Annex

Material data

The basic parameters of acoustic materials are the impedance and the surface shape. The equations given in Sect. 3.1 are applicable as first-order approximations of the impedance and reflection factor of acoustic materials. To discuss more details, other information such as angle-dependent impedance, porosity, tortuosity, etc., is required. These material data include all necessary information required for calculation of the reflected and the transmitted field. In many cases of sound prediction, however, the absorbed or transmitted energy is a sufficient quantity. Thus, for the scope of predicting the exterior sound field for auralization, the absorption coefficient and the scattering coefficient for random incidence are important input data used in room acoustics simulation software. To predict sound insulation, the sound reduction index or other standardized sound transmission data are required.

Most data in the following tables are extracted from the most recently established and widely used database of absorption coefficients. The database was developed by Ingolf Bork in the project of the "round robin" on room acoustical computer simulations.[93] Other data were obtained from product data given by manufacturers.

The reference methods used for determining these data are standardized methods for material testing, ISO354 for absorption coefficients, ISO17497, part 1 for scattering coefficients and ISO140 for sound insulation quantities. All standards describe measurement methods obtained in reverberation chambers. For more details, see Bork (2005b)[94] and the listed ISO standards.

These data are applicable for geometric or other energetic prediction models such as ray tracing or SEA. They don't have the precision and information required for numerical wave models.

[93] http://www.ptb.de/en/org/1/17/173/roundrobin.htm
[94] http://www.ptb.de/en/org/1/17/173/datenbank.htm

Tables of random-incidence absorption coefficients, α

Unless not explicitly specified otherwise, the data given are random-incidence absorption coefficients, α_s (see Sect. 3.1)

Massive constructions and hard surfaces

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Walls, hard surfaces average (brick walls, plaster, hard floors, etc.)	0.02	0.02	0.03	0.03	0.04	0.05	0.05
Walls, rendered brickwork	0.01	0.02	0.02	0.03	0.03	0.04	0.04
Rough concrete	0.02	0.03	0.03	0.03	0.04	0.07	0.07
Smooth unpainted concrete	0.01	0.01	0.02	0.02	0.02	0.05	0.05
Rough lime wash	0.02	0.03	0.04	0.05	0.04	0.03	0.02
Smooth brickwork with flush pointing, painted	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Smooth brickwork, 10 mm deep pointing, pit sand mortar	0.08	0.09	0.12	0.16	0.22	0.24	0.24
Brick wall, stuccoed with a rough finish	0.03	0.03	0.03	0.04	0.05	0.07	0.07
Ceramic tiles with a smooth surface	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Limestone walls	0.02	0.02	0.03	0.04	0.05	0.05	0.05
Reverberation chamber walls	0.01	0.01	0.01	0.02	0.02	0.04	0.04
Concrete floor	0.01	0.03	0.05	0.02	0.02	0.02	0.02
Marble floor	0.01	0.01	0.01	0.02	0.02	0.02	0.02

Lightweight constructions and linings

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
2 * 13 mm plasterboard on steel frame, 50 mm mineral wool in cavity, surface painted	0.15	0.10	0.06	0.04	0.04	0.05	0.05
Wooden lining, 12 mm fixed on frame	0.27	0.23	0.22	0.15	0.10	0.07	0.06

Glazing

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Single pane of glass, 3 mm	0.08	0.04	0.03	0.03	0.02	0.02	0.02
Glass window, 0.68 kg/m^2	0.10	0.05	0.04	0.03	0.03	0.03	0.03
Lead glazing	0.30	0.20	0.14	0.10	0.05	0.05	–
Double glazing, 2–3 mm glass, > 30 mm gap	0.15	0.05	0.03	0.03	0.02	0.02	0.02
Double glazing, 2–3 mm glass, 10 mm gap	0.10	0.07	0.05	0.03	0.02	0.02	0.02
Double glazing, lead on the inside	0.15	0.30	0.18	0.10	0.05	0.05	–

Wood

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Wood, 1.6 cm thick, on 4 cm wooden planks	0.18	0.12	0.10	0.09	0.08	0.07	0.07
Thin plywood panelling	0.42	0.21	0.10	0.08	0.06	0.06	–
16 mm wood on 40 mm studs	0.18	0.12	0.10	0.09	0.08	0.07	0.07
Audience floor, 2 layers, 33 mm on sleepers over concrete	0.09	0.06	0.05	0.05	0.05	0.04	–
Wood, stage floor, 2 layers, 27 mm over airspace	0.10	0.07	0.06	0.06	0.06	0.06	–
Solid wooden door	0.14	0.10	0.06	0.08	0.10	0.10	0.10

Floor coverings

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Linoleum, asphalt, rubber, or cork tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02	–
Cotton carpet	0.07	0.31	0.49	0.81	0.66	0.54	0.48
Loop pile tufted carpet, 1.4 kg/m^2, 9.5 mm pile height: On hair pad, 3.0 kg/m^2	0.10	0.40	0.62	0.70	0.63	0.88	–
Thin carpet, cemented to concrete	0.02	0.04	0.08	0.20	0.35	0.40	–
6 mm pile carpet bonded to closed-cell foam underlay	0.03	0.09	0.25	0.31	0.33	0.44	0.44

Floor coverings (cont'd)

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
6 mm pile carpet bonded to open-cell foam underlay	0.03	0.09	0.20	0.54	0.70	0.72	0.72
9 mm tufted pile carpet on felt underlay	0.08	0.08	0.30	0.60	0.75	0.80	0.80
Needle felt 5 mm stuck to concrete	0.02	0.02	0.05	0.15	0.30	0.40	0.40
10 mm soft carpet on concrete	0.09	0.08	0.21	0.26	0.27	0.37	–
Hairy carpet on 3 mm felt	0.11	0.14	0.37	0.43	0.27	0.25	0.25
5 mm rubber carpet on concrete	0.04	0.04	0.08	0.12	0.10	0.10	–
Carpet 1.35 kg/m^2, on hair felt or foam rubber	0.08	0.24	0.57	0.69	0.71	0.73	–
Cocos fibre roll felt, 29 mm thick (unstressed), reverse side clad with paper, 2.2 kg/m^2, 2 Rayl	0.10	0.13	0.22	0.35	0.47	0.57	–

Curtains

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Cotton curtains (0.5 kg/m^2) draped to 3/4 area approx. 130 mm from wall	0.30	0.45	0.65	0.56	0.59	0.71	0.71
Curtains (0.2 kg/m^2) hung 90 mm from wall	0.05	0.06	0.39	0.63	0.70	0.73	0.73
Cotton cloth (0.33 kg/m^2) folded to 7/8 area	0.03	0.12	0.15	0.27	0.37	0.42	–
Densely woven window curtains 90 mm from wall	0.06	0.10	0.38	0.63	0.70	0.73	–
Vertical blinds, 15 cm from wall, half opened (45°)	0.03	0.09	0.24	0.46	0.79	0.76	–
Vertical blinds, 15 cm from wall, open (90°)	0.03	0.06	0.13	0.28	0.49	0.56	–
Tight velvet curtains	0.05	0.12	0.35	0.45	0.38	0.36	0.36
Curtain fabric, 15 cm from wall	0.10	0.38	0.63	0.52	0.55	0.65	–
Curtain fabric, folded, 15 cm from wall	0.12	0.60	0.98	1.0	1.0	1.0	1.0
Curtains of close-woven glass mat hung 50 mm from wall	0.03	0.03	0.15	0.40	0.50	0.50	0.50
Studio curtains, 22 cm from wall	0.36	0.26	0.51	0.45	0.62	0.76	–

Seating (2 seats per m²)

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Wooden chairs without cushion	0.05	0.08	0.10	0.12	0.12	0.12	–
Unoccupied plastic chairs	0.06	0.10	0.10	0.20	0.30	0.20	0.20
Medium upholstered concert chairs, empty	0.49	0.66	0.80	0.88	0.82	0.70	–
Heavily upholstered seats, unoccupied	0.70	0.76	0.81	0.84	0.84	0.81	–
Empty chairs, upholstered with cloth cover	0.44	0.60	0.77	0.89	0.82	0.70	0.70
Empty chairs, upholstered with leather cover	0.40	0.50	0.58	0.61	0.58	0.50	0.50
Unoccupied, moderately upholstered chairs (0.90 m × 0.55 m)	0.44	0.56	0.67	0.74	0.83	0.87	–

Audience (unless not specified explicitly, 2 persons per m²)

	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Areas with audience, orchestra or choir including narrow aisles	0.60	0.74	0.88	0.96	0.93	0.85	0.85
Audience on wooden chairs, 1 per m^2	0.16	0.24	0.56	0.69	0.81	0.78	0.78
Audience on wooden chairs, 2 per m^2	0.24	0.40	0.78	0.98	0.96	0.87	0.87
Orchestra with instruments on podium, 1.5 m^2 per person	0.27	0.53	0.67	0.93	0.87	0.80	0.80
Audience area, 0.72 persons / m^2	0.10	0.21	0.41	0.65	0.75	0.71	–
Audience area, 1 person / m^2	0.16	0.29	0.55	0.80	0.92	0.90	–
Audience area, 1.5 persons / m^2	0.22	0.38	0.71	0.95	0.99	0.99	–
Audience area, 2 persons / m^2	0.26	0.46	0.87	0.99	0.99	0.99	–
Audience in moderately upholstered chairs 0,85 m × 0,63 m	0.72	0.82	0.91	0.93	0.94	0.87	–
Audience in moderately upholstered chairs 0,90 m × 0,55 m	0.55	0.86	0.83	0.87	0.90	0.87	–

Wall absorbers

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Fabric-covered panel, 6 pcf rockwool core	0.46	0.93	1.0	1.0	1.0	1.0	1.0
Fabric-covered panel, 8 pcf rockwool core	0.21	0.66	1.0	1.0	0.97	0.98	0.98
Facing-brick brickwork, open butt joins, brick dimensions 230 × 50 × 55 mm	0.04	0.14	0.49	0.35	0.31	0.36	–
Acoustical plaster, approx. 25 mm thick, 3.5 kg/m^2/cm	0.17	0.36	0.66	0.65	0.62	0.68	–
Rockwool thickness = 50 mm, 80 kg/m^3	0.22	0.6	0.92	0.90	0.88	0.88	0.88
Rockwool thickness = 50 mm, 40 kg/m^3	0.23	0.59	0.86	0.86	0.86	0.86	086
50 mm mineral wool (40 kg/m^3), glued to wall, untreated surface	0.15	0.70	0.60	0.60	0.85	0.90	0.90
50 mm mineral wool (70 kg/m^3) 300 mm in front of wall	0.70	0.45	0.65	0.60	0.75	0.65	0.65
Gypsum board, perforation 19.6%, hole diameter 15 mm, backed by fibrous web 12 Rayl, 100 mm cavity filled with mineral fibre mat 1,05 kg/m^2, 7,5 Rayl	0.30	0.69	1.0	0.81	0.66	0.62	–
Perforated veneered chipboard, 50 mm, 1 mm holes, 3 mm spacing, 9% hole surface ratio, 150 mm cavity filled with 30 mm mineral wool	0.41	0.67	0.58	0.59	0.68	0.35	–
Fibre absorber, mineral fibre, 20 mm thick, 3.4 kg/m^2, 50 mm cavity	0.20	0.56	0.82	0.87	0.70	0.53	–
Fibre absorber, mats of porous flexible fibrous web fabric, self-extinguishing	0.07	0.07	0.2	0.41	0.75	0.97	–

Ceiling absorbers

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Plasterboard ceiling on battens with large air-space above	0.20	0.15	0.10	0.08	0.04	0.02	–
Fibre absorber on perforated sheet metal cartridge, 0,5 mm zinc-plated steel, 1.5 mm hole diameter, 200 mm cavity filled with 20 mm mineral wool (20 kg/m^3), inflammable	0.48	0.97	1.0	0.97	1.0	1.0	1.0
Fissured ceiling tile	0.49	0.53	0.53	0.75	0.92	0.99	–
Perforated 27 mm gypsum board (16%), d = 4,5 mm, 300 mm from ceiling	0.45	0.55	0.60	0.90	0.86	0.75	–
Wedge-shaped, melamine foam, ceiling tile	0.12	0.33	0.83	0.97	0.98	0.95	–
Metal panel ceiling, backed by 20 mm Sillan acoustic tiles, panel width 85 mm, panel spacing 15 mm, cavity 35 cm	0.59	0.80	0.82	0.65	0.27	0.23	–

Special absorbers

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Microperforated foil “Microsorber” (Kaefer)	0.06	0.28	0.70	0.68	0.74	0.53	–
Microperforated glass sheets, 5 mm cavity	0.10	0.45	0.85	0.30	0.10	0.05	–
Hanging absorber panels (foam), 400 mm depth, 400 mm distance	0.25	0.45	0.80	0.90	0.85	0.80	–
Hanging absorber panels (foam), 400 mm depth, 700 mm distance	0.20	0.30	0.60	0.75	0.70	0.70	–

Equivalent absorption area, A, of single objects in m²

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Single chair, wood	0.02	0.02	0.03	0.04	0.04	0.04	–
Single chair, upholstered	0.10	0.20	0.25	0.30	0.35	0.35	–
Single person in group, sitting or standing, 1 per 6 m^2 area; typical minimum	0.05	0.10	0.20	0.35	0.50	0.65	–
Single person in a group, sitting, 1 per 6 m^2 area; typical maximum	0.12	0.45	0.80	0.90	0.95	1.0	1.1
Single person in a group, standing, 1 per 6 m^2 area; typical maximum	0.12	0.45	0.80	1.20	1.30	1.40	1.45

Air attenuation coefficient, in 10^{-3} m^{-1}

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
10°, 30–50%	0.1	0.2	0.5	1.1	2.7	9.4	29.0
10°, 50–70%	0.1	0.2	0.5	0.8	1.8	5.9	21.1
10°, 70–90%	0.1	0.2	0.5	0.7	1.4	4.4	15.8
20°, 30–50%	0.1	0.3	0.6	1.0	1.9	5.8	20.3
20°, 50–70%	0.1	0.3	0.6	1.0	1.7	4.1	13.5
20°, 70–90%	0.1	0.3	0.6	1.1	1.7	3.5	10.6

Tables of random-incidence scattering coefficients, *s*

Random-incidence scattering coefficients according to the definition in ISO 17497-1 (see also Sect. 3.3.2) are related to the surface shape and size. Relevant surface parameters are the characteristic length and depth of surface corrugations. It is assumed that the total surface area is large compared with the corrugations and the wavelengths. Note that this concept is not applicable to single scattering objects.[95]

To consider the amount of scattering, it is essential that the shape is described by its characteristic dimensions, the average structural depth, *h*, and the average structural length, *a*. The random-incidence scattering coefficients, *s*, given, are dependent on the normalized frequency $a/\lambda = f\,a/c$. Below $a/\lambda = 0.125$, the random-incidence scattering coefficient, *s*, is generally smaller than 0.05.

The data listed are rounded values from publications by (Vorländer and Mommertz 2000; Jeon et al. 2003; Jeon et al. 2004; Embrechts et al. 2004) and results from other measurements. More information on diffusers and more detailed data are in given in (Cox and D'Antonio 2004).

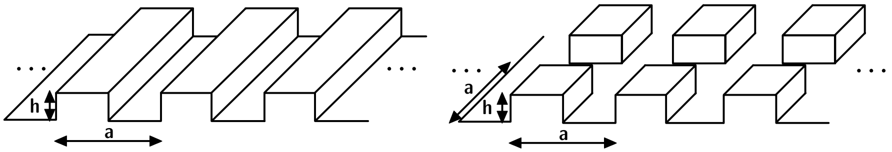


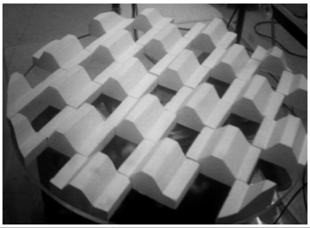
Fig. A.1. Definition of surface dimensions of 1-D and 2-D corrugations

[95] See Cox and D'Antonio (2004) for more information on the single-object diffusion coefficient.

2-D surfaces

Shape of corrugation	a/λ						
	0.125	0.25	0.5	1	2	4	8
Hemispheres of average radius h, randomly distributed, coverage 40% ($h/a \approx 0.25$)	0.1	0.2	0.5	0.6	0.6	0.7	0.8
							
Densely placed identical hemispheres of radius h, $h/a = 0.5$ in regular pattern	0.05	0.05	0.1	0.6	0.6	0.6	–
Hemispheres of average radius h, randomly distributed, coverage 25% ($h/a \approx 0.15$)	0.1	0.1	0.2	0.3	0.4	0.4	0.4
Wooden cubes, regular pattern, $h/a = 0.5$	0.05	0.05	0.25	0.3	0.7	0.9	–
Wooden cubes, random distance and orientation $h/a = 0.5$	0.05	0.05	0.2	0.3	0.6	0.7	–
Ceramic tiles, densely packed; heights h distributed in a range between 1 and 10, average $h/a \approx 1$.	0.1	0.4	0.9	0.7	0.7	0.7	–
							

2-D surfaces (cont'd)

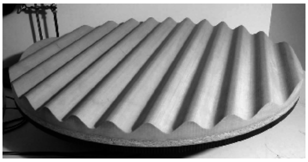
Shape of corrugation	a/λ						
	0.125	0.25	0.5	1	2	4	8
Wooden boxes of various sizes, random pattern, average $h/a = 0.5$ 	0.05	0.05	0.15	0.4	0.7	0.9	–
Trapezoidal grating $h/a \approx 0.5$ 	0.05	0.05	0.1	0.9	0.8	0.9	0.9

1-D surfaces

Shape of corrugation	a/λ						
	0.125	0.25	0.5	1	2	4	8
Stairs (sawtooth) $h/a = 0.3$	0.05	0.05	0.2	0.3	0.4	0.45	–
Aperiodically distributed rectangular battens, $h/a = 0.5$	0.1	0.6	0.5	0.4	0.3	0.4	–
Periodically distributed rectangular battens, $h/a = 0.5$	0.1	0.6	0.6	0.5	0.5	0.5	–

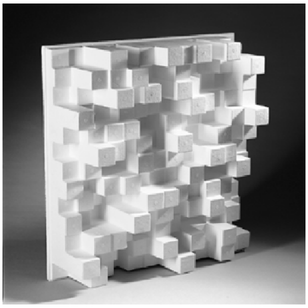
1-D surfaces (cont'd)

Shape of corrugation	a/λ						
	0.125	0.25	0.5	1	2	4	8
Periodically distributed hemicylinders $h/a = 0.25$	0.1	0.1	0.3	0.7	0.8	0.8	–
Sinusoidal, $h/a = 0.31$	0.05	0.05	0.2	0.7	0.8	0.85	–



Diffusers

Type	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
RPG "Skyline"	0.01	0.08	0.45	0.82	1.0	–	–
RPG "QRD"	0.06	0.15	0.45	0.95	0.88	0.91	–

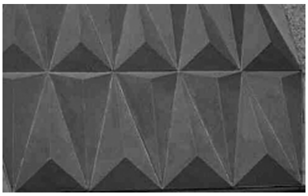


(Courtesy of RPG Diffusor Systems, Inc.; www.rpginc.com)

Seating and audience

Shape of corrugation	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Theatre audience	0.3	0.5	0.6	0.6	0.7	0.7	0.7
Amphitheatre steps, length 82 cm, height 30 cm (Farnetani 2005)	0.05	0.45	0.75	0.9	0.9	–	–
Rows of classroom tables and persons on chairs	0.2	0.3	0.4	0.5	0.5	0.6	0.6

Round Robin III – wall and ceiling

Shape of corrugation	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Rectangular and prism boxes (studio wall) "Round Robin III" (after (Bork 2005a)) 	0.50	0.90	0.95	0.95	0.95	0.95	–
Trapezoidal boxes (studio ceiling) "Round Robin III" (after (Bork 2005a)) 	0.13	0.56	0.95	0.95	0.95	0.95	–

Tables of sound reduction indices, *R*

Masonry

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Lightweight concrete (1200 kg/m^3) 140 mm	30.9	32.1	42.0	49.1	54.4	59.9	45
Concrete (2300 kg/m^3) 240 mm	45.6	51.9	58.7	66.0	70.7	72.3	63
Aerated concrete (400 kg/m^3) 150 mm, render 2 × 10 mm	24.1	25.9	35.6	42.4	47.7	53.2	39
Brick (1400 kg/m^3) 175 mm, render 2 × 15 mm	28.6	43.0	50.3	58.1	63.2	68.1	52
Calcium silicate (1200 kg/m^3) 115 mm	29.1	33.0	40.1	47.8	54.9	60.4	44
Calcium silicate (2000 kg/m^3) 175 mm, render 2 × 15 mm	39.6	45.6	52.7	60.3	65.4	70.0	56

Lightweight constructions

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Gypsum board 2 × 12.5 mm with 25 mm filled gap	30.0	43.0	53.0	60.0	65.0	50.0	51
2 × 15 mm WallBoard 146 mm, ‘C’ studs, 25 mm Isowool APR 1200	33.8	35.6	51.7	56.2	59.5	49.8	51

Doors

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Chipboard. 13 mm, P 3 20 mm, chipboard. 13 mm	19.2	35.0	37.9	3.9	35.6	42.0	38
Veener 6 mm, TW 1 40 mm, gypsum board. 12.5 mm, veneer 10 mm	22.0	33.0	40.0	40.0	44.0	40.0	40
Veneer 6 mm, TW 1 50 mm, veneer 10 mm	21.0	21.0	36.0	37.0	41.0	40.0	35
Wood fibre 3.5 mm, slats, wood fibre 3.5 mm	27.0	27.0	29.0	28.0	30.0	35.0	30

Glazing

Material	Octave band frequency in Hz						
	125	250	500	1k	2k	4k	8k
Single pane 3 mm	18.7	22.0	24.2	28.6	34.7	29.4	29
6 mm	23.4	27.4	31.8	35.2	26.8	35.5	32
10 mm	26.6	30.1	32.2	30.6	34.9	45.3	33
12 mm	31.3	33.1	31.5	32.3	39.4	45.7	34
Double glazing 4-6-4	25.7	25.0	23.4	34.1	40.4	36.5	31
Double glazing 8-12-8	29.2	27.3	31.1	36.8	35.0	46.7	34

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Index

D

E

F

G

H