INTERNATIONAL STANDARD

ISO 9613-1

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Acoustics — Attenuation of sound during propagation outdoors —

Part 1:
Calculation of the absorption of sound by the atmosphere

Acoustique — Attenuation du son lors de sa propagation à l'air libre —
Partie 1: Calcul de l'absorption atmosphérique

Reference number
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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9613-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Sub-Committee SC 1, *Noise*.

ISO 9613 consists of the following parts, under the general title *Acoustics — Attenuation of sound during propagation outdoors*:

— *Part 1: Calculation of the absorption of sound by the atmosphere*

— *Part 2: A general method of calculation*

Annexes A, B, C, D, E and F of this part of ISO 9613 are for information only.

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Introduction

The aim of this International Standard is to specify methods of calculating the attenuation of sound propagating outdoors in order to predict the level of environmental noise at distant locations from various sound sources.

Acoustics — Attenuation of sound during propagation outdoors —

Part 1:
Calculation of the absorption of sound by the atmosphere

1 Scope

This part of ISO 9613 specifies an analytical method of calculating the attenuation of sound as a result of atmospheric absorption for a variety of meteorological conditions when the sound from any source propagates through the atmosphere outdoors.

For pure-tone sounds, attenuation due to atmospheric absorption is specified in terms of an attenuation coefficient as a function of four variables: the frequency of the sound, and the temperature, humidity and pressure of the air. Computed attenuation coefficients are provided in tabular form for ranges of the variables commonly encountered in the prediction of outdoor sound propagation:

- frequency from 50 Hz to 10 kHz,
- temperature from – 20 °C to + 50 °C,
- relative humidity from 10 % to 100 %, and
- pressure of 101,325 kPa (one atmosphere).

Formulae are also provided for wider ranges suitable for particular uses, for example, at ultrasonic frequencies for acoustical scale modelling, and at lower pressures for propagation from high altitudes to the ground.

For wideband sounds analysed by fractional-octave band filters (e.g. one-third-octave band filters), a method is specified for calculating the attenuation due to atmospheric absorption from that specified for pure-tone sounds at the midband frequencies. An alternative spectrum-integration method is described in annex D. The spectrum of the sound may be wideband with no significant discrete-frequency components or it may be a combination of wideband and discrete frequency sounds.

This part of ISO 9613 applies to an atmosphere with uniform meteorological conditions. It may also be used to determine adjustments to be applied to measured sound pressure levels to account for differences between atmospheric absorption losses under different meteorological conditions. Extension of the method to inhomogeneous atmospheres is considered in annex C, in particular to meteorological conditions that vary with height above the ground.

This part of ISO 9613 accounts for the principal absorption mechanisms present in an atmosphere devoid of significant fog or atmospheric pollutants. The calculation of sound attenuation by mechanisms other than atmospheric absorption, such as refraction or ground reflection, is described in ISO 9613-2.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9613. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9613 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2533:1975, *Standard Atmosphere.*

ISO 266:1975, *Acoustics — Preferred frequencies for measurements.*

IEC 225:1966, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

3 Symbols

- f frequency of the sound, in hertz
- f_m midband frequency, in hertz
- h molar concentration of water vapour, as a percentage
- p_r reference ambient atmospheric pressure, in kilopascals
- p_i initial sound pressure amplitude, in pascals
- p_t sound pressure amplitude, in pascals
- p_0 reference sound pressure amplitude (20 µPa)
- p_a ambient atmospheric pressure, in kilopascals
- s distance, in metres, through which the sound propagates
- T ambient atmospheric temperature, in kelvins
- T_0 reference air temperature, in kelvins
- α pure-tone sound attenuation coefficient, in decibels per metre, for atmospheric absorption

  NOTE 1 For convenience, in this part of ISO 9613, the shortened term "attenuation coefficient" will be used for α in place of the full description.

- δL_t attenuation due to atmospheric absorption, in decibels

4 Reference atmospheric conditions

4.1 Composition

Atmospheric absorption is sensitive to the composition of the air, particularly to the widely varying concentration of water vapour. For clean, dry air at sea level, the standard molar concentrations, or fractional volumes of the three principal, normally fixed, constituents of nitrogen, oxygen and carbon dioxide are: 0,780 84; 0,209 476; and 0,000 314, respectively (taken from ISO 2533). For dry air, other minor trace constituents, which have no significant influence on atmospheric absorption, make up the remaining fraction of 0,009 37. For atmospheric absorption calculations, the standard molar concentrations of the three principal constituents of dry air may be assumed to hold for altitudes up to at least 50 km above mean sea level. However, the molar concentration of water vapour, which has a major influence on atmospheric absorption, varies widely near the ground and by over two orders of magnitude from sea level to 10 km.

4.2 Atmospheric pressure and temperature

For the purposes of this part of ISO 9613, the reference ambient atmospheric pressure, p_r, is that of the International Standard Atmosphere at mean sea level, namely 101,325 kPa. The reference air temperature, T_0, is 293,15 K (20 °C), i.e. the temperature at which the most reliable data supporting this part of ISO 9613 were obtained.

5 Attenuation coefficients due to atmospheric absorption for pure-tone sounds

5.1 Basic expression for attenuation

As a pure-tone sound propagates through the atmosphere over a distance s, the sound pressure amplitude p_t decreases exponentially as a result of the atmospheric absorption effects covered by this part of ISO 9613 from its initial value p_i, in accordance with the decay formula for plane sound waves in free space

$$p_t = p_i \exp(-0{,}115\,1 \alpha s) \qquad \ldots (1)$$

NOTE 2 The term $\exp(-0{,}115\,1\alpha s)$ represents the base e of Naperian logarithms raised to the exponent indicated by the argument in parentheses and the constant $0{,}115\,1 = 1/[10\ \lg(e^2)]$.

5.2 Attenuation of sound pressure levels

The attenuation due to atmospheric absorption $\delta L_t(f)$, in decibels, in the sound pressure level of a pure tone with frequency f, from the initial level at $s = 0$ to the level at distance s, is given by

$$\delta L_t(f) = 10\ \lg(p_i^2/p_t^2)\ \text{dB} = \alpha s \qquad \ldots (2)$$

6 Calculation procedure for pure-tone attenuation coefficients

6.1 Variables

The acoustic and atmospheric variables, i.e. frequency of the sound, ambient atmospheric temperature, molar concentration of water vapour and ambient atmospheric pressure, are listed in clause 3, together with their symbols and units.

NOTES

3 For a specific sample of moist air, the molar concentration of water vapour is the ratio (expressed as a percentage) of the number of kilomoles (i.e. the number of kilogram molecular weights) of water vapour to the sum of the number of kilomoles of dry air and water vapour. By Avogadro's law, the molar concentration of water vapour is also the ratio of the partial pressure of water vapour to the atmospheric pressure.

4 Molar concentrations of water vapour range from about 0,2 % to 2 % for commonly encountered meteorological conditions at altitudes near mean sea level, but decrease to well below 0,01 % at altitudes above 10 km.

6.2 Formulae

As described in annex A, the attenuation due to atmospheric absorption is a function of two relaxation frequencies, f_{rO} and f_{rN}, the oxygen and nitrogen relaxation frequencies, respectively. Values of f_{rO} and f_{rN}, in hertz, shall be calculated from

$$f_{rO} = \frac{p_a}{p_r}\left(24 + 4{,}04 \times 10^4 h \frac{0{,}02 + h}{0{,}391 + h}\right) \qquad \ldots (3)$$

and

$$f_{rN} = \frac{p_a}{p_r}\left(\frac{T}{T_0}\right)^{-1/2} \times \left(9 + 280h \exp\left\{-4{,}170\left[\left(\frac{T}{T_0}\right)^{-1/3} - 1\right]\right\}\right) \qquad \ldots (4)$$

The attenuation coefficient α, in decibels per metre, for atmospheric absorption shall be calculated from

$$\alpha = 8{,}686 f^2 \left(\left[1{,}84 \times 10^{-11}\left(\frac{p_a}{p_r}\right)^{-1}\left(\frac{T}{T_0}\right)^{1/2}\right] + \left(\frac{T}{T_0}\right)^{-5/2} \times \left\{0{,}012\,75\left[\exp\left(\frac{-2\,239{,}1}{T}\right)\right]\left[f_{rO} + \left(\frac{f^2}{f_{rO}}\right)\right]^{-1} + 0{,}106\,8\left[\exp\left(\frac{-3\,352{,}0}{T}\right)\right]\left[f_{rN} + \left(\frac{f^2}{f_{rN}}\right)\right]^{-1}\right\}\right) \qquad \ldots (5)$$

Values for f_{rO} and f_{rN} are taken from equations (3) and (4).

In equations (3) to (5), $p_r = 101{,}325$ kPa and $T_0 = 293{,}15$ K.

Equations (3) to (5) combine, in a condensed form suitable for computations, formulae giving contributions from the individual physical mechanisms described in annex A.

6.3 Computation of the attenuation coefficient

Equations (3) to (5) are all that is needed to calculate the pure-tone attenuation coefficient for atmospheric absorption for selected values of the variables. Although air temperature and air pressure data may not be supplied in the units of measure given in clause 3, conversion factors are readily available to convert the given unit to kelvins or kilopascals respectively. Humidity data, on the other hand, are rarely supplied in terms of molar concentration of water vapour. Annex B provides information on conversion of humidity data that are supplied in terms of relative humidity, dewpoint and other measures, to corresponding values of molar concentration.

The means by which a real inhomogeneous atmosphere may be approximated by the uniform atmosphere assumed in the formulae of 6.2 are discussed in annex C.

6.4 Tabular values of the attenuation coefficient

For selected values of T, h and f at a pressure of one standard atmosphere (101,325 kPa), table 1 lists pure-tone attenuation coefficients for atmospheric absorption calculated by use of equations (3) to (5), but using the unit "decibels per kilometre" for convenience in applications to sound propagation outdoors over path lengths of the order of a few kilometres. Tabular values are presented in scientific notation to preserve accuracy at low frequencies. Users of table 1 should not interpolate between the entries, or extrapolate beyond the table range, but should use equations (3) to (5) to calculate the specific pure-tone attenuation coefficients for desired conditions.

NOTES

5 For convenience, the frequencies shown in table 1 are the preferred frequencies for one-third-octave band filters (see ISO 266 and IEC 225). However, the attenuation coefficients in table 1 were calculated for the exact midband frequencies f_m, in hertz, using the general expression according to the base 10 system

$$f_m = (1\,000)\,(10^{3b/10})^k \qquad \ldots (6)$$

where 1 000 Hz is the exact reference frequency and b is a rational fraction that serves as the bandwidth designator for any fractional-octave band filter (e.g. with $b = 1/3$ for one-third-octave band filters, and so on for other bandwidths). For table 1, index k is an integer from -13 to $+10$, corresponding to preferred frequencies from 50 Hz to 10 kHz. For exact ultrasonic frequencies at one-third-octave-band intervals from 10 kHz to 1 MHz, equation (6) may be used with k ranging from $+10$ to $+30$.

6 Relative humidities given as column headings in table 1 are with respect to saturation over a surface of liquid water at all temperatures; see annex B. The saturated vapour

pressure was calculated from the formulae used to generate the *International Meteorological Tables*[2]. See annex B.

7 Accuracy of calculated pure-tone attenuation coefficients for various ranges of the variables

7.1 Accuracy of ± 10 %

The accuracy of the calculated pure-tone attenuation coefficients for atmospheric absorption is estimated to be ± 10 % for variables within the following ranges:

molar concentration of water vapour: 0,05 % to 5 %

air temperature: 253,15 K to 323,15 K (– 20 °C to + 50 °C)

atmospheric pressure: less than 200 kPa (2 atm)

frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa (40 Hz/atm to 1 MHz/atm)

NOTE 7 Combinations of molar concentration of water vapour and temperature which imply a relative humidity greater than 100 % in 7.1 to 7.3 are excluded from the corresponding accuracy estimates.

7.2 Accuracy of ± 20 %

The accuracy of the calculated pure-tone attenuation coefficients for atmospheric absorption is estimated to be ± 20 % for variables within the following ranges:

molar concentration of water vapour: 0,005 % to 0,05 %, and greater than 5 %

air temperature: 253,15 K to 323,15 K (– 20 °C to + 50 °C)

atmospheric pressure: less than 200 kPa (2 atm)

frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa

7.3 Accuracy of ± 50 %

The accuracy of the calculated pure-tone attenuation coefficients due to atmospheric absorption is estimated to be ± 50 % for variables within the following ranges, which include environmental conditions encountered at altitudes up to 10 km:

molar concentration of water vapour: less than 0,005 %

air temperature: greater than 200 K (– 73 °C)

atmospheric pressure: less than 200 kPa (2 atm)

frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa

8 Calculation of attenuation by atmospheric absorption for wideband sound analysed by fractional-octave-band filters

8.1 Description of the general problem and calculation methods

8.1.1 Previous clauses of this part of ISO 9613 have considered the effects of atmospheric absorption on the reduction in the level of a pure tone during propagation through the atmosphere. In practice, however, the spectrum of most sounds covers a wide range of frequencies, and spectral analysis is normally performed by fractional-octave-band filters that yield sound pressure levels in frequency bands.

Table 1 — Pure-tone atmospheric-absorption attenuation coefficients, in decibels per kilometre, at an air pressure of one standard atmosphere (101,325 kPa)

(a) Air temperature: −20 °C

Preferred frequency, Hz	Relative humidity, % 10	15	20	30	40	50	60	70	80	90	100
50	$5,89 \times 10^{-1}$	$5,09 \times 10^{-1}$	$4,18 \times 10^{-1}$	$2,85 \times 10^{-1}$	$2,11 \times 10^{-1}$	$1,68 \times 10^{-1}$	$1,42 \times 10^{-1}$	$1,25 \times 10^{-1}$	$1,14 \times 10^{-1}$	$1,05 \times 10^{-1}$	$9,92 \times 10^{-2}$
63	$7,56 \times 10^{-1}$	$7,04 \times 10^{-1}$	$6,02 \times 10^{-1}$	$4,21 \times 10^{-1}$	$3,08 \times 10^{-1}$	$2,41 \times 10^{-1}$	$2,00 \times 10^{-1}$	$1,73 \times 10^{-1}$	$1,55 \times 10^{-1}$	$1,42 \times 10^{-1}$	$1,33 \times 10^{-1}$
80	$9,24 \times 10^{-1}$	$9,35 \times 10^{-1}$	$8,46 \times 10^{-1}$	$6,19 \times 10^{-1}$	$4,55 \times 10^{-1}$	$3,52 \times 10^{-1}$	$2,86 \times 10^{-1}$	$2,43 \times 10^{-1}$	$2,14 \times 10^{-1}$	$1,94 \times 10^{-1}$	$1,79 \times 10^{-1}$
100	1,08	1,18	1,15	$9,02 \times 10^{-1}$	$6,75 \times 10^{-1}$	$5,21 \times 10^{-1}$	$4,19 \times 10^{-1}$	$3,50 \times 10^{-1}$	$3,03 \times 10^{-1}$	$2,69 \times 10^{-1}$	$2,45 \times 10^{-1}$
125	1,20	1,43	1,49	1,28	$9,98 \times 10^{-1}$	$7,76 \times 10^{-1}$	$6,22 \times 10^{-1}$	$5,14 \times 10^{-1}$	$4,39 \times 10^{-1}$	$3,84 \times 10^{-1}$	$3,44 \times 10^{-1}$
160	1,30	1,64	1,83	1,77	1,45	1,16	$9,30 \times 10^{-1}$	$7,66 \times 10^{-1}$	$6,48 \times 10^{-1}$	$5,61 \times 10^{-1}$	$4,96 \times 10^{-1}$
200	1,37	1,82	2,15	2,33	2,06	1,70	1,39	1,15	$9,70 \times 10^{-1}$	$8,34 \times 10^{-1}$	$7,31 \times 10^{-1}$
250	1,43	1,95	2,42	2,93	2,83	2,46	2,06	1,73	1,46	1,26	1,09
315	1,46	2,05	2,63	3,49	3,70	3,43	3,00	2,57	2,20	1,90	1,65
400	1,49	2,12	2,79	3,99	4,60	4,59	4,23	3,74	3,27	2,85	2,50
500	1,52	2,17	2,91	4,38	5,45	5,86	5,72	5,29	4,76	4,23	3,76
630	1,55	2,22	3,00	4,68	6,17	7,10	7,39	7,19	6,71	6,13	5,55
800	1,59	2,27	3,08	4,92	6,75	8,22	9,07	9,31	9,09	8,60	7,98
1 000	1,65	2,34	3,16	5,11	7,21	9,14	1,06 × 10	1,15 × 10	1,17 × 10	1,16 × 10	1,11 × 10
1 250	1,74	2,43	3,27	5,28	7,57	9,88	1,19 × 10	1,35 × 10	1,44 × 10	1,48 × 10	1,47 × 10
1 600	1,88	2,58	3,42	5,48	7,90	1,05 × 10	1,30 × 10	1,52 × 10	1,69 × 10	1,80 × 10	1,86 × 10
2 000	2,10	2,80	3,65	5,73	8,24	1,10 × 10	1,39 × 10	1,66 × 10	1,90 × 10	2,10 × 10	2,24 × 10
2 500	2,44	3,15	4,00	6,10	8,66	1,16 × 10	1,47 × 10	1,78 × 10	2,08 × 10	2,35 × 10	2,58 × 10
3 150	2,99	3,69	4,55	6,66	9,26	1,23 × 10	1,55 × 10	1,90 × 10	2,24 × 10	2,57 × 10	2,88 × 10
4 000	3,86	4,56	5,42	7,54	1,02 × 10	1,32 × 10	1,66 × 10	2,02 × 10	2,40 × 10	2,78 × 10	3,14 × 10
5 000	5,24	5,94	6,80	8,92	1,16 × 10	1,46 × 10	1,81 × 10	2,19 × 10	2,59 × 10	3,00 × 10	3,41 × 10
6 300	7,42	8,12	8,98	1,11 × 10	1,38 × 10	1,69 × 10	2,04 × 10	2,42 × 10	2,83 × 10	3,27 × 10	3,71 × 10
8 000	1,09 × 10	1,16 × 10	1,24 × 10	1,46 × 10	1,72 × 10	2,03 × 10	2,39 × 10	2,78 × 10	3,20 × 10	3,65 × 10	4,11 × 10
10 000	1,64 × 10	1,71 × 10	1,79 × 10	2,01 × 10	2,27 × 10	2,58 × 10	2,94 × 10	3,33 × 10	3,76 × 10	4,22 × 10	4,70 × 10

(b) Air temperature: −15 °C

Preferred frequency, Hz	Relative humidity, % 10	15	20	30	40	50	60	70	80	90	100
50	$5,73 \times 10^{-1}$	$4,25 \times 10^{-1}$	$3,21 \times 10^{-1}$	$2,12 \times 10^{-1}$	$1,64 \times 10^{-1}$	$1,39 \times 10^{-1}$	$1,24 \times 10^{-1}$	$1,14 \times 10^{-1}$	$1,07 \times 10^{-1}$	$1,02 \times 10^{-1}$	$9,68 \times 10^{-2}$
63	$7,93 \times 10^{-1}$	$6,18 \times 10^{-1}$	$4,72 \times 10^{-1}$	$3,05 \times 10^{-1}$	$2,28 \times 10^{-1}$	$1,88 \times 10^{-1}$	$1,66 \times 10^{-1}$	$1,52 \times 10^{-1}$	$1,42 \times 10^{-1}$	$1,35 \times 10^{-1}$	$1,30 \times 10^{-1}$
80	1,06	$8,85 \times 10^{-1}$	$6,93 \times 10^{-1}$	$4,46 \times 10^{-1}$	$3,24 \times 10^{-1}$	$2,60 \times 10^{-1}$	$2,24 \times 10^{-1}$	$2,02 \times 10^{-1}$	$1,87 \times 10^{-1}$	$1,77 \times 10^{-1}$	$1,70 \times 10^{-1}$
100	1,34	1,23	1,01	$6,60 \times 10^{-1}$	$4,71 \times 10^{-1}$	$3,68 \times 10^{-1}$	$3,08 \times 10^{-1}$	$2,71 \times 10^{-1}$	$2,48 \times 10^{-1}$	$2,32 \times 10^{-1}$	$2,21 \times 10^{-1}$
125	1,62	1,65	1,44	$9,79 \times 10^{-1}$	$6,95 \times 10^{-1}$	$5,32 \times 10^{-1}$	$4,35 \times 10^{-1}$	$3,74 \times 10^{-1}$	$3,34 \times 10^{-1}$	$3,08 \times 10^{-1}$	$2,89 \times 10^{-1}$
160	1,88	2,11	1,99	1,45	1,04	$7,86 \times 10^{-1}$	$6,30 \times 10^{-1}$	$5,31 \times 10^{-1}$	$4,64 \times 10^{-1}$	$4,18 \times 10^{-1}$	$3,86 \times 10^{-1}$
200	2,08	2,57	2,63	2,10	1,55	1,17	$9,32 \times 10^{-1}$	$7,72 \times 10^{-1}$	$6,63 \times 10^{-1}$	$5,87 \times 10^{-1}$	$5,32 \times 10^{-1}$
250	2,24	2,99	3,32	2,97	2,30	1,76	1,40	1,15	$9,73 \times 10^{-1}$	$8,47 \times 10^{-1}$	$7,56 \times 10^{-1}$
315	2,35	3,33	3,98	4,05	3,34	2,64	2,11	1,73	1,45	1,25	1,10
400	2,43	3,59	4,56	5,27	4,73	3,89	3,17	2,61	2,19	1,88	1,65
500	2,50	3,78	5,03	6,52	6,43	5,61	4,70	3,93	3,32	2,85	2,49
630	2,55	3,93	5,39	7,67	8,35	7,81	6,83	5,85	5,01	4,33	3,78
800	2,61	4,05	5,66	8,65	1,03 × 10	1,04 × 10	9,62	8,53	7,46	6,53	5,74
1 000	2,67	4,15	5,87	9,44	1,21 × 10	1,32 × 10	1,30 × 10	1,21 × 10	1,09 × 10	9,69	8,63
1 250	2,77	4,28	6,07	1,01 × 10	1,37 × 10	1,60 × 10	1,67 × 10	1,63 × 10	1,53 × 10	1,40 × 10	1,28 × 10
1 600	2,92	4,44	6,28	1,06 × 10	1,49 × 10	1,84 × 10	2,05 × 10	2,11 × 10	2,07 × 10	1,97 × 10	1,83 × 10
2 000	3,14	4,67	6,54	1,10 × 10	1,59 × 10	2,06 × 10	2,39 × 10	2,60 × 10	2,67 × 10	2,64 × 10	2,54 × 10
2 500	3,49	5,03	6,92	1,15 × 10	1,68 × 10	2,22 × 10	2,69 × 10	3,05 × 10	3,27 × 10	3,37 × 10	3,37 × 10
3 150	4,04	5,59	7,49	1,22 × 10	1,78 × 10	2,37 × 10	2,95 × 10	3,45 × 10	3,84 × 10	4,10 × 10	4,25 × 10
4 000	4,92	6,47	8,38	1,31 × 10	1,89 × 10	2,52 × 10	3,18 × 10	3,79 × 10	4,34 × 10	4,78 × 10	5,11 × 10
5 000	6,31	7,86	9,78	1,46 × 10	2,04 × 10	2,71 × 10	3,41 × 10	4,12 × 10	4,79 × 10	5,40 × 10	5,91 × 10
6 300	8,52	1,01 × 10	1,20 × 10	1,68 × 10	2,27 × 10	2,96 × 10	3,70 × 10	4,47 × 10	5,24 × 10	5,98 × 10	6,65 × 10
8 000	1,20 × 10	1,36 × 10	1,55 × 10	2,03 × 10	2,63 × 10	3,32 × 10	4,09 × 10	4,90 × 10	5,74 × 10	6,58 × 10	7,39 × 10
10 000	1,75 × 10	1,91 × 10	2,10 × 10	2,59 × 10	3,19 × 10	3,89 × 10	4,67 × 10	5,51 × 10	6,40 × 10	7,30 × 10	8,21 × 10

(c) Air temperature: −10 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$4,82 \times 10^{-1}$	$3,25 \times 10^{-1}$	$2,45 \times 10^{-1}$	$1,74 \times 10^{-1}$	$1,46 \times 10^{-1}$	$1,31 \times 10^{-1}$	$1,21 \times 10^{-1}$	$1,13 \times 10^{-1}$	$1,06 \times 10^{-1}$	$1,00 \times 10^{-1}$	$9,46 \times 10^{-2}$
63	$7,00 \times 10^{-1}$	$4,75 \times 10^{-1}$	$3,50 \times 10^{-1}$	$2,38 \times 10^{-1}$	$1,95 \times 10^{-1}$	$1,74 \times 10^{-1}$	$1,61 \times 10^{-1}$	$1,52 \times 10^{-1}$	$1,45 \times 10^{-1}$	$1,38 \times 10^{-1}$	$1,32 \times 10^{-1}$
80	$9,99 \times 10^{-1}$	$6,97 \times 10^{-1}$	$5,09 \times 10^{-1}$	$3,32 \times 10^{-1}$	$2,61 \times 10^{-1}$	$2,28 \times 10^{-1}$	$2,10 \times 10^{-1}$	$1,99 \times 10^{-1}$	$1,91 \times 10^{-1}$	$1,84 \times 10^{-1}$	$1,79 \times 10^{-1}$
100	1,39	1,02	$7,49 \times 10^{-1}$	$4,72 \times 10^{-1}$	$3,57 \times 10^{-1}$	$3,02 \times 10^{-1}$	$2,73 \times 10^{-1}$	$2,57 \times 10^{-1}$	$2,46 \times 10^{-1}$	$2,39 \times 10^{-1}$	$2,33 \times 10^{-1}$
125	1,86	1,48	1,11	$6,88 \times 10^{-1}$	$5,01 \times 10^{-1}$	$4,09 \times 10^{-1}$	$3,60 \times 10^{-1}$	$3,32 \times 10^{-1}$	$3,15 \times 10^{-1}$	$3,04 \times 10^{-1}$	$2,97 \times 10^{-1}$
160	2,38	2,10	1,63	1,02	$7,21 \times 10^{-1}$	$5,69 \times 10^{-1}$	$4,85 \times 10^{-1}$	$4,36 \times 10^{-1}$	$4,06 \times 10^{-1}$	$3,88 \times 10^{-1}$	$3,76 \times 10^{-1}$
200	2,89	2,87	2,37	1,52	1,06	$8,16 \times 10^{-1}$	$6,76 \times 10^{-1}$	$5,91 \times 10^{-1}$	$5,37 \times 10^{-1}$	$5,03 \times 10^{-1}$	$4,80 \times 10^{-1}$
250	3,36	3,75	3,35	2,27	1,58	1,20	$9,69 \times 10^{-1}$	$8,26 \times 10^{-1}$	$7,34 \times 10^{-1}$	$6,72 \times 10^{-1}$	$6,29 \times 10^{-1}$
315	3,74	4,66	4,56	3,35	2,38	1,79	1,43	1,19	1,04	$9,28 \times 10^{-1}$	$8,53 \times 10^{-1}$
400	4,03	5,51	5,93	4,86	3,57	2,70	2,13	1,76	1,51	1,33	1,20
500	4,24	6,24	7,32	6,82	5,30	4,07	3,23	2,65	2,24	1,95	1,73
630	4,41	6,82	8,61	9,20	7,70	6,10	4,89	4,01	3,38	2,92	2,57
800	4,53	7,26	9,71	$1,18 \times 10$	$1,08 \times 10$	8,99	7,36	6,09	5,14	4,43	3,88
1 000	4,65	7,60	$1,06 \times 10$	$1,44 \times 10$	$1,46 \times 10$	$1,29 \times 10$	$1,09 \times 10$	9,19	7,82	6,75	5,91
1 250	4,78	7,87	$1,13 \times 10$	$1,68 \times 10$	$1,88 \times 10$	$1,79 \times 10$	$1,58 \times 10$	$1,37 \times 10$	$1,18 \times 10$	$1,03 \times 10$	9,02
1 600	4,94	8,14	$1,18 \times 10$	$1,88 \times 10$	$2,30 \times 10$	$2,36 \times 10$	$2,21 \times 10$	$1,98 \times 10$	$1,75 \times 10$	$1,55 \times 10$	$1,37 \times 10$
2 000	5,18	8,44	$1,23 \times 10$	$2,05 \times 10$	$2,68 \times 10$	$2,97 \times 10$	$2,96 \times 10$	$2,78 \times 10$	$2,54 \times 10$	$2,29 \times 10$	$2,06 \times 10$
2 500	5,54	8,85	$1,28 \times 10$	$2,18 \times 10$	$3,01 \times 10$	$3,56 \times 10$	$3,78 \times 10$	$3,74 \times 10$	$3,55 \times 10$	$3,29 \times 10$	$3,02 \times 10$
3 150	6,11	9,44	$1,35 \times 10$	$2,31 \times 10$	$3,29 \times 10$	$4,09 \times 10$	$4,59 \times 10$	$4,79 \times 10$	$4,75 \times 10$	$4,57 \times 10$	$4,31 \times 10$
4 000	7,00	$1,03 \times 10$	$1,45 \times 10$	$2,44 \times 10$	$3,54 \times 10$	$4,55 \times 10$	$5,35 \times 10$	$5,85 \times 10$	$6,07 \times 10$	$6,06 \times 10$	$5,90 \times 10$
5 000	8,40	$1,18 \times 10$	$1,59 \times 10$	$2,61 \times 10$	$3,79 \times 10$	$4,97 \times 10$	$6,02 \times 10$	$6,84 \times 10$	$7,39 \times 10$	$7,67 \times 10$	$7,74 \times 10$
6 300	$1,06 \times 10$	$1,40 \times 10$	$1,82 \times 10$	$2,86 \times 10$	$4,08 \times 10$	$5,38 \times 10$	$6,64 \times 10$	$7,75 \times 10$	$8,64 \times 10$	$9,28 \times 10$	$9,67 \times 10$
8 000	$1,42 \times 10$	$1,75 \times 10$	$2,17 \times 10$	$3,22 \times 10$	$4,48 \times 10$	$5,86 \times 10$	$7,27 \times 10$	$8,62 \times 10$	$9,82 \times 10$	$1,08 \times 10^{2}$	$1,16 \times 10^{2}$
10 000	$1,97 \times 10$	$2,31 \times 10$	$2,73 \times 10$	$3,79 \times 10$	$5,07 \times 10$	$6,51 \times 10$	$8,02 \times 10$	$9,54 \times 10$	$1,10 \times 10^{2}$	$1,23 \times 10^{2}$	$1,35 \times 10^{2}$

(d) Air temperature: −5 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$3,76 \times 10^{-1}$	$2,56 \times 10^{-1}$	$2,05 \times 10^{-1}$	$1,64 \times 10^{-1}$	$1,45 \times 10^{-1}$	$1,31 \times 10^{-1}$	$1,20 \times 10^{-1}$	$1,11 \times 10^{-1}$	$1,02 \times 10^{-1}$	$9,45 \times 10^{-2}$	$8,78 \times 10^{-2}$
63	$5,47 \times 10^{-1}$	$3,61 \times 10^{-1}$	$2,79 \times 10^{-1}$	$2,16 \times 10^{-1}$	$1,92 \times 10^{-1}$	$1,77 \times 10^{-1}$	$1,66 \times 10^{-1}$	$1,55 \times 10^{-1}$	$1,46 \times 10^{-1}$	$1,37 \times 10^{-1}$	$1,29 \times 10^{-1}$
80	$8,01 \times 10^{-1}$	$5,18 \times 10^{-1}$	$3,87 \times 10^{-1}$	$2,85 \times 10^{-1}$	$2,49 \times 10^{-1}$	$2,32 \times 10^{-1}$	$2,20 \times 10^{-1}$	$2,10 \times 10^{-1}$	$2,01 \times 10^{-1}$	$1,92 \times 10^{-1}$	$1,83 \times 10^{-1}$
100	1,17	$7,55 \times 10^{-1}$	$5,49 \times 10^{-1}$	$3,81 \times 10^{-1}$	$3,23 \times 10^{-1}$	$2,98 \times 10^{-1}$	$2,84 \times 10^{-1}$	$2,75 \times 10^{-1}$	$2,67 \times 10^{-1}$	$2,59 \times 10^{-1}$	$2,51 \times 10^{-1}$
125	1,69	1,11	$7,96 \times 10^{-1}$	$5,22 \times 10^{-1}$	$4,23 \times 10^{-1}$	$3,81 \times 10^{-1}$	$3,61 \times 10^{-1}$	$3,50 \times 10^{-1}$	$3,43 \times 10^{-1}$	$3,37 \times 10^{-1}$	$3,30 \times 10^{-1}$
160	2,38	1,65	1,17	$7,36 \times 10^{-1}$	$5,68 \times 10^{-1}$	$4,93 \times 10^{-1}$	$4,58 \times 10^{-1}$	$4,40 \times 10^{-1}$	$4,31 \times 10^{-1}$	$4,25 \times 10^{-1}$	$4,21 \times 10^{-1}$
200	3,23	2,42	1,75	1,07	$7,86 \times 10^{-1}$	$6,56 \times 10^{-1}$	$5,91 \times 10^{-1}$	$5,57 \times 10^{-1}$	$5,39 \times 10^{-1}$	$5,30 \times 10^{-1}$	$5,25 \times 10^{-1}$
250	4,20	3,49	2,60	1,58	1,12	$9,03 \times 10^{-1}$	$7,85 \times 10^{-1}$	$7,20 \times 10^{-1}$	$6,83 \times 10^{-1}$	$6,62 \times 10^{-1}$	$6,51 \times 10^{-1}$
315	5,19	4,87	3,83	2,36	1,65	1,28	1,08	$9,61 \times 10^{-1}$	$8,89 \times 10^{-1}$	$8,45 \times 10^{-1}$	$8,18 \times 10^{-1}$
400	6,10	6,53	5,53	3,55	2,46	1,87	1,54	1,33	1,20	1,11	1,06
500	6,87	8,34	7,72	5,31	3,71	2,80	2,25	1,90	1,68	1,52	1,42
630	7,48	$1,01 \times 10$	$1,03 \times 10$	7,83	5,61	4,22	3,36	2,80	2,43	2,16	1,97
800	7,94	$1,17 \times 10$	$1,32 \times 10$	$1,13 \times 10$	8,42	6,40	5,09	4,20	3,59	3,16	2,84
1 000	8,29	$1,31 \times 10$	$1,60 \times 10$	$1,57 \times 10$	$1,24 \times 10$	9,68	7,74	6,38	5,42	4,72	4,20
1 250	8,58	$1,41 \times 10$	$1,85 \times 10$	$2,08 \times 10$	$1,79 \times 10$	$1,45 \times 10$	$1,17 \times 10$	9,73	8,25	7,16	6,33
1 600	8,85	$1,49 \times 10$	$2,07 \times 10$	$2,64 \times 10$	$2,49 \times 10$	$2,12 \times 10$	$1,76 \times 10$	$1,48 \times 10$	$1,26 \times 10$	$1,09 \times 10$	9,65
2 000	9,16	$1,56 \times 10$	$2,24 \times 10$	$3,18 \times 10$	$3,32 \times 10$	$3,01 \times 10$	$2,60 \times 10$	$2,22 \times 10$	$1,91 \times 10$	$1,67 \times 10$	$1,48 \times 10$
2 500	9,57	$1,63 \times 10$	$2,38 \times 10$	$3,66 \times 10$	$4,21 \times 10$	$4,11 \times 10$	$3,72 \times 10$	$3,28 \times 10$	$2,88 \times 10$	$2,54 \times 10$	$2,25 \times 10$
3 150	$1,02 \times 10$	$1,71 \times 10$	$2,50 \times 10$	$4,07 \times 10$	$5,08 \times 10$	$5,35 \times 10$	$5,13 \times 10$	$4,70 \times 10$	$4,23 \times 10$	$3,79 \times 10$	$3,41 \times 10$
4 000	$1,11 \times 10$	$1,81 \times 10$	$2,64 \times 10$	$4,42 \times 10$	$5,87 \times 10$	$6,64 \times 10$	$6,77 \times 10$	$6,50 \times 10$	$6,05 \times 10$	$5,55 \times 10$	$5,07 \times 10$
5 000	$1,25 \times 10$	$1,96 \times 10$	$2,81 \times 10$	$4,75 \times 10$	$6,57 \times 10$	$7,87 \times 10$	$8,51 \times 10$	$8,60 \times 10$	$8,33 \times 10$	$7,88 \times 10$	$7,36 \times 10$
6 300	$1,48 \times 10$	$2,19 \times 10$	$3,06 \times 10$	$5,10 \times 10$	$7,21 \times 10$	$9,00 \times 10$	$1,02 \times 10^{2}$	$1,08 \times 10^{2}$	$1,10 \times 10^{2}$	$1,07 \times 10^{2}$	$1,03 \times 10^{2}$
8 000	$1,83 \times 10$	$2,55 \times 10$	$3,43 \times 10$	$5,54 \times 10$	$7,86 \times 10$	$1,00 \times 10^{2}$	$1,18 \times 10^{2}$	$1,31 \times 10^{2}$	$1,38 \times 10^{2}$	$1,40 \times 10^{2}$	$1,39 \times 10^{2}$
10 000	$2,40 \times 10$	$3,11 \times 10$	$4,00 \times 10$	$6,16 \times 10$	$8,62 \times 10$	$1,11 \times 10^{2}$	$1,34 \times 10^{2}$	$1,52 \times 10^{2}$	$1,66 \times 10^{2}$	$1,74 \times 10^{2}$	$1,79 \times 10^{2}$

(e) Air temperature: 0 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$3,02 \times 10^{-1}$	$2,26 \times 10^{-1}$	$1,95 \times 10^{-1}$	$1,65 \times 10^{-1}$	$1,44 \times 10^{-1}$	$1,28 \times 10^{-1}$	$1,14 \times 10^{-1}$	$1,03 \times 10^{-1}$	$9,28 \times 10^{-2}$	$8,46 \times 10^{-2}$	$7,77 \times 10^{-2}$
63	$4,24 \times 10^{-1}$	$3,02 \times 10^{-1}$	$2,56 \times 10^{-1}$	$2,19 \times 10^{-1}$	$1,98 \times 10^{-1}$	$1,81 \times 10^{-1}$	$1,65 \times 10^{-1}$	$1,51 \times 10^{-1}$	$1,38 \times 10^{-1}$	$1,27 \times 10^{-1}$	$1,18 \times 10^{-1}$
80	$6,07 \times 10^{-1}$	$4,11 \times 10^{-1}$	$3,37 \times 10^{-1}$	$2,84 \times 10^{-1}$	$2,63 \times 10^{-1}$	$2,46 \times 10^{-1}$	$2,30 \times 10^{-1}$	$2,15 \times 10^{-1}$	$2,01 \times 10^{-1}$	$1,87 \times 10^{-1}$	$1,75 \times 10^{-1}$
100	$8,84 \times 10^{-1}$	$5,73 \times 10^{-1}$	$4,49 \times 10^{-1}$	$3,64 \times 10^{-1}$	$3,38 \times 10^{-1}$	$3,23 \times 10^{-1}$	$3,09 \times 10^{-1}$	$2,96 \times 10^{-1}$	$2,81 \times 10^{-1}$	$2,67 \times 10^{-1}$	$2,53 \times 10^{-1}$
125	1,30	$8,18 \times 10^{-1}$	$6,14 \times 10^{-1}$	$4,69 \times 10^{-1}$	$4,27 \times 10^{-1}$	$4,11 \times 10^{-1}$	$4,01 \times 10^{-1}$	$3,90 \times 10^{-1}$	$3,79 \times 10^{-1}$	$3,67 \times 10^{-1}$	$3,54 \times 10^{-1}$
160	1,92	1,19	$8,65 \times 10^{-1}$	$6,16 \times 10^{-1}$	$5,41 \times 10^{-1}$	$5,14 \times 10^{-1}$	$5,04 \times 10^{-1}$	$4,98 \times 10^{-1}$	$4,91 \times 10^{-1}$	$4,83 \times 10^{-1}$	$4,74 \times 10^{-1}$
200	2,80	1,77	1,25	$8,35 \times 10^{-1}$	$6,96 \times 10^{-1}$	$6,44 \times 10^{-1}$	$6,26 \times 10^{-1}$	$6,19 \times 10^{-1}$	$6,16 \times 10^{-1}$	$6,14 \times 10^{-1}$	$6,10 \times 10^{-1}$
250	4,00	2,63	1,85	1,17	$9,22 \times 10^{-1}$	$8,21 \times 10^{-1}$	$7,79 \times 10^{-1}$	$7,63 \times 10^{-1}$	$7,59 \times 10^{-1}$	$7,60 \times 10^{-1}$	$7,61 \times 10^{-1}$
315	5,53	3,91	2,76	1,69	1,27	1,08	$9,92 \times 10^{-1}$	$9,51 \times 10^{-1}$	$9,34 \times 10^{-1}$	$9,30 \times 10^{-1}$	$9,32 \times 10^{-1}$
400	7,33	5,71	4,14	2,49	1,80	1,47	1,30	1,21	1,17	1,15	1,14
500	9,25	8,14	6,16	3,73	2,63	2,08	1,78	1,61	1,51	1,45	1,42
630	$1,11 \times 10$	$1,12 \times 10$	9,03	5,63	3,93	3,03	2,52	2,21	2,02	1,90	1,82
800	$1,27 \times 10$	$1,47 \times 10$	$1,29 \times 10$	8,49	5,93	4,52	3,68	3,16	2,82	2,59	2,43
1 000	$1,40 \times 10$	$1,83 \times 10$	$1,77 \times 10$	$1,27 \times 10$	9,00	6,83	5,50	4,64	4,06	3,66	3,37
1 250	$1,51 \times 10$	$2,18 \times 10$	$2,33 \times 10$	$1,86 \times 10$	$1,36 \times 10$	$1,04 \times 10$	8,32	6,96	6,01	5,34	4,85
1 600	$1,59 \times 10$	$2,48 \times 10$	$2,91 \times 10$	$2,64 \times 10$	$2,03 \times 10$	$1,58 \times 10$	$1,27 \times 10$	$1,06 \times 10$	9,07	7,98	7,16
2 000	$1,66 \times 10$	$2,72 \times 10$	$3,46 \times 10$	$3,60 \times 10$	$2,98 \times 10$	$2,38 \times 10$	$1,93 \times 10$	$1,61 \times 10$	$1,38 \times 10$	$1,21 \times 10$	$1,08 \times 10$
2 500	$1,72 \times 10$	$2,92 \times 10$	$3,95 \times 10$	$4,70 \times 10$	$4,23 \times 10$	$3,53 \times 10$	$2,92 \times 10$	$2,46 \times 10$	$2,11 \times 10$	$1,85 \times 10$	$1,65 \times 10$
3 150	$1,80 \times 10$	$3,09 \times 10$	$4,36 \times 10$	$5,82 \times 10$	$5,77 \times 10$	$5,09 \times 10$	$4,35 \times 10$	$3,73 \times 10$	$3,23 \times 10$	$2,83 \times 10$	$2,52 \times 10$
4 000	$1,90 \times 10$	$3,26 \times 10$	$4,70 \times 10$	$6,90 \times 10$	$7,52 \times 10$	$7,10 \times 10$	$6,33 \times 10$	$5,55 \times 10$	$4,88 \times 10$	$4,32 \times 10$	$3,86 \times 10$
5 000	$2,05 \times 10$	$3,45 \times 10$	$5,03 \times 10$	$7,86 \times 10$	$9,34 \times 10$	$9,48 \times 10$	$8,90 \times 10$	$8,07 \times 10$	$7,25 \times 10$	$6,51 \times 10$	$5,87 \times 10$
6 300	$2,28 \times 10$	$3,71 \times 10$	$5,37 \times 10$	$8,71 \times 10$	$1,11 \times 10^{2}$	$1,21 \times 10^{2}$	$1,20 \times 10^{2}$	$1,13 \times 10^{2}$	$1,05 \times 10^{2}$	$9,61 \times 10$	$8,80 \times 10$
8 000	$2,64 \times 10$	$4,09 \times 10$	$5,81 \times 10$	$9,52 \times 10$	$1,27 \times 10^{2}$	$1,47 \times 10^{2}$	$1,54 \times 10^{2}$	$1,53 \times 10^{2}$	$1,47 \times 10^{2}$	$1,38 \times 10^{2}$	$1,29 \times 10^{2}$
10 000	$3,22 \times 10$	$4,67 \times 10$	$6,43 \times 10$	$1,04 \times 10^{2}$	$1,42 \times 10^{2}$	$1,72 \times 10^{2}$	$1,90 \times 10^{2}$	$1,98 \times 10^{2}$	$1,97 \times 10^{2}$	$1,91 \times 10^{2}$	$1,83 \times 10^{2}$

(f) Air temperature: 5 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,68 \times 10^{-1}$	$2,20 \times 10^{-1}$	$1,97 \times 10^{-1}$	$1,64 \times 10^{-1}$	$1,38 \times 10^{-1}$	$1,18 \times 10^{-1}$	$1,03 \times 10^{-1}$	$9,09 \times 10^{-2}$	$8,12 \times 10^{-2}$	$7,33 \times 10^{-2}$	$6,67 \times 10^{-2}$
63	$3,59 \times 10^{-1}$	$2,88 \times 10^{-1}$	$2,61 \times 10^{-1}$	$2,27 \times 10^{-1}$	$1,99 \times 10^{-1}$	$1,75 \times 10^{-1}$	$1,55 \times 10^{-1}$	$1,38 \times 10^{-1}$	$1,24 \times 10^{-1}$	$1,13 \times 10^{-1}$	$1,03 \times 10^{-1}$
80	$4,88 \times 10^{-1}$	$3,75 \times 10^{-1}$	$3,37 \times 10^{-1}$	$3,03 \times 10^{-1}$	$2,76 \times 10^{-1}$	$2,50 \times 10^{-1}$	$2,27 \times 10^{-1}$	$2,06 \times 10^{-1}$	$1,88 \times 10^{-1}$	$1,72 \times 10^{-1}$	$1,58 \times 10^{-1}$
100	$6,80 \times 10^{-1}$	$4,92 \times 10^{-1}$	$4,31 \times 10^{-1}$	$3,91 \times 10^{-1}$	$3,69 \times 10^{-1}$	$3,45 \times 10^{-1}$	$3,21 \times 10^{-1}$	$2,98 \times 10^{-1}$	$2,76 \times 10^{-1}$	$2,56 \times 10^{-1}$	$2,38 \times 10^{-1}$
125	$9,71 \times 10^{-1}$	$6,61 \times 10^{-1}$	$5,54 \times 10^{-1}$	$4,93 \times 10^{-1}$	$4,74 \times 10^{-1}$	$4,58 \times 10^{-1}$	$4,38 \times 10^{-1}$	$4,16 \times 10^{-1}$	$3,93 \times 10^{-1}$	$3,71 \times 10^{-1}$	$3,49 \times 10^{-1}$
160	1,42	$9,14 \times 10^{-1}$	$7,29 \times 10^{-1}$	$6,17 \times 10^{-1}$	$5,94 \times 10^{-1}$	$5,85 \times 10^{-1}$	$5,74 \times 10^{-1}$	$5,58 \times 10^{-1}$	$5,39 \times 10^{-1}$	$5,18 \times 10^{-1}$	$4,96 \times 10^{-1}$
200	2,09	1,30	$9,88 \times 10^{-1}$	$7,81 \times 10^{-1}$	$7,35 \times 10^{-1}$	$7,27 \times 10^{-1}$	$7,25 \times 10^{-1}$	$7,20 \times 10^{-1}$	$7,10 \times 10^{-1}$	$6,96 \times 10^{-1}$	$6,78 \times 10^{-1}$
250	3,11	1,90	1,38	1,01	$9,15 \times 10^{-1}$	$8,92 \times 10^{-1}$	$8,92 \times 10^{-1}$	$8,97 \times 10^{-1}$	$8,98 \times 10^{-1}$	$8,96 \times 10^{-1}$	$8,88 \times 10^{-1}$
315	4,58	2,82	2,00	1,36	1,16	1,10	1,09	1,09	1,10	1,11	1,12
400	6,64	4,23	2,95	1,90	1,53	1,39	1,34	1,33	1,34	1,35	1,37
500	9,34	6,32	4,42	2,74	2,10	1,82	1,69	1,64	1,63	1,64	1,66
630	$1,26 \times 10$	9,34	6,66	4,04	2,97	2,47	2,22	2,09	2,03	2,01	2,01
800	$1,63 \times 10$	$1,35 \times 10$	9,99	6,06	4,34	3,49	3,03	2,76	2,61	2,53	2,49
1 000	$2,00 \times 10$	$1,89 \times 10$	$1,48 \times 10$	9,18	6,48	5,08	4,29	3,80	3,50	3,31	3,20
1 250	$2,34 \times 10$	$2,54 \times 10$	$2,15 \times 10$	$1,39 \times 10$	9,81	7,58	6,26	5,43	4,89	4,52	4,27
1 600	$2,62 \times 10$	$3,26 \times 10$	$3,01 \times 10$	$2,09 \times 10$	$1,49 \times 10$	$1,15 \times 10$	9,35	7,99	7,06	6,42	5,95
2 000	$2,85 \times 10$	$3,96 \times 10$	$4,05 \times 10$	$3,09 \times 10$	$2,27 \times 10$	$1,75 \times 10$	$1,42 \times 10$	$1,20 \times 10$	$1,05 \times 10$	9,39	8,58
2 500	$3,04 \times 10$	$4,61 \times 10$	$5,19 \times 10$	$4,46 \times 10$	$3,41 \times 10$	$2,66 \times 10$	$2,17 \times 10$	$1,82 \times 10$	$1,58 \times 10$	$1,41 \times 10$	$1,27 \times 10$
3 150	$3,19 \times 10$	$5,16 \times 10$	$6,32 \times 10$	$6,20 \times 10$	$5,04 \times 10$	$4,03 \times 10$	$3,31 \times 10$	$2,79 \times 10$	$2,42 \times 10$	$2,14 \times 10$	$1,92 \times 10$
4 000	$3,35 \times 10$	$5,62 \times 10$	$7,37 \times 10$	$8,26 \times 10$	$7,25 \times 10$	$6,02 \times 10$	$5,02 \times 10$	$4,27 \times 10$	$3,70 \times 10$	$3,27 \times 10$	$2,94 \times 10$
5 000	$3,54 \times 10$	$6,02 \times 10$	$8,28 \times 10$	$1,05 \times 10^{2}$	$1,01 \times 10^{2}$	$8,78 \times 10$	$7,52 \times 10$	$6,48 \times 10$	$5,66 \times 10$	$5,02 \times 10$	$4,51 \times 10$
6 300	$3,80 \times 10$	$6,43 \times 10$	$9,09 \times 10$	$1,27 \times 10^{2}$	$1,33 \times 10^{2}$	$1,24 \times 10^{2}$	$1,10 \times 10^{2}$	$9,70 \times 10$	$8,58 \times 10$	$7,66 \times 10$	$6,91 \times 10$
8 000	$4,18 \times 10$	$6,91 \times 10$	$9,87 \times 10$	$1,47 \times 10^{2}$	$1,69 \times 10^{2}$	$1,68 \times 10^{2}$	$1,56 \times 10^{2}$	$1,42 \times 10^{2}$	$1,28 \times 10^{2}$	$1,16 \times 10^{2}$	$1,05 \times 10^{2}$
10 000	$4,77 \times 10$	$7,57 \times 10$	$1,07 \times 10^{2}$	$1,67 \times 10^{2}$	$2,05 \times 10^{2}$	$2,18 \times 10^{2}$	$2,14 \times 10^{2}$	$2,01 \times 10^{2}$	$1,86 \times 10^{2}$	$1,72 \times 10^{2}$	$1,58 \times 10^{2}$

(g) Air temperature: 10 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,62 \times 10^{-1}$	$2,24 \times 10^{-1}$	$1,97 \times 10^{-1}$	$1,55 \times 10^{-1}$	$1,26 \times 10^{-1}$	$1,05 \times 10^{-1}$	$9,01 \times 10^{-2}$	$7,85 \times 10^{-2}$	$6,96 \times 10^{-2}$	$6,24 \times 10^{-2}$	$5,65 \times 10^{-2}$
63	$3,42 \times 10^{-1}$	$2,98 \times 10^{-1}$	$2,71 \times 10^{-1}$	$2,25 \times 10^{-1}$	$1,88 \times 10^{-1}$	$1,60 \times 10^{-1}$	$1,39 \times 10^{-1}$	$1,22 \times 10^{-1}$	$1,08 \times 10^{-1}$	$9,75 \times 10^{-2}$	$8,85 \times 10^{-2}$
80	$4,45 \times 10^{-1}$	$3,85 \times 10^{-1}$	$3,59 \times 10^{-1}$	$3,16 \times 10^{-1}$	$2,74 \times 10^{-1}$	$2,39 \times 10^{-1}$	$2,10 \times 10^{-1}$	$1,86 \times 10^{-1}$	$1,67 \times 10^{-1}$	$1,51 \times 10^{-1}$	$1,38 \times 10^{-1}$
100	$5,85 \times 10^{-1}$	$4,90 \times 10^{-1}$	$4,61 \times 10^{-1}$	$4,25 \times 10^{-1}$	$3,86 \times 10^{-1}$	$3,47 \times 10^{-1}$	$3,11 \times 10^{-1}$	$2,80 \times 10^{-1}$	$2,54 \times 10^{-1}$	$2,31 \times 10^{-1}$	$2,12 \times 10^{-1}$
125	$7,88 \times 10^{-1}$	$6,23 \times 10^{-1}$	$5,79 \times 10^{-1}$	$5,51 \times 10^{-1}$	$5,22 \times 10^{-1}$	$4,86 \times 10^{-1}$	$4,47 \times 10^{-1}$	$4,11 \times 10^{-1}$	$3,78 \times 10^{-1}$	$3,48 \times 10^{-1}$	$3,22 \times 10^{-1}$
160	1,09	$8,06 \times 10^{-1}$	$7,25 \times 10^{-1}$	$6,92 \times 10^{-1}$	$6,78 \times 10^{-1}$	$6,53 \times 10^{-1}$	$6,20 \times 10^{-1}$	$5,84 \times 10^{-1}$	$5,47 \times 10^{-1}$	$5,12 \times 10^{-1}$	$4,79 \times 10^{-1}$
200	1,56	1,07	$9,19 \times 10^{-1}$	$8,52 \times 10^{-1}$	$8,49 \times 10^{-1}$	$8,43 \times 10^{-1}$	$8,25 \times 10^{-1}$	$7,97 \times 10^{-1}$	$7,64 \times 10^{-1}$	$7,28 \times 10^{-1}$	$6,92 \times 10^{-1}$
250	2,29	1,48	1,20	1,05	1,04	1,05	1,05	1,04	1,02	$9,96 \times 10^{-1}$	$9,63 \times 10^{-1}$
315	3,39	2,11	1,62	1,31	1,27	1,28	1,30	1,31	1,31	1,30	1,29
400	5,06	3,08	2,26	1,70	1,56	1,55	1,57	1,60	1,63	1,64	1,65
500	7,52	4,59	3,27	2,28	1,98	1,90	1,90	1,93	1,97	2,00	2,03
630	$1,10 \times 10$	6,89	4,84	3,17	2,60	2,39	2,32	2,33	2,36	2,40	2,45
800	$1,57 \times 10$	$1,04 \times 10$	7,27	4,58	3,56	3,13	2,94	2,87	2,86	2,89	2,93
1 000	$2,16 \times 10$	$1,54 \times 10$	$1,10 \times 10$	6,77	5,07	4,26	3,86	3,66	3,57	3,54	3,55
1 250	$2,84 \times 10$	$2,26 \times 10$	$1,66 \times 10$	$1,02 \times 10$	7,42	6,04	5,29	4,86	4,62	4,48	4,42
1 600	$3,55 \times 10$	$3,21 \times 10$	$2,47 \times 10$	$1,55 \times 10$	$1,11 \times 10$	8,83	7,52	6,73	6,23	5,92	5,72
2 000	$4,23 \times 10$	$4,38 \times 10$	$3,62 \times 10$	$2,35 \times 10$	$1,68 \times 10$	$1,32 \times 10$	$1,10 \times 10$	9,66	8,76	8,14	7,71
2 500	$4,83 \times 10$	$5,72 \times 10$	$5,14 \times 10$	$3,54 \times 10$	$2,57 \times 10$	$2,00 \times 10$	$1,65 \times 10$	$1,43 \times 10$	$1,27 \times 10$	$1,16 \times 10$	$1,08 \times 10$
3 150	$5,32 \times 10$	$7,10 \times 10$	$7,02 \times 10$	$5,27 \times 10$	$3,91 \times 10$	$3,06 \times 10$	$2,51 \times 10$	$2,15 \times 10$	$1,90 \times 10$	$1,71 \times 10$	$1,57 \times 10$
4 000	$5,73 \times 10$	$8,40 \times 10$	$9,15 \times 10$	$7,66 \times 10$	$5,90 \times 10$	$4,67 \times 10$	$3,84 \times 10$	$3,28 \times 10$	$2,87 \times 10$	$2,57 \times 10$	$2,35 \times 10$
5 000	$6,10 \times 10$	$9,56 \times 10$	$1,13 \times 10^{2}$	$1,08 \times 10^{2}$	$8,75 \times 10$	$7,08 \times 10$	$5,88 \times 10$	$5,02 \times 10$	$4,39 \times 10$	$3,92 \times 10$	$3,56 \times 10$
6 300	$6,48 \times 10$	$1,06 \times 10^{2}$	$1,35 \times 10^{2}$	$1,45 \times 10^{2}$	$1,27 \times 10^{2}$	$1,06 \times 10^{2}$	$8,94 \times 10$	$7,69 \times 10$	$6,74 \times 10$	$6,01 \times 10$	$5,44 \times 10$
8 000	$6,94 \times 10$	$1,15 \times 10^{2}$	$1,54 \times 10^{2}$	$1,87 \times 10^{2}$	$1,77 \times 10^{2}$	$1,55 \times 10^{2}$	$1,34 \times 10^{2}$	$1,17 \times 10^{2}$	$1,03 \times 10^{2}$	$9,24 \times 10$	$8,37 \times 10$
10 000	$7,59 \times 10$	$1,25 \times 10^{2}$	$1,72 \times 10^{2}$	$2,30 \times 10^{2}$	$2,37 \times 10^{2}$	$2,20 \times 10^{2}$	$1,97 \times 10^{2}$	$1,75 \times 10^{2}$	$1,57 \times 10^{2}$	$1,41 \times 10^{2}$	$1,28 \times 10^{2}$

(h) Air temperature: 15 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,68 \times 10^{-1}$	$2,24 \times 10^{-1}$	$1,89 \times 10^{-1}$	$1,41 \times 10^{-1}$	$1,11 \times 10^{-1}$	$9,14 \times 10^{-2}$	$7,74 \times 10^{-2}$	$6,70 \times 10^{-2}$	$5,91 \times 10^{-2}$	$5,28 \times 10^{-2}$	$4,77 \times 10^{-2}$
63	$3,53 \times 10^{-1}$	$3,10 \times 10^{-1}$	$2,72 \times 10^{-1}$	$2,12 \times 10^{-1}$	$1,71 \times 10^{-1}$	$1,42 \times 10^{-1}$	$1,21 \times 10^{-1}$	$1,05 \times 10^{-1}$	$9,27 \times 10^{-2}$	$8,31 \times 10^{-2}$	$7,52 \times 10^{-2}$
80	$4,54 \times 10^{-1}$	$4,13 \times 10^{-1}$	$3,78 \times 10^{-1}$	$3,11 \times 10^{-1}$	$2,57 \times 10^{-1}$	$2,17 \times 10^{-1}$	$1,87 \times 10^{-1}$	$1,63 \times 10^{-1}$	$1,45 \times 10^{-1}$	$1,30 \times 10^{-1}$	$1,18 \times 10^{-1}$
100	$5,77 \times 10^{-1}$	$5,31 \times 10^{-1}$	$5,04 \times 10^{-1}$	$4,41 \times 10^{-1}$	$3,78 \times 10^{-1}$	$3,26 \times 10^{-1}$	$2,85 \times 10^{-1}$	$2,51 \times 10^{-1}$	$2,24 \times 10^{-1}$	$2,02 \times 10^{-1}$	$1,84 \times 10^{-1}$
125	$7,35 \times 10^{-1}$	$6,67 \times 10^{-1}$	$6,47 \times 10^{-1}$	$6,01 \times 10^{-1}$	$5,39 \times 10^{-1}$	$4,79 \times 10^{-1}$	$4,26 \times 10^{-1}$	$3,81 \times 10^{-1}$	$3,43 \times 10^{-1}$	$3,12 \times 10^{-1}$	$2,85 \times 10^{-1}$
160	$9,56 \times 10^{-1}$	$8,28 \times 10^{-1}$	$8,06 \times 10^{-1}$	$7,86 \times 10^{-1}$	$7,40 \times 10^{-1}$	$6,81 \times 10^{-1}$	$6,21 \times 10^{-1}$	$5,65 \times 10^{-1}$	$5,16 \times 10^{-1}$	$4,73 \times 10^{-1}$	$4,36 \times 10^{-1}$
200	1,28	1,04	$9,91 \times 10^{-1}$	$9,89 \times 10^{-1}$	$9,73 \times 10^{-1}$	$9,30 \times 10^{-1}$	$8,74 \times 10^{-1}$	$8,15 \times 10^{-1}$	$7,57 \times 10^{-1}$	$7,04 \times 10^{-1}$	$6,55 \times 10^{-1}$
250	1,78	1,33	1,22	1,21	1,23	1,22	1,18	1,13	1,07	1,02	$9,59 \times 10^{-1}$
315	2,55	1,77	1,54	1,47	1,50	1,53	1,53	1,51	1,47	1,41	1,36
400	3,74	2,44	2,00	1,79	1,81	1,87	1,91	1,92	1,91	1,89	1,85
500	5,58	3,49	2,70	2,23	2,18	2,24	2,31	2,36	2,40	2,41	2,41
630	8,36	5,11	3,80	2,89	2,68	2,69	2,75	2,84	2,91	2,97	3,01
800	$1,25 \times 10$	7,63	5,50	3,89	3,41	3,29	3,31	3,38	3,48	3,57	3,65
1 000	$1,84 \times 10$	$1,15 \times 10$	8,17	5,45	4,51	4,16	4,06	4,08	4,15	4,25	4,35
1 250	$2,65 \times 10$	$1,74 \times 10$	$1,23 \times 10$	7,90	6,22	5,49	5,17	5,05	5,05	5,11	5,20
1 600	$3,69 \times 10$	$2,60 \times 10$	$1,86 \times 10$	$1,17 \times 10$	8,90	7,55	6,86	6,51	6,35	6,30	6,32
2 000	$4,93 \times 10$	$3,83 \times 10$	$2,82 \times 10$	$1,77 \times 10$	$1,31 \times 10$	$1,08 \times 10$	9,50	8,75	8,31	8,07	7,95
2 500	$6,25 \times 10$	$5,48 \times 10$	$4,22 \times 10$	$2,69 \times 10$	$1,97 \times 10$	$1,59 \times 10$	$1,36 \times 10$	$1,22 \times 10$	$1,14 \times 10$	$1,08 \times 10$	$1,04 \times 10$
3 150	$7,55 \times 10$	$7,57 \times 10$	$6,21 \times 10$	$4,10 \times 10$	$2,99 \times 10$	$2,38 \times 10$	$2,01 \times 10$	$1,77 \times 10$	$1,61 \times 10$	$1,50 \times 10$	$1,43 \times 10$
4 000	$8,73 \times 10$	$9,99 \times 10$	$8,88 \times 10$	$6,20 \times 10$	$4,57 \times 10$	$3,62 \times 10$	$3,03 \times 10$	$2,64 \times 10$	$2,37 \times 10$	$2,17 \times 10$	$2,03 \times 10$
5 000	$9,74 \times 10$	$1,26 \times 10^{2}$	$1,22 \times 10^{2}$	$9,24 \times 10$	$6,97 \times 10$	$5,54 \times 10$	$4,62 \times 10$	$3,99 \times 10$	$3,55 \times 10$	$3,22 \times 10$	$2,98 \times 10$
6 300	$1,06 \times 10^{2}$	$1,51 \times 10^{2}$	$1,61 \times 10^{2}$	$1,35 \times 10^{2}$	$1,05 \times 10^{2}$	$8,47 \times 10$	$7,08 \times 10$	$6,11 \times 10$	$5,40 \times 10$	$4,87 \times 10$	$4,47 \times 10$
8 000	$1,14 \times 10^{2}$	$1,74 \times 10^{2}$	$2,02 \times 10^{2}$	$1,90 \times 10^{2}$	$1,56 \times 10^{2}$	$1,29 \times 10^{2}$	$1,08 \times 10^{2}$	$9,37 \times 10$	$8,28 \times 10$	$7,46 \times 10$	$6,81 \times 10$
10 000	$1,23 \times 10^{2}$	$1,95 \times 10^{2}$	$2,42 \times 10^{2}$	$2,57 \times 10^{2}$	$2,26 \times 10^{2}$	$1,92 \times 10^{2}$	$1,65 \times 10^{2}$	$1,44 \times 10^{2}$	$1,27 \times 10^{2}$	$1,15 \times 10^{2}$	$1,05 \times 10^{2}$

(i) Air temperature: 20 °C

Preferred frequency Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,70 \times 10^{-1}$	$2,14 \times 10^{-1}$	$1,74 \times 10^{-1}$	$1,25 \times 10^{-1}$	$9,65 \times 10^{-2}$	$7,84 \times 10^{-2}$	$6,60 \times 10^{-2}$	$5,70 \times 10^{-2}$	$5,01 \times 10^{-2}$	$4,47 \times 10^{-2}$	$4,03 \times 10^{-2}$
63	$3,70 \times 10^{-1}$	$3,10 \times 10^{-1}$	$2,60 \times 10^{-1}$	$1,92 \times 10^{-1}$	$1,50 \times 10^{-1}$	$1,23 \times 10^{-1}$	$1,04 \times 10^{-1}$	$8,97 \times 10^{-2}$	$7,90 \times 10^{-2}$	$7,05 \times 10^{-2}$	$6,37 \times 10^{-2}$
80	$4,87 \times 10^{-1}$	$4,32 \times 10^{-1}$	$3,77 \times 10^{-1}$	$2,90 \times 10^{-1}$	$2,31 \times 10^{-1}$	$1,91 \times 10^{-1}$	$1,62 \times 10^{-1}$	$1,41 \times 10^{-1}$	$1,24 \times 10^{-1}$	$1,11 \times 10^{-1}$	$1,00 \times 10^{-1}$
100	$6,22 \times 10^{-1}$	$5,79 \times 10^{-1}$	$5,29 \times 10^{-1}$	$4,29 \times 10^{-1}$	$3,51 \times 10^{-1}$	$2,94 \times 10^{-1}$	$2,52 \times 10^{-1}$	$2,20 \times 10^{-1}$	$1,94 \times 10^{-1}$	$1,74 \times 10^{-1}$	$1,58 \times 10^{-1}$
125	$7,76 \times 10^{-1}$	$7,46 \times 10^{-1}$	$7,12 \times 10^{-1}$	$6,15 \times 10^{-1}$	$5,21 \times 10^{-1}$	$4,45 \times 10^{-1}$	$3,86 \times 10^{-1}$	$3,39 \times 10^{-1}$	$3,02 \times 10^{-1}$	$2,72 \times 10^{-1}$	$2,47 \times 10^{-1}$
160	$9,65 \times 10^{-1}$	$9,31 \times 10^{-1}$	$9,19 \times 10^{-1}$	$8,49 \times 10^{-1}$	$7,52 \times 10^{-1}$	$6,60 \times 10^{-1}$	$5,82 \times 10^{-1}$	$5,18 \times 10^{-1}$	$4,65 \times 10^{-1}$	$4,21 \times 10^{-1}$	$3,84 \times 10^{-1}$
200	1,22	1,14	1,14	1,12	1,05	$9,50 \times 10^{-1}$	$8,58 \times 10^{-1}$	$7,76 \times 10^{-1}$	$7,05 \times 10^{-1}$	$6,44 \times 10^{-1}$	$5,91 \times 10^{-1}$
250	1,58	1,39	1,39	1,42	1,39	1,32	1,23	1,13	1,04	$9,66 \times 10^{-1}$	$8,95 \times 10^{-1}$
315	2,12	1,74	1,69	1,75	1,78	1,75	1,68	1,60	1,50	1,41	1,33
400	2,95	2,23	2,06	2,10	2,19	2,23	2,21	2,16	2,08	2,00	1,90
500	4,25	2,97	2,60	2,52	2,63	2,73	2,79	2,80	2,77	2,71	2,63
630	6,26	4,12	3,39	3,06	3,13	3,27	3,40	3,48	3,52	3,52	3,49
800	9,36	5,92	4,62	3,84	3,77	3,89	4,05	4,19	4,31	4,39	4,43
1 000	$1,41 \times 10$	8,72	6,53	5,01	4,65	4,66	4,80	4,98	5,15	5,30	5,42
1 250	$2,11 \times 10$	$1,31 \times 10$	9,53	6,81	5,97	5,75	5,78	5,92	6,10	6,29	6,48
1 600	$3,13 \times 10$	$1,98 \times 10$	$1,42 \times 10$	9,63	8,00	7,37	7,17	7,18	7,31	7,48	7,68
2 000	$4,53 \times 10$	$2,99 \times 10$	$2,15 \times 10$	$1,41 \times 10$	$1,12 \times 10$	9,86	9,25	9,02	8,98	9,06	9,21
2 500	$6,35 \times 10$	$4,48 \times 10$	$3,26 \times 10$	$2,10 \times 10$	$1,61 \times 10$	$1,37 \times 10$	$1,25 \times 10$	$1,18 \times 10$	$1,15 \times 10$	$1,13 \times 10$	$1,13 \times 10$
3 150	$8,54 \times 10$	$6,62 \times 10$	$4,94 \times 10$	$3,18 \times 10$	$2,39 \times 10$	$1,98 \times 10$	$1,75 \times 10$	$1,61 \times 10$	$1,53 \times 10$	$1,48 \times 10$	$1,45 \times 10$
4 000	$1,09 \times 10^{2}$	$9,51 \times 10$	$7,41 \times 10$	$4,85 \times 10$	$3,61 \times 10$	$2,94 \times 10$	$2,54 \times 10$	$2,29 \times 10$	$2,13 \times 10$	$2,02 \times 10$	$1,94 \times 10$
5 000	$1,33 \times 10^{2}$	$1,32 \times 10^{2}$	$1,09 \times 10^{2}$	$7,39 \times 10$	$5,51 \times 10$	$4,44 \times 10$	$3,79 \times 10$	$3,36 \times 10$	$3,06 \times 10$	$2,86 \times 10$	$2,71 \times 10$
6 300	$1,56 \times 10^{2}$	$1,75 \times 10^{2}$	$1,56 \times 10^{2}$	$1,12 \times 10^{2}$	$8,42 \times 10$	$6,78 \times 10$	$5,74 \times 10$	$5,04 \times 10$	$4,54 \times 10$	$4,18 \times 10$	$3,91 \times 10$
8 000	$1,75 \times 10^{2}$	$2,21 \times 10^{2}$	$2,15 \times 10^{2}$	$1,66 \times 10^{2}$	$1,28 \times 10^{2}$	$1,04 \times 10^{2}$	$8,78 \times 10$	$7,66 \times 10$	$6,86 \times 10$	$6,26 \times 10$	$5,81 \times 10$
10 000	$1,93 \times 10^{2}$	$2,67 \times 10^{2}$	$2,84 \times 10^{2}$	$2,42 \times 10^{2}$	$1,94 \times 10^{2}$	$1,59 \times 10^{2}$	$1,35 \times 10^{2}$	$1,18 \times 10^{2}$	$1,05 \times 10^{2}$	$9,53 \times 10$	$8,79 \times 10$

(j) Air temperature: 25 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,62 \times 10^{-1}$	$1,97 \times 10^{-1}$	$1,56 \times 10^{-1}$	$1,09 \times 10^{-1}$	$8,30 \times 10^{-2}$	$6,71 \times 10^{-2}$	$5,63 \times 10^{-2}$	$4,85 \times 10^{-2}$	$4,26 \times 10^{-2}$	$3,79 \times 10^{-2}$	$3,42 \times 10^{-2}$
63	$3,74 \times 10^{-1}$	$2,95 \times 10^{-1}$	$2,38 \times 10^{-1}$	$1,69 \times 10^{-1}$	$1,30 \times 10^{-1}$	$1,06 \times 10^{-1}$	$8,88 \times 10^{-2}$	$7,65 \times 10^{-2}$	$6,73 \times 10^{-2}$	$6,00 \times 10^{-2}$	$5,41 \times 10^{-2}$
80	$5,15 \times 10^{-1}$	$4,29 \times 10^{-1}$	$3,57 \times 10^{-1}$	$2,61 \times 10^{-1}$	$2,03 \times 10^{-1}$	$1,66 \times 10^{-1}$	$1,40 \times 10^{-1}$	$1,21 \times 10^{-1}$	$1,06 \times 10^{-1}$	$9,48 \times 10^{-2}$	$8,56 \times 10^{-2}$
100	$6,81 \times 10^{-1}$	$6,04 \times 10^{-1}$	$5,23 \times 10^{-1}$	$3,97 \times 10^{-1}$	$3,14 \times 10^{-1}$	$2,58 \times 10^{-1}$	$2,19 \times 10^{-1}$	$1,90 \times 10^{-1}$	$1,67 \times 10^{-1}$	$1,49 \times 10^{-1}$	$1,35 \times 10^{-1}$
125	$8,67 \times 10^{-1}$	$8,16 \times 10^{-1}$	$7,40 \times 10^{-1}$	$5,91 \times 10^{-1}$	$4,79 \times 10^{-1}$	$3,99 \times 10^{-1}$	$3,40 \times 10^{-1}$	$2,96 \times 10^{-1}$	$2,62 \times 10^{-1}$	$2,35 \times 10^{-1}$	$2,13 \times 10^{-1}$
160	1,07	1,06	1,01	$8,56 \times 10^{-1}$	$7,17 \times 10^{-1}$	$6,08 \times 10^{-1}$	$5,25 \times 10^{-1}$	$4,60 \times 10^{-1}$	$4,09 \times 10^{-1}$	$3,67 \times 10^{-1}$	$3,33 \times 10^{-1}$
200	1,31	1,32	1,31	1,20	1,05	$9,09 \times 10^{-1}$	$7,97 \times 10^{-1}$	$7,06 \times 10^{-1}$	$6,31 \times 10^{-1}$	$5,70 \times 10^{-1}$	$5,20 \times 10^{-1}$
250	1,61	1,60	1,64	1,60	1,47	1,32	1,18	1,06	$9,63 \times 10^{-1}$	$8,76 \times 10^{-1}$	$8,03 \times 10^{-1}$
315	2,02	1,93	1,99	2,05	1,99	1,86	1,71	1,57	1,44	1,32	1,22
400	2,63	2,35	2,38	2,53	2,57	2,51	2,38	2,24	2,10	1,96	1,83
500	3,56	2,92	2,86	3,04	3,19	3,23	3,18	3,08	2,95	2,80	2,66
630	5,00	3,78	3,50	3,61	3,84	4,00	4,06	4,05	3,97	3,86	3,73
800	7,24	5,09	4,44	4,31	4,55	4,80	4,99	5,09	5,12	5,09	5,02
1 000	$1,07 \times 10$	7,13	5,87	5,27	5,39	5,68	5,96	6,19	6,35	6,44	6,47
1 250	$1,61 \times 10$	$1,03 \times 10$	8,09	6,68	6,52	6,73	7,04	7,35	7,62	7,84	8,00
1 600	$2,43 \times 10$	$1,53 \times 10$	$1,16 \times 10$	8,85	8,16	8,14	8,36	8,68	9,01	9,33	9,61
2 000	$3,66 \times 10$	$2,30 \times 10$	$1,70 \times 10$	$1,22 \times 10$	$1,07 \times 10$	$1,02 \times 10$	$1,02 \times 10$	$1,04 \times 10$	$1,07 \times 10$	$1,10 \times 10$	$1,14 \times 10$
2 500	$5,42 \times 10$	$3,49 \times 10$	$2,55 \times 10$	$1,75 \times 10$	$1,45 \times 10$	$1,33 \times 10$	$1,28 \times 10$	$1,28 \times 10$	$1,29 \times 10$	$1,32 \times 10$	$1,35 \times 10$
3 150	$7,86 \times 10$	$5,29 \times 10$	$3,86 \times 10$	$2,58 \times 10$	$2,06 \times 10$	$1,81 \times 10$	$1,69 \times 10$	$1,63 \times 10$	$1,62 \times 10$	$1,62 \times 10$	$1,64 \times 10$
4 000	$1,10 \times 10^{2}$	$7,94 \times 10$	$5,88 \times 10$	$3,88 \times 10$	$3,01 \times 10$	$2,57 \times 10$	$2,32 \times 10$	$2,19 \times 10$	$2,11 \times 10$	$2,08 \times 10$	$2,06 \times 10$
5 000	$1,49 \times 10^{2}$	$1,17 \times 10^{2}$	$8,91 \times 10$	$5,90 \times 10$	$4,50 \times 10$	$3,76 \times 10$	$3,32 \times 10$	$3,05 \times 10$	$2,88 \times 10$	$2,77 \times 10$	$2,71 \times 10$
6 300	$1,91 \times 10^{2}$	$1,68 \times 10^{2}$	$1,33 \times 10^{2}$	$9,00 \times 10$	$6,83 \times 10$	$5,62 \times 10$	$4,88 \times 10$	$4,41 \times 10$	$4,08 \times 10$	$3,86 \times 10$	$3,71 \times 10$
8 000	$2,33 \times 10^{2}$	$2,32 \times 10^{2}$	$1,96 \times 10^{2}$	$1,37 \times 10^{2}$	$1,04 \times 10^{2}$	$8,54 \times 10$	$7,34 \times 10$	$6,54 \times 10$	$5,98 \times 10$	$5,58 \times 10$	$5,28 \times 10$
10 000	$2,74 \times 10^{2}$	$3,08 \times 10^{2}$	$2,79 \times 10^{2}$	$2,07 \times 10^{2}$	$1,60 \times 10^{2}$	$1,31 \times 10^{2}$	$1,12 \times 10^{2}$	$9,89 \times 10$	$8,96 \times 10$	$8,28 \times 10$	$7,76 \times 10$

(k) Air temperature: 30 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,45 \times 10^{-1}$	$1,77 \times 10^{-1}$	$1,37 \times 10^{-1}$	$9,39 \times 10^{-2}$	$7,13 \times 10^{-2}$	$5,74 \times 10^{-2}$	$4,81 \times 10^{-2}$	$4,14 \times 10^{-2}$	$3,63 \times 10^{-2}$	$3,23 \times 10^{-2}$	$2,92 \times 10^{-2}$
63	$3,62 \times 10^{-1}$	$2,70 \times 10^{-1}$	$2,12 \times 10^{-1}$	$1,47 \times 10^{-1}$	$1,12 \times 10^{-1}$	$9,07 \times 10^{-2}$	$7,60 \times 10^{-2}$	$6,54 \times 10^{-2}$	$5,74 \times 10^{-2}$	$5,12 \times 10^{-2}$	$4,62 \times 10^{-2}$
80	$5,21 \times 10^{-1}$	$4,06 \times 10^{-1}$	$3,26 \times 10^{-1}$	$2,30 \times 10^{-1}$	$1,76 \times 10^{-1}$	$1,43 \times 10^{-1}$	$1,20 \times 10^{-1}$	$1,03 \times 10^{-1}$	$9,08 \times 10^{-2}$	$8,10 \times 10^{-2}$	$7,31 \times 10^{-2}$
100	$7,21 \times 10^{-1}$	$5,95 \times 10^{-1}$	$4,92 \times 10^{-1}$	$3,56 \times 10^{-1}$	$2,76 \times 10^{-1}$	$2,24 \times 10^{-1}$	$1,89 \times 10^{-1}$	$1,63 \times 10^{-1}$	$1,43 \times 10^{-1}$	$1,28 \times 10^{-1}$	$1,16 \times 10^{-1}$
125	$9,58 \times 10^{-1}$	$8,45 \times 10^{-1}$	$7,25 \times 10^{-1}$	$5,43 \times 10^{-1}$	$4,28 \times 10^{-1}$	$3,51 \times 10^{-1}$	$2,96 \times 10^{-1}$	$2,56 \times 10^{-1}$	$2,26 \times 10^{-1}$	$2,02 \times 10^{-1}$	$1,82 \times 10^{-1}$
160	1,22	1,15	1,03	$8,15 \times 10^{-1}$	$6,55 \times 10^{-1}$	$5,43 \times 10^{-1}$	$4,62 \times 10^{-1}$	$4,02 \times 10^{-1}$	$3,55 \times 10^{-1}$	$3,18 \times 10^{-1}$	$2,88 \times 10^{-1}$
200	1,51	1,50	1,42	1,19	$9,87 \times 10^{-1}$	$8,32 \times 10^{-1}$	$7,15 \times 10^{-1}$	$6,25 \times 10^{-1}$	$5,55 \times 10^{-1}$	$4,98 \times 10^{-1}$	$4,52 \times 10^{-1}$
250	1,82	1,88	1,87	1,68	1,45	1,25	1,09	$9,63 \times 10^{-1}$	$8,60 \times 10^{-1}$	$7,75 \times 10^{-1}$	$7,05 \times 10^{-1}$
315	2,20	2,28	2,35	2,28	2,07	1,84	1,63	1,46	1,32	1,20	1,09
400	2,69	2,73	2,86	2,95	2,83	2,61	2,38	2,17	1,98	1,82	1,67
500	3,40	3,26	3,41	3,67	3,70	3,57	3,36	3,14	2,91	2,71	2,52
630	4,46	3,96	4,04	4,41	4,63	4,66	4,55	4,36	4,14	3,92	3,70
800	6,10	4,98	4,85	5,21	5,60	5,82	5,88	5,81	5,66	5,47	5,25
1 000	8,67	6,52	6,00	6,15	6,63	7,03	7,29	7,41	7,41	7,32	7,17
1 250	$1,27 \times 10$	8,91	7,72	7,39	7,80	8,31	8,75	9,08	9,28	9,37	9,37
1 600	$1,89 \times 10$	$1,26 \times 10$	$1,04 \times 10$	9,17	9,30	9,78	$1,03 \times 10$	$1,08 \times 10$	$1,12 \times 10$	$1,15 \times 10$	$1,17 \times 10$
2 000	$2,85 \times 10$	$1,85 \times 10$	$1,45 \times 10$	$1,18 \times 10$	$1,14 \times 10$	$1,17 \times 10$	$1,22 \times 10$	$1,27 \times 10$	$1,33 \times 10$	$1,38 \times 10$	$1,42 \times 10$
2 500	$4,31 \times 10$	$2,76 \times 10$	$2,10 \times 10$	$1,60 \times 10$	$1,46 \times 10$	$1,43 \times 10$	$1,46 \times 10$	$1,51 \times 10$	$1,57 \times 10$	$1,63 \times 10$	$1,68 \times 10$
3 150	$6,48 \times 10$	$4,18 \times 10$	$3,12 \times 10$	$2,25 \times 10$	$1,94 \times 10$	$1,83 \times 10$	$1,81 \times 10$	$1,83 \times 10$	$1,88 \times 10$	$1,93 \times 10$	$1,99 \times 10$
4 000	$9,60 \times 10$	$6,35 \times 10$	$4,71 \times 10$	$3,27 \times 10$	$2,70 \times 10$	$2,45 \times 10$	$2,34 \times 10$	$2,31 \times 10$	$2,31 \times 10$	$2,35 \times 10$	$2,40 \times 10$
5 000	$1,39 \times 10^{2}$	$9,62 \times 10$	$7,16 \times 10$	$4,87 \times 10$	$3,90 \times 10$	$3,41 \times 10$	$3,16 \times 10$	$3,03 \times 10$	$2,97 \times 10$	$2,96 \times 10$	$2,97 \times 10$
6 300	$1,94 \times 10^{2}$	$1,44 \times 10^{2}$	$1,09 \times 10^{2}$	$7,37 \times 10$	$5,77 \times 10$	$4,93 \times 10$	$4,44 \times 10$	$4,16 \times 10$	$3,98 \times 10$	$3,89 \times 10$	$3,84 \times 10$
8 000	$2,60 \times 10^{2}$	$2,11 \times 10^{2}$	$1,65 \times 10^{2}$	$1,13 \times 10^{2}$	$8,71 \times 10$	$7,31 \times 10$	$6,47 \times 10$	$5,93 \times 10$	$5,57 \times 10$	$5,33 \times 10$	$5,18 \times 10$
10 000	$3,32 \times 10^{2}$	$3,01 \times 10^{2}$	$2,46 \times 10^{2}$	$1,72 \times 10^{2}$	$1,33 \times 10^{2}$	$1,11 \times 10^{2}$	$9,65 \times 10$	$8,71 \times 10$	$8,07 \times 10$	$7,61 \times 10$	$7,28 \times 10$

(l) Air temperature: 35 °C

Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$2,22 \times 10^{-1}$	$1,56 \times 10^{-1}$	$1,19 \times 10^{-1}$	$8,10 \times 10^{-2}$	$6,13 \times 10^{-2}$	$4,93 \times 10^{-2}$	$4,12 \times 10^{-2}$	$3,54 \times 10^{-2}$	$3,11 \times 10^{-2}$	$2,77 \times 10^{-2}$	$2,50 \times 10^{-2}$
63	$3,37 \times 10^{-1}$	$2,42 \times 10^{-1}$	$1,87 \times 10^{-1}$	$1,28 \times 10^{-1}$	$9,68 \times 10^{-2}$	$7,80 \times 10^{-2}$	$6,52 \times 10^{-2}$	$5,61 \times 10^{-2}$	$4,92 \times 10^{-2}$	$4,39 \times 10^{-2}$	$3,96 \times 10^{-2}$
80	$5,01 \times 10^{-1}$	$3,71 \times 10^{-1}$	$2,91 \times 10^{-1}$	$2,01 \times 10^{-1}$	$1,53 \times 10^{-1}$	$1,23 \times 10^{-1}$	$1,03 \times 10^{-1}$	$8,88 \times 10^{-2}$	$7,79 \times 10^{-2}$	$6,95 \times 10^{-2}$	$6,27 \times 10^{-2}$
100	$7,25 \times 10^{-1}$	$5,60 \times 10^{-1}$	$4,47 \times 10^{-1}$	$3,14 \times 10^{-1}$	$2,40 \times 10^{-1}$	$1,94 \times 10^{-1}$	$1,63 \times 10^{-1}$	$1,40 \times 10^{-1}$	$1,23 \times 10^{-1}$	$1,10 \times 10^{-1}$	$9,92 \times 10^{-2}$
125	1,01	$8,26 \times 10^{-1}$	$6,78 \times 10^{-1}$	$4,86 \times 10^{-1}$	$3,76 \times 10^{-1}$	$3,05 \times 10^{-1}$	$2,57 \times 10^{-1}$	$2,21 \times 10^{-1}$	$1,95 \times 10^{-1}$	$1,74 \times 10^{-1}$	$1,57 \times 10^{-1}$
160	1,35	1,18	1,00	$7,46 \times 10^{-1}$	$5,84 \times 10^{-1}$	$4,78 \times 10^{-1}$	$4,03 \times 10^{-1}$	$3,49 \times 10^{-1}$	$3,07 \times 10^{-1}$	$2,74 \times 10^{-1}$	$2,48 \times 10^{-1}$
200	1,73	1,62	1,45	1,12	$8,98 \times 10^{-1}$	$7,42 \times 10^{-1}$	$6,30 \times 10^{-1}$	$5,47 \times 10^{-1}$	$4,83 \times 10^{-1}$	$4,32 \times 10^{-1}$	$3,91 \times 10^{-1}$
250	2,13	2,13	2,00	1,65	1,36	1,14	$9,77 \times 10^{-1}$	$8,53 \times 10^{-1}$	$7,56 \times 10^{-1}$	$6,78 \times 10^{-1}$	$6,14 \times 10^{-1}$
315	2,56	2,69	2,66	2,36	2,01	1,73	1,50	1,32	1,17	1,06	$9,62 \times 10^{-1}$
400	3,05	3,27	3,37	3,23	2,89	2,55	2,26	2,01	1,81	1,64	1,49
500	3,66	3,88	4,12	4,22	4,00	3,66	3,32	3,01	2,73	2,50	2,30
630	4,52	4,59	4,90	5,30	5,29	5,05	4,72	4,38	4,05	3,74	3,47
800	5,78	5,48	5,76	6,40	6,69	6,67	6,46	6,15	5,81	5,47	5,14
1 000	7,71	6,74	6,82	7,55	8,15	8,43	8,45	8,30	8,03	7,71	7,37
1 250	$1,07 \times 10$	8,61	8,28	8,85	9,65	$1,03 \times 10$	$1,06 \times 10$	$1,07 \times 10$	$1,06 \times 10$	$1,04 \times 10$	$1,02 \times 10$
1 600	$1,54 \times 10$	$1,15 \times 10$	$1,04 \times 10$	$1,05 \times 10$	$1,13 \times 10$	$1,21 \times 10$	$1,28 \times 10$	$1,32 \times 10$	$1,35 \times 10$	$1,35 \times 10$	$1,35 \times 10$
2 000	$2,28 \times 10$	$1,60 \times 10$	$1,37 \times 10$	$1,28 \times 10$	$1,34 \times 10$	$1,42 \times 10$	$1,51 \times 10$	$1,59 \times 10$	$1,64 \times 10$	$1,68 \times 10$	$1,71 \times 10$
2 500	$3,42 \times 10$	$2,31 \times 10$	$1,88 \times 10$	$1,62 \times 10$	$1,61 \times 10$	$1,68 \times 10$	$1,78 \times 10$	$1,87 \times 10$	$1,95 \times 10$	$2,02 \times 10$	$2,08 \times 10$
3 150	$5,18 \times 10$	$3,41 \times 10$	$2,68 \times 10$	$2,15 \times 10$	$2,02 \times 10$	$2,04 \times 10$	$2,11 \times 10$	$2,20 \times 10$	$2,30 \times 10$	$2,40 \times 10$	$2,48 \times 10$
4 000	$7,83 \times 10$	$5,13 \times 10$	$3,93 \times 10$	$2,97 \times 10$	$2,65 \times 10$	$2,57 \times 10$	$2,58 \times 10$	$2,65 \times 10$	$2,74 \times 10$	$2,83 \times 10$	$2,93 \times 10$
5 000	$1,18 \times 10^{2}$	$7,80 \times 10$	$5,90 \times 10$	$4,26 \times 10$	$3,63 \times 10$	$3,38 \times 10$	$3,29 \times 10$	$3,29 \times 10$	$3,34 \times 10$	$3,42 \times 10$	$3,51 \times 10$
6 300	$1,73 \times 10^{2}$	$1,19 \times 10^{2}$	$8,95 \times 10$	$6,28 \times 10$	$5,17 \times 10$	$4,64 \times 10$	$4,37 \times 10$	$4,26 \times 10$	$4,23 \times 10$	$4,25 \times 10$	$4,31 \times 10$
8 000	$2,49 \times 10^{2}$	$1,79 \times 10^{2}$	$1,36 \times 10^{2}$	$9,45 \times 10$	$7,59 \times 10$	$6,62 \times 10$	$6,07 \times 10$	$5,77 \times 10$	$5,60 \times 10$	$5,52 \times 10$	$5,50 \times 10$
10 000	$3,45 \times 10^{2}$	$2,67 \times 10^{2}$	$2,07 \times 10^{2}$	$1,44 \times 10^{2}$	$1,14 \times 10^{2}$	$9,73 \times 10$	$8,74 \times 10$	$8,13 \times 10$	$7,74 \times 10$	$7,49 \times 10$	$7,34 \times 10$

(m) Air temperature: 40 °C

Preferred frequency Hz	Relative humidity, % 10	15	20	30	40	50	60	70	80	90	100
50	1,98 × 10^{-1}	1,36 × 10^{-1}	1,04 × 10^{-1}	7,00 × 10^{-2}	5,29 × 10^{-2}	4,25 × 10^{-2}	3,55 × 10^{-2}	3,05 × 10^{-2}	2,68 × 10^{-2}	2,39 × 10^{-2}	2,15 × 10^{-2}
63	3,06 × 10^{-1}	2,14 × 10^{-1}	1,63 × 10^{-1}	1,11 × 10^{-1}	8,36 × 10^{-2}	6,72 × 10^{-2}	5,62 × 10^{-2}	4,83 × 10^{-2}	4,24 × 10^{-2}	3,78 × 10^{-2}	3,41 × 10^{-2}
80	4,66 × 10^{-1}	3,32 × 10^{-1}	2,56 × 10^{-1}	1,74 × 10^{-1}	1,32 × 10^{-1}	1,06 × 10^{-1}	8,90 × 10^{-2}	7,66 × 10^{-2}	6,72 × 10^{-2}	5,99 × 10^{-2}	5,40 × 10^{-2}
100	6,95 × 10^{-1}	5,11 × 10^{-1}	3,98 × 10^{-1}	2,74 × 10^{-1}	2,08 × 10^{-1}	1,68 × 10^{-1}	1,41 × 10^{-1}	1,21 × 10^{-1}	1,06 × 10^{-1}	9,48 × 10^{-2}	8,56 × 10^{-2}
125	1,01	7,74 × 10^{-1}	6,15 × 10^{-1}	4,29 × 10^{-1}	3,28 × 10^{-1}	2,65 × 10^{-1}	2,22 × 10^{-1}	1,92 × 10^{-1}	1,68 × 10^{-1}	1,50 × 10^{-1}	1,35 × 10^{-1}
160	1,42	1,15	9,35 × 10^{-1}	6,67 × 10^{-1}	5,14 × 10^{-1}	4,17 × 10^{-1}	3,51 × 10^{-1}	3,02 × 10^{-1}	2,66 × 10^{-1}	2,37 × 10^{-1}	2,14 × 10^{-1}
200	1,91	1,65	1,39	1,03	8,00 × 10^{-1}	6,53 × 10^{-1}	5,51 × 10^{-1}	4,76 × 10^{-1}	4,19 × 10^{-1}	3,75 × 10^{-1}	3,39 × 10^{-1}
250	2,45	2,28	2,02	1,55	1,23	1,02	8,63 × 10^{-1}	7,48 × 10^{-1}	6,60 × 10^{-1}	5,90 × 10^{-1}	5,34 × 10^{-1}
315	3,03	3,03	2,82	2,30	1,88	1,57	1,34	1,17	1,03	9,27 × 10^{-1}	8,40 × 10^{-1}
400	3,63	3,84	3,77	3,30	2,79	2,38	2,06	1,81	1,61	1,45	1,32
500	4,28	4,68	4,82	4,56	4,04	3,54	3,12	2,77	2,48	2,25	2,05
630	5,08	5,55	5,92	6,02	5,64	5,12	4,61	4,16	3,77	3,44	3,16
800	6,14	6,51	7,04	7,61	7,53	7,13	6,62	6,10	5,62	5,19	4,80
1 000	7,68	7,68	8,25	9,24	9,62	9,52	9,14	8,66	8,14	7,62	7,14
1 250	1,00 × 10	9,28	9,68	1,09 × 10	1,18 × 10	1,21 × 10	1,21 × 10	1,18 × 10	1,14 × 10	1,09 × 10	1,03 × 10
1 600	1,36 × 10	1,16 × 10	1,16 × 10	1,28 × 10	1,40 × 10	1,49 × 10	1,53 × 10	1,54 × 10	1,52 × 10	1,48 × 10	1,44 × 10
2 000	1,93 × 10	1,52 × 10	1,43 × 10	1,50 × 10	1,64 × 10	1,77 × 10	1,86 × 10	1,92 × 10	1,94 × 10	1,94 × 10	1,93 × 10
2 500	2,82 × 10	2,08 × 10	1,84 × 10	1,80 × 10	1,92 × 10	2,07 × 10	2,20 × 10	2,31 × 10	2,39 × 10	2,44 × 10	2,46 × 10
3 150	4,21 × 10	2,95 × 10	2,49 × 10	2,25 × 10	2,30 × 10	2,44 × 10	2,59 × 10	2,73 × 10	2,85 × 10	2,96 × 10	3,03 × 10
4 000	6,36 × 10	4,32 × 10	3,50 × 10	2,93 × 10	2,85 × 10	2,92 × 10	3,06 × 10	3,21 × 10	3,37 × 10	3,51 × 10	3,63 × 10
5 000	9,64 × 10	6,47 × 10	5,08 × 10	3,99 × 10	3,68 × 10	3,63 × 10	3,71 × 10	3,84 × 10	3,99 × 10	4,15 × 10	4,30 × 10
6 300	1,46 × 10^{2}	9,79 × 10	7,56 × 10	5,66 × 10	4,97 × 10	4,72 × 10	4,67 × 10	4,72 × 10	4,83 × 10	4,97 × 10	5,13 × 10
8 000	2,17 × 10^{2}	1,49 × 10^{2}	1,14 × 10^{2}	8,28 × 10	6,99 × 10	6,40 × 10	6,14 × 10	6,05 × 10	6,07 × 10	6,15 × 10	6,27 × 10
10 000	3,18 × 10^{2}	2,26 × 10^{2}	1,74 × 10^{2}	1,24 × 10^{2}	1,02 × 10^{2}	9,04 × 10	8,43 × 10	8,10 × 10	7,95 × 10	7,91 × 10	7,94 × 10

(n) Air temperature: 45 °C

Preferred frequency, Hz	Relative humidity, % 10	15	20	30	40	50	60	70	80	90	100
50	1,75 × 10^{-1}	1,19 × 10^{-1}	9,02 × 10^{-2}	6,07 × 10^{-2}	4,58 × 10^{-2}	3,68 × 10^{-2}	3,07 × 10^{-2}	2,64 × 10^{-2}	2,32 × 10^{-2}	2,07 × 10^{-2}	1,86 × 10^{-2}
63	2,73 × 10^{-1}	1,87 × 10^{-1}	1,42 × 10^{-1}	9,60 × 10^{-2}	7,25 × 10^{-2}	5,82 × 10^{-2}	4,87 × 10^{-2}	4,18 × 10^{-2}	3,67 × 10^{-2}	3,27 × 10^{-2}	2,95 × 10^{-2}
80	4,22 × 10^{-1}	2,94 × 10^{-1}	2,24 × 10^{-1}	1,52 × 10^{-1}	1,15 × 10^{-1}	9,22 × 10^{-2}	7,71 × 10^{-2}	6,63 × 10^{-2}	5,82 × 10^{-2}	5,18 × 10^{-2}	4,68 × 10^{-2}
100	6,44 × 10^{-1}	4,57 × 10^{-1}	3,52 × 10^{-1}	2,39 × 10^{-1}	1,81 × 10^{-1}	1,46 × 10^{-1}	1,22 × 10^{-1}	1,05 × 10^{-1}	9,21 × 10^{-2}	8,21 × 10^{-2}	7,41 × 10^{-2}
125	9,65 × 10^{-1}	7,05 × 10^{-1}	5,48 × 10^{-1}	3,77 × 10^{-1}	2,86 × 10^{-1}	2,30 × 10^{-1}	1,93 × 10^{-1}	1,66 × 10^{-1}	1,46 × 10^{-1}	1,30 × 10^{-1}	1,17 × 10^{-1}
160	1,41	1,07	8,48 × 10^{-1}	5,90 × 10^{-1}	4,50 × 10^{-1}	3,64 × 10^{-1}	3,05 × 10^{-1}	2,63 × 10^{-1}	2,31 × 10^{-1}	2,06 × 10^{-1}	1,86 × 10^{-1}
200	1,98	1,59	1,29	9,18 × 10^{-1}	7,06 × 10^{-1}	5,73 × 10^{-1}	4,81 × 10^{-1}	4,15 × 10^{-1}	3,65 × 10^{-1}	3,26 × 10^{-1}	2,94 × 10^{-1}
250	2,68	2,30	1,93	1,41	1,10	8,98 × 10^{-1}	7,57 × 10^{-1}	6,54 × 10^{-1}	5,76 × 10^{-1}	5,14 × 10^{-1}	4,65 × 10^{-1}
315	3,47	3,21	2,82	2,15	1,70	1,40	1,19	1,03	9,06 × 10^{-1}	8,11 × 10^{-1}	7,34 × 10^{-1}
400	4,30	4,28	3,96	3,19	2,59	2,16	1,85	1,61	1,42	1,27	1,15
500	5,15	5,46	5,34	4,61	3,88	3,29	2,84	2,49	2,22	1,99	1,81
630	6,05	6,68	6,87	6,42	5,65	4,92	4,32	3,83	3,43	3,10	2,82
800	7,09	7,92	8,47	8,55	7,93	7,16	6,42	5,78	5,23	4,76	4,36
1 000	8,45	9,25	1,01 × 10	1,09 × 10	1,07 × 10	1,00 × 10	9,27	8,51	7,82	7,20	6,65
1 250	1,04 × 10	1,08 × 10	1,18 × 10	1,33 × 10	1,38 × 10	1,35 × 10	1,29 × 10	1,22 × 10	1,14 × 10	1,06 × 10	9,94
1 600	1,33 × 10	1,29 × 10	1,38 × 10	1,57 × 10	1,70 × 10	1,74 × 10	1,72 × 10	1,67 × 10	1,60 × 10	1,52 × 10	1,45 × 10
2 000	1,78 × 10	1,59 × 10	1,63 × 10	1,84 × 10	2,02 × 10	2,14 × 10	2,19 × 10	2,19 × 10	2,16 × 10	2,10 × 10	2,03 × 10
2 500	2,48 × 10	2,05 × 10	1,99 × 10	2,15 × 10	2,37 × 10	2,56 × 10	2,69 × 10	2,76 × 10	2,79 × 10	2,78 × 10	2,74 × 10
3 150	3,58 × 10	2,75 × 10	2,52 × 10	2,56 × 10	2,77 × 10	3,00 × 10	3,20 × 10	3,35 × 10	3,45 × 10	3,52 × 10	3,54 × 10
4 000	5,30 × 10	3,86 × 10	3,35 × 10	3,15 × 10	3,29 × 10	3,52 × 10	3,75 × 10	3,97 × 10	4,15 × 10	4,29 × 10	4,39 × 10
5 000	7,98 × 10	5,60 × 10	4,65 × 10	4,06 × 10	4,03 × 10	4,20 × 10	4,43 × 10	4,67 × 10	4,90 × 10	5,11 × 10	5,29 × 10
6 300	1,21 × 10^{2}	8,32 × 10	6,69 × 10	5,46 × 10	5,15 × 10	5,17 × 10	5,33 × 10	5,56 × 10	5,80 × 10	6,05 × 10	6,28 × 10
8 000	1,83 × 10^{2}	1,26 × 10^{2}	9,89 × 10	7,66 × 10	6,88 × 10	6,65 × 10	6,66 × 10	6,80 × 10	7,00 × 10	7,24 × 10	7,48 × 10
10 000	2,76 × 10^{2}	1,91 × 10^{2}	1,49 × 10^{2}	1,11 × 10^{2}	9,60 × 10	8,94 × 10	8,68 × 10	8,65 × 10	8,74 × 10	8,91 × 10	9,12 × 10

(p) Air temperature: 50 °C											
Preferred frequency, Hz	Relative humidity, %										
	10	15	20	30	40	50	60	70	80	90	100
50	$1,54 \times 10^{-1}$	$1,04 \times 10^{-1}$	$7,86 \times 10^{-2}$	$5,28 \times 10^{-2}$	$3,98 \times 10^{-2}$	$3,19 \times 10^{-2}$	$2,67 \times 10^{-2}$	$2,30 \times 10^{-2}$	$2,02 \times 10^{-2}$	$1,80 \times 10^{-2}$	$1,62 \times 10^{-2}$
63	$2,42 \times 10^{-1}$	$1,64 \times 10^{-1}$	$1,24 \times 10^{-1}$	$8,36 \times 10^{-2}$	$6,30 \times 10^{-2}$	$5,06 \times 10^{-2}$	$4,23 \times 10^{-2}$	$3,64 \times 10^{-2}$	$3,19 \times 10^{-2}$	$2,85 \times 10^{-2}$	$2,57 \times 10^{-2}$
80	$3,77 \times 10^{-1}$	$2,59 \times 10^{-1}$	$1,96 \times 10^{-1}$	$1,32 \times 10^{-1}$	$9,98 \times 10^{-2}$	$8,02 \times 10^{-2}$	$6,71 \times 10^{-2}$	$5,77 \times 10^{-2}$	$5,06 \times 10^{-2}$	$4,51 \times 10^{-2}$	$4,07 \times 10^{-2}$
100	$5,84 \times 10^{-1}$	$4,05 \times 10^{-1}$	$3,09 \times 10^{-1}$	$2,09 \times 10^{-1}$	$1,58 \times 10^{-1}$	$1,27 \times 10^{-1}$	$1,06 \times 10^{-1}$	$9,13 \times 10^{-2}$	$8,02 \times 10^{-2}$	$7,15 \times 10^{-2}$	$6,45 \times 10^{-2}$
125	$8,93 \times 10^{-1}$	$6,32 \times 10^{-1}$	$4,85 \times 10^{-1}$	$3,30 \times 10^{-1}$	$2,50 \times 10^{-1}$	$2,01 \times 10^{-1}$	$1,68 \times 10^{-1}$	$1,45 \times 10^{-1}$	$1,27 \times 10^{-1}$	$1,13 \times 10^{-1}$	$1,02 \times 10^{-1}$
160	1,34	$9,75 \times 10^{-1}$	$7,57 \times 10^{-1}$	$5,19 \times 10^{-1}$	$3,94 \times 10^{-1}$	$3,18 \times 10^{-1}$	$2,66 \times 10^{-1}$	$2,29 \times 10^{-1}$	$2,01 \times 10^{-1}$	$1,79 \times 10^{-1}$	$1,62 \times 10^{-1}$
200	1,96	1,49	1,17	$8,14 \times 10^{-1}$	$6,21 \times 10^{-1}$	$5,01 \times 10^{-1}$	$4,20 \times 10^{-1}$	$3,62 \times 10^{-1}$	$3,18 \times 10^{-1}$	$2,84 \times 10^{-1}$	$2,56 \times 10^{-1}$
250	2,78	2,22	1,79	1,27	$9,74 \times 10^{-1}$	$7,89 \times 10^{-1}$	$6,63 \times 10^{-1}$	$5,72 \times 10^{-1}$	$5,03 \times 10^{-1}$	$4,49 \times 10^{-1}$	$4,06 \times 10^{-1}$
315	3,78	3,22	2,69	1,96	1,52	1,24	1,04	$9,02 \times 10^{-1}$	$7,94 \times 10^{-1}$	$7,09 \times 10^{-1}$	$6,41 \times 10^{-1}$
400	4,90	4,51	3,93	2,98	2,35	1,93	1,64	1,42	1,25	1,12	1,01
500	6,09	6,05	5,55	4,44	3,60	2,99	2,55	2,22	1,96	1,76	1,59
630	7,30	7,75	7,53	6,45	5,39	4,57	3,94	3,45	3,06	2,76	2,50
800	8,55	9,51	9,75	9,02	7,89	6,85	5,99	5,30	4,74	4,29	3,91
1 000	9,95	$1,13 \times 10$	$1,21 \times 10$	$1,21 \times 10$	$1,11 \times 10$	$1,00 \times 10$	8,94	8,03	7,25	6,60	6,05
1 250	$1,17 \times 10$	$1,32 \times 10$	$1,44 \times 10$	$1,55 \times 10$	$1,51 \times 10$	$1,41 \times 10$	$1,30 \times 10$	$1,19 \times 10$	$1,09 \times 10$	$1,00 \times 10$	9,24
1 600	$1,42 \times 10$	$1,53 \times 10$	$1,69 \times 10$	$1,90 \times 10$	$1,96 \times 10$	$1,91 \times 10$	$1,82 \times 10$	$1,71 \times 10$	$1,59 \times 10$	$1,49 \times 10$	$1,39 \times 10$
2 000	$1,79 \times 10$	$1,81 \times 10$	$1,96 \times 10$	$2,26 \times 10$	$2,43 \times 10$	$2,48 \times 10$	$2,44 \times 10$	$2,36 \times 10$	$2,25 \times 10$	$2,14 \times 10$	$2,03 \times 10$
2 500	$2,36 \times 10$	$2,20 \times 10$	$2,30 \times 10$	$2,63 \times 10$	$2,91 \times 10$	$3,07 \times 10$	$3,13 \times 10$	$3,12 \times 10$	$3,06 \times 10$	$2,97 \times 10$	$2,87 \times 10$
3 150	$3,25 \times 10$	$2,79 \times 10$	$2,78 \times 10$	$3,07 \times 10$	$3,41 \times 10$	$3,68 \times 10$	$3,86 \times 10$	$3,95 \times 10$	$3,98 \times 10$	$3,96 \times 10$	$3,89 \times 10$
4 000	$4,64 \times 10$	$3,71 \times 10$	$3,49 \times 10$	$3,63 \times 10$	$3,98 \times 10$	$4,32 \times 10$	$4,61 \times 10$	$4,82 \times 10$	$4,96 \times 10$	$5,04 \times 10$	$5,06 \times 10$
5 000	$6,82 \times 10$	$5,14 \times 10$	$4,58 \times 10$	$4,44 \times 10$	$4,71 \times 10$	$5,06 \times 10$	$5,42 \times 10$	$5,73 \times 10$	$5,99 \times 10$	$6,18 \times 10$	$6,32 \times 10$
6 300	$1,02 \times 10^{2}$	$7,39 \times 10$	$6,29 \times 10$	$5,66 \times 10$	$5,73 \times 10$	$6,02 \times 10$	$6,39 \times 10$	$6,76 \times 10$	$7,10 \times 10$	$7,40 \times 10$	$7,65 \times 10$
8 000	$1,55 \times 10^{2}$	$1,09 \times 10^{2}$	$8,97 \times 10$	$7,54 \times 10$	$7,26 \times 10$	$7,38 \times 10$	$7,67 \times 10$	$8,03 \times 10$	$8,41 \times 10$	$8,78 \times 10$	$9,12 \times 10$
10 000	$2,35 \times 10^{2}$	$1,64 \times 10^{2}$	$1,32 \times 10^{2}$	$1,05 \times 10^{2}$	$9,63 \times 10$	$9,43 \times 10$	$9,54 \times 10$	$9,80 \times 10$	$1,01 \times 10^{2}$	$1,05 \times 10^{2}$	$1,09 \times 10^{2}$

NOTE — Atmospheric-absorption attenuation coefficients were calculated by use of equation (6) for the exact midband frequencies of one-third-octave-band filters (i.e. $b = 1/3$), over the range of preferred frequencies indicated with index k ranging from − 13 to + 10.

8.1.2 When a wideband sound pressure signal is analysed by fractional-octave-band filters, calculation of the attenuation caused by atmospheric absorption is complicated by errors in the measured band sound pressure levels. These errors occur because the equivalent power passed by a practical filter will be greater, or less, than the equivalent power passed by a corresponding ideal bandpass filter with unity transfer gain in the passband and infinite rejection outside the passband. The magnitude of the band-level errors varies with the slope of the spectrum of the signal applied to the filter and the shape of the attenuation response of the filter. Sound pressure level measurements at the location of a distant receiver are particularly vulnerable to high-frequency band-level errors because the attenuation by atmospheric absorption normally increases rapidly with increasing frequency, thereby causing large negative spectral slopes for the sound pressure signal incident on a microphone.

8.1.3 Because of the unavoidable band-level errors inherent in an analysis by fractional-octave-band filters of sounds with steep spectral slopes, and the complexity of the procedure for dealing with the errors in a practical manner, this part of ISO 9613 provides (in 8.2) a calculation method based solely on a discrete-frequency approximation of the attenuation actually experienced by a wideband sound over the frequency ranges of the bandpass filters employed for a spectral analysis. The discrete-frequency (pure-tone) calculation method is applicable to many practical situations, but is limited to combinations of atmospheric and propagation conditions such that the attenuation by atmospheric absorption over the sound-propagation path is not more than approximately 15 dB for the frequency band of interest. See 8.2.2 for specific criteria.

8.1.4 A procedure is also described in 8.3 to apply the pure-tone calculation method to estimate A-weighted sound pressure levels from measurements (or specifications) of unweighted fractional-octave-band sound pressure levels. A general description is also provided (in 8.4) for application of the pure-tone calculation method when the spectrum of the sound is a combination of discrete-frequency components superimposed on a wideband spectrum.

8.1.5 An optional alternative calculation method is described in annex D that requires knowledge of the sound pressure signal as a continuous function of frequency. The method in annex D employs a numerical integration procedure to determine the attenuation by atmospheric absorption for sound pressure levels in frequency bands. The spectrum-integration method yields more accurate estimates for band-level attenuations caused by atmospheric absorption and is applicable over a wider range of conditions than the pure-tone method described in 8.2.

8.2 Pure-tone method to approximate band-level attenuation

8.2.1 For each fractional-octave band of interest and specified uniform meteorological conditions along the sound propagation path, calculate the attenuation coefficient resulting from atmospheric absorption for the exact midband frequency [as determined from equation (6)], using the procedure for pure tones described in clause 6. The band-level attenuation for each frequency band, in decibels, is then the product of the attenuation coefficient for the midband frequency and the path length, as in equation (2) for pure tones. Non-uniform meteorological conditions may occur along long sound paths, as discussed in annex C.

8.2.2 The error in band-level attenuation introduced by this pure-tone method of calculation is estimated to not exceed $\pm$ 0,5 dB provided that:

a) the bandpass filters comply with the Class 1 or Class 0 tolerance limits of IEC 225;

b) for one-third-octave-band filters, the product of the source-receiver path length, in kilometres, and the square of the midband frequency, in kilohertz, does not exceed 6 km·kHz^2, nor does the path length exceed 6 km (at any midband frequency);

c) for octave-band filters, the product of the source-receiver path length, in kilometres, and the square of the midband frequency, in kilohertz, does not exceed 3 km·kHz^2, nor does the path length exceed 3 km (at any midband frequency).

8.2.3 The method described in 8.2.1 is applicable to the calculation of band-level attenuation of the sound produced by stationary or moving sound sources. If the sound source moves during the period of interest, the attenuation from atmospheric absorption will vary with time because the effective frequency (or effective wavelength) varies with time owing to the Döppler effect. This effect should be taken into account by calculating the attenuation coefficient for the Döppler-shifted frequency applicable to the sound-emission angle for each time of interest.

8.3 Calculation of atmospheric-absorption attenuation for A-weighted sound pressure levels

Because the effects of atmospheric absorption are very frequency dependent, the recommended procedure for predicting the influence of atmospheric absorption on A-weighted sound pressure levels, as described by an example in annex E, is first to determine the band-level attenuations applicable to the atmospheric conditions. Apply the calculated band-level attenuations to the band sound pressure levels determined at a reference distance. Account for other losses as appropriate for the reference distances, and apply the standard A-frequency weightings to the band sound pressure levels at the prediction distance.

NOTE 8 As the length of the sound propagation path increases above the limiting values described in 8.2.2, the errors in calculating the band-level attenuation δL_B by the method described in 8.2.1 increase also, and often rapidly. However, even when this error in sound pressure level for individual frequency bands becomes large, it may still be practical to use the method given in 8.2.1 for wideband sound because the error in the calculation of A-frequency-weighted sound pressure level, obtained by combining the band levels, is often very much smaller. The reason is that the attenuation due to atmospheric absorption, and hence the filter errors described in 8.1.2, will be large only in the heavily attenuated bands that may not contribute substantially to the A-frequency-weighted sound pressure level.

Annex E provides a worked example of the calculation of atmospheric-absorption attenuation for A-weighted sound pressure levels.

8.4 Combined wideband and pure-tone sounds

For sound signals made up of a wideband component plus one or more pure-tone components, the following procedure should be used to calculate the attenuation of fractional-octave-band sound pressure levels as a result of atmospheric absorption. The procedure is applicable to sound produced by stationary or moving sources. If the source is moving, attenuation coefficients should be calculated for the Döppler-shifted frequencies of the pure-tone components or the midband frequencies of the wideband component, as described in 8.2.3.

Step 1: Separate the measured spectrum, on the basis of time-mean-square sound pressures, into pure-tone and wideband components. For pure-tone components, the frequency of the tone may be determined by spectrum analysis with a narrow-band filter, by prior knowledge of the source of the tones, or by a defined protocol for estimating the presence and level of a tone based solely on relative changes in the level of adjacent fractional-octave-band sound pressure levels. For the latter case, the frequency of the tone may be assumed to be the exact midband frequency of the filter band. However, if the pure tone approximation method given in 8.2 is used for the wideband element, and if the frequency of the tone is also assumed to be the exact midband frequency of the filter band, then the procedure of separating the spectral components is not necessary because the same pure-tone attenuation would apply to both the wideband and discrete-frequency components.

Step 2: Calculate the attenuation over the specified path length for each spectral component separately, employing the methods specified in 5.2 and 6.3 for the pure-tone components, and in 8.2 for the wideband component.

Step 3: If the initial spectrum is that of the sound at a source location, subtract the calculated atmospheric-absorption attenuations from the separate discrete-frequency and wideband components to obtain estimates for the sound pressure levels of the separate components of the spectrum at a receiver location accounting for atmospheric-absorption losses alone. If the initial spectrum is that for a sound at a receiver location, add the calculated atmospheric-absorption attenuations to obtain estimates for the corresponding sound pressure levels at a source location. Also subtract (or add) estimates for attenuation by other mechanisms (e.g. wave divergence) to the frequency-band sound pressure levels of the initial spectrum.

Step 4: Combine the estimates for the time-mean-square sound pressures of the separate components of the spectrum to obtain the estimated band sound pressure levels of the composite spectrum at the receiver or source location.

Annex A
(informative)

Physical mechanisms

A.1 Equations (3) to (5) in 6.2, for calculating the attenuation coefficient α due to atmospheric absorption, combine the contributions from a number of physical mechanisms into a form suitable for computation. However, understanding of the process is necessarily lost in the complexity of these formulae. Formulae describing the contributions of the individual mechanisms are given here in the interest of providing an understanding of what is covered by equations (3) to (5).

A.2 The form of the equations for individual mechanisms is physical in nature (taken to fit the best available theoretical understanding of the physical processes) rather than empirical. The constants in the equations were obtained from theory and from analysis of an extensive collection of laboratory measurements of atmospheric-absorption losses in moist and dry air and in component gases.

A.3 The attenuation coefficient α, in decibels per metre, is expressed by the sum of four terms as

$$\alpha = \alpha_{cl} + \alpha_{rot} + \alpha_{vib,O} + \alpha_{vib,N} \qquad \ldots \text{(A.1)}$$

where

α_{cl} represents the classical absorption caused by the transport processes of "classical" physics;

α_{rot} represents the molecular absorption caused by rotational relaxation; and

$\alpha_{vib,O}$ and $\alpha_{vib,N}$ represent the molecular absorption caused by vibrational relaxation of oxygen and nitrogen, respectively.

NOTE 9 Within the accuracy limits specified in clause 7, the small amount of molecular absorption contributed by the presence of carbon dioxide is adequately accounted for in the vibrational relaxation terms for oxygen and nitrogen.

A.4 The portion of the attenuation coefficient due to classical and rotational absorption is given, to a close approximation for air temperatures of concern to this part of ISO 9613, by their sum, α_{cr}

$$\alpha_{cr} = \alpha_{cl} + \alpha_{rot} = \frac{1{,}60 \times 10^{-10} (T/T_0)^{1/2} f^2}{p_a/p_r} \qquad \ldots \text{(A.2)}$$

The reference air pressure and temperature are as given in 4.2.

A.5 The two vibrational relaxation terms in equation (A.1) have the same form, namely

$$\alpha_{vib,O} = [(\alpha\lambda)_{max,O}](f/c) \times \times \left\{ 2(f/f_{rO}) \left[1 + (f/f_{rO})^2 \right]^{-1} \right\} \qquad \ldots \text{(A.3)}$$

and

$$\alpha_{vib,N} = [(\alpha\lambda)_{max,N}](f/c) \times \times \left\{ 2(f/f_{rN}) \left[1 + (f/f_{rN})^2 \right]^{-1} \right\} \qquad \ldots \text{(A.4)}$$

where

the subscript O is for oxygen and N for nitrogen relaxations;

c is the speed of sound, in metres per second;

f_r is a relaxation frequency, in hertz;

$(\alpha\lambda)_{max}$ is the maximum attenuation, in decibels, caused by a vibrational relaxation over a distance of one wavelength, λ, in metres.

Formulae for oxygen and nitrogen relaxation frequencies are given by equations (3) and (4) in 6.2.

A.6 For the purposes of this part of ISO 9613, the speed of sound in equations (A.3) and (A.4), in metres per second, is computed from

$$c = 343{,}2\ (T/T_0)^{1/2} \qquad \ldots \text{(A.5)}$$

NOTE 10 Equation (A.5) neglects the small effect of water vapour on the speed of sound; i.e. an effect that is less than 0,3 % under the atmospheric conditions covered by the ranges given in clause 7.

A.7 The maximum atmospheric attenuation $(\alpha\lambda)_{max}$ over a distance of one wavelength, as a result of vibrational relaxation, depends only on the temperature of the air, and has the same form for both oxygen and nitrogen relaxations. It is determined, in decibels, from

$$(\alpha\lambda)_{max,O} = 1,559 X_O (\theta_O/T)^2 \exp(-\theta_O/T) \quad \ldots (A.6)$$

and

$$(\alpha\lambda)_{max,N} = 1,559 X_N (\theta_N/T)^2 \exp(-\theta_N/T) \quad \ldots (A.7)$$

where

θ is the characteristic vibrational temperature;

X is the non-dimensional fractional molar concentration (in dry air) of oxygen (subscript O) and of nitrogen (subscript N).

A.8 For the purposes of this part of ISO 9613, the characteristic vibrational temperature and the fractional molar concentration have the following values:

$\theta = 2\ 239,1$ K for oxygen and 3 352,0 K for nitrogen;

$X = 0,209$ for oxygen and 0,781 for nitrogen (see 4.1).

The constant 1,559 in equations (A.6) and (A.7) is obtained from the theoretical expression $(2\pi/35)(10 \lg e^2)$.

A.9 Equation (5) in 6.2 is obtained by substituting equations (A.2) to (A.7) in equation (A.1).

Annex B
(informative)

Conversion of humidity data to molar concentration of water vapour

In the main text of this part of ISO 9613, a method is given for calculating the attenuation of sound pressure levels as a result of atmospheric absorption. The method is in the form of analytical equations suitable for computations. The purpose of this annex is to complete the computational package by providing analytical expressions, not readily available in the literature, to calculate the molar concentration of water vapour from measurements or specification of relative humidity, air temperature and dewpoint. Other measures of humidity, such as the wet and dry bulb temperatures, should first be converted to relative humidity and then to molar concentration.

B.1 Relative humidity

For a sample of moist air at a given temperature, relative humidity is the ratio, expressed as a percentage, of the vapour pressure of water in moist air to the saturation vapour pressure, p_{sat}, with respect to a plane surface of liquid water at the same temperature and pressure that characterize the sample of moist air. For a given temperature and pressure, the molar concentration, h, of water vapour, as a percentage, may be calculated for a specified relative humidity, h_r, as a percentage, from

$$h = h_r (p_{sat}/p_r)/(p_a/p_r) \qquad \ldots (B.1)$$

where

p_a is the atmospheric pressure, in kilopascals;

p_r is the reference ambient atmospheric pressure from 4.2.

NOTE 11 By convention, relative humidity at temperatures less than 0 °C is evaluated with respect to saturation over a surface of liquid water, not ice.

B.2 Saturation vapour pressure

The saturation vapour pressure, p_{sat}, of aqueous vapour over a plane surface of liquid water is a function solely of the air temperature T. Tabulations of p_{sat} versus T, and the equations that generated the tables, are available in various reference handbooks.

For computations, however, it may be more convenient to utilize equations (B.2) and (B.3) which provide saturation vapour pressures that are a close approximation to those calculated by the World Meteorological Organization and tabulated in the International Meteorological Tables[2]:

$$p_{sat}/p_r = 10^C \qquad \ldots (B.2)$$

with exponent C given by

$$C = -6{,}834\,6(T_{01}/T)^{1{,}261} + 4{,}615\,1 \qquad \ldots (B.3)$$

where the temperature T is in kelvins and T_{01} is the triple-point isotherm temperature of 273,16 K (i.e. +0,01 °C).

To find h for given values of T, p_a and h_r, first find the value of the ratio p_{sat}/p_r by use of equations (B.2) and (B.3) for the air temperature. Then, find h by use of equation (B.1) for the relative humidity and air pressure with p_r = 101,325 kPa.

B.3 Dewpoint temperature

The dewpoint temperature, T_D, of a sample of moist air, at a temperature T, pressure p_a and molar concentration h, is the equilibrium temperature to which the sample must be cooled to be saturated over a surface of liquid water at the same given pressure.

To calculate the molar concentration of water vapour, given a measurement of dewpoint for some air temperature, first determine the saturation vapour pressure ratio p_{sat}/p_r at the dewpoint temperature T_D by the use of equations (B.2) and (B.3) with T_D for temperature T. Then determine the molar concentration by use of equation (B.1) for the given ratio p_a/p_r with relative humidity h_r equal to 100 %.

NOTE 12 Measurements of dewpoints at low air temperatures may, in fact, yield frostpoints, corresponding to saturation over a surface of ice instead of supercooled water. Due account for the conventional definition of relative humidity should be considered when frostpoints are measured. Equations (B.2) and (B.3) apply only for saturation vapour pressures over liquid water, not ice or frost.

Annex C
(informative)

Effect of inhomogeneous, real atmospheres

In the main text of this part of ISO 9613, the atmosphere through which a sound propagates has been assumed to be uniform along the sound propagation path; that is, the pressure, temperature and molar concentration of water vapour could each be specified by single fixed numbers. The effects of variation in the meteorological variables during propagation through an inhomogeneous real atmosphere are considered here.

C.1 Variation with altitude

The vertical profile of mean annual molar concentration of water vapour h_m (as a percentage) in table C.1 was constructed from the best available data[3] to be consistent with the vertical profiles of mean annual temperature T_m (in kelvins) and pressure p_m (in kilopascals) at mid-latitudes near 45° north from the ISO Standard Atmosphere (see ISO 2533). The following equations were used to fit these profiles over two ranges of geopotential altitude H (in kilometres) from 0 to 11 km (the troposphere), and from 11 km to 20 km (the stratosphere).

a) For sea-level to 11 km:

$$T_m = T_{ms} - 6{,}5\,H \qquad \text{. . . (C.1)}$$

$$p_m = p_{ms}\,(T_m/T_{ms})^{5{,}255\,88} \qquad \text{. . . (C.2)}$$

$$h_m = A_0 \times 10^{G_1} \qquad \text{. . . (C.3)}$$

where

$$G_1 = A_1H + A_2H^2 + A_3H^3 + A_4H^4 + A_5H^5 + A_6H^6$$

b) For 11 km to 20 km:

$$T_m = 216{,}65 \qquad \text{. . . (C.4)}$$

$$p_m = 22{,}632 \times \exp[-0{,}157\,688\,(H-11)] \qquad \text{. . . (C.5)}$$

$$h_m = A_7 \times 10^{G_2} \qquad \text{. . . (C.6)}$$

where

$$G_2 = A_8H + A_9H^2 + A_{10}H^3 + A_{11}H^4$$

and T_{ms} and p_{ms} are the mean annual temperature (288,15 K) and pressure (101,325 kPa) at sea level.

The constants are:

$A_0 = 1{,}002\,71$; $A_1 = -0{,}122\,23$; $A_2 = 0{,}045\,46$;
$A_3 = -0{,}031\,545$; $A_4 = 0{,}007\,647\,2$;
$A_5 = -0{,}000\,799\,06$; $A_6 = 0{,}000\,029\,429$;
$A_7 = 1{,}839\,5 \times 10^{-20}$; $A_8 = 5{,}448\,94$; $A_9 = -0{,}606\,83$;
$A_{10} = 0{,}028\,364\,3$; $A_{11} = -0{,}000\,474\,746$

The pure-tone attenuation coefficients for atmospheric absorption shown in table C.1 were calculated for these atmospheric parameters using equations (3) to (5) with exact midband frequencies calculated from equation (6). Note the large variation in the mean annual attenuation with altitude for all frequencies.

C.2 Local variation

C.2.1 The local variations in atmospheric pressure, temperature and humidity from the mean values shown in table C.1 are complex. The effects of these variations under meteorological conditions on atmospheric absorption may be summarized as follows.

C.2.2 For a given height above sea level, variations in atmospheric pressure are rarely greater than ± 5 % of the pressures in table C.1. A variation of ± 5 % in atmospheric pressure will cause less than a variation of ± 5 % in the attenuation coefficient. Therefore, for practical purposes, deviations from the mean profile of atmospheric pressure in table C.1 may usually be ignored.

C.2.3 For a fixed altitude, there are large variations with time and place in air temperature and molar concentration of water vapour. For example, the range of variation near the ground is comparable to that shown in table C.1 for the mean variation with altitude. As a result, for calculations of attenuation by atmospheric absorption, there is no substitute for local information concerning temperature and molar concentration for the time and place for which the calculation is made.

Usually, however, meteorological information is limited to time averages measured at (or forecast for) one place near the surface of the ground, often for a height above local ground level of approximately 10 m. The time-averaged data leave the user with the problem of judging how representative they may be for conditions along a sound propagation path close to the earth at a particular time.

Table C.1 — Dependence of temperature, pressure, molar concentration of water vapour and pure-tone atmospheric-attenuation coefficient, at mid-latitudes, on geopotential altitude above mean sea level

Geopotential altitude	Temperature	Pressure	Molar concentration	Attenuation coefficient α_m dB/km							
				Preferred frequency, Hz							
H, km	T_m, K	p_m, kPa	h_m, %	63	125	250	500	1 000	2 000	4 000	8 000
0	288,15	101,325	1,002 71	0,12	0,43	1,18	2,30	4,06	9,53	30,48	109,03
0,5	284,90	95,461	0,887 02	0,13	0,44	1,10	2,02	3,81	10,04	34,01	121,27
1	281,65	89,875	0,793 85	0,14	0,43	1,00	1,79	3,70	10,76	37,76	132,05
2	275,15	79,495	0,609 35	0,15	0,40	0,79	1,53	4,02	13,61	48,49	151,09
3	268,65	70,109	0,435 13	0,15	0,34	0,66	1,65	5,41	19,26	61,61	143,83
4	262,15	61,640	0,302 50	0,14	0,29	0,70	2,27	8,03	25,81	60,50	99,20
5	255,65	54,020	0,211 67	0,12	0,30	0,96	3,38	10,87	25,46	40,67	58,97
6	249,15	47,181	0,144 86	0,14	0,43	1,48	4,68	10,62	16,26	21,95	37,47
7	242,65	41,061	0,088 43	0,22	0,74	2,14	4,16	5,66	7,17	11,55	28,53
8	236,15	35,600	0,043 22	0,43	0,90	1,26	1,48	1,82	3,05	7,89	27,19
9	229,65	30,742	0,016 46	0,26	0,30	0,33	0,42	0,77	2,16	7,69	29,72
10	223,15	26,436	0,005 95	0,10	0,11	0,13	0,24	0,64	2,23	8,57	33,82
11	216,65	22,632	0,003 80	0,06	0,07	0,10	0,21	0,67	2,51	9,81	38,87
12	216,65	19,330	0,002 74	0,05	0,06	0,09	0,23	0,77	2,91	11,46	45,49
13	216,65	16,510	0,002 01	0,04	0,05	0,09	0,25	0,88	3,39	13,40	53,24
14	216,65	14,102	0,001 60	0,03	0,05	0,09	0,28	1,02	3,96	15,68	62,32
15	216,65	12,045	0,001 44	0,03	0,04	0,10	0,32	1,18	4,63	18,34	72,95
16	216,65	10,287	0,001 47	0,03	0,04	0,11	0,36	1,37	5,41	21,47	85,41
17	216,65	8,787	0,001 68	0,03	0,04	0,12	0,42	1,60	6,33	25,13	99,99
18	216,65	7,505	0,002 07	0,02	0,05	0,13	0,48	1,87	7,40	29,42	117,06
19	216,65	6,410	0,002 57	0,02	0,05	0,15	0,56	2,19	8,66	34,44	137,05
20	216,65	5,475	0,002 93	0,02	0,05	0,17	0,65	2,56	10,14	40,31	160,45

NOTES

1 Attenuation coefficients were calculated for air temperatures, atmospheric pressures, and molar concentrations determined from equations (C.1) to (C.6).

2 The values of α_m were calculated for the exact one-third-octave midband frequencies corresponding to the eight preferred frequencies from 63 Hz to 8 0000 Hz. Subscript m denotes mean annual conditions.

C.2.4 When meteorological information is limited to surface data, two facts should be recognized:

a) the atmospheric variable that dominates the behaviour of atmospheric absorption according to equations (3) to (5) is the molar concentration of water vapour; and

b) the molar concentration of water vapour tends to be constant throughout the boundary layer closest to the earth during normal daytime hours because of the mixing of the atmosphere which occurs as a result of the action of winds.

If the propagation path is well within the mixed layer, the attenuation due to atmospheric absorption may be calculated to an accuracy suitable for many applications by use of meteorological measurements near the ground, under the assumption that the molar concentration is constant up to the height of the top of the mixed layer. The thickness of the mixed layer may vary from approximately 10 m at night to approximately 1 km on a sunny afternoon in summer. When this thickness is in doubt, radiosonde observations or expert knowledge should be consulted.

C.3 Applications to stratified atmospheres

C.3.1 Pure tones

C.3.1.1 The mean attenuation coefficients given in table C.1 show that the variation with altitude can become much too large for the atmosphere to be assumed homogeneous when calculating absorption losses for vertical or slant-range propagation over long distances, also bearing in mind the limitations given in 8.2.2. To avoid the introduction of large errors, the atmosphere should be modelled by a stack of horizontal layers. The calculation of absorption losses then proceeds as follows.

C.3.1.2 Values of temperature T, atmospheric pressure p and molar concentration h are defined at selected points along a propagation path through the stratified atmosphere. These values are obtained from measurements or prediction models such as that used for table C.1. The attenuation coefficient for a frequency f is then computed at the selected points by use of equations (3) to (5). A sufficient number of points should be chosen to allow continuous variation of the attenuation coefficient along the path to be approximated over a set of n finite pathlength segments, each much longer than the wavelength of sound, and such that the attenuation coefficient is sensibly constant over each segment.

C.3.1.3 The total pure-tone absorption loss $\delta L_t(f)$ over the entire path is then obtained by the following summation over the n segments:

$$\delta L_t(f) = \sum_{i=1}^{n} [\alpha_i(f)] [\delta s_i] \qquad \ldots (C.7)$$

where $\alpha_i(f)$ is the average attenuation coefficient for atmospheric absorption at a frequency f at the midpoint of the i^{th} path segment of length δs_i.

C.3.2 Wideband sound analysed by fractional-octave-band filters

C.3.2.1 The attenuation of a wideband sound propagating through an inhomogeneous atmosphere may be calculated by the methods identified in 8.1 for wideband sounds, when augmented by the procedures given in C.3.1.

C.3.2.2 If the pure-tone method of 8.2 is used, then the procedures in C.3.1 follow naturally. The frequency f in C.3.1.2 becomes the midband frequency f_m from equation (6) for the desired band, and $\delta L_t(f_m)$ in equation (C.7) gives the total atmospheric-absorption attenuation of the band sound pressure level over the propagation path from source to receiver (or from a receiver location back to the source).

C.3.2.3 If the spectrum-integration method described in annex D is chosen, then the calculation becomes more formidable. The procedures of C.3.1 are followed for selected frequencies within each frequency band in order to obtain $\delta L_t(f)$ via equation (C.7) as a discrete function of frequency. This set of pure-tone attenuation coefficients must then be substituted into equation (D.1) and numerically integrated over frequency, as described in annex D, to obtain δL_B, the attenuation in band sound pressure level over the path from source to receiver (or receiver to source).

However, for Case 2 described in D.3, where the band sound pressure levels at the receiver are known, the sound-propagation pathlengths over which the pure-tone attenuation coefficients need to be developed as a function of frequency will commonly be sufficiently long for this method to fail because of the large errors introduced, as described in 8.1.2, by the inadequate attenuation of practical bandpass filters at frequencies outside the passband of the filter.

Annex D
(informative)

General spectrum-integration method for calculating the attenuation of wideband sounds analysed by fractional-octave-band filters

D.1 Introduction

D.1.1 This annex describes a general spectrum-integration method to calculate the attenuation by atmospheric absorption applicable to fractional-octave-band sound pressure levels. The method may be applied to various practical situations without the limitations given in 8.2.2.

D.1.2 A user of the method should be aware of practical limitations regarding such matters as the time required to carry out the computations and the fact that some sound pressure levels that might be calculated (or which should have been measured) may, in fact, not be measurable with commercially available instruments because of limitations imposed by the ambient acoustical background noise, the electrical noise floor of the instruments, or the inherent errors introduced by the use of practical bandpass filters (see 8.1.2). On the other hand, the method described in this annex, while more complicated than the approximate pure-tone method described in 8.2, can yield more accurate estimates for frequency-band sound pressure levels than the pure-tone method.

D.1.3 The general features of the calculation method are described for three cases. For Case 1, band sound pressure levels are known at the location of a sound source and band sound pressure levels are to be determined at the location of a distant receiver. For Case 2, band sound pressure levels are known at a receiver and corresponding band sound pressure levels are to be determined at the source of sound. For Case 3, band sound pressure levels are known at a receiver for one set of meteorological conditions along the sound propagation path, and the band sound pressure levels are to be determined that would have been measured at the same location but under different meteorological conditions. For all cases, the calculation method described in this annex is limited to attenuation by atmospheric-absorption processes. Attenuation by other mechanisms is neglected.

D.1.4 The analytical procedures described in this annex assume that the bandpass filters were designed according to the base 10 system for midband and bandedge frequencies, see equation equation (6). If the base 2 system was used, the applicable equations should be appropriately modified.

D.2 Case 1: Band sound pressure levels known at the source

D.2.1 The fractional-octave-band sound pressure level $L_{BR}(f_m)$ (in decibels, with respect to p_0^2 where p_0 is the reference sound pressure of 20 µPa), at receiver location R and after attenuation from atmospheric absorption over the path from the source to the receiver, may be calculated from

$$L_{BR}(f_m) = 10 \lg \left(\left\{ \int_{f_L}^{f_U} 10^{0,1[L_s(f) - \delta L_t(f) - \Delta A(f)]} \mathrm{d}f \right\} / f_0 \right) \text{ dB} \quad \ldots (D.1)$$

where

$L_S(f)$ is the pressure spectrum level (in decibels, with respect to p_0^2/f_0 where f_0 is the reference bandwidth of 1 Hz) of the sound at the source;

$\delta L_t(f)$ is the pure-tone attenuation, in decibels, from atmospheric absorption as calculated by use of equation (C.7) over the total length of the path from the source to the receiver;

f_L and f_U are the effective lower and upper frequency limits in hertz; and

$\Delta A(f)$ is the relative-attenuation, in decibels, of the filter employed for analysis of both source and receiver signals.

NOTE 13 Frequencies f, f_L and f_U may be normalized by the exact midband frequency f_m for convenience in carrying out the integration over the entire frequency range of interest for each filter band. Exact midband frequencies are calculated using equation (6).

D.2.2 If analytical functions are available for the pressure spectrum level, pure-tone attenuation and filter relative-attenuation response as continuous functions of frequency, equation (D.1) can, in principle, be evaluated in closed form. In practice, the integral is usually evaluated numerically by a summation over a range of frequency with the three elements of the integrand specified at discrete frequencies.

D.2.3 The pressure spectrum level at the source, $L_S(f)$, is usually determined from frequency-band sound pressure levels $L_{BS}(f_m)$ measured or predicted for the effective location of the sound source under specified operating conditions. For the purposes of this part of ISO 9613, the pressure spectrum level of the sound at the source $L_S(f_m)$, in decibels, may be estimated at the midband frequency of each filter band by subtracting a correction for the bandwidth of the corresponding ideal bandpass filter. Thus

$$L_S(f_m) = L_{BS}(f_m) - 10 \lg(BW_i/f_0) \text{ dB} \qquad \ldots (D.2)$$

where the bandwidth BW_i, in hertz, of the corresponding ideal filter is given by

$$BW_i = f_2 - f_1 = f_m(10^{3b/20} - 10^{-3b/20}) \qquad \ldots (D.3)$$

where

f_2 and f_1 are the upper and lower bandedge frequencies;

b is the bandwidth designator as described in note 5 in 6.4.

D.2.4 The procedure indicated by equation (D.2) is applicable only for a sound spectrum that is continuous and wideband without discrete-frequency components. If the spectrum contains both wideband and discrete-frequency components, the procedures described in 8.4 should first be employed to determine estimates for the separate components of the composite spectrum. For the discrete-frequency components, follow the procedure of clause 6 to determine attenuation. In this case, the ideal-filter bandwidth correction should not be subtracted from the indicated band sound pressure level.

D.2.5 For the wideband component of the spectrum, the pressure spectrum level at any frequency between successive midband frequencies may be determined by linear interpolation to yield estimated values for $L_S(f)$ at each desired frequency. Because of the need to cover frequencies in the lower transition bands of the relative-attenuation response for the filters used to establish the initial low-frequency band sound pressure levels of the sound at the source, as well as to cover frequencies in the upper transition bands of the relative-attenuation response for the filters used to establish the last high-frequency band sound pressure levels, a special protocol may be needed to estimate pressure spectrum levels at frequencies below or above the lower and upper bandedge frequencies of the lowest and highest frequency bands, respectively.

NOTE 14 For most sound sources of practical interest, omission of the initial one or two low-frequency band sound pressure levels and the final high-frequency band sound pressure level from the set of band sound pressure levels calculated for the receiver location will not significantly affect the accuracy of a calculation of frequency-weighted sound pressure level at the receiver.

D.2.6 If the meteorological conditions are uniform over the sound propagation path from the source to the receiver, the pure-tone attenuation $\delta L_t(f)$ may be readily calculated at any frequency by application of the procedure indicated by equations (2) to (5). If the meteorological conditions over the sound-propagation path are not uniform, the atmosphere should be modelled as a series of horizontal layers with average conditions specified over the thickness of each layer. The procedures given in C.3.1 should then be followed to determine the pure-tone atmospheric-absorption attenuation over the path for each frequency required to carry out the integration of equation equation (D.1) for each filter band and for each discrete-frequency component that may be present.

D.2.7 The relative-attenuation response characteristics $\Delta A(f)$ in equation (D.1) for the filters used to establish the band sound pressure levels at the source should be the same as those for the filters at the receiver. The relative-attenuation response (i.e. filter attenuation minus the reference attenuation specified by the manufacturer) is preferably determined experimentally for each filter band or supplied by the manufacturer. Alternatively, analytical representations of the relative-attenuation response of a selected filter design may be utilized for evaluation of equation (D.1). The filter manufacturer should be consulted for advice on analytical representations for the relative-attenuation responses of the filters in a spectrum analyser.

D.2.8 The remaining items that need to be specified in order to evaluate the integral in equation (D.1) are the frequency limits and the size of the steps in a numerical integration between the lower and upper limits.

D.2.9 The relative-attenuation response of many practical filters is not symmetrical and is not the same for each filter band in a set of fractional-octave-band filters; the rate of change of attenuation with increasing frequency is often more rapid in the upper transition band (i.e. from the passband toward the high-attenuation region of the upper stopband) than it is in the lower transition band. In addition, at low-to-mid frequencies in the audio-frequency range, the slope of the pressure spectrum level of many wideband sound sources often is either slightly positive with increasing frequency or is nearly independent of frequency. At high frequencies (e.g. above approximately 1 kHz), the slope of the wideband pressure spectrum level is often negative. For those reasons, for general applications it is recommended that the frequency limits in equation (D.1) be set to

$$f_L = (1/5) f_1 \text{ and } f_U = 2f_2 \qquad \ldots (D.4)$$

For any fractional-octave-band filter, the reference bandedge frequencies are calculated, for a base 10 design, from

$$f_1 = (10^{-3b/20}) f_m \quad \text{and} \quad f_2 = (10^{3b/20}) f_m \qquad \text{. . . (D.5)}$$

Specific situations may require that the limits of integration be set to encompass a wider range of frequencies than from one-fifth of f_1 to twice f_2; in other cases, a narrower range may suffice.

D.2.10 The size of the frequency steps should be chosen with care (1/72 of an octave for one-third-octave-band filters). In the passband between f_1 and f_2 where the relative-attenuation response of a bandpass filter is approximately constant, the interval between successive frequencies may be increased to approximately 1/24 of an octave for one-third-octave-band filters.

D.3 Case 2: Band sound pressure levels known at a receiver location

D.3.1 For Case 2, the fractional-octave-band sound pressure level $L_{BS}(f_m)$, in decibels, at source location S and considering only attenuation from atmospheric absorption over the path from the receiver to the source, may be calculated from a modified version of equation (D.1) using

$$L_{BS}(f_m) = 10 \lg \left(\left\{ \int_{f_L}^{f_U} 10^{0,1[L_R(f) + \delta L_t(f) - \Delta A(f)]} df \right\} / f_0 \right) \text{ dB} \qquad \text{. . . (D.6)}$$

where the sign of $\delta L_t(f)$ is positive instead of negative as in equation (D.1) to indicate an increase in the sound pressure level in going from the receiver back to the source.

D.3.2 The pressure spectrum levels at the receiver should be determined with special care since measured band sound pressure levels will include, by necessity, any errors introduced by the filters used for the analysis (see 8.1.2).

D.3.3 An approximate method of determining the pressure spectrum level of the sound at the receiver is to subtract the ideal-filter bandwidth correction, as given in equation (D.2) for the band sound pressure levels at the source, from the band sound pressure levels at the receiver. However, because the slope of the pressure spectrum level often changes much more rapidly with frequency at a receiver location than at a source location (especially at frequencies greater than 1 kHz), very careful consideration should be given to the procedure selected to interpolate values for pressure spectrum level at frequencies between the midband frequencies. Linear interpolation of the pressure spectrum levels between midband frequencies may not be suitable for midband frequencies greater than approximately 2 kHz. Pressure spectrum levels should not be extrapolated to frequencies greater than the upper bandedge frequency of the highest midband frequency of the measured band sound pressure levels at the receiver, nor lower than lower bandedge frequency of the lowest frequency band.

D.3.4 If the band sound pressure levels at the receiver represent data measured over a long sound-propagation distance or under highly absorptive conditions, it has often been observed that the indicated band sound pressure levels in the high-frequency bands are contaminated by contributions from the electrical noise floor of the instruments. In this case, the band sound pressure levels of the actual signal from the source were not measured and the contaminated band sound pressure levels should be removed from the analysis to avoid calculation of spurious band sound pressure levels at the source. Alternatively, an appropriate extrapolation procedure may be utilized to provide estimates for band sound pressure levels that are missing because of contamination.

D.3.5 After an appropriate estimate has been determined for the pressure spectrum level of the sound at the receiver and for the pure-tone atmospheric-absorption attenuation along the path, the calculations for equation (D.6) proceed as described for Case 1 with band sound pressure levels known at a source. However, a calculation of a band sound pressure level should not be attempted when the absolute magnitude of the negative slope of the estimated pressure spectrum level across the frequency range of integration for the lower transition band of a filter (usually a high-frequency band) exceeds the corresponding absolute magnitude of the positive slope of the relative-attenuation characteristic of the filter in the lower transition band.

D.4 Case 3: Adjusting measured sound pressure levels at a receiver location for differences in attenuation by atmospheric absorption resulting from different meteorological conditions along a sound-propagation path

D.4.1 The following expression may be applied to adjust fractional-octave-band sound pressure levels $L_{BR1}(f_m)$, measured at a receiver under meteorological conditions 1 (e.g. test-day conditions), to band sound pressure levels $L_{BR2}(f_m)$, in decibels, that would have been measured under meteorological conditions 2 (e.g. reference meteorological conditions):

$$L_{BR2}(f_m) = 10 \lg\left(\left\{\int_{f_L}^{f_U} 10^{0,1[L_{R1}(f) + \delta L_{t1}(f) - \delta L_{t2}(f) - \Delta A(f)]} \mathrm{d}f\right\} / f_0\right) \text{ dB} \quad \ldots \text{(D.7)}$$

where

$L_{R1}(f)$ and $\delta L_{t1}(f)$ are, respectively, the pressure spectrum level of the sound at the receiver and the pure-tone atmospheric-absorption attenuation under meteorological conditions 1;

$\delta L_{t2}(f)$ is the pure-tone atmospheric-absorption attenuation under meteorological conditions 2.

D.4.2 The procedure for evaluating the integral in equation (D.7) proceeds as described for evaluation of the corresponding expressions for Cases 1 and 2, once the input quantities are specified. Special care should be given to remarks given in D.3.4 and D.3.5.

Annex E
(informative)

Example of calculation of attenuation for A-weighted sound pressure levels

E.1 To clarify the calculation procedure described in 8.3, consider the problem of determining an estimate for the equivalent-continuous A-weighted sound pressure level at a distance of 500 m from a location near a highway with high-speed truck and automobile traffic. Source noise levels are provided as long-time-average octave-band sound pressure levels at a distance of 15 m. The air temperature is 15 °C, the relative humidity is 50 %, and the air pressure is 1 standard atmosphere.

E.2 The equivalent-continuous-octave-band sound pressure levels, $L_{p,500}$ at 500 m, are estimated from the equivalent-continuous octave-band sound pressure levels $L_{p,15}$ at 15 m according to

$$L_{p,500} = L_{p,15} - \alpha_t s - \Delta \qquad \text{... (E.1)}$$

where

α_t is the attenuation coefficient for atmospheric absorption at the exact midband frequency;

s is the length of the sound propagation path;

Δ is attenuation by mechanisms other than atmospheric absorption.

E.3 Assume the attenuation by other mechanisms (divergence, ground effect, etc.) to be 30,5 dB, independent of frequency. Attenuation coefficients could be calculated by use of equations (3) to (6), but may be read from table 1 for the given temperature, relative humidity and air pressure. The sound propagation path length, in kilometres, is found from

$$s = (500 - 15)/1\,000 = 0{,}485 \text{ km} \qquad \text{... (E.2)}$$

E.4 Steps in the calculation proceed as illustrated in table E.1.

E.5 Ten times the common logarithm of the sum of the time-mean-square, A-weighted, octave-band sound pressures from the last column of table E.1 yields an estimate of 51,8 dB for the equivalent-continuous A-weighted sound pressure level at a distance of 500 m. The 4-kHz and 8-kHz octave-band sound pressure levels at a distance of 500 m are omitted from the above sample calculation because the criterion of 8.2.2 is not satisfied for the distance and frequency. However, the sound pressure levels that would be calculated for the 4-kHz and 8-kHz bands would clearly be quite low and would make a negligible contribution to the equivalent-continuous A-weighted sound pressure level.

Table E.1 — Calculation of attenuation

f Hz	$L_{p,15}$ dB	Δ dB	α_t dB/km	$\alpha_t s$ dB	$L_{p,500}$ dB	A weightings dB	$L_{pA,500}$ dB
31,5	75	30,5	≈0	≈0	44,5	−39,4	5,1
63	80	30,5	≈0,1	≈0	49,5	−26,2	23,3
125	83	30,5	≈0,5	0,2	52,3	−16,1	36,2
250	84	30,5	≈1,3	0,6	52,9	−8,6	44,3
500	83	30,5	≈2,2	1,1	51,4	−3,2	48,2
1 000	79	30,5	≈4,2	2,0	46,5	0	46,5
2 000	74	30,5	10,1	4,9	38,6	+1,2	39,8
4 000	70	30,5	36,2	17,6	—	+1,0	—
8 000	62	30,5	129,0	62,6	—	−1,1	—

NOTE — The attenuation coefficients are given as approximate values, and the standard A-frequency weightings are from IEC 651.

Annex F
(informative)

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