Building Physics tables and formulas

Climate data

Outdoor climate
(Adapted from data of KNMI in De Bilt)

Table 1 mentions the monthly averages in De Bilt for

- Temperature ($\overline{T}_e$)
- Vapour pressure ($\overline{P}_e$)

Table 1
Monthly averages in De Bilt of temperature and vapour pressure

month	$\overline{T}_e$ °C	$\overline{P}_e$ (Pa)
january	2.3	650
february	2.5	650
march	4.9	720
april	7.8	855
may	12.4	1095
june	14.8	1316
july	16.6	1575
august	16.0	1525
september	13.6	1375
oktober	9.6	1095
november	5.0	860
december	2.9	715

Table 2 mentions the amount of hours in which a temperature is undercut annually. In parentheses the amount of hours that fall in the range of office hours (7:00 – 19:00, 5-day week).

Table 2
Amount of hours in which a certain outdoor temperature is undercut

Temperature (°C)	Amount of hours in which a certain outdoor temperature is undercut	
–10	35	(8)
–5	180	(45)
0	781	(202)
5	2 432	(661)

Indoor climate
For various climate classes, the average vapour pressure during winter months ($\overline{p}_{iw}$) and the corresponding relative humidity at 20 °C (φ_{iw}) can be indicated.
This division in climate classes is done according to SBR publication no. 51.

I $\overline{p}_{iw}$ = 700 Pa; φ_{iw} = 30% (if heated): buildings with negligible moisture production, such as sheds, garages and store rooms.;

II $\overline{p}_{iw}$ = 935 Pa; φ_{iw} = 40%: buildings with minor moisture production, such as dwellings, offices and shops (all without humidification)

III $\overline{p}_{iw}$ = 1170 Pa; φ_{iw} = 50%: buildings with higher moisture production, such as schools, retirement homes and buildings with minor humidification

IV $\overline{p}_{iw}$ = 1400 Pa or above; φ_{iw} = 60% or above: buildings with major moisture production, such as laundries, swimming pools, dairy plants and buildings with major humidification, such as printing houses and texile mills

Heat and moisture

Global approximation of internal condensation in the winter period

$$m = \frac{100}{\Sigma\mu \cdot d} \text{ [g/m}^2\text{] for climate class I}$$

$$m = \frac{600}{\Sigma\mu \cdot d} \text{ [g/m}^2\text{] for climate class II}$$

$$m = \frac{1000}{\Sigma\mu \cdot d} \text{ [g/m}^2\text{] for climate class III}$$

herein:

m amount of condensing moisture during winter in g/m^2

$\Sigma\mu \cdot d$ the sum of the $\mu \cdot d$-values from the inner surface to the surface of condensing

Heat transfer through radiation between tow parallel surfaces

$$q = \frac{\varepsilon_1 \cdot \varepsilon_2}{\varepsilon_1 - \varepsilon_1 \cdot \varepsilon_2 + \varepsilon_2} \cdot 56.7 \cdot 10^{-9} \cdot \left(T_1{}^4 - T_2{}^4\right) \quad [\text{W/m}^2]$$

herein:

q_s the net radiation transfer in W/m^2
ε_1, ε_2 the emission coefficient of surface 1 and 2 respectively
T_1, T_2 the temperature in Kelvin of surface 1 and 2 respectively

Heat transfer through radiation with formula below

$$q_s = \varepsilon \cdot 56.7 \cdot 10^{-9} \cdot T^4 = \varepsilon \cdot q_{sz} \quad [\text{W/m}^2]$$

herein:

q_s the heat flow density of the emitted radiation in W/m^2
ε the emission coefficient of the material's surface
T the absolute temperature in Kelvin
q_{sz} the heat radiation of the 'black body'
$56.7 \cdot 10^{-9}$ the Stefan-Boltzmann constant

$$Q = \rho \cdot c \cdot d \cdot \Delta T \quad [\text{J/m}^2]$$

herein:

Q the amount of heat that has accumulated in the construction layer per m²
ρ the density of the material in kg/m³
c the specific heat in J/kg · K
d the thickness of the layer in m
ΔT the rise in temperature of the layer in K

Table 3
Hygroscopic moisture of various materials

material	$\varphi = 40\%$	$\varphi = 65\%$	$\varphi = 95\%$
gravel concrete	2	3	7
wood	6	10	18
brick etc.	–	–	–
lime	2	4	10
plaster	1	2	4
wood wool cement	2	3	6

Table 4
Heat radiation emission/absorption coefficient for some material surfaces

material surface	ε
glossy polished metals	0.02–0.07
galvanised steel	0.20–0.30
aluminium, regular smooth	0.07–0.09
aluminium, anodised	0.40–0.50
aluminium lacquer	0.35–0.40
regular lacquer, any colour	0.90–0.95
brick, concrete, roofing felt, wood and almost all other building materials	0.90–0.95

Table 5
Expansion of various materials

material	linear expansion coefficient α (m/m · K)
brick	$5 \cdot 10^{-6}$ (0,000 005)
concrete	$10 \cdot 10^{-6}$
steel	$12 \cdot 10^{-6}$
aluminium	$23 \cdot 10^{-6}$
polystyrene foam	$70 \cdot 10^{-6}$
polyurethane foam (coated plate)	$27 \cdot 10^{-6}$
foam glass	$9 \cdot 10^{-6}$

Table 6
Heat resistance (R_w) of some often-applied construction layers, finishes and coatings

layer	R_w (m² · K/W)
flexible roofing, either weighted with gravel or not	0.04
roofing with tiles, inc. the layer of air between the tiles and the decking	0.06
plaster on an inner surface	0.02

Table 7 *U*-values to use according to NEN 5128 for windows and doors

double glazing, pane distance 12 mm covering layer	cavity filling	wood/ synthetics	metal (thermally inerrupted)	other
none	air	2.8	3.2	4.0
heat reflecting				
emission coefficient	air	2.4	2.8	3.4
0.15–0.25	argon	2.2	2.6	3.2
heat reflecting				
emission coefficient	air	2.2	2.6	3.2
< 0.15	> 80% argon	1.8	2.2	3.0
double glazing, pane distance 6 mm covering layer	**cavity filling**	**wood/ synthetics**	**metal (thermally inerrupted)**	**other**
none	air	3.2	3.6	4.2
heat reflecting				
emission coefficient	air	2.8	3.2	4.0
0.15–0.25	argon	2.6	3.0	3.6
heat reflecting				
emission coefficient	air	2.6	3.0	3.8
< 0.15	> 80% argon	2.4	2.8	3.4
single glazing		5.0		
doors without translucent parts		3.4	5.4	6.2
Thermal transmittance of windows and doors forming a separation with an adjacent closed room or adjacent unheated conservatory				
doors without translucent parts		2.8		
doors and windows with single glazing		4.0		
doors and windows with double glazing		2.8		

Table 8 Standard values for sunscreen data, light entry and *U*-values for various window systems

Window system	*ZTA*	*CF*	*LTA*	*U* (W/m² · K)
single glazing (6 mm), unshielded	0.80	0.01	0.84	5.7
single glazing, indoor blinds colour)	0.45	0.5	0.15	5.4
single glazing, outdoor blind	0.15	0.05	0.12	4.9
double glazing, unshielded	0.7	0.04	0.74	3.2
double glazing, indoor blind (light colour)	0.47	0.55	0.12	3.1
double glazing, indoor textile with deposited metal layer				
– light	0.5	0.3	0.3	3,0
– heavy	0.3	0.5	0.05	2.9
double glazing, outdoor blinds	0.12	0.05	0.1	2.8
double glazing, vertically strained cloth				
– light	0.2	0.1	0.15	2.8
– heavy	0.13	0.15	0.05	2.8
double glazing, roller screens (not continuous)	0.15	0.15	0.14	2.8
double glazing, canopy	0.11	0.18	0.05	2.8
reflecting double glazing				
– light	0.45	0.02	0.65	*
– heavy	0.25	0.05	0.35	*
absorbing double glazing				
– light	0.45	0.06	0.35	3.2
– heavy	0.25	0.1	0.1	3.2
double glazing with spectrally selective coating and adapted cavity	0.65	0.05	0.55	1.6
filling (heat insulation)	0.57	0.07	0.5	2.2
triple glazing				

* If a window's reflection is realised by a deposited metal layer at the inside of the outer pane, the heat transfer in the cavity will also be reduced and the *U*-value might drop to 1.8 – 2.0 W/m² · K and even to 1.4 W/m² · K if another cavity filling than air is applied.

N.B. The values in the table should be considered standard values. Specific products can have strongly differing properties. Furthermore, in many structures (glass surfaces), the angle of incidence of direct solar radiation is of influence on the reflection of the outer surface. In this table an angle of 45° is assumed. With blinds, the screening is also dependent on the position/angle of the blinds. In this table an angle of 45° is assumed, so perpendicular to the solar radiation.

Table 9

Maximal vapour concentration and vapour pressure dependent on temperature

C_{max}		The saturated vapour pressure p_s in N/m²									
g/m³	Temp. °C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
39.56	+ 35	5627	5657	5688	5720	5752	5784	5816	5848	5880	5912
37.54	34	5323	5352	5381	5412	5443	5472	5503	5533	5564	5595
35.62	33	5033	5061	5090	5118	5146	5176	5205	5234	5264	5293
33.77	32	4757	4785	4812	4838	4866	4893	4921	4949	4977	5005
32.02	31	4496	4521	4546	4573	4598	4625	4650	4677	4704	4730
30.34	30	4245	4270	4294	4319	4344	4369	4393	4418	4443	4469
28.73	29	4007	4031	4054	4078	4102	4125	4149	4173	4197	4221
27.21	28	3782	3803	3826	3848	3871	3893	3915	3939	3962	3984
25.75	27	3567	3588	3610	3630	3651	3674	3695	3716	3738	3760
24.36	26	3363	3383	3403	3423	3443	3463	3484	3504	3530	3546
23.05	25	3169	3188	3207	3226	3246	3264	3284	3303	3323	3343
21.78	24	2985	3003	3022	3040	3058	3076	3095	3114	3132	3151
20.55	23	2811	2828	2844	2861	2879	2896	2915	2932	2949	2967
19.43	22	2645	2661	2677	2693	2710	2727	2744	2760	2778	2793
18.35	21	2488	2504	2518	2535	2549	2565	2581	2597	2613	2629
17.28	20	2340	2353	2368	2382	2397	2412	2428	2442	2457	2473
16.30	19	2198	2212	2225	2240	2253	2268	2281	2296	2310	2325
15.37	18	2065	2077	2090	2104	2117	2130	2144	2157	2170	2184
14.47	17	1938	1950	1962	1978	1988	2001	2014	2026	2034	2052
13.65	16	1818	1830	1842	1854	1866	1878	1890	1902	1914	1926
12.85	15	1706	1717	1728	1739	1750	1761	1773	1784	1796	1808
12.07	14	1599	1609	1619	1630	1641	1651	1662	1673	1684	1696
11.35	13	1498	1507	1518	1527	1538	1547	1558	1569	1578	1589
10.65	12	1403	1413	1422	1431	1441	1450	1459	1469	1478	1489
10.01	11	1313	1321	1331	1339	1349	1358	1366	1375	1385	1394
9.40	10	1229	1237	1245	1253	1262	1270	1278	1287	1295	1305
8.82	9	1148	1156	1164	1172	1179	1187	1195	1203	1212	1220
8.27	8	1072	1080	1087	1095	1103	1110	1118	1126	1132	1140
7.76	7	1002	1008	1016	1023	1030	1036	1044	1051	1059	1066
7.28	6	935	942	948	955	962	968	975	982	988	995
6.83	5	872	879	884	891	898	903	910	916	923	928
6.40	4	814	819	826	831	836	843	848	855	860	867
5.99	3	758	763	768	775	780	786	791	796	802	808
5.59	2	706	711	716	722	727	732	736	742	747	752
5.21	1	657	661	667	671	676	681	685	691	696	701
4.84	+ 0	611	615	620	624	628	633	637	643	647	652
4.84	– 0	611	605	600	596	591	587	581	576	572	567
4.48	– 1	563	557	553	548	544	539	535	531	525	521
4.14	– 2	517	513	508	504	500	496	492	488	484	480
3.82	– 3	476	472	468	464	460	456	452	448	444	440
3.53	– 4	437	433	429	425	423	419	415	412	408	404
3.26	– 5	401	397	395	391	388	384	381	377	375	371
3.01	– 6	368	365	361	359	356	352	349	347	344	340
2.77	– 7	337	335	332	329	327	323	320	317	315	312
2.55	– 8	309	307	304	301	299	296	293	291	288	285
2.34	– 9	283	281	279	276	273	271	269	267	264	261
2.15	– 10	260	257	255	252	251	248	245	244	241	240
1.98	– 11	237	235	233	231	229	227	225	223	221	219
1.82	– 12	217	215	213	211	209	207	205	204	201	200
1.67	– 13	199	196	195	193	191	189	188	185	184	183
1.53	– 14	181	179	177	176	175	173	171	169	168	167
1.41	– 15	165	164	163	160	159	157	156	155	153	152
1.29	– 16	151	149	148	147	145	144	143	141	140	139
1.18	– 17	137	136	135	133	132	131	129	128	127	125
1.08	– 18	124	124	123	121	120	119	117	116	116	115
0.99	– 19	113	112	111	111	109	108	107	105	105	104
0.90	– 20	103	101	101	100	98.7	98.7	97.4	96.0	94.7	94.7

Table 10

Density ρ, heat conduction coefficient λ, specific heat c and vapour diffusion resistance figure μ of building materials

Material type	ρ (kg/m³)	λ (W/m · K) I *)	λ (W/m · K) II *)	c (J/kg · K)	μ –
Metals					
Lead	12250	35	35	130	∞
Copper	9000	370	370	390	∞
Iron	7900	72	72	530	∞
Steel	7800	41–52	41–52	480–530	∞
Zinc	7200	110	110	390	∞
Aluminium	2800	200	200	880	∞
Stone					
Basalt	3000	35	35		–
Granite	3000	35	35		–
Limestone	2750	23	29		–
Freestone	2750	23	29	840	–
Marble	2750	2.3	2.9		–
Sandstone	2000–2300	2–4	4–6		15
Tuff	1100–1500	0.35–0.50	0.5–0.7		5–10
Bricks					
Clinkers (façade)	2100	0.8	1.3		31
Clinkers "Hardgrauw"	1700–1900	0.65–0.70	1.0–1.2		9–14
	1700	0.65	1.0		9
Clinkers "Rood/Boerengrauw"	1500	0.55	0.85	840	8
	1300	0.45	0.75		75
Light weight brick	1000	0.3			–
Sand-lime	2000	1.0	1.5		25
Gravel concrete					
Compacted, reinforced	2500	1.9	2.3		37–200
Compacted, not reinforced	2400	1.7	2.2		31–200
Not compacted, reinforced	2300	1.4	1.9	840	27–200
Not compacted, not reinforced	2200	1.3	1.7		23–200
Lightweight concrete					
	1900	0.95	1.4		130
	1600	0.70	1.2		80
	1300	0.45	0.8		75
General indication	1000	0.35	0.5	840	65
	700	0.23			55
	500	0.17			45
	300	0.12			35
	200	0.08			28
Pumice concrete	700–1000	0.23–0.35		840	6
	1000–1400	0.35–0.50			6.5–12
Concrete with expanded clay and such as aggregate	500–1000	0.18–0.35		840	5–6.5
	1000–1800	0.35–0.85			6.5–12
	220	0.07			4.5–5.5
Polystyrene concrete	400	0.11			16–20
	650	0.20			–
	1300	0.50	1.2		7.5–9
Cellular concrete	1000	0.35	0.7		5.5–7.5
	700	0.23			4.5–7.5
	400	0.17		840	3–7.5
Cement-based cellular concrete					
Lime-based cellular concrete	400–750	0.17–0.26			3.7–6.5
	1900	0.70	1.0		14
Blast furnace slag-based concrete	1600	0.45	0.7	840	10
	1300	0.30	0.45		8
	1000	0.23	0.35		6.5
Other anorganic materials					
Asbestos cement	1600–1900	0.35–0.70	0.95–1.2		37–150
Gypsum board	800–1400	0.23–0.46	(–)–0.65		6
Glass (mirrored or plain)	2500	0.8	0.8		∞
Glass ceramics	2500	1.4	1.4	840	–
Foam glass	120–150	0.05–0.06			∞
Mineral aggregate for concrete	50–800	0.04–0.23			–
Mineral wool	35–250	0.041			1.1–1.8

Plasters					
Cement plaster	1900	0.93	1.5		15–41
Lime plaster	1600	0.70	0.8	840	9–41
Gypsum plaster	1300	0.52	0.8		7–10
Tiles					
Hard-baked tiles	2000	1.2	1.3	840	28
Floor tiles	1700	0.8	1.1		23
Organic materials, bound or other (excluding wood products and plastics)					
Expanded cork	100–200	0.041–0.046		1760	4.5–29
Expanded impregnated cork	100–200	0.041–0.046		1760	9–46
Linoleum	1200	0.17		1470	1800
Rubber	1200–1500	0.17–0.29		1470	900
Expanded ebonite	100	0.35		1470	450–900
Cane fiber board	250–350	0.08–0.09		2100	3
Straw fiber board	200–400	0.08–0.12		2100	3
Flaxboard bound with resin	300–700	0.08–0.17		1880	7–46
Flaxboard bound with cement	330–700	0.08–0.12		1470	3.5–7
Wood products					
Hardwood	800	0.17[1])	0.23[1])		–
Pine	550	0.14[1])	0.17[1])	1880	–
Plywood	700	0.17	0.23		–
Hardboard	1000	0.29		1680	46–75
Softboard	250–300	0.08		2100	–
	450	0.10			–
Chipboard	600	0.15		1880	–
	1000	0.29			–
Woodchip cement plate					
Wood wool cement plate	350–700	0.09–0.21		1470	3.7–10
Wood wool magnesite plate	400–500	0.10–0.12			3.7–10
Hard plastics					
Polyester board (reinforced with glass fiber)	1200				
Polyethene	920–950				
Polymethacrylate	1200	0.2		1470	9000
Polypropylene	900				
Polyvinylchloride	1400				
ABS polymers	1100				
Plastic foams					
Expanded polystyrene foam	15–30	0.035			23–150
Extruded polystyrene foam	30–40	0.027			150–300
Urea resin foam	8–20	0.054[2])		1470	1.5–3
Polyurethane foam	30–60	0.021–0.026			23–185
Phenolic resin foam (hard)	25–200	0.035			3.7
Polyvinylchloride foam	25–50	0.035			92–260

Note: when two values of ρ and λ are given, λ can be linearly interpolated for intermediate values of ρ.

1 Perpendicular to the fibers

2 When applied as cavity filing

3 When aging due to disappearing of freon filling, can rise to 0.035 W/mK

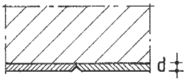
– Little is known yet about the μ-value of wood products. The μ-value also depends strongly on the moisture content.

* Column I concerns circumstances where the vapour is mainly determined by the indoor climate. Column II refers to circumstances where a higher vapour value is to be expected.

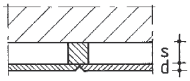
Table 11
Vapour barriers

Name	d (10^{-3} m)	μ (10^{3} –)	$\mu \cdot d$ (m)
Blown bitumen	–	70–120	1
Asphalt felt 330-37	–	–	20
Bituminised glass fleece	–	–	20–180
Sanded asphalt felt 500-56	2.6	–	50
Tar felt280-40/45	–	–	14
Single-sided bituminated paper	0.1	–	0.7
Flintkote (bitumen mix)	–	0.75	–
Polyester film	0.1	13	1.3
Polystyrene film	0.1	42	4.2
Polyvinylchloride film	0.1	10–100	1–10
Polyethylene film	0.1	50–100	5–10
Bitumen with aluminium foil lining	–	–	100-∞
Aluminium foil 0.06 mm, coated single-sided with plastic	–	–	100
Aluminium foil 0.08 mm, coated doube-sided with plastic	–	–	160
Some of the data in this table was made available by ‘Vedidak’.			

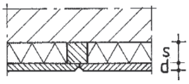
Table 12
Acoustics absorption coefficients (from: *Bouwfysisch Tabellarium*, TU Delft)



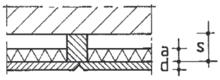
A = material directly on hard surface



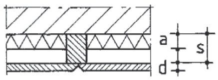
B = material on battens, air cavity



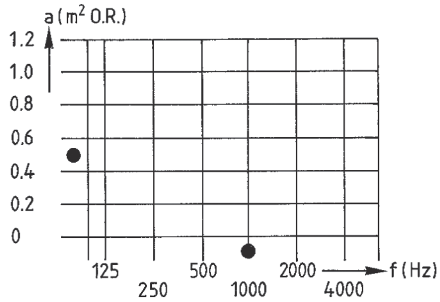
C = material on battens, cavity filled completely with acoustic material



D = material on battens, cavity filled partially with acoustic material



E = material on battens, cavity filled partially with acoustic material



Reference characteristic

Table 12 (vervolg)

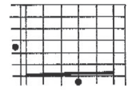
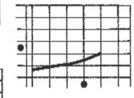
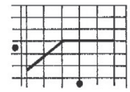
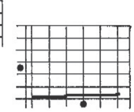
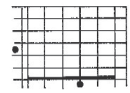
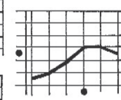
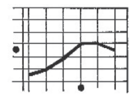
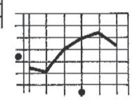
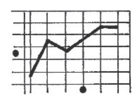
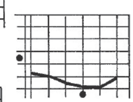
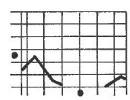
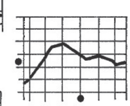
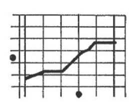
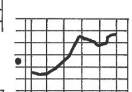
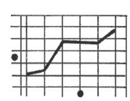
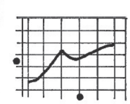
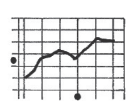
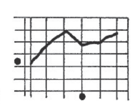
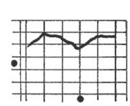
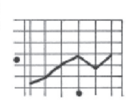
Nr.	Material (measurements in mm)	Type	Absorption coefficients α (m^2 O.R.) at center frequencies						Characteristics
			125	250	500	1000	2000	4000	
	Stony materials								
1	gravel concrete, ca. 500 kg/m^2		0.01	0.01	0.02	0.02	0.03	0.04	
2	aerated concrete, 70 kg/m^2		0.14	0.19	0.24	0.32	0.41	–	
3	pumice concrete		0.15	0.40	0.60	0.60	0.60	0.60	
4	brick masonry		0.02	0.03	0.03	0. 04	0.05	0.07	
	Plaster								
5	lime plaster, directly on stony surface	A	0.01	0.01	0.02	0.02	0.02	0.04	
6	acoustic plaster, applied in several layers	A	0.15	0.20	0.20	0.60	0.60	0.50	 
7	sprayed asbestos	A	0.29	0.24	0.65	0.79	0.88	0.65	
	Acoustic materials								
8	softboard (unpainted), d = 19; s = 23	B	0.13	0.72	0.59	0.76	0.90	0.92	
9	half hardboard (unpainted), *d* = 6.2; *s* = 50	B	0.24	0.20	0.09	0.04	0.04	0.12	
10	chipboard, 5,0 kg/m^2, *d* = 8; *s* = 30	B	0.25	0.22	0.04	0.00	0.03	0.08	
11	lightweight chipboard, 6.4 kg/m^2, *d* = 19; *s* = 50	B	0.16	0.58	0.75	0.53	0.54	0.42	
12	wood wool cement board, acoustic, *d* = 25	A	0.15	0.23	0.23	0.51	0.73	0.75	
13	wood wool cement board, acoustic, *d* = 25; *s* = 10	B	0.30	0.26	0.51	0.91	0.79	0.95	
14	wood wool cement board, acoustic, *d* = 25; *s* = 30	B	0.25	0.29	0.79	0.76	0.74	0.93	
15	wood wool cement board, acoustic, *d* = 25; *s* = 50	B	0.11	0.33	0.67	0.53	0.64	0.80	
16	wood wool cement board, acoustic, *d* = 25; *s* = 80	B	0.23	0.55	0.64	0.57	0.81	0.80	
17	wood wool cement board, acoustic, *d* = 25; *s* = 30, *a* = 30	C	0.43	0.80	1.00	0.79	0.80	0.98	
18	wood wool cement board, acoustic, *d* = 25; *s* = 80, *a* = 30	D	0.76	1.00	0.90	0.73	0.94	0.95	
19	cork board, acoustic, painted, d = 20; s = 25	B	0.08	0.15	0.44	0.54	0.38	0.60	

Table 12 (vervolg)

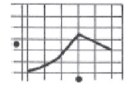
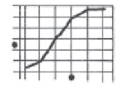
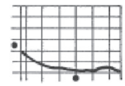
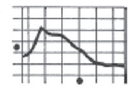
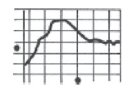
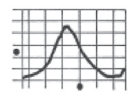
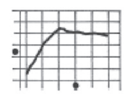
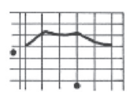
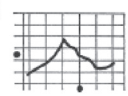
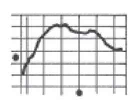
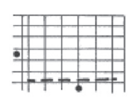
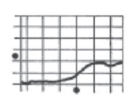
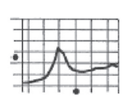
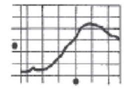
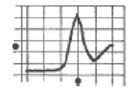
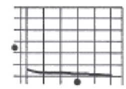
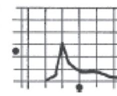
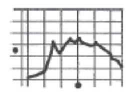
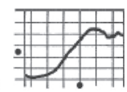
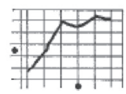
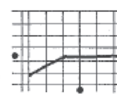
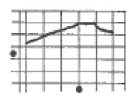
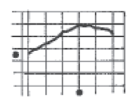
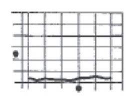
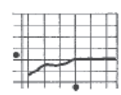
Nr.	Material (measurements in mm)	Type	Absorption coefficients α (m^2 O.R.) at center frequencies						Characteristics
			125	250	500	1000	2000	4000	
20	polystyrene foam board, d = 10; s = 4	B	0.05	0.11	0.31	0.73	0.58	0.47	
21	wood pulp, whitewashed, d = 22	A	0.07	0.20	0.60	1.00	1.13	1.13	
	Perforated board								
22	gypsum board, not perforated, d = 9,5; s = 100; a = 30	D	0.28	0.14	0.09	0.06	0.05	0.10	
23	gypsum board, perforated 6%, d = 9,5; s = 100; a = 30, holes ∅8, ∅15, ∅20	D	0.39	0.81	0.68	0.44	0.25	0.20	
24	gypsum board, perforated 19.6%, d = 9,5; s = 100; a = 30, holes ∅15	D	0.30	0.69	1.01	0.81	0.66	0.62	
25	gypsum board, cutting slots, d = 9.5; s = 30; a = 20, slots 2.3	D	0.10	0.26	0.92	0.55	0.20	0.10	
26	asbestos cement board, not perforated, d = 4; s = 50	B	0.43	0.15	0.10	0.05	0.04	0.02	
27	asbestos cement board, perforated 16%, d = 4; s = 50	C	0.13	0.65	0.90	0.82	0.82	0.77	
	Panelling								
28	wooden slats, wide 50, interspace 25 mm, d = 12; s = 200; a = 25	E	0.60	0.85	0.80	0.82	0.70	0.62	
29	wooden slats, wide 45, interspace 16 mm, mineral wool on bitumen paper in cavity, d = 25; s = 50; a = 20	E	0.19	0.36	0.73	0.50	0.25	0.31	
30	aluminium strips, wide 50, interspace 12.5 mm, d = 0,3; s = 176; a = 20	D	–	0.89	1.00	0.88	0.88	0.61	
	Flooring								
31	linoleum, glued to surface	A	0.02	–	0.30	–	0.04	–	
32	parquetry. glued to surface	A	0.04	0.04	0.06	0.12	0.10	15.00	
33	carpet, 1.87 kg/m^2, d = 4.5	A	0.00	0.02	0.04	0.15	0.36	0.32	
34	carpet, 1.87 kg/m^2, with underlay (8 mm felt), d = 4.5	A	0.05	0.13	0.60	0.24	0.28	0.32	
35	carpet, 1.98 kg/m^2, d = 5.3	A	0.00	0.03	0.05	0.11	0.31	0.58	

Table 12 (vervolg)

Nr.	Material (measurements in mm)	Type	Absorption coefficients α (m^2 O.R.) at center frequencies						Characteristics
			125	250	500	1000	2000	4000	
36	carpet, 1.98 kg/m^2, with underlay (8 mm felt), d = 5.3	A	0.04	0.10	0.31	0.70	0.93	0.74	
37	coconut flooring, loose on surface, 2 kg/m^2, d = 10	A	0.03	0.03	0.07	1.13	0.28	0.55	
	Miscellaneous								
38	glass		0.10	0.04	0.03	0.02	0.02	0.02	
39	plastic film, tightly strained, PVC 0.2 kg/m^2, d = 0.2; s = 20	B	0.00	0.00	0.64	0.17	0.12	0.04	
40	plastic film, folded 3:1, PVC 0.2 kg/m^2, d = 0.2, s = 20	B	0.00	0.13	0.51	0.66	0.59	0.30	
41	curtain, cotton, tightly strained, 0.2 kg/m^2, s = 50, ca. 0.4 kg/m^2	B	0.04	0.09	0.37	0.68	0.89	0.72	
42	curtain, cotton, folded 3:1 s = 50, ca. 0.4 kg/m^2	B	0.15	0.45	0.96	0.97	1.06	1.02	
43	a single seated person		0.15	0.30	0.45	0.45	0.45	0.45	
44	a single person in a space with much reverb (e.g. church)		0.65	0.75	0.85	0.95	0.95	0.80	
45	audience (including orchestra) per m^2		0.52	0.68	0.85	0.97	0.93	0.85	
46	wooden chair (unoccupied)		0.02	0.02	0.02	0.04	0.04	0.03	
47	lined chair (unoccupied)		0.15	0.30	0.30	0.40	0.40	0.40	

Note: The table above presents only general values derived from literature. More complete data with more accurate values with product description etc. can be found in:

- Bobran, H.W.: *Handbuch der Bauphysik*. Berlin, Ullstein, 1967.
- Bouwcentrum/Ratiobouw: *Akoestische materialen*. Uitgave NL 1962.
- Deutscher Normenausschuss (DNA): *Schallabsorptionsgrad-Tabelle*. Berlin, Beuth-Vertrieb, 1968.
- Furrer, W.: *Room and buidling acoustics and noise abatement*. London, Butterworths, 1964.
- Hartmann, G.: *Praktische Akustik*; Band 2: *Raum- und Bauakustik*. München, Oldenbourg, 1968.

Table 13 Coincidence threshold frequency for various materials

		example		example	
material	$f_g \cdot d$	d (mm)	f_g (Hz)	d (mm)	f_g (Hz)
aluminium	12 500	2	6 250	5	2 500
steel	12 800	1	12 800	3	4 267
glass	12 800	4	3 200	8	1 600
concrete	17 300	120	144	200	87
glass concrete	38 000	80	475	200	190
sand-lime	21 400	105	204	210	102
poriso	26 000	50	520	90	289
lightweight concrete	32 000	80	400	200	160
gypsum	35 500	50	710	70	507
drywall	35 500	9	3 944	15	2367
wood	25 000	12	2 083	22	1136
chipboard	25 000	8	3 125	18	1389
lead	51 200	0.5	102 400	2	25 600

Table 14 Standard values for airborne sound insulation

Octave band with middle frequency, in Hz	125	250	500	1000	2000
Standard values for standardised airborne sound insulation (D_{nT}), in dB	34	43	50	53	54

Table 15 Standard values for impact sound insulation

Octave band with middle frequency, in Hz	125	250	500	1000	2000
Standard values for standardised impact sound insulation (L_{nT}), in dB	70	66	66	66	70

Table 16 Attenuation or strengthening according to the A-weighting

frequency in Hz	A-weighting in dB
63	–26.1
125	–16.1
250	–8.6
500	–3.2
1000	0.0
2000	1.2
4000	1.0
8000	–1.0

Table 17 Standard values for reverberation times in various spaces

furnished room	T = ca. 0,5 s
office room	T = 0,5–0,7 s
open-space office	T = 0,7–0,9 s
classroom	T = 0,6–0,8 s
music room	T = 0,8–1,2 s
theatre	T = 0,9–1,3 s
chamber music room	T = 1,2–1,5 s
opera hall	T = 1,2–1,6 s
concert hall	T = 1,7–2,3 s
church (organ music)	T = 1,5–2,5 s

Figure 1 Adding sound pressure levels

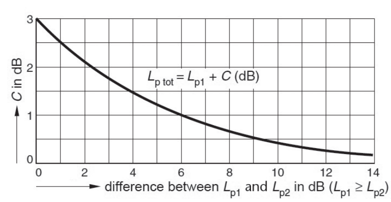


Figure 2 Reduction of insulation due to a part with less insulation

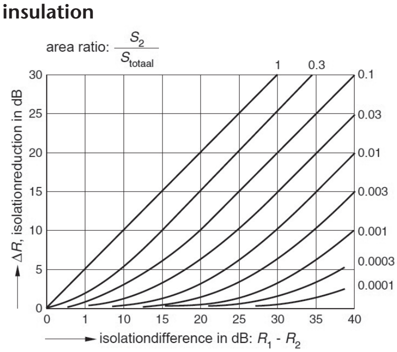


Table 18
Allowable sound levels in work rooms

	interference from outside etc. L_{eg} in dB (A)		background noise of installations etc. L_{95} in dB (A)	
room/type of work	preferred	max	preferred	max
single rooms for study, thought work etc. reading rooms	30–35	40	30–35	40
single room or multi-person room for design, editorial work etc. classroom	35–40	45	30–35	40
large office spaces for administrative work, drawing etc.	40	45	35	40
large office rooms for typing, mechanic administration etc.	45	50	40	45
telex rooms, computer rooms etc.	45–55	60	45–55	60

Note: in large office rooms (open-space offices) it is often desirable to have a background noise level of 50-55 dB(A). In this rather high sound level other sounds are masked, resulting in increased privacy. Various other conditions apply to open-space offices.

Table 19
Airborne sound insulation

	airborne sound insulation index I_{lu} respectively $I_{lu;k}$ in dB	
separation	minimal requirement	preference
between chambers of different dwellings	0	5
between chambers in the same dwelling	–20	–15
between office space where large privacy (confidential talks) is desired	0	5
between rooms with high sound production (typin rooms, multi-person rooms) and more quiet rooms (single rooms)	–5	0
between classrooms	–10	–5
between similar, regular office spaces	–15	–10
between rooms and hallways	–20	–15

Formulas sound

Sound pressure level

$$L_p = 10 \log \frac{p_{eff}^2}{p_0^2}$$

Here:
L_p the sound pressure level in decibel
p_{eff} the effective sound pressure
p_0 the reference sound pressure ($2 \cdot 10^{-5}$ Pa)

Sound intensity

$$I = \frac{p^2}{4 \cdot \rho \cdot c}$$ for a diffuse sound field

$$I = \frac{p^2}{\rho \cdot c}$$ for a plane wave

Here:
I the sound intensity in W/m^2 (energy)
p the sound pressure in Pa
ρ the density of the air in km/m^3
c the speed of sound in m/s
$\rho \cdot c$ for average conditions, numerical value ca. 400

Sound power level

$$L_w = 10 \log \frac{W}{W_0} \qquad \text{[dB]}$$

Here:

L_w the sound power level in dB
W the sound power in Watt
W_0 the reference power (10^{-12} W)

Adding sound pressure levels

$$L_{ptotal} = 10 \log (10^{Lp\frac{1}{10}} + 10^{Lp\frac{2}{10}} + 10^{Lp\frac{3}{10}} \ldots) \quad \text{[dB]}$$

Here:

L_{p1} the sound pressure level of sound 1
L_{p2} the sound pressure level of sound 2
L_{ptotal} the resulting sound pressure level in dB

Wavelength and frequency

$$c = f \cdot \lambda \qquad \text{[m/s]}$$

Here:

c the propagation speed of the sound in m/s
f the frequency in Hz
λ the wavelength in m

Mass-spring resonance in cavity constructions

$$f_0 = 60 \sqrt{\frac{m_1 + m_2}{m_1 \cdot m_2} \cdot \frac{1}{b}} \qquad \text{[Hz]}$$

Here:

f_0 the resonance frequency at perpendicular incidence
m_1 mass of the first cavity leaf in kg/m^2
m_2 mass of the second cavity leaf
b width of the cavity in m

Sound insulation o a construction

$$R = L_z - L_o + 10 \log \frac{S}{A} \qquad \text{[dB]}$$

Here:

L_z the sound pressure level in the send room in dB
L_o the sound pressure level in the receiver room in dB
S the area of the wall
A the absorption in the receiver room

The standardised airborne sound insulation according to NEN 1070

$$D_{nT} = L_z - L_o + 10 \log \frac{T}{T_0} \qquad \text{[dB]}$$

Here:

D_{nT} the standardised airborne sound insulation in dB
L_z the sound pressure level in the send room in dB
L_o the sound pressure level in the receiver room in dB
T the measured reverberation time in the receiver room
T_0 the standardised reverberation time (= 0.5 s)

The standardised impact sound insulation according to NEN 1070

$$L_{nT} = L_{co} - 10 \log \frac{T}{T_0} \qquad \text{[dB]}$$

Here:

L_{nT} the standardised impact sound insulation in dB
L_{co} the sound pressure level measured in the receiver room in dB

Characteristic airborne sound insulation index $I_{lu;k}$

$$I_{lu;k} = I_{lu} - 10 \log \left(\frac{V}{6T_0 \cdot S}\right) - 1$$

Here:

$I_{lu;k}$ characteristic insulation index for airborne sound in dB
I_{lu} insulation index for airborne sound in dB
V net volume of the receiver room in m^3
T_0 reference reverberation tim in *s*
S area of the surface between send and receiver room in m^2

1. If the ratio
   $$\frac{V}{6T_0 \cdot S} > 2.5$$
   then this ratio must beqa assumed 2.5 for calculation of $I_{lu;k}$;
2. If there is no common part of the separation construction between send and receiver room, S must be assumed 10 m^2 for calculation of $I_{lu;k}$.

Figure 3
Illuminance in the free field

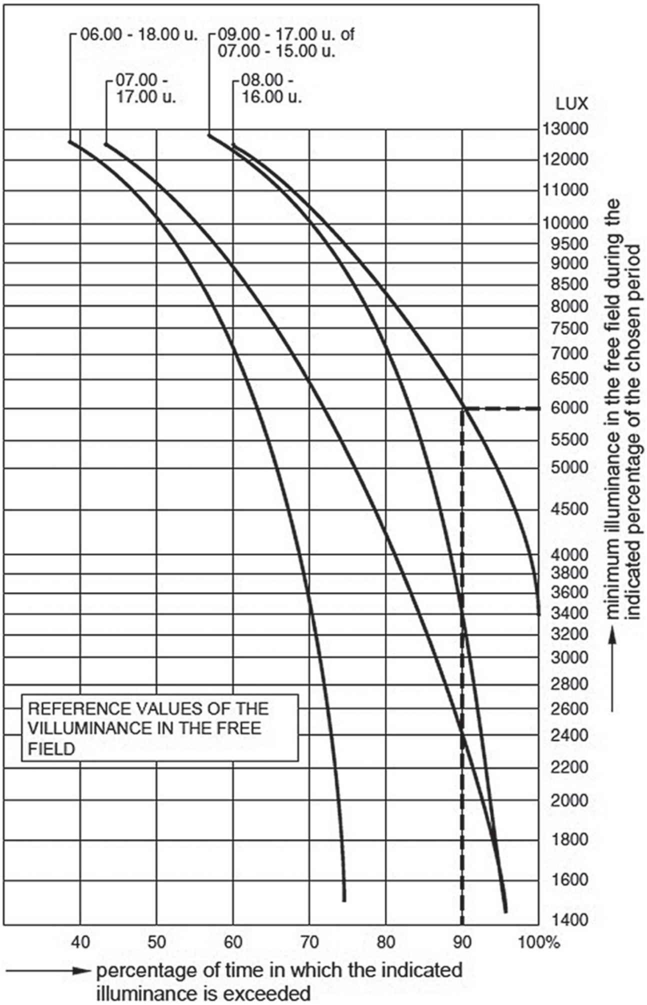


Table 20
Internal reflection component in % for various reflection factors of wall finish in the room. Reflection factor ceiling ca. 70%, floors ca. 20%.

Glass area related to floor area in %	reflection factor of walls			
	20%	40%	60%	80%
10	0.2	0.3	0.6	0.9
20	0.3	0.6	1.1	1.7
30	0.5	0.9	1.5	2.4
40	0.6	1.2	2.0	3.1