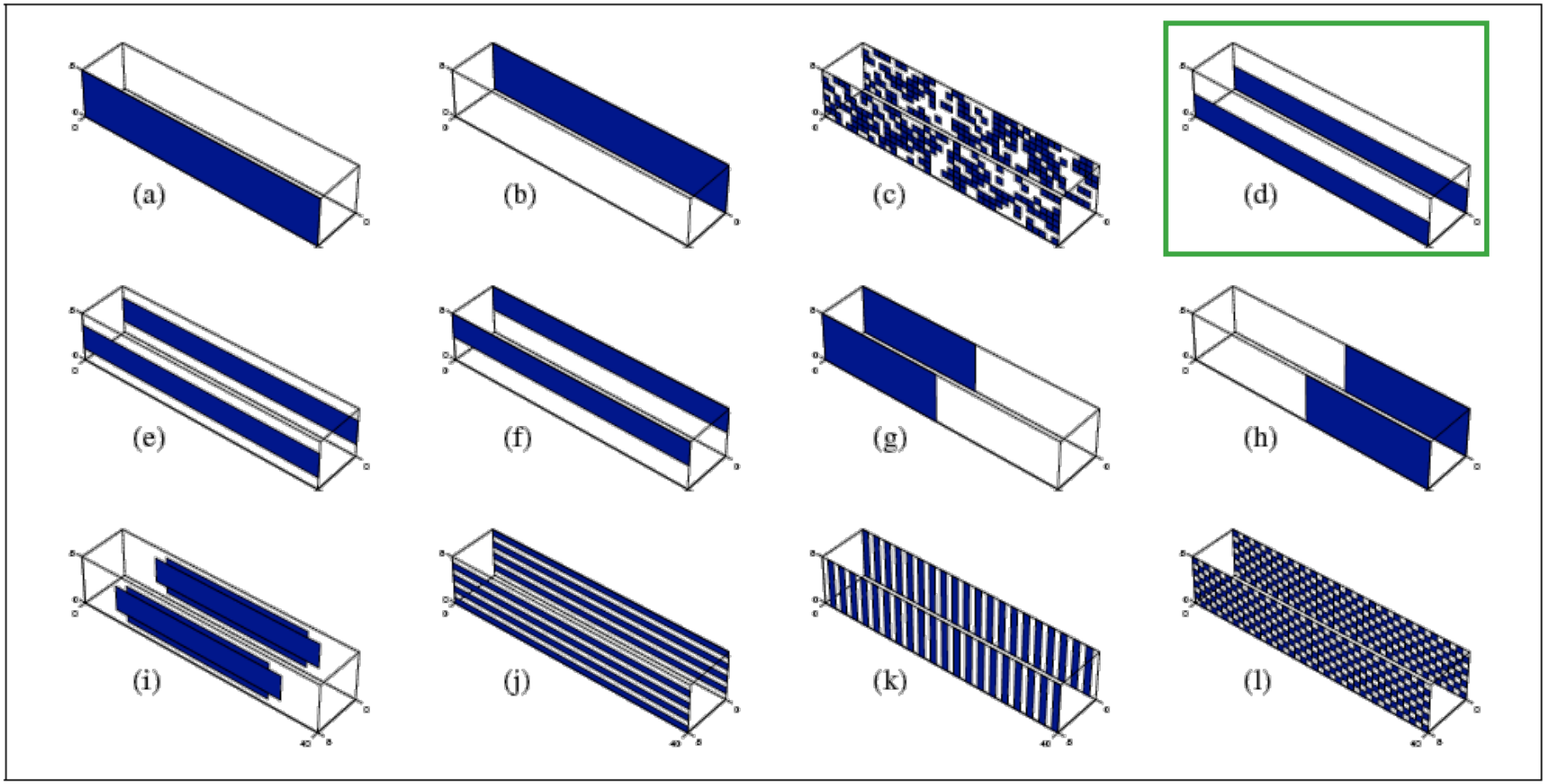


Figure 7. Diffusors arrangement (in blue) on the building façades, with $p = 50\%$: (a) right façade (RF), (b) left façade (LF), (c) random arrangement (RA), (d) lower part of the façade (LO), (e) middle part (MI), (f) upper part (UP), (g) half-part of the façade away from the sound source (HA), (h) half-part of the façade close to the sound source (HC), (i) center of the façade (CE), (j) horizontal arrangement (HO), (k) vertical arrangement (VE), (l) regular arrangement (RE).

Diffuseur urbain

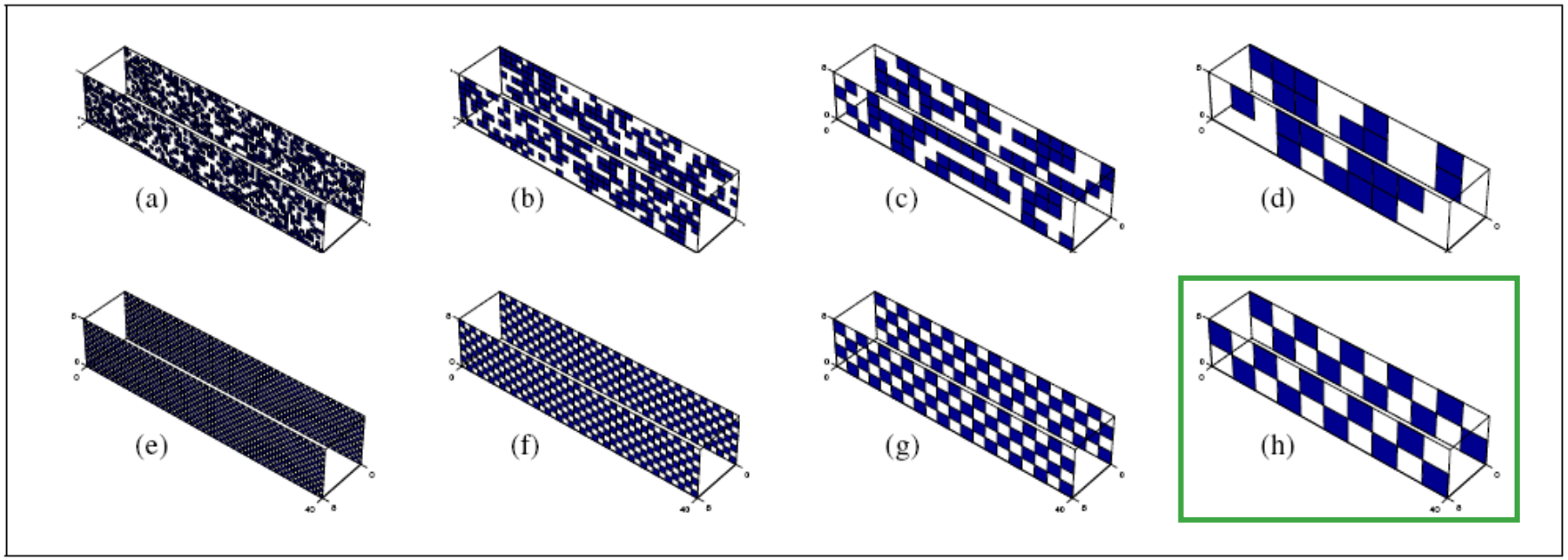


Figure 10. Random and regular arrangement of acoustic diffusors of different sizes. Random arrangement of diffusors of size: (a) 0.5 m×0.5 m (RA05), (b) 1 m×1 m (RA1), (c) 2 m×2 m (RA2), (d) 4 m×4 m (RA4). Regular arrangement of diffusors of size: (e) 0.5 m×0.5 m (RE05), (f) 1 m×1 m (RE1), (g) 2 m×2 m (RE2), (h) 4 m×4 m (RE4). 50% of the building façades is covered by diffusors.

Diffuseur urbain

Table VI. Effect of absorption of the sound propagation in a street, in terms of global sound decay (RT30, EDT) and sound attenuation (m, $\overline{\Delta L}$), for 9 absorption configurations A0 to A8, for each of the LO, LF and RA configurations. $\bar{\alpha}$ is the mean absorption of the façades. Absorption configurations have been sorted by the mean absorption coefficient. The relative deviations σ_m and σ_{RT} (in %) with the reference configuration A0 is also given in parenthesis.

	α_f	α_d	$\bar{\alpha}$	
A0	0.00	0.00	0.00	
A1	0.00	0.10	0.05	
A6	0.10	0.10	0.10	
A2	0.00	0.20	0.10	
A3	0.00	0.30	0.15	
A4	0.00	0.50	0.25	
A7	0.30	0.30	0.30	
A5	0.00	0.60	0.30	
A8	0.50	0.50	0.50	

Results for LO configuration

	RT30 (s)	EDT (s)	m (dB/m)	$\overline{\Delta L}$ (dB)
A0	0.42	0.46	0.43	—
A1	0.39 (7.1%)	0.43 (6.5%)	0.43 (0.0%)	0.39
A6	0.36 (14.3%)	0.43 (6.5%)	0.43 (0.0%)	0.49
A2	0.37 (11.9%)	0.41 (10.9%)	0.43 (0.0%)	0.78
A3	0.35 (16.7%)	0.38 (17.4%)	0.44 (−2.3%)	1.18
A4	0.31 (26.2%)	0.33 (28.3%)	0.45 (−4.7%)	1.99
A7	0.31 (26.2%)	0.36 (21.7%)	0.45 (−4.7%)	1.45
A5	0.28 (33.3%)	0.31 (32.6%)	0.45 (−4.7%)	2.40
A8	0.26 (38.1%)	0.31 (32.6%)	0.46 (−7.0%)	2.41

Results for LF configuration

	RT30 (s)	EDT (s)	m (dB/m)	$\overline{\Delta L}$ (dB)
A0	0.52	0.53	0.38	—
A1	0.49 (5.8%)	0.50 (5.7%)	0.39 (−2.6%)	0.32
A6	0.46 (11.5%)	0.51 (3.8%)	0.40 (−5.3%)	0.64
A2	0.46 (11.5%)	0.47 (11.3%)	0.40 (−5.3%)	0.63
A3	0.43 (17.3%)	0.44 (17.0%)	0.41 (−7.9%)	0.96
A4	0.37 (28.8%)	0.37 (30.2%)	0.42 (−10.5%)	1.62
A7	0.37 (28.8%)	0.41 (22.6%)	0.42 (−10.5%)	1.84
A5	0.34 (34.6%)	0.33 (37.7%)	0.43 (−13.2%)	1.96
A8	0.30 (42.3%)	0.33 (37.2%)	0.44 (−15.8%)	2.99

Results for RA configuration

	RT30 (s)	EDT (s)	m (dB/m)	$\overline{\Delta L}$ (dB)
A0	0.53	0.50	0.37	—
A1	0.53 (0.0%)	0.54 (8.0%)	0.37 (0.0%)	0.16
A6	0.49 (7.5%)	0.52 (−4.0%)	0.39 (−5.4%)	0.54
A2	0.49 (7.5%)	0.48 (4.0%)	0.36 (−2.7%)	0.66
A3	0.46 (13.2%)	0.47 (6.0%)	0.40 (−8.1%)	0.82
A4	0.41 (22.6%)	0.41 (18.0%)	0.40 (−8.1%)	1.40
A7	0.37 (30.2%)	0.41 (18.0%)	0.42 (−3.5%)	1.56
A5	0.37 (30.2%)	0.37 (26.0%)	0.39 (−5.4%)	2.06
A8	0.29 (45.3%)	0.32 (36.0%)	0.43 (−16.1%)	2.94

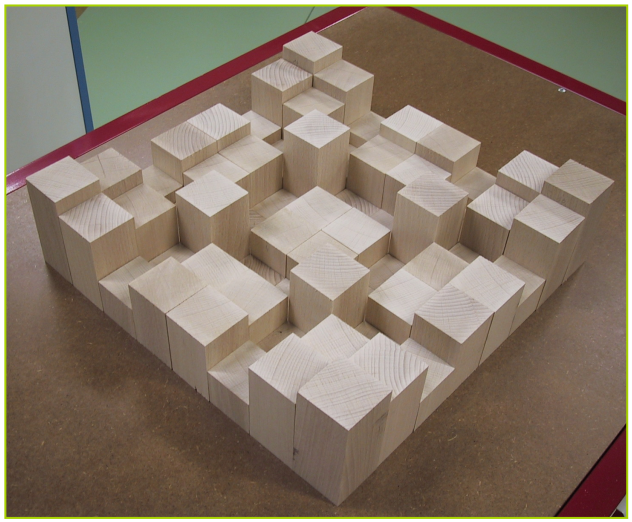
Diffuseur urbain

- Configuration optimale
  - **Loi de réflexion : uniforme**
  - **Surface relative :**
    - **50% : effet significatif**
    - **20% : effet visible**
  - **Disposition :**
    - **Partie basse**
    - **Deux façades simultanément**
  - **Taille : Pas pertinent**
  - **Absorption : Localisée sur les diffuseurs**

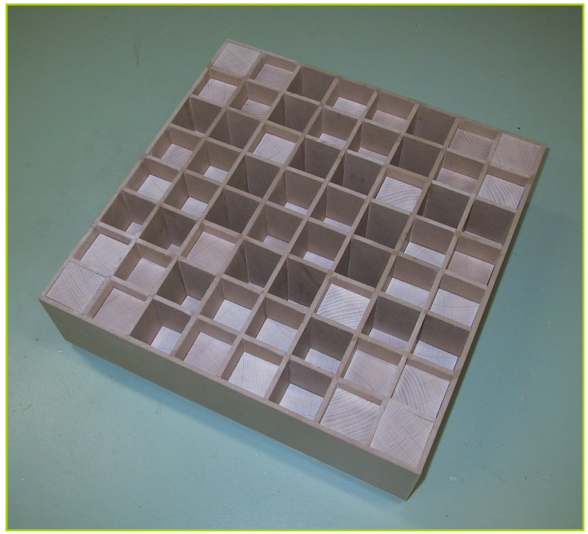
Diffuseur urbain

- 2D Quadratic Residue Diffuser (QRD)
  - **Longueur : N = 7**
  - **Période : 1 x N + 1**
  - **Profondeur maximale : 18 cm**
  - **Largeur : 10 cm**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1	4	2	2	4	1	0	1	4	2	2	4	1
2	1	2	5	3	3	5	2	1	2	5	3	3	5	2
3	4	5	1	6	6	1	5	4	5	1	6	6	1	5
4	2	3	6	4	4	6	3	2	3	6	4	4	6	3
5	2	3	6	4	4	6	3	2	3	6	4	4	6	3
6	4	5	1	6	6	1	5	4	5	1	6	6	1	5
7	1	2	5	3	3	5	2	1	2	5	3	3	5	2
8	0	1	4	2	2	4	1	0	1	4	2	2	4	1
9	1	2	5	3	3	5	2	1	2	5	3	3	5	2
10	4	5	1	6	6	1	5	4	5	1	6	6	1	5
11	2	3	6	4	4	6	3	2	3	6	4	4	6	3
12	2	3	6	4	4	6	3	2	3	6	4	4	6	3
13	4	5	1	6	6	1	5	4	5	1	6	6	1	5
14	1	2	5	3	3	5	2	1	2	5	3	3	5	2

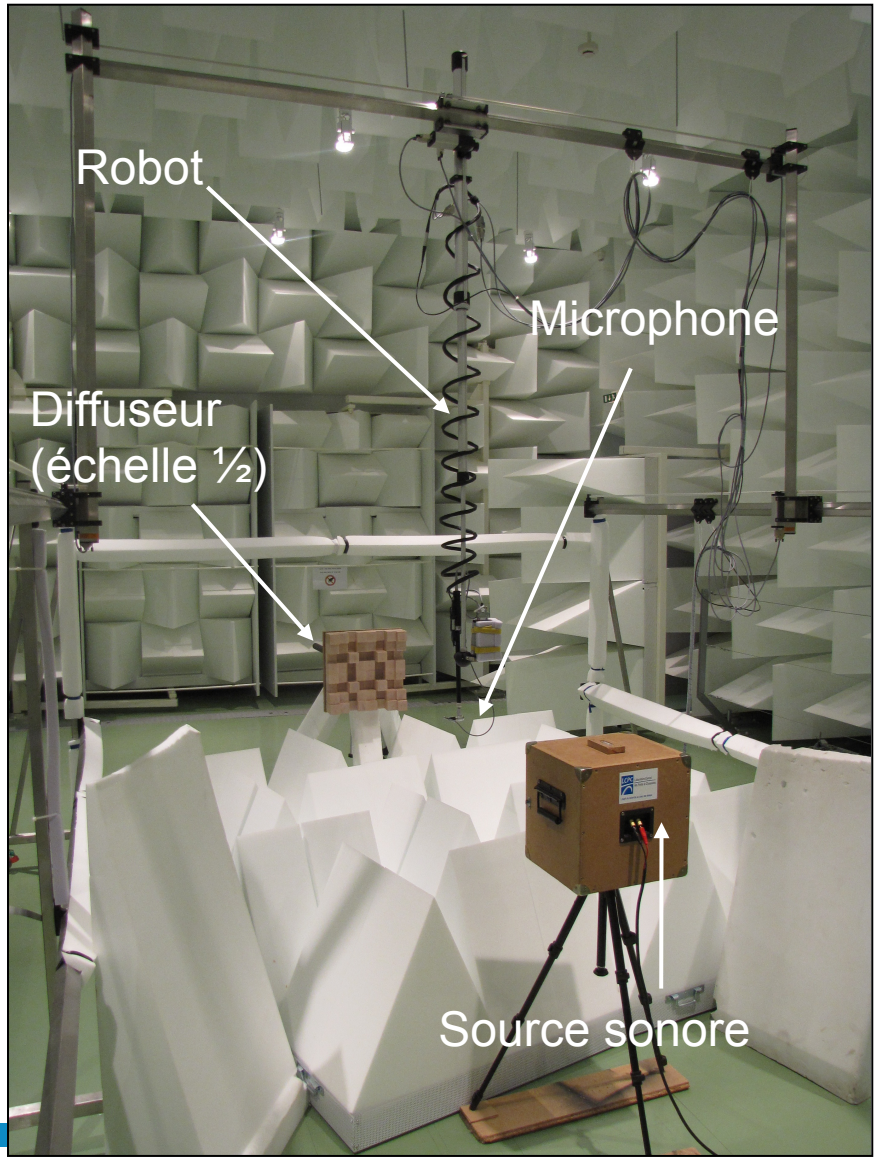


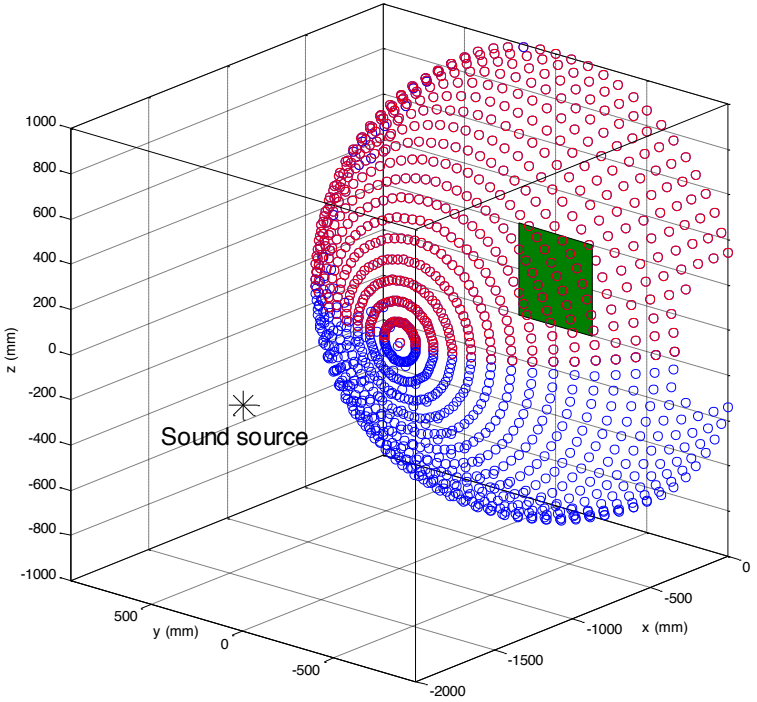
Sans cloison



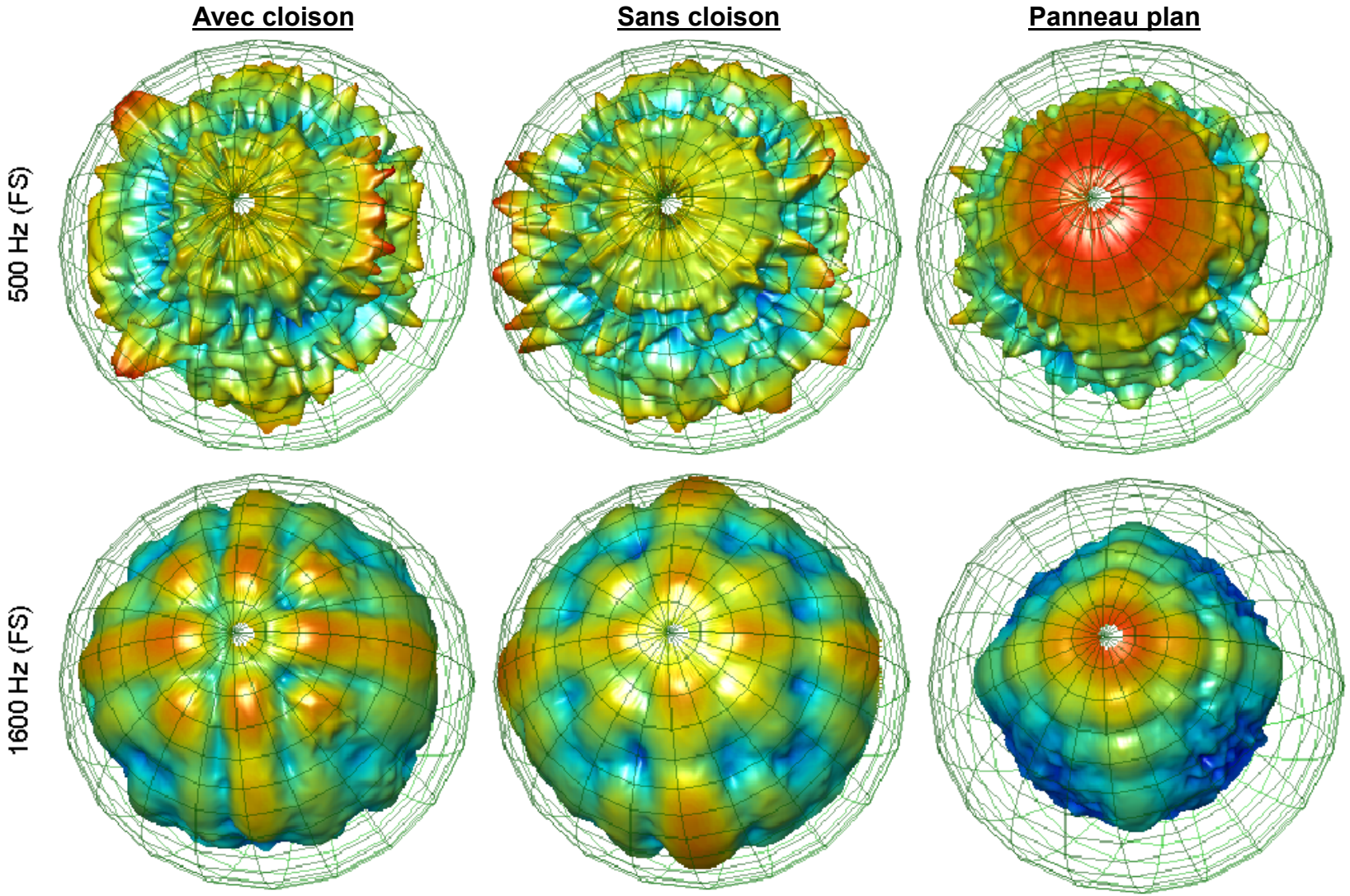
Avec cloison

Diffuseur urbain

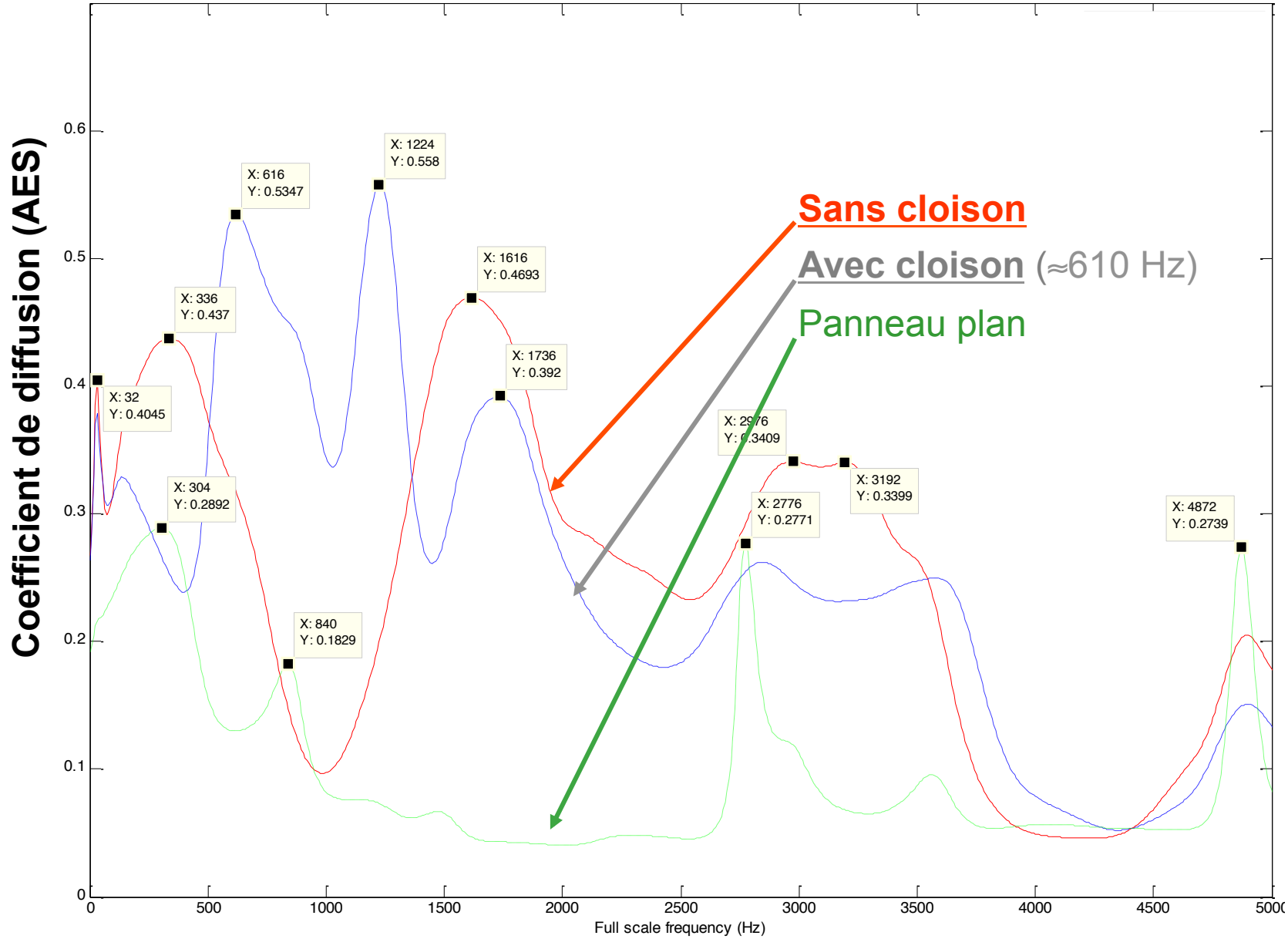




Diffuseur urbain



Diffuseur urbain



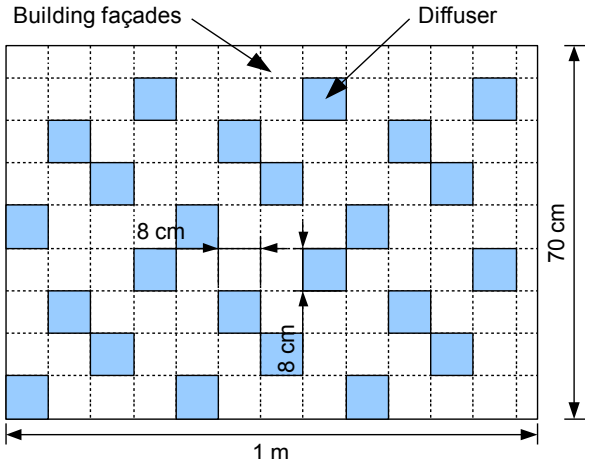
Diffuseur urbain

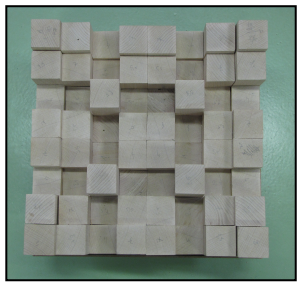
- Configuration optimale
  - **QRD** avec cloison
    - **[500-1400] Hz (i.e. trafic routier)**
    - **Coefficient de diffusion > 0.5**
    - **Fréquence d'optimisation : 610 Hz**
    - **Limite supérieure : 2000 Hz**
  - **QRD** sans cloison
    - **<500 Hz & >1400 Hz (compl. au trafic routier)**
    - **Coefficient de diffusion > 0.4**
    - **Limite supérieure : 2000 Hz**

Diffuseur urbain

Façades

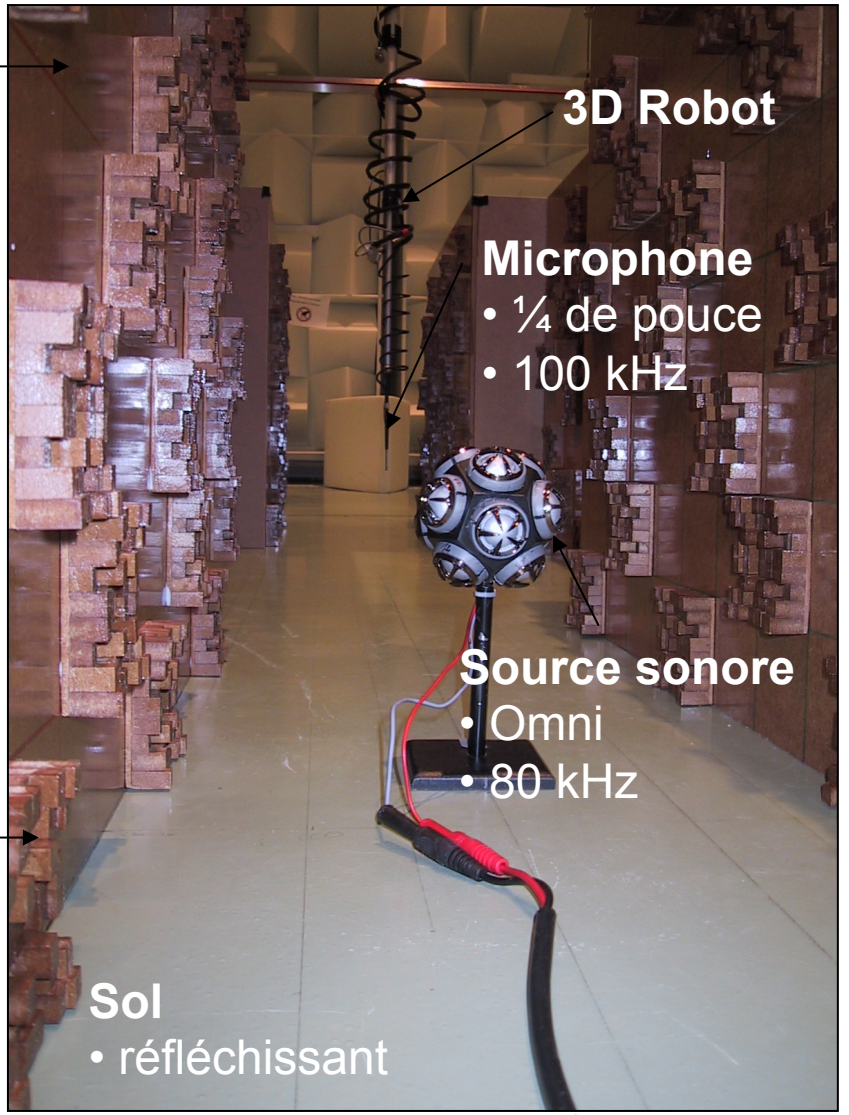
- 70 cm@haut (7 mFS) x 4 m@long (40 mFS)
- Bois vernis
- Disposition aléatoire des diffuseurs (22%)





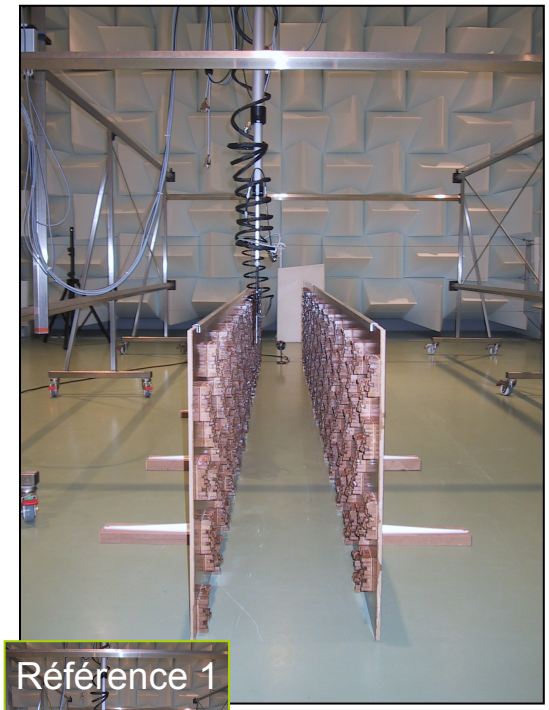
Diffuseur

- 2D QRD sans cloison
- 8 cm (80 cm FS)
- Bois vernis



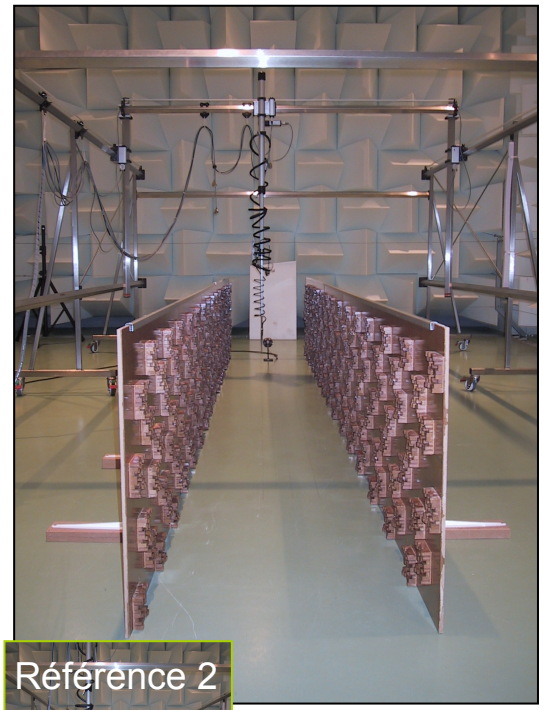
Diffuseur urbain

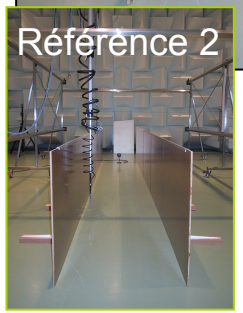
Configuration 1 (largeur : 4 mFS)





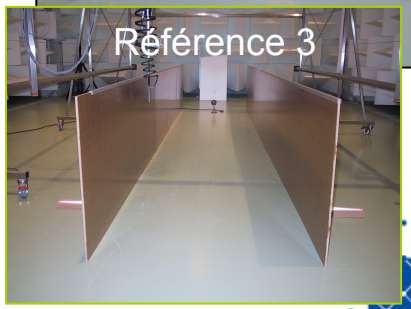
Configuration 2 (largeur : 7 mFS)



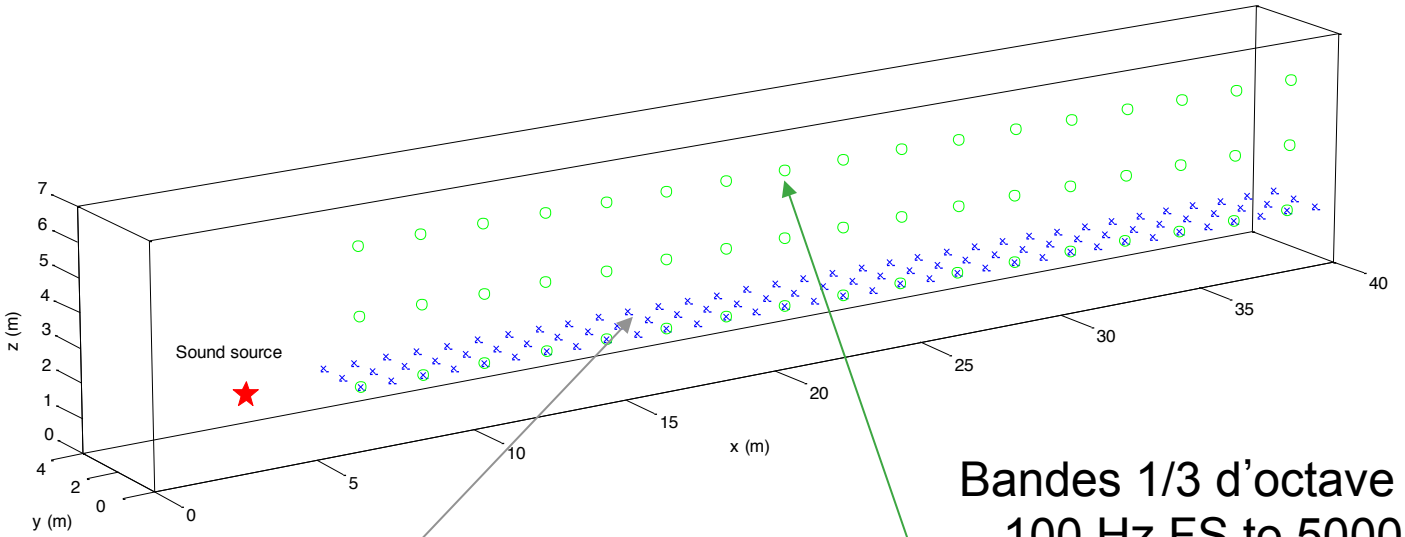


Configuration 3 (largeur : 10 mFS)





Diffuseur urbain



Bandes 1/3 d'octave d'étude :
100 Hz FS to 5000 Hz FS

Plan de mesure horizontal

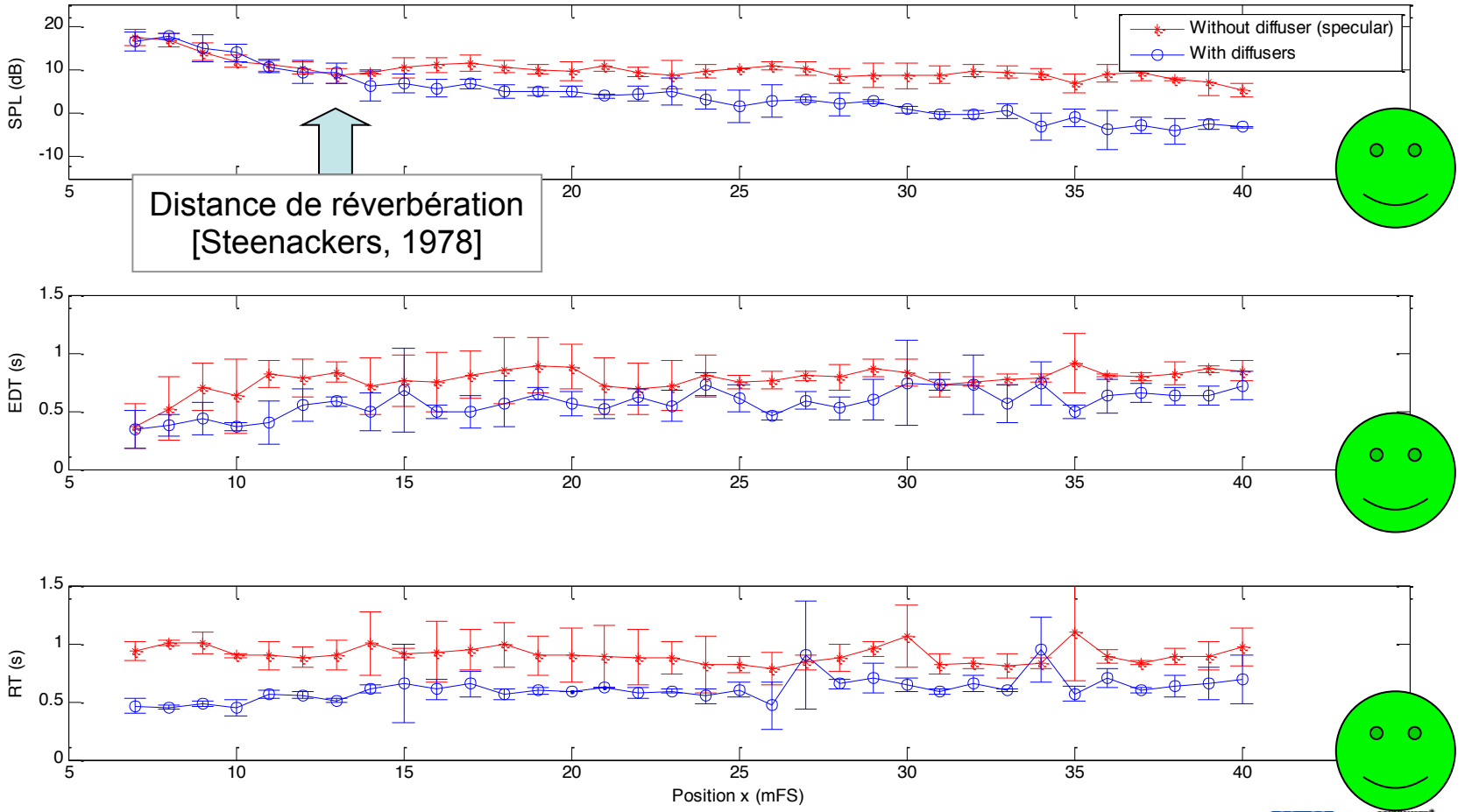
- 34 x 3 = 102 positions (Conf. 1)
- 34 x 6 = 204 positions (Conf. 2)
- 34 x 9 = 306 positions (Conf. 3)
- pas spatial : 1 mFS
- hauteur de la source (1.5 mFS)

Mesure verticale

- 17 x 3 = 51 positions
- pas : 2 mFS
- à partir de la hauteur de source

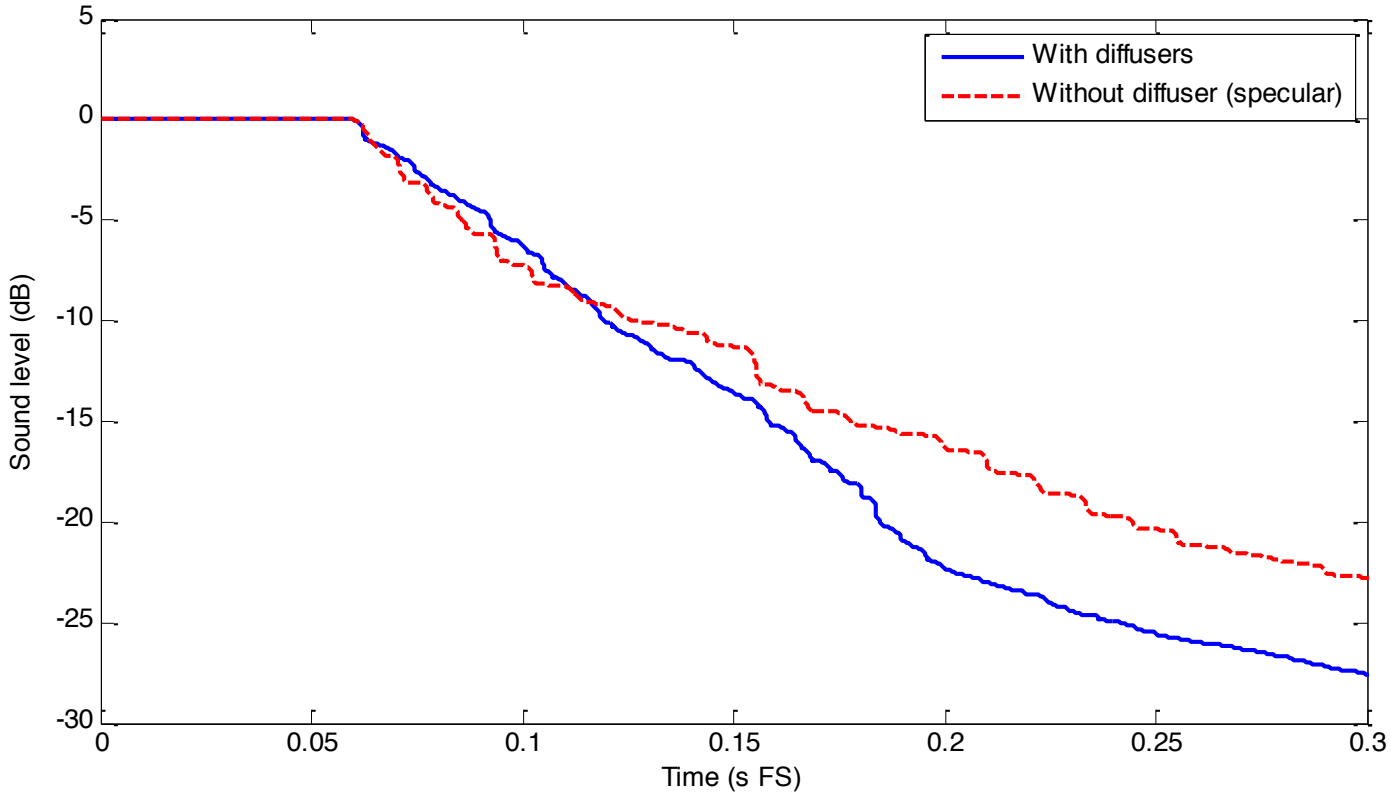
Diffuseur urbain

Configuration 1 @ **400 Hz FS**



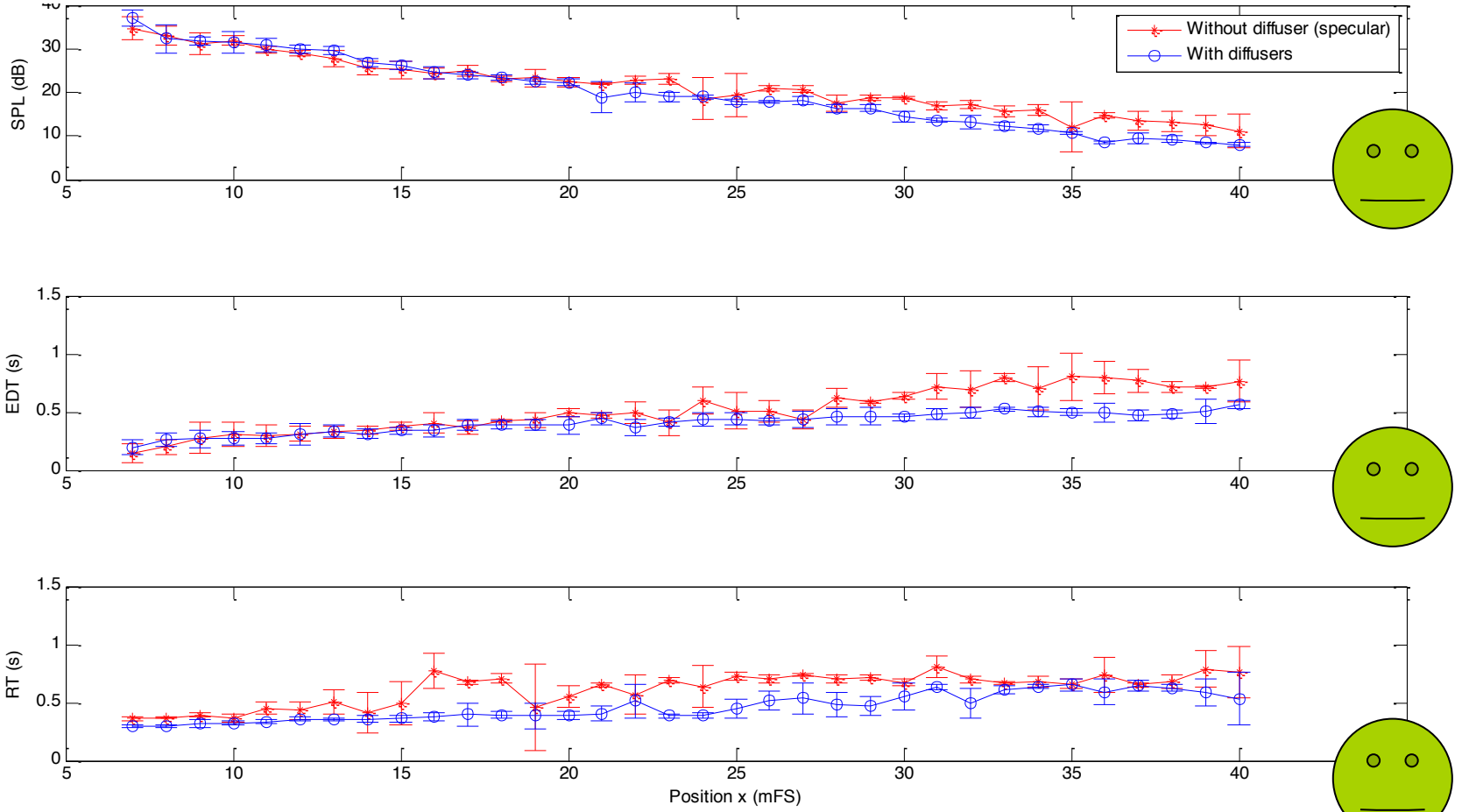
Diffuseur urbain

Configuration 1 @ **400 Hz FS**
Décroissance à 21 mFS de la source



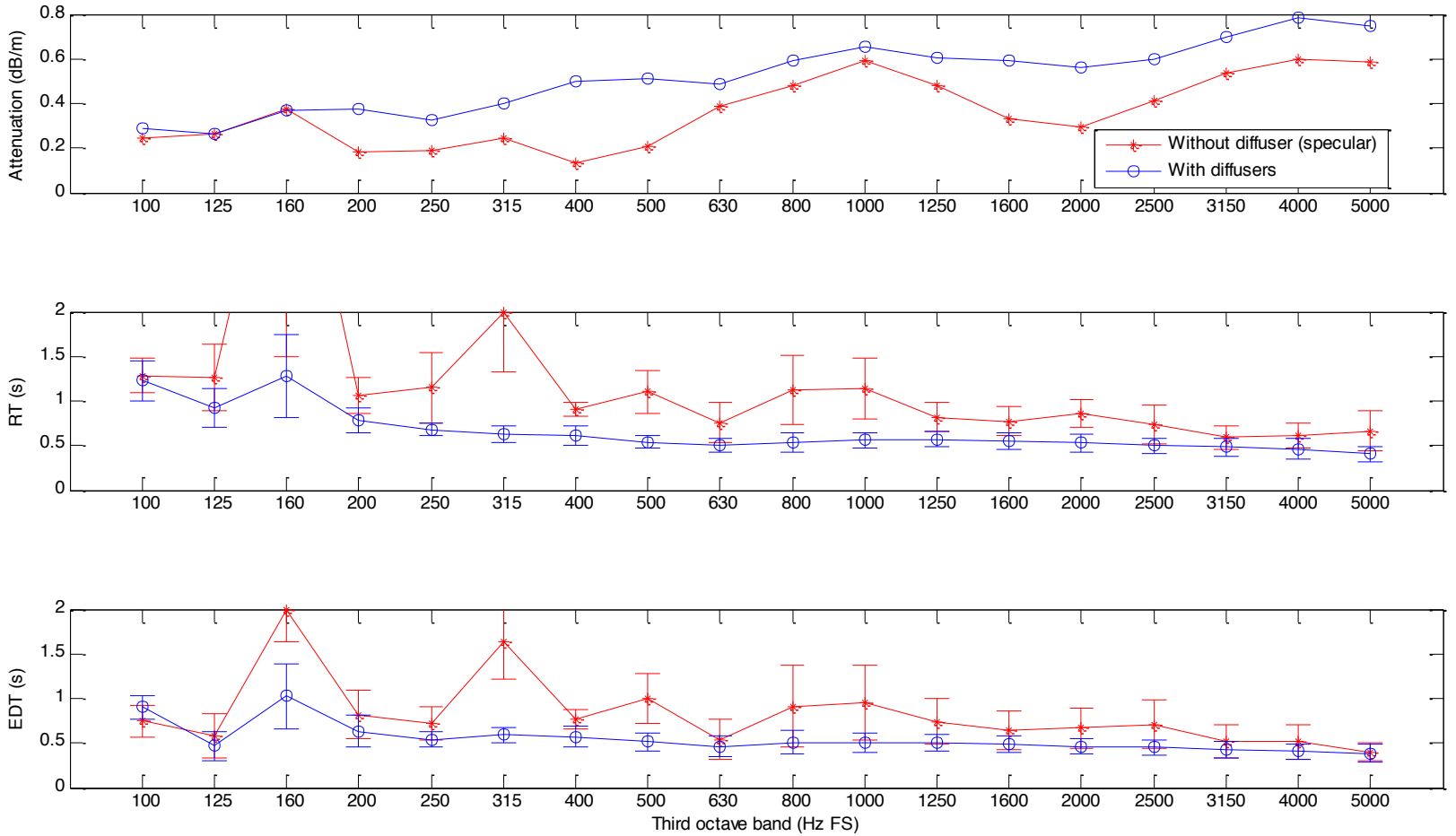
Diffuseur urbain

Configuration 1 @ **4000 Hz FS**

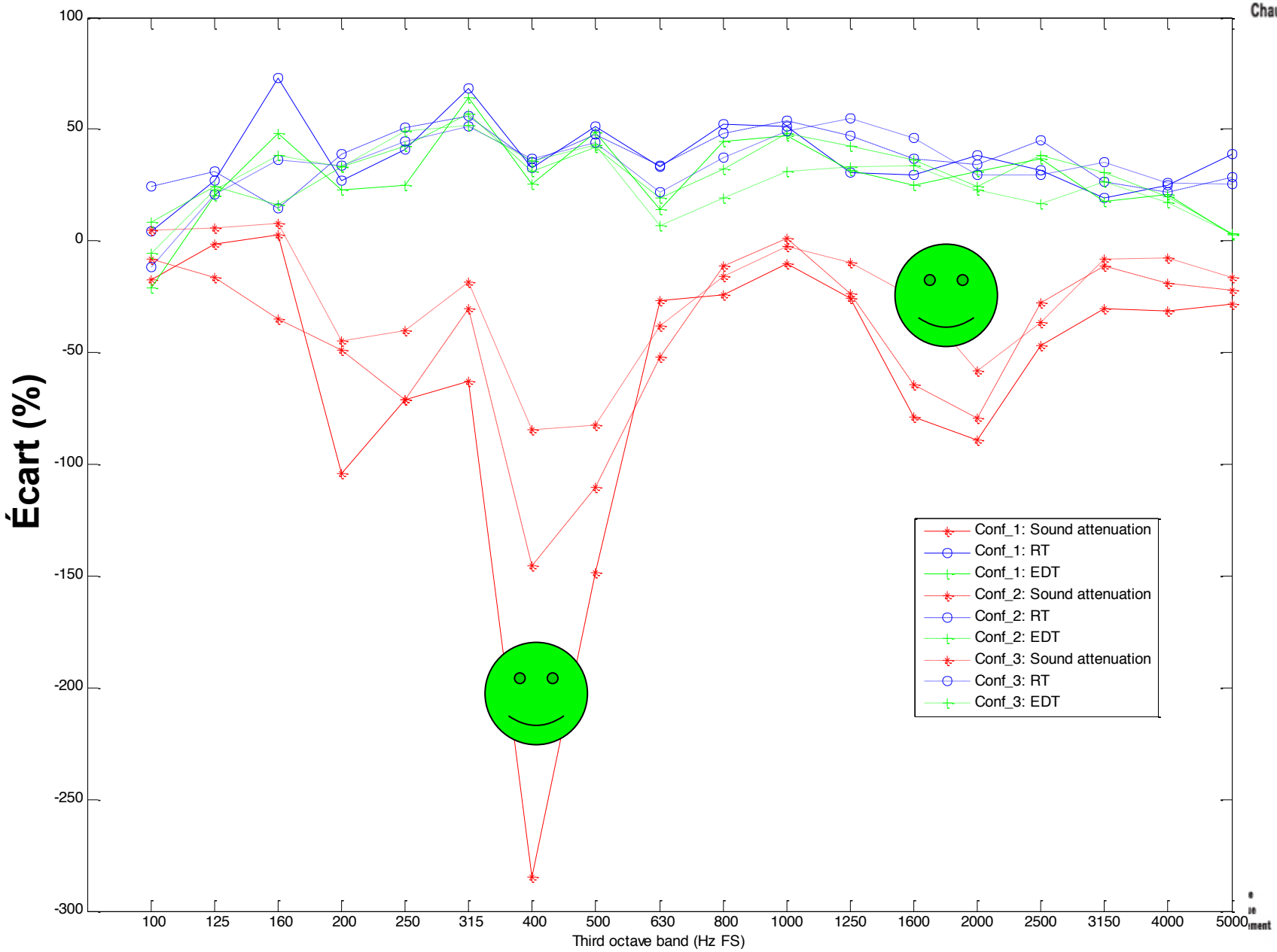


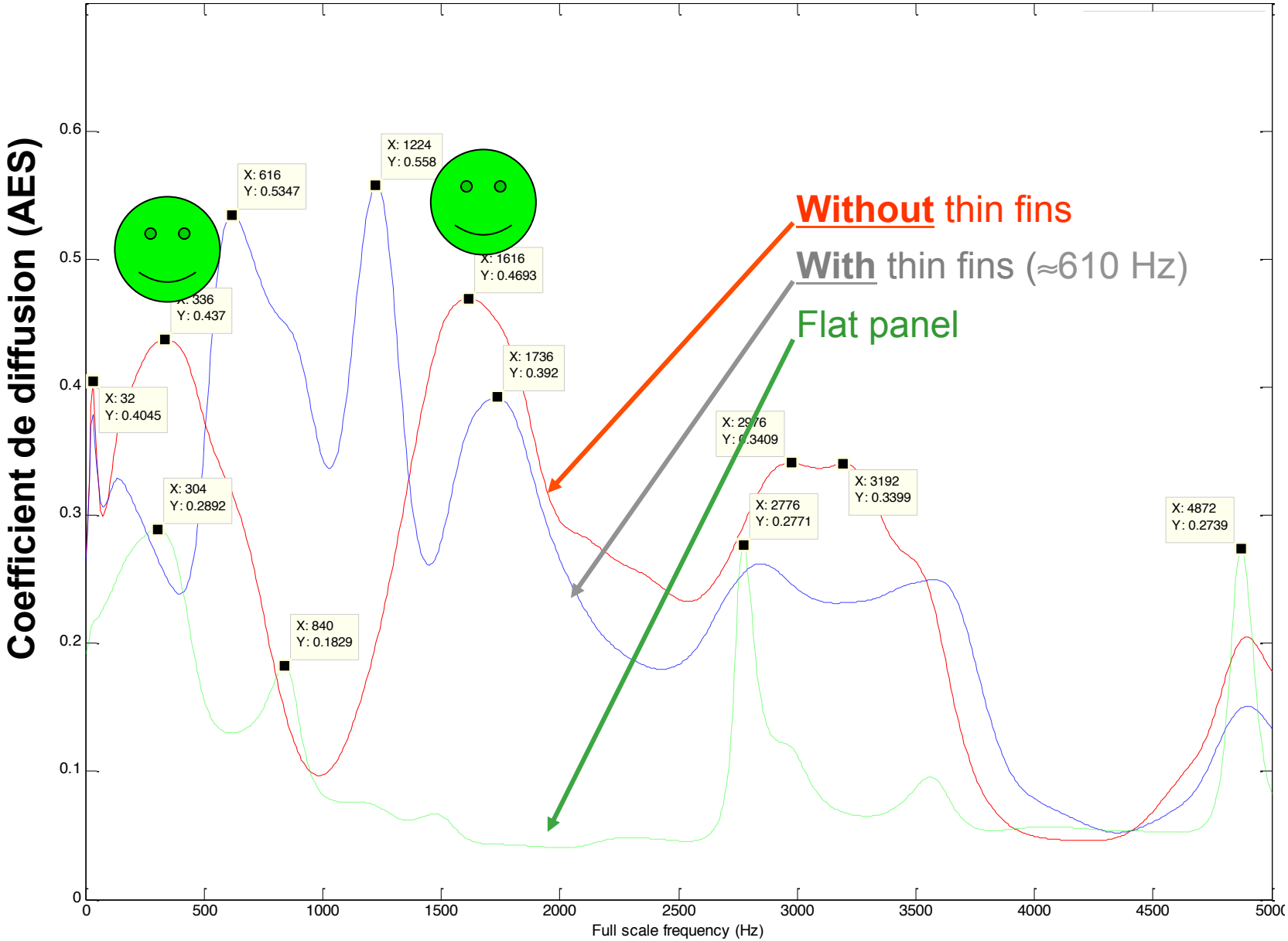
Diffuseur urbain

Configuration 1 (valeurs moyennes)



Configurations 1-3 (écart @ référence)




Coefficient de diffusion (AES)
Full scale frequency (Hz)
Without thin fins
With thin fins (≈610 Hz)
Flat panel
X: 32
Y: 0.4045
X: 336
Y: 0.437
X: 616
Y: 0.5347
X: 304
Y: 0.2892
X: 840
Y: 0.1829
X: 1224
Y: 0.558
X: 1616
Y: 0.4693
X: 1736
Y: 0.392
X: 2776
Y: 0.2771
X: 3192
Y: 0.3399
X: 4872
Y: 0.2739

- Éfficacité des diffuseurs ? **Vérifiée**
  - Diminution de la réverbération jusqu'à 50% quelque soit la fréquence et la largeur de rue
  - Augmentation de l'atténuation sonore (effet en champ lointain)
    - Rue de faible largeur
    - Bandes de fréquence de "design" des diffuseurs
  - L'ajout d'absorption sur les diffuseurs augmenterait ces effets

- Pertinence réelle du dispositif ? **Discutable**
  - Effet en champ lointain
    @ lignes sources
  - Façades réelles (avec des irrégularités)
    @ diffusion acoustique naturelle
  - Efficacité des diffuseurs
    @ nombre de diffuseurs (surface relative)

- Quelle suite ?
  - Validation expérimentale sur maquette ½ avec des diffuseurs absorbants (matériau adéquate)

Merci de votre attention

Judicael.Picaut@lcpc.fr

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