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Determination of Diffuse Field Sound Absorption from a Normal Incidence Impedance Measurement

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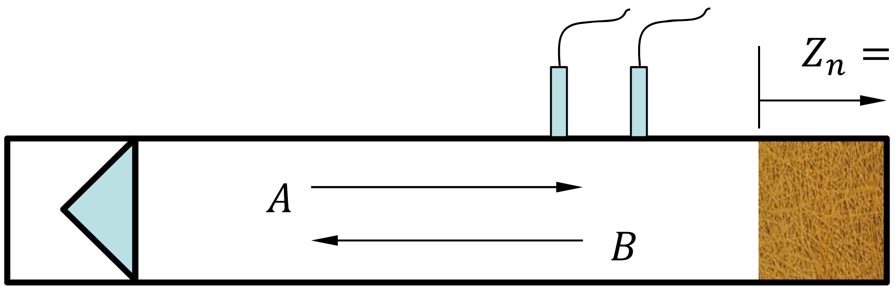
Overview

- Normal and Diffuse Absorption Coefficient
  - ✓ Normal Incidence Absorption – ASTM E1050
  - ✓ Diffuse Field Absorption – ASTM C423
- Sample Size for ASTM C423
- Diffusiveness in the Chamber
- Sensitivity Studies

Normal Incident Absorption ASTM E1050

Characteristic impedance

$$Z_n = R_n + iX_n$$



Sound source

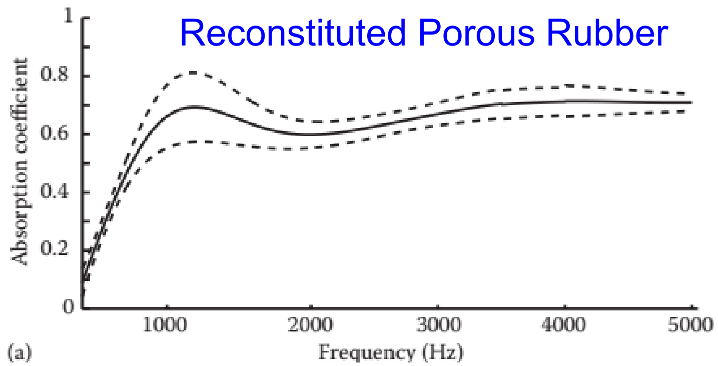
Reflection coefficient

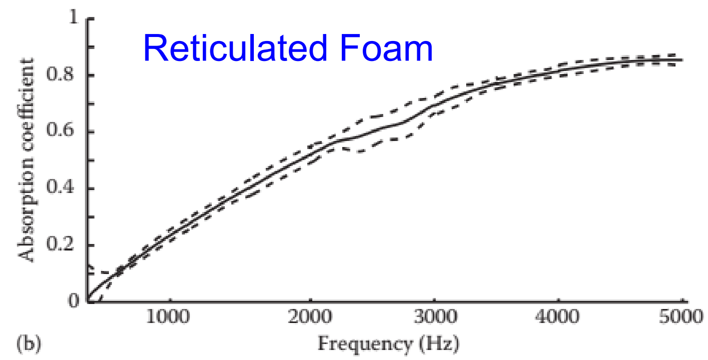
$$R = \frac{B}{A} = \frac{Z_n - 1}{Z_n + 1}$$

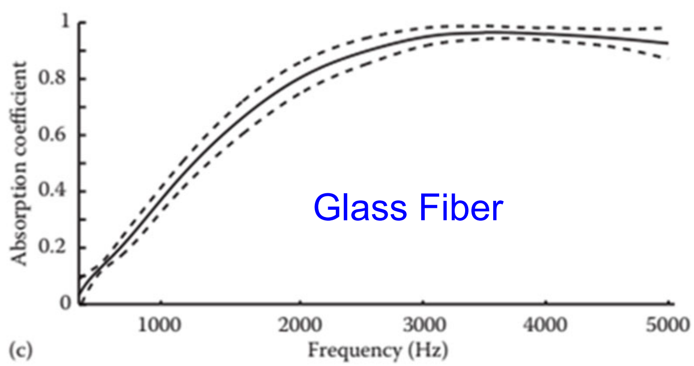
Normal-incidence absorption

$$\alpha_n = 1 - |R|^2$$

Normal Incidence Absorption Variation





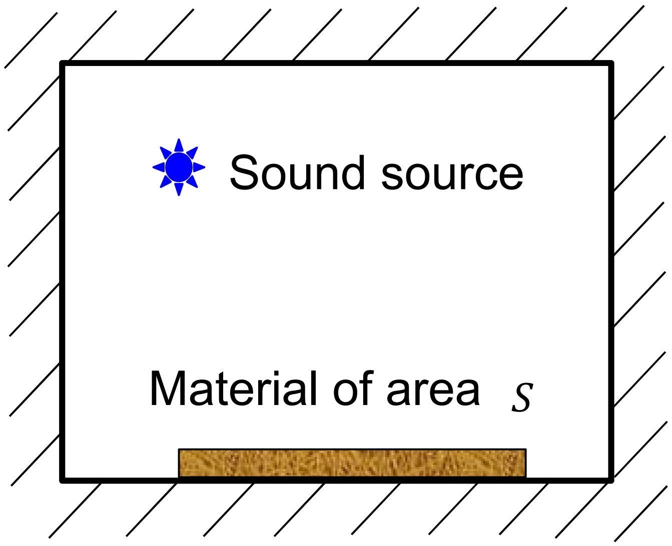


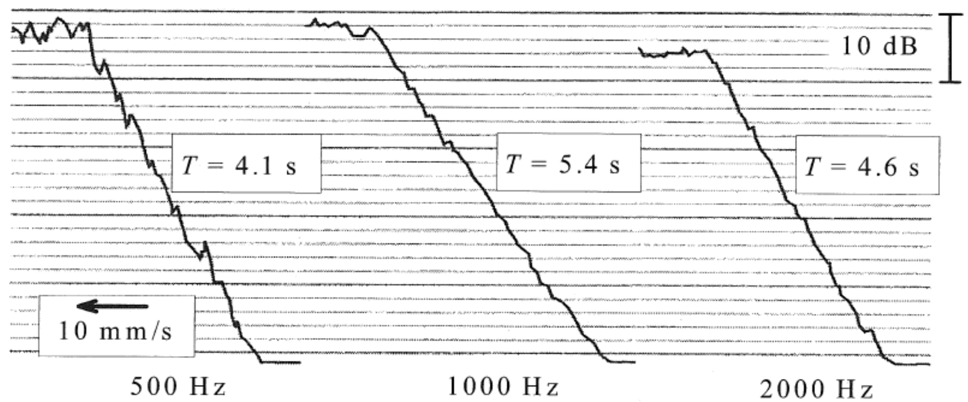
Solid line indicates the mean sound absorption. Error bars indicate the 95% confidence limit in any one laboratory based on round robin tests.

- ASTM E1050 is very repeatable.
- α_n is always less than 1.0.

Cox and D'Antonio, 2017 adapted from Horoshenkov et al., 2007

Diffuse Field Absorption ASTM C423





$$\alpha_d = 0.9210\frac{Vd}{cS}$$

V: Volume of reverberation room

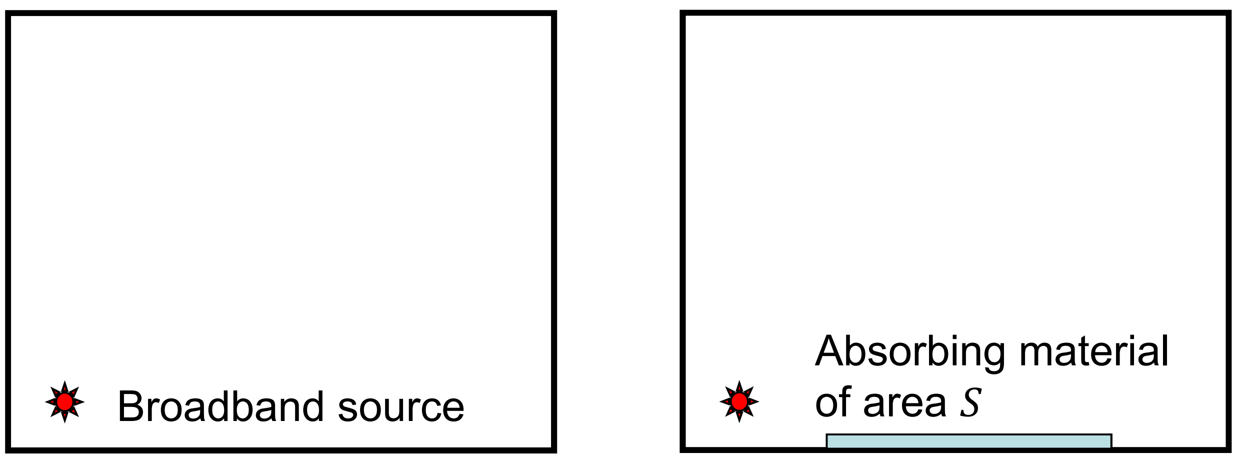
c: speed of sound

d: decay rate, dB/s

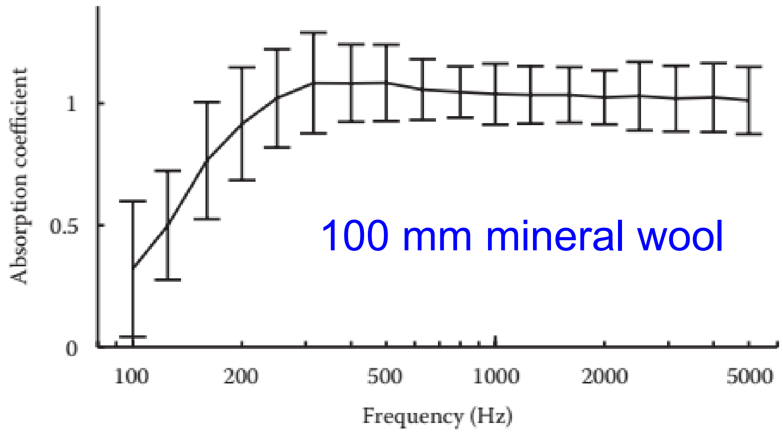
Diffuse Field Absorption

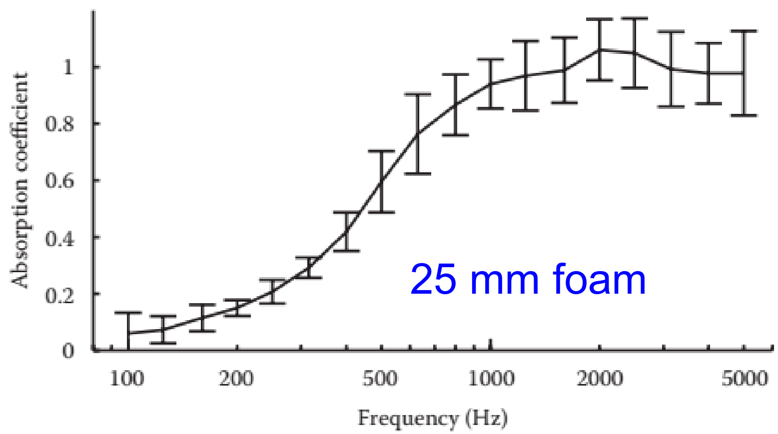
$$T_1 = \frac{55.3V}{c\left(\alpha_0\left(S_{room} - S_{sample}\right) + \alpha_s S_{sample}\right) + 4Vm_1}$$

S_{sample}	Sample area
S_{room}	Room surface area
α_0	Average absorption coefficient of empty room
m_1	Air attenuation
V	Volume



Diffuse Field Absorption Variation



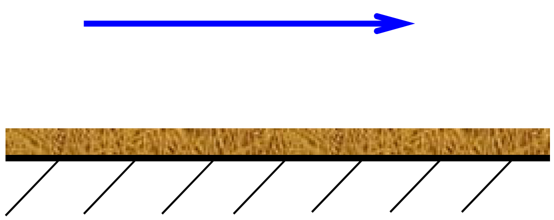


Solid line indicates the mean sound absorption. Error bars indicate the 95% confidence limit in any one laboratory measurement on round robin tests (13 laboratories).

- ASTM C423 is not as repeatable from to room to room.
- May exceed 1.0.

Cox and D'Antonio, 2017 adapted from Horoshenkov et al., 2007

Absorption Greater than 1.0



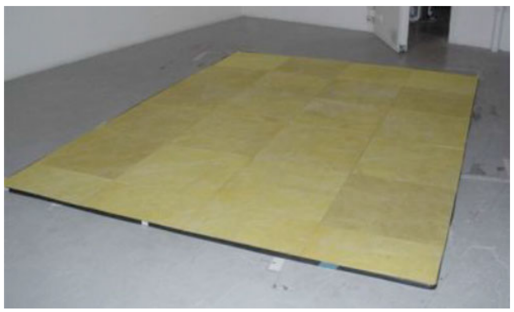
For a grazing wave, sound power is absorbed but there is technically no “incident power”. The absorbed power increases when the sample has a finite size.

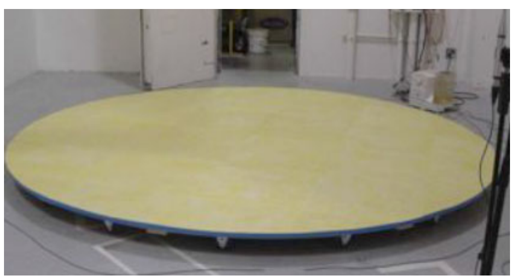
ASTM C423

Section 5.3 Diffraction effects usually cause the apparent area of a specimen to be greater than its geometrical area, thereby increasing the coefficients measured according to this test method. When the test specimen is highly absorptive, these values may exceed unity.

Section 5.4 Regardless of the differences and the necessity for judgment, coefficients measured by the test method have been used successfully by architects and consultants in the acoustical design of architectural spaces.

Discrepancy Edge Effect



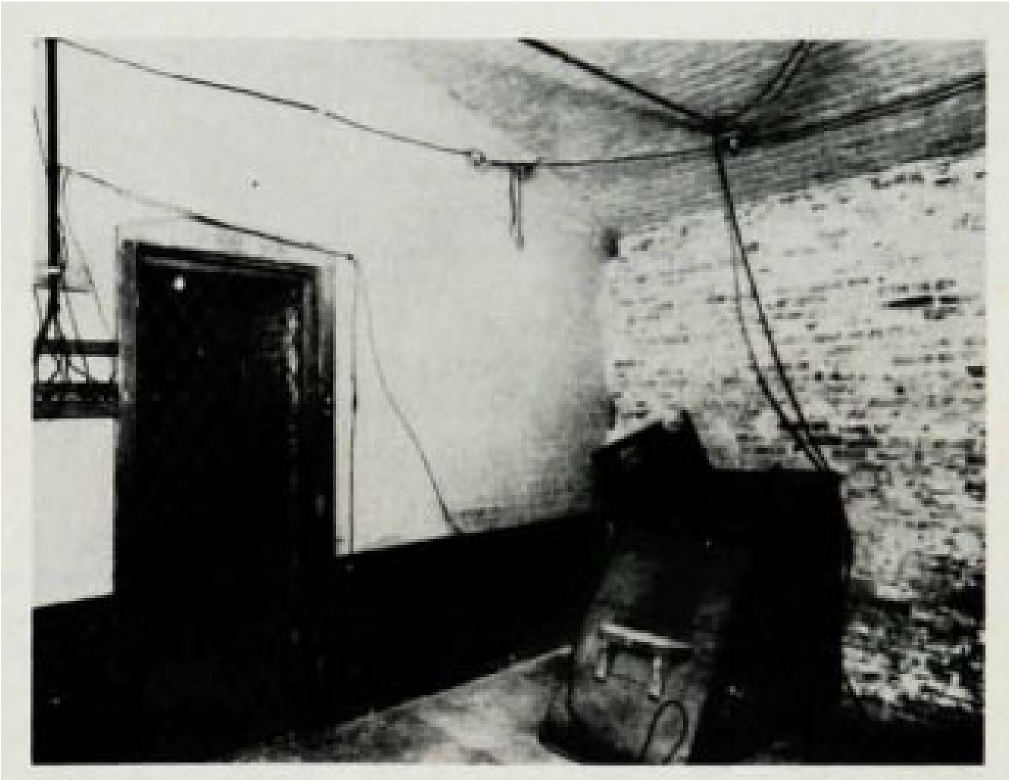


$$\alpha_d = \alpha_\infty + \beta E$$

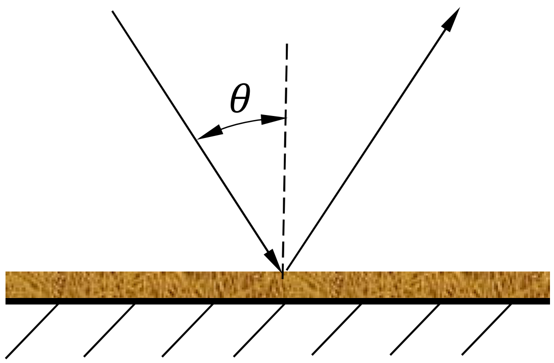
- E ratio of edges to area of sample
- α_∞ random incidence absorption coefficient of infinitely large sample ($E=0$)
- β constant that depends on frequency, the absorption, and the room.

Reverberation Room

Wallace Sabine at Harvard University



Discrepancy Between

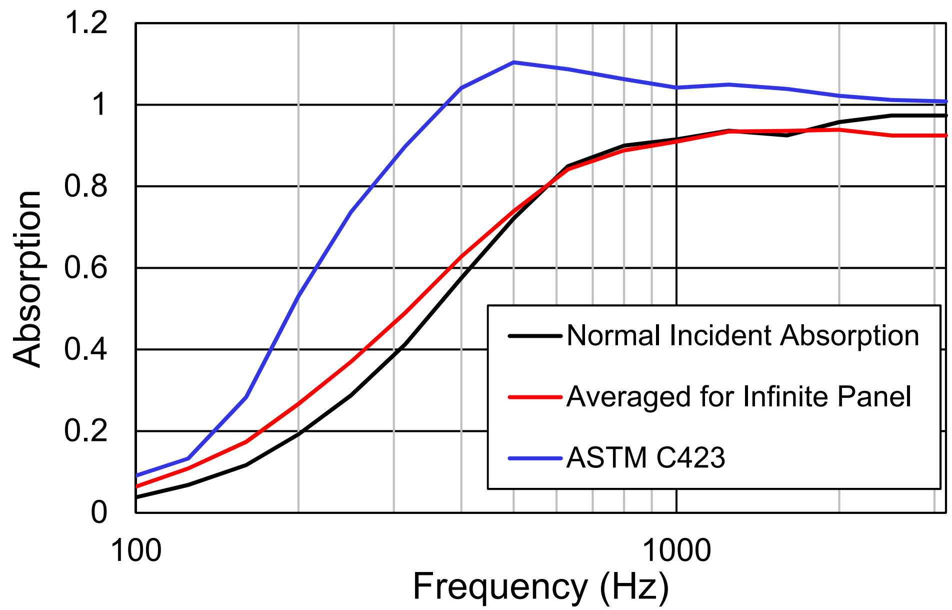


$$\alpha(\theta) = \frac{4R_n \cos\theta}{(1 + R_n \cos\theta)^2 + (X_n \cos\theta)^2}$$

Average for diffusive incidence:

$$\bar{\alpha} = 2\int_0^{\pi} \alpha(\theta) \sin\theta \cos\theta \, d\theta$$

5 cm thick mineral wool
(2.4 m x 2.4 m sample)



Overview

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  - ✓ ASTM C423
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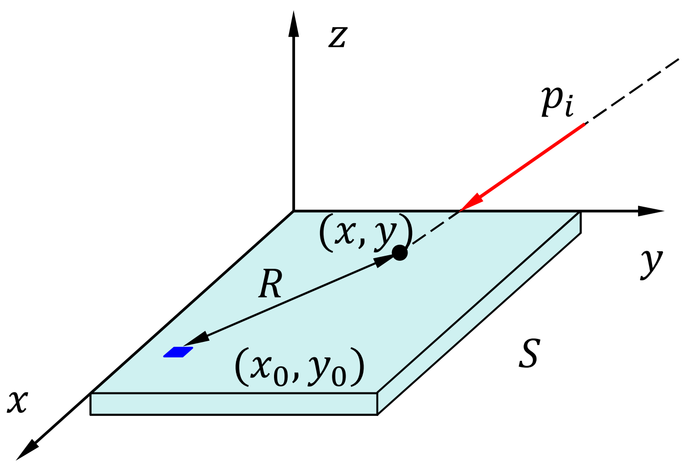
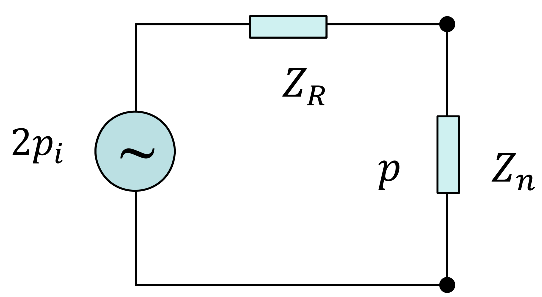
Radiation Impedance





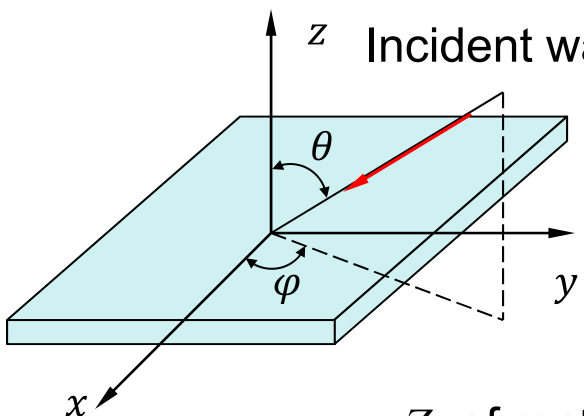
Integral on area S :

$$p(x,y,0) = \frac{Z_n}{Z_n + Z_R} 2p_i(x,y,0)$$

Z_R : Radiation Impedance

Z_R is a function of the geometry of the absorber, frequency, and angle of incidence.

Radiation Impedance



Assuming a diffusive field

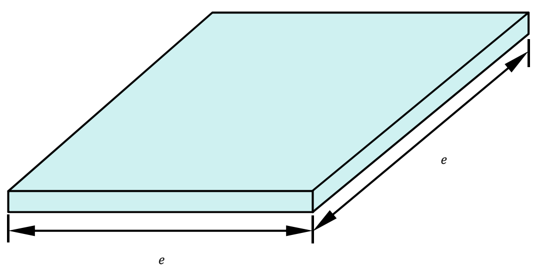
$$\alpha_d \approx 8\,\mathrm{Re}(Z_n)\int_{\theta}^{\pi/2} \frac{\sin(\theta)}{|Z_n + Z_R|}\,d\theta$$

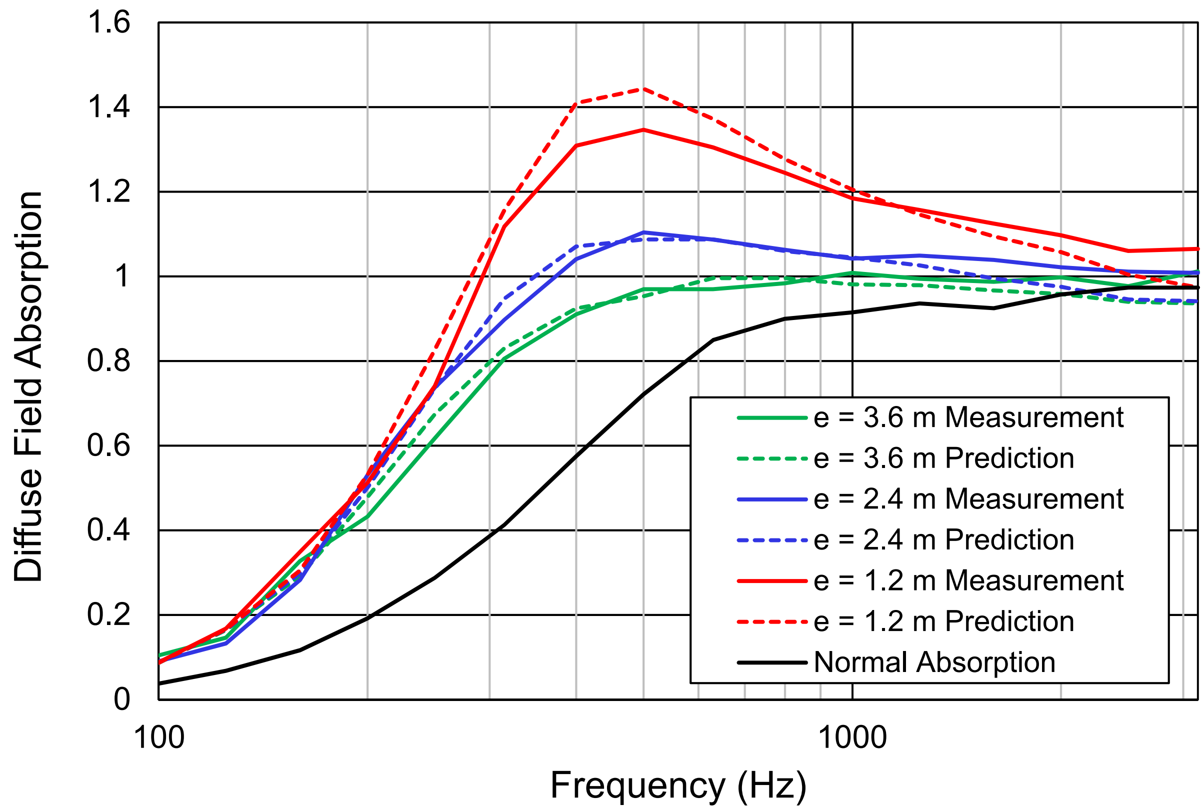
Z_R of rectangular sample (2.44 m x 2.74 m)

Z_R	$\theta = 0$	$\theta = \pi/6$	…	$\theta = \pi/2$
f = 63 Hz	0.27+0.55i	0.27+0.55i	…	0.24+0.52i
f = 125 Hz	0.79+0.65i	0.77+0.66i	…	0.51+0.68i
…	…	…	…	…
f = 4000 Hz	1.00+0.01i	1.04+0.02i	…	3.37+3.41i

Size Correction

5 cm mineral wool sample





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Diffuse Field

Redstone Arsenal – U.S. Army

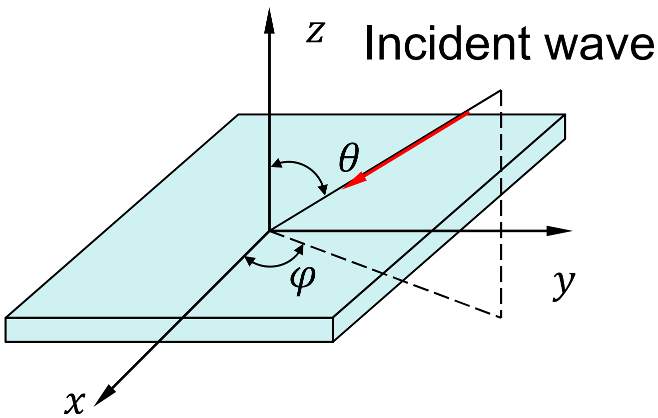
Technical University of Denmark

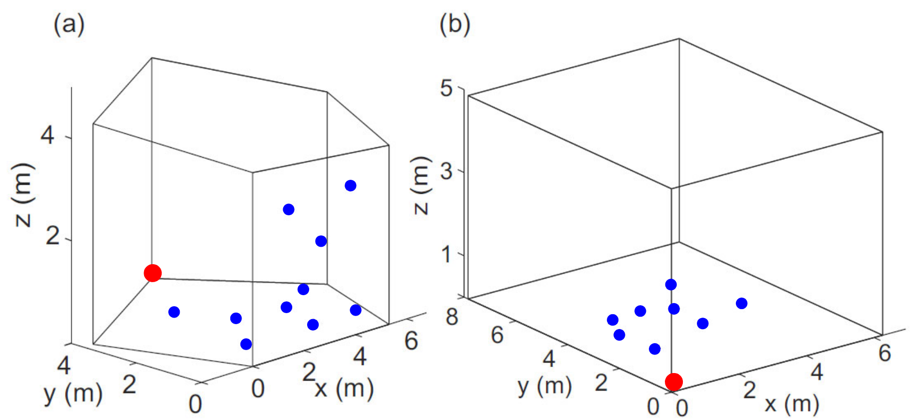
Diffuse Field means

- Sound pressure is uniform inside reverberation chamber
- Sound intensity distribution is uniform over all possible directions

Jeong, 2010
Kang, 2000

Sound Intensity Distribution





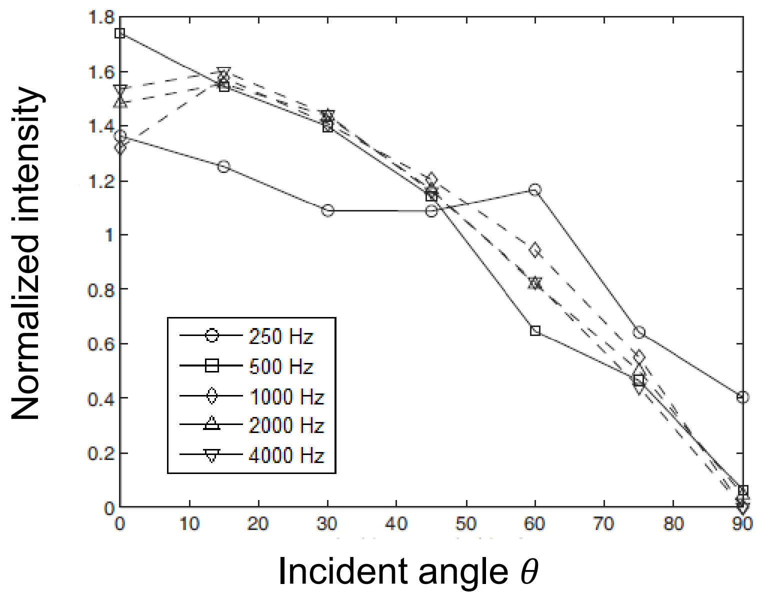
θ: Incident angle
φ: Azimuthal angle

● : Point source
● : Observation point

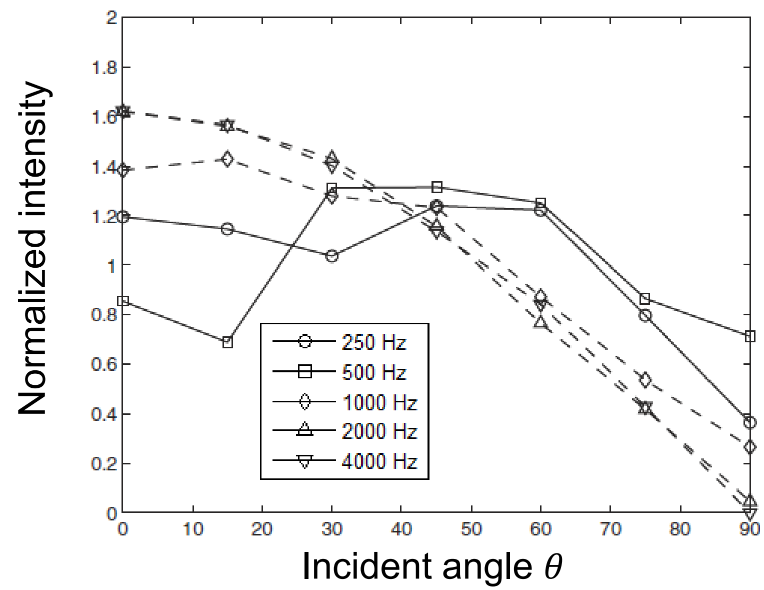
Simulation method by Jeong (2010) used beam tracing method.

Sound Intensity Distribution

Irregular room



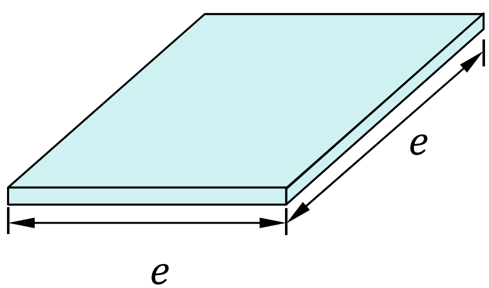
Rectangular room



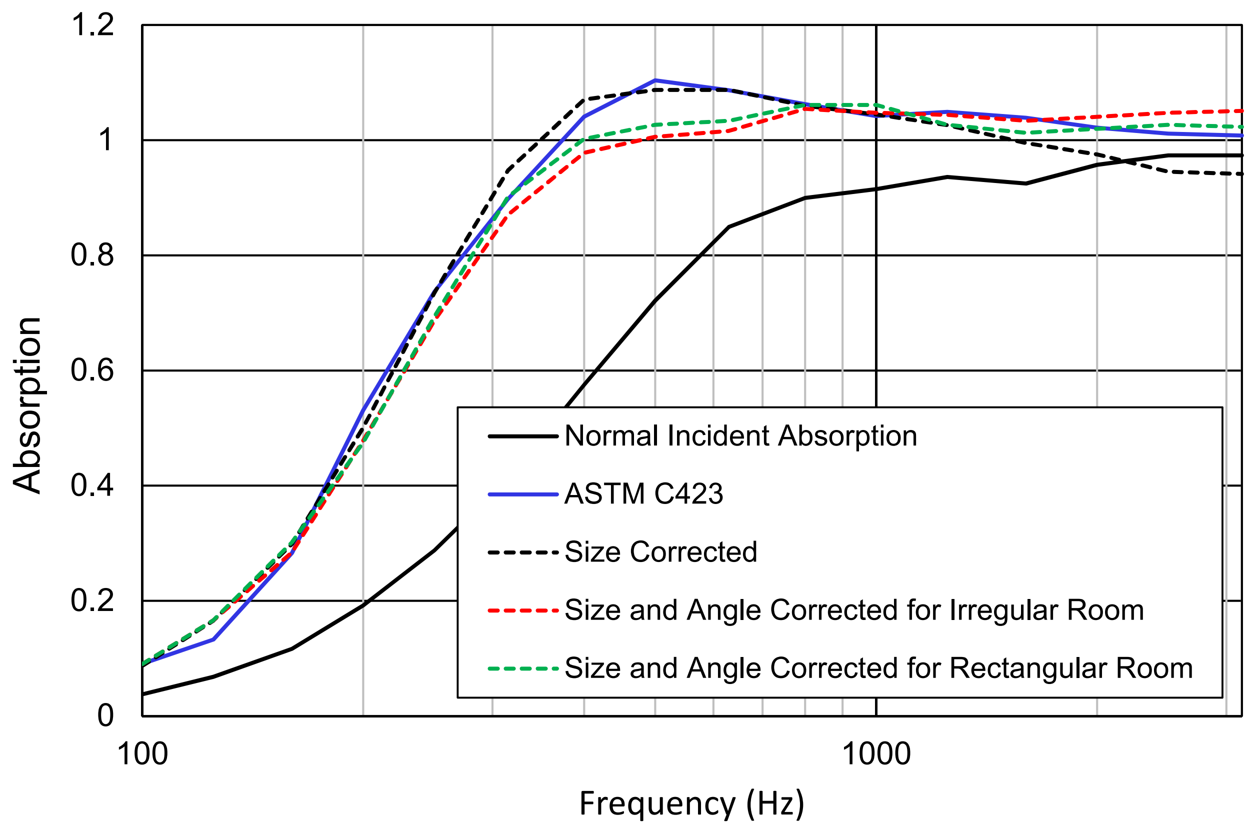
The high frequency intensity is nearly independent of the room geometry, the location of the absorber and the absorption coefficient of the specimen. – Jeong, 2010

Intensity Distribution Correction

5 cm mineral wool sample



$e = 2.4$ m



Overview

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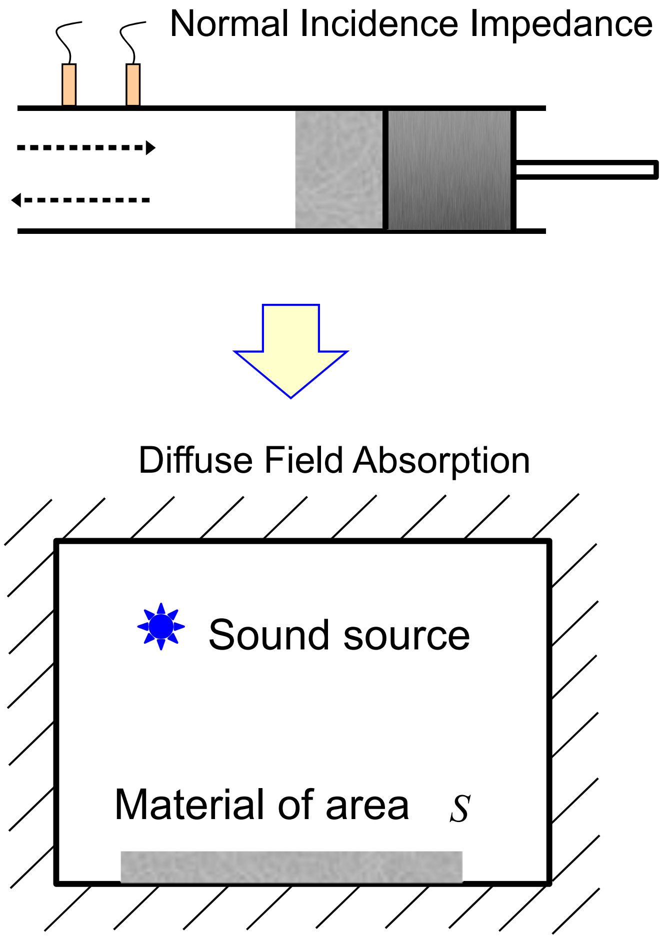
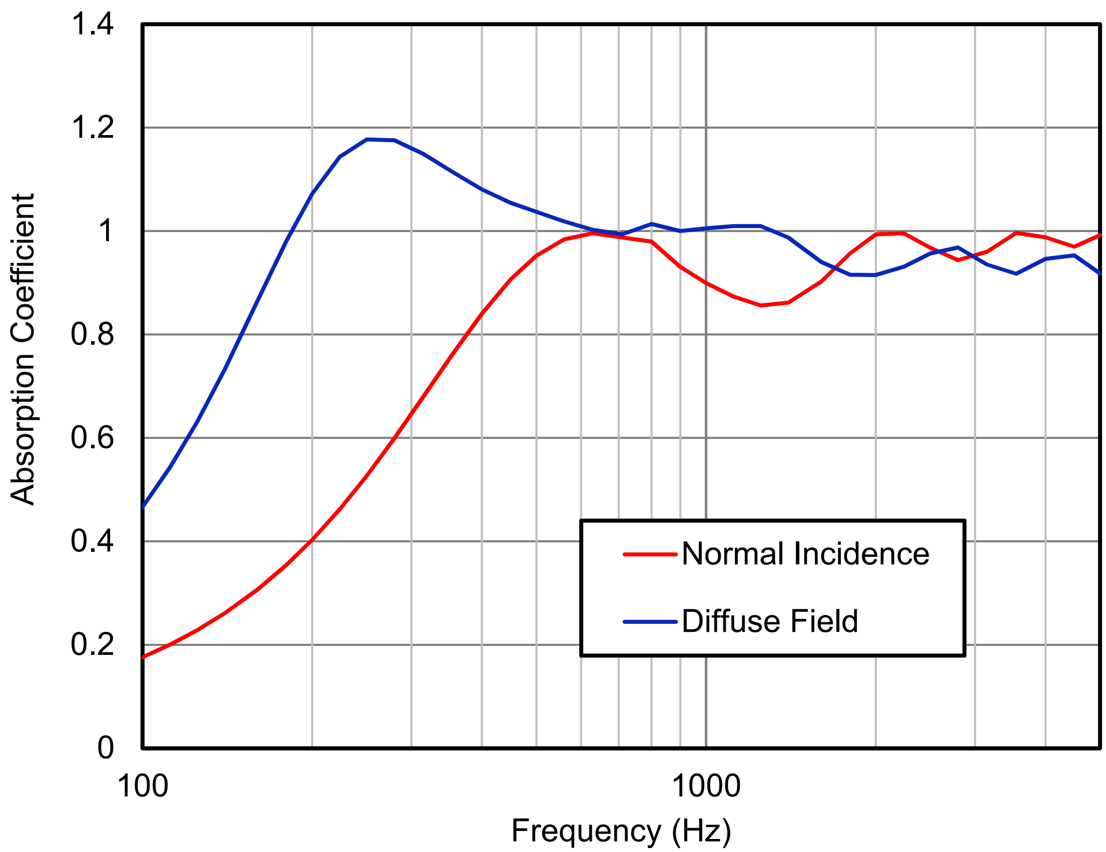
Procedure



1. Input layered sound absorber properties (thickness, flow resistivity, etc.).
2. Use empirical models and transfer matrix theory to determine normal incidence impedance (Z_n) and normal incidence sound absorption (α_n) in 1/6 octave bands.
3. Use normal incidence impedance and sample size to determine diffuse field sound absorption (α_d).

Normal Incidence vs. Diffuse Field



10 cm (4 in) plastic foam

$\sigma = 5000 \text{ Rayls/m}$

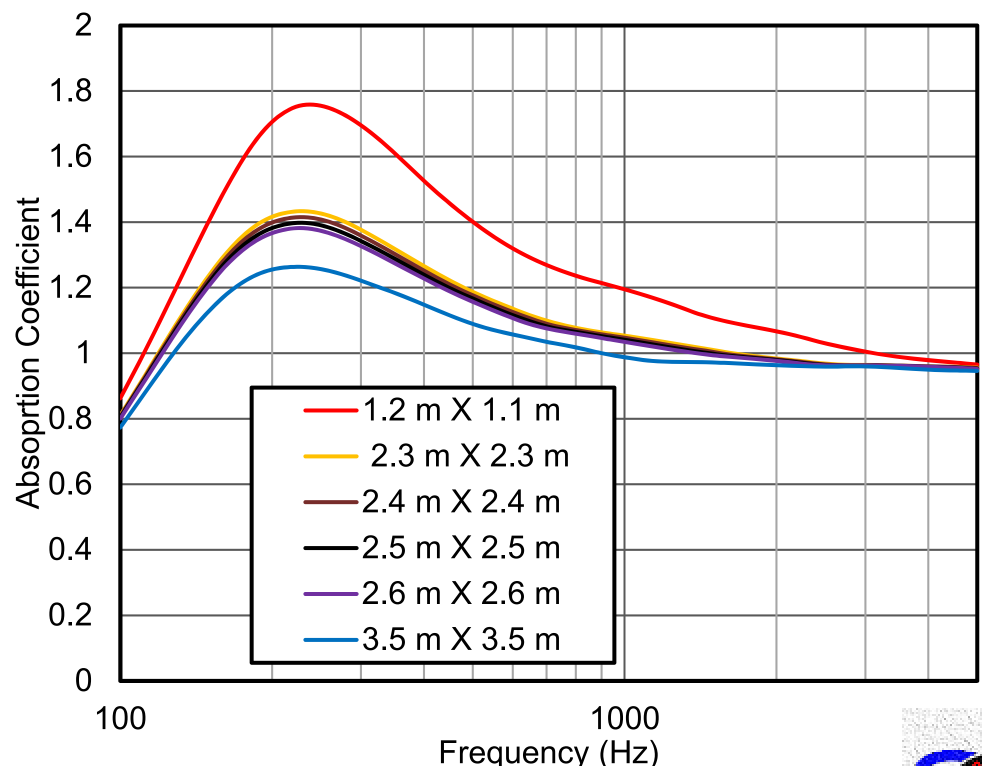
ASTM C423 Effect of Sample Size

ASTM C423

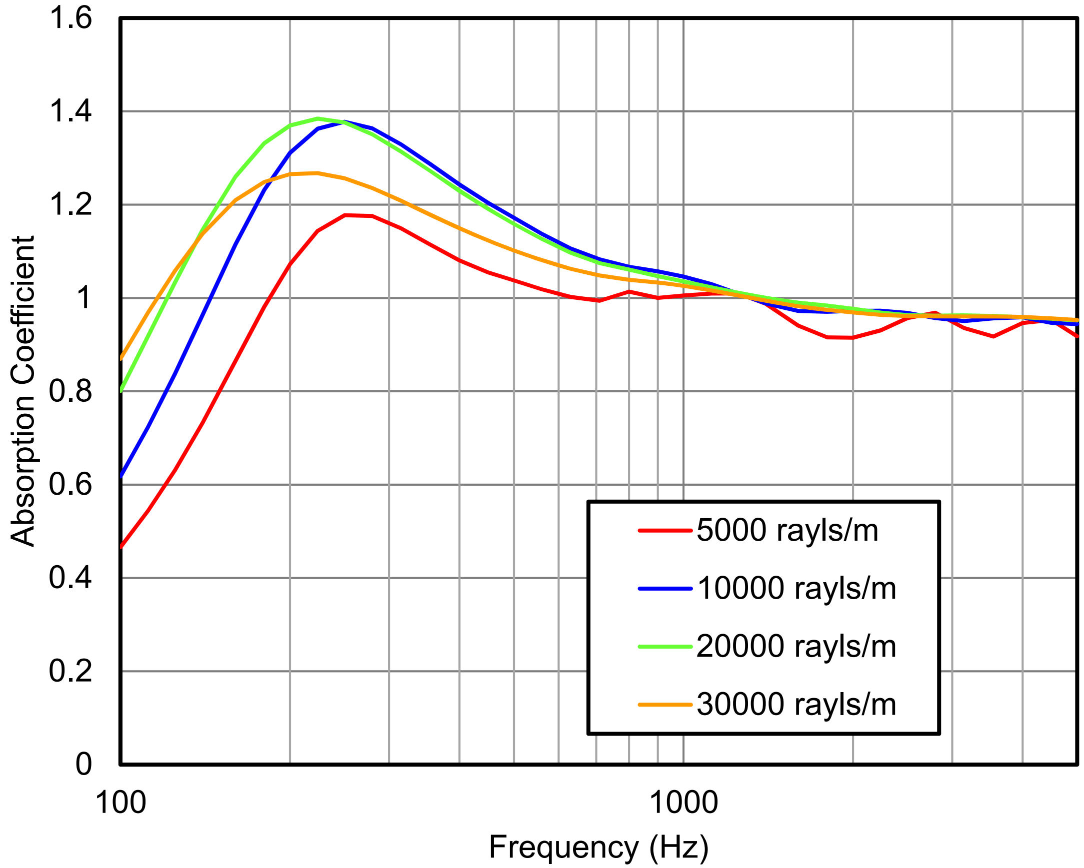
- 6.69 m^2 (72 ft^2) is recommended.
- Sample size 2.44 m $\times$ 2.74 m (8 ft $\times$ 9 ft).
- Area may not be less than 5.57 m^2 (60 ft^2).

10 cm (4 in) plastic foam

$\sigma = 20{,}000$ Rayls/m

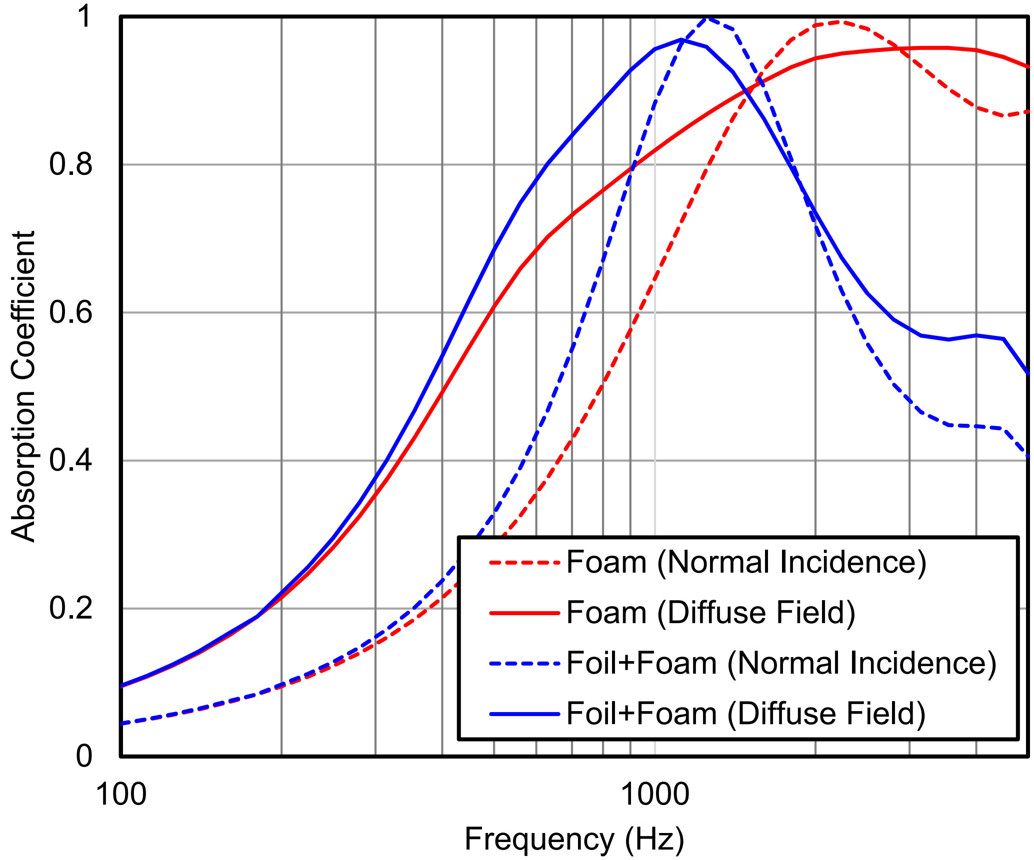


ASTM C423 Effect of Flow Resistivity



10 cm (4 in) plastic foam

ASTM C423 Effect of Mass Layer



Foil + Foam
Foam Thickness: 2.54 cm (1 inch)
Foam Flow Resistivity: 30000 rayls/m
Foil Surface Density: 0.05 kg/m^2

References

- ASTM C423-09a, 2009, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.
- ASTM E1050-12, 2012, Standard Test Method for Impedance and Absorption of Acoustical Material Using a Tube, Two Microphones and a Digital Frequency Analysis System.
- Thomasson, S. I. (1980). On the Absorption Coefficient. *Acta Acustica*, *44*(4), 265-273.
- Thomasson, S. I. (1982). Theory and Experiments on the Sound Absorption as Function of the Area. Report No. TRITA-TAK 8201, Department of Technical Acoustics, KTH, Stockholm, Sweden.
- Jeong, C. H. (2010). Non-Uniform Sound Intensity Distributions when Measuring Absorption Coefficients in Reverberation Chambers using a Phased Beam Tracing. *The Journal of the Acoustical Society of America*, *127*(6), 3560-3568.
- Kang, H. J., Ih, J. G., Kim, J. S., and Kim, H. S. (2000). Prediction of Sound Transmission Loss through Multilayered Panels by using Gaussian Distribution of Directional Incident Energy. *The Journal of the Acoustical Society of America*,*107*(3), 1413-1420.