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Sub-unità: HC.torino_3.corrado
Autori: A. Astolfi, V. Corrado, C. Divizia
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Measuring procedures for the environmental parameters: Acoustic comfort

Abstract

Measuring procedures for selected environmental parameters related to acoustic comfort are shown here.
All protocols are based on current international and national standards, proposed standards and literature.

Table 1. Environmental parameters for which measuring procedures are provided here for different purposes.

	Listening	Intelligibility	HVAC system noise	Environmental noise
Sound pressure level (in octave bands)	√	√		√
Equivalent continuous sound pressure level (in octave bands)		√	√	√
Equivalent continuous A-weighted sound pressure level		√	√	√
Modulation Transfer Function (for each octave band and modulation frequency) *		√		

* not complete

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Parameter	Sound pressure level (in octave bands)	
Symbol	$L_{p,f}$	
Unit	[dB]	
Definition	For each octave band f, it is given by the formula: $$L_{p,f} = 10\log\left(\frac{p_f}{p_0}\right)^2 \ [dB]$$ where: p_0 is the reference sound pressure (20 μPa); p_f is the root mean square sound pressure of the sound signal in the octave band f [Pa]	ISO 1996-1:1992
Applies to	• Listening Reverberation time; • Intelligibility Reverberation time (applicability of various indices, and calculation of STI); • Environmental noise Reverberation time (assessment of the amount of room absorption)	
Equipment	Omni-directional microphones shall be used; the measurement equipment shall meet the requirements of a type 1 sound level meter according to IEC 60651:1979. The octave filters shall conform to EN 61260:1995. The microphone should be as small as possible, and preferably have a maximum diameter of 13 mm.	ISO 3382:1997 IEC 60651:1979 IEC 61260:1995

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Measurement	• *Sound source* Sound source shall be as close to omni-directional as possible. It should produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range without contamination by background noise. For the measurement of the reverberation time two methods are available: - the *interrupted noise method* – a loudspeaker source shall be used and a signal fed into the loudspeaker shall be derived from broadband random or pseudo-random electrical noise; - the *integrated impulse method* - an impulse source shall be used such as a pistol shot or any other source that is not reverberant itself. Special sound signals may be used which yield the impulse response only after special processing of the recorded microphone signal. Generate for each band the decay curve by a backward integration of the squared impulse response. The bandwidth of the signal shall be greater than one octave and the spectrum shall be flat within the actual band to be measured; alternatively the broadband noise spectrum may be shaped to provide an approximately pink spectrum of steady-state reverberant sound from 125 Hz to 4 kHz with the reverberation time being measured simultaneously in different octave bands. • *Conditions* Measurement shall be made with the room in any or all states of occupancy: - occupied state: when 80% to 100% of the seats are occupied; - unoccupied state: room prepared for use, but without persons present; - studio state: room occupied by the talkers only, without audience (at rehearsals). • *Position* *Microphone positions*: at least 2 m apart, at least 1 m from reflecting surfaces and not too close to any source position; the minimum distance from a source position can be calculated by the equation: $$d_{min} = 2\sqrt{\frac{V}{cT}}\ [m];$$ where: V is the volume [m^3]; c is the speed of sound [m/s]; T is an estimate of the expected reverberation time [s]. *For listening:* a distribution of microphone positions at audience seats locations should be chosen which anticipates the major influences likely to cause differences in reverberation time throughout the room.	ISO 3382:1997

	For intelligibility and environmental noise: three or four microphone positions in areas where people normally are present or in centre of seating areas are required. With the interrupted noise method, a minimum of three measurements shall be made for each position and the results averaged (find the individual reverberation times for all the decay curves and take the mean value). *Source position:* *For listening*: number and location of source positions should be chosen so as to include all areas likely to be occupied by the talkers; a minimum of two source positions shall be used. *For intelligibility and environmental noise*: two source positions which are representative of those where noise sources are located or of those used by the talkers. The results measured for the range of source and microphone positions can be combined either for separate identified areas or for the room as a whole to give spatial average values. The spatial average is given by taking the mean of the individual reverberation times for all the relevant source and microphone positions. • *Level* *Microphone:* listeners' ears level (1.2 m) • *Period/ Rate* With the interrupted noise method, the duration of excitation of the room needs to be sufficient to have achieved a steady-state before being allowed to decay.	

Parameter	Equivalent continuous sound pressure level (in octave bands)	
Symbol	$L_{p,eq,T,f}$	
Unit	[dB]	
Definition	For each octave band f, the equivalent continuous sound pressure level is the value of the sound pressure level of a continuous, steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula: $$L_{p,eq,T,f} = 10\log\left[\frac{1}{T}\int_{t_1}^{t_2}\frac{p_f^2(t)}{p_0^2}dt\right] [dB]$$ where: $L_{p,eq,T,f}$ is the equivalent continuous sound pressure level, for each octave band f, determined over a time interval T starting at t_1 and ending at t_2 [dB]; p_0 is the reference sound pressure (20 µPa); $p_f(t)$ is the instantaneous sound pressure of the sound signal in the octave band f [Pa]	ISO 1996-1:1992
Applies to	• Intelligibility SIL in free field up to 8 m in rooms with $T_{60,500Hz} < 2$ s (procedure 1); SII in free fields or in rooms with minimal reverberation (procedure 1); SII in reverberating fields (procedure 2); STI in rooms with statistical acoustics conditions (procedure 1); • Environmental noise NCB (procedure 1) • HVAC system noise RC (procedure 3);	
Equipment	Compliant with IEC 60651, IEC 61260 and IEC 60804 standards	ISO 9921-1:1996 IEC 60651:1979 IEC 61260:1998 IEC 60804:1985
Measurement	Depending on environmental conditions, the measurement procedures of $L_{p,eq,T,f}$ can be classified as: • Environmental noise and HVAC system noise (procedures 1 and 3); • Steady-state source noise and talkers (procedure 2)	

Measurement **(procedure 1)**	• *Conditions* The measurement must be done in occupied spaces, while normal activities are in progress and the HVAC systems are in operation. The noise must have a continuous frequency spectrum and contain no pure-tone components, and must be non intermittent. • *Position* *Microphone position:* *For intelligibility (SIL, SII, STI):* position(s) normally occupied by the listener concerned, the person being absent. *For environmental noise (NCB):* at locations between the interested parties, while they're not talking. • *Level* *Microphone*: Listeners' ears level. • *Period/ Rate* During noise situations which are typical for the communication period.	ISO 9921-1:1996 ANSI S3.5:1997 (Beranek, 1989) (Houtgast et al., 1980)

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Measurement (procedure 2)

ANSI S3.5:1997

- *Sound source*

Provide a test signal selected from one of the following choices:

- a random noise shaped in such a way that in a free field at a distance of 1 m, in each frequency band, its spectrum level equals the standard speech spectrum level for the desired vocal effort (see table 1);

Table 1. Frequencies and standard speech spectra.

Frequency band: Nominal midband freq [Hz]	Standard speech spectrum level for stated vocal effort [dB]: Normal	Raised	Loud	Shout
250	34.75	38.98	41.55	42.50
500	34.27	40.15	44.85	49.24
1000	25.01	33.86	42.16	51.31
2000	17.32	25.32	34.39	44.32
4000	9.33	16.78	25.41	34.41
8000	1.13	5.07	11.39	20.72

- an approximate speech spectrum whose relative form does not depend on the vocal effort; for normal vocal effort, this speech spectrum level is equal to the standard speech spectrum level for normal vocal effort; for raised, loud and shouted vocal efforts this spectrum should be increased in steps of 7.8 dB per step of vocal effort;

- a sound pressure spectrum level of 35 dB from 100 to 500 Hz, decreasing at frequencies greater than 500 Hz at the rate of 9 dB per octave; for raised, loud, and shouting vocal efforts the normal voice spectrum levels are increased by 7.8 dB for each incremental step of vocal effort.

On the reference axes, at 0°C azimuth and 0° elevation, the sound source should have a directivity index of 1 to 3 dB for frequencies lower than or equal to 1000 Hz, and 2 to 5 dB for frequencies higher than 1000 Hz. The sound source should be mounted in an enclosure with dimensions of the same order as the human head.

- *Position*

Microphone positions: centre of the listener's head, the listener being absent;

Source position: position of the talker

- *Level*

Microphone: Listeners' ears level

- *Period/ Rate*

Measurement shall be made in presence of the speech signal during noise situations which are typical for the communication period.

Measurement **(procedure 3)**	• *Conditions* The measurement must be done in unoccupied spaces, while HVAC systems are in operation. • *Position* *Microphone:* calculate the average value over several points in a defined area or specific points. • *Level* *Microphone:* Listeners' ears level • *Period/ Rate* During noise situations which are typical for the HVAC operating scheme.	(Blazier, 1981)

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Parameter	Equivalent continuous A-weighted sound pressure level	
Symbol	$L_{Aeq,T}$	
Unit	[dB(A)]	
Definition	Ten times the logarithm of the ratio of A-weighted squared sound pressure to the squared reference sound pressure of 20 μPa of a continuous, steady sound that, within a specified time interval T, has the same mean-square sound pressure as a sound under consideration whose level varies with time. It is the value of the A-weighted sound pressure level of a continuous, steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula: $$L_{Aeq,T} = 10\log\left[\frac{1}{T}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}dt\right][dB(A)]$$ where: $L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level, determined over a time interval T starting at t_1 and ending at t_2 [dB]; p_0 is the reference sound pressure (20 μPa); $p_A(t)$ is the instantaneous A-weighted sound pressure of the sound signal [Pa] The A-weighting is the frequency weighting of a spectrum determined by use of frequency weighting network "A"	ISO 1996-1:1982 IEC 60651:1979
Applies to	• Intelligibility SIL in free field up to 8 m in rooms with $T_{60,500Hz}$ < 2 s (procedure 1); • Environmental noise (procedure 2); • HVAC system noise (procedure 3)	
Equipment	Compliant with IEC 60651, IEC 60804, IEC 61260, IEC 61094-1, IEC 61094-2, IEC 61094-3, IEC 61094-4, IEC 60942 standards.	DPCM 16 Marzo 1998 IEC 60651:1979 IEC 61260:1998 IEC 60942:1997 IEC 61094-1:1992 IEC 61094-2:1992 IEC 61094-3:1995 IEC 61094-4:1995

Measurement **(procedure 1)**	• *Position* *Microphone positions*: talker's position. • *Level* *Microphone*: talker's head level. • *Period/ Rate* During noise situations which are typical for the communication period.	ISO 9921-1:1996
Measurement **(procedure 2)**	• *Conditions* Measurement must be done in the reference time T_R, both with open and closed windows, to find out the worst situation, and both with and without specific annoying noise sources. The reference time is the period of the day during which measurements are done. The day is divided into two reference times: daytime in which 6 AM $\leq T_R \leq$ 10 PM and night time in which 10 PM $\leq T_R \leq$ 6 AM. The measured value must be rounded within 0.5 dB. During daytime, in the case of particular noises lasting less than 1 hour the sound pressure level must be lowered by 3 dB, in the case of particular noises lasting less than 15 minutes, it must be lowered by 5 dB. • *Position* *Microphone position* *With open windows*: at 1m from an open window, and at least 1m apart from reflecting surfaces. *With closed windows*: where the maximum sound pressure level is supposed to be found, and at least 1m apart from reflecting surfaces. • *Level* *Microphone:* 1.5 m • *Period/ Rate* Continuous integration during the reference time TR, without considering the time intervals in which abnormal conditions occur.	DPCM 16 Marzo 1998

Measurement **(procedure 3)**	Measure the $L_{p,Aeq,T}$ both with and without the HVAC system noise. The HVAC system noise level can be determined by the following equations: $\text{if } L_a - L_r \geq 10 \text{ dB(A) then } L_i = L_a$ $\text{if } 6 < L_a - L_r < 10 \text{ dB(A) then } L_i = 10\log\left(10^{\frac{L_a}{10}} - 10^{\frac{L_r}{10}}\right)$ $\text{if } L_a - L_r \leq 6 \text{ dB(A) then } L_i = L_a - 1.6$ where: L_a is the sound pressure level with HVAC system noise [dB(A)]; L_r is the sound pressure level without HVAC system noise [dB(A)]; L_i is the HVAC system noise level [dB(A)]. The HVAC system noise level must be corrected in the case of unfurnished rooms by the following equation: $$L_{ic} = L_i - K_T$$ where: L_{ic} is the corrected HVAC system noise level [dB(A)]; K_T is the correction value obtained by the following equation: $$K_T = 10\log\frac{T_{1000}}{T_0}$$ where: T_{1000} is the reverberation time in the room at 1000 Hz [s]; T_0 is the reference reverberation time [s] obtained by the following equations: $\text{if } V \leq 100 \text{ m}^3 \text{ then } T_0 = 0.5 \text{ [s]};$ $\text{if } 100 < V < 2500 \text{ m}^3 \text{ then } T_0 = \sqrt{\frac{V}{400}} \text{ [s]};$ $\text{if } V \geq 2500 \text{ m}^3 \text{ then } T_0 = 2.5 \text{ [s]}$ where V is the room volume [m^3] • *Conditions* The noise without HVAC system must be the lowest possible. • *Position* *Microphone position:* As far as the measurement of the sound pressure level with HVAC system noise is concerned, follow the next indications: *Rooms less than 20 m^2*: centre of room, at a distance of 1 m from each wall and reflective surface.	UNI 8199:1998

	Other rooms: - if the occupants positions is known, a number of occupied positions at a distance of 1 m from each wall and reflective surface should be considered, to find out the position in which the sound pressure level is maximum; - if occupants' positions are unknown, in at least five heavenly distributed points in the occupied zone at a distance of 1 m from each wall and reflective surface; calculate the average of these sound pressure levels as follows: $L_{eq,T} = 10 \log\left(1/N \sum 10^{(L_a)j/10}\right)$ The sound pressure level without HVAC system noise must be measured in at least one position in which the sound pressure level with HVAC system noise has been measured. • *Level* *Microphone:* 1.2 to 1.5 m • *Period/ Rate* A sufficient period of time to achieve a significant evaluation of maximum noise situation.	
Validity conditions		
Comfort limits **(procedure 2)**	For measurements done with specific annoying noise source: Daytime with open windows: $L_{Aeq,T} \leq 50$ dB (A); Daytime with closed windows: $L_{Aeq,T} \leq 35$ dB (A); Night time with open windows: $L_{Aeq,T} \leq 40$ dB (A); Night time with closed windows: $L_{Aeq,T} \leq 25$ dB (A). If these conditions are not verified, differential limits apply.	DPCM 14 Novembre 1997

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Comfort limits (procedure 3)	The HVAC system noise level must be lower than or equal to the following reference levels.		UNI 8199:1998
	Space	$L_{Aeq,T,rif}$	
	Dwellings		
	Bedrooms	30	
	Living rooms	40	
	Hotels and motels		
	Bedrooms	30	
	Meeting rooms	35	
	Dining rooms	45	
	Service areas	40	
	Offices		
	Executive offices	35	
	Employees (single)	40	
	Employees	45	
	Public lobbies	45	
	Hospitals and clinics		
	Private rooms	30	
	Ward	40	
	Operating rooms	35	
	Corridors	40	
	Public areas	40	
	Service areas	40	
	Churches		
	Schools		
	Rooms	30	
	Gyms, Swimming pools	45	
	Libraries	35	
	Meeting rooms	30	
	Recording studios, concert halls	25	
	Cinemas	35	
	Restaurants, shops	45	

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Parameter	Modulation Transfer Function	
Symbol	$m_{F,f}$	
Unit	[-]	
Definition	For each octave band f, the $m_{F,f}$ is the reduction factor of the modulation index as the function of modulation frequency F, i.e. the ratio of the modulation index at the talker's position to the modulation index at the listener's position.	IEC 60268-16:1998
Applies to	• Intelligibility SII in reverberating field (procedure 1) STI (procedure 2)	
Equipment		

Measurement

(procedure 1)

ANSI S3.5:1997

- *Sound Source*

Provide a test signal selected from one of the following choices:

- a random noise shaped in such a way that in a free field at a distance of 1 m, in each frequency band, its spectrum level equals the standard speech spectrum level for the desired vocal effort (see table 1);

Table 1. Frequencies and standard speech spectra.

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- a sound pressure spectrum level of 35 dB from 100 to 500 Hz, decreasing at frequencies greater than 500 Hz at the rate of 9 dB per octave. For raised, loud, and shouting vocal efforts the normal voice spectrum levels are increased by 7.8 dB for each incremental step of vocal effort.

On the reference axis, at 0° azimuth and 0° elevation, the sound source should have a directivity index of 1 to 3 dB for $f \leq 1000$ Hz and 2 to 5 for $f > 1000$ Hz; the sound source should be mounted in an enclosure with dimensions of the same order as the human head; the frequency response across the relevant bands should be uniform within ± 2 dB.

The test signal shall be sinusoidally modulated in intensity using a modulation index of one, at each of the following nine modulation frequencies (one at a time): 0.5 Hz, 1.0 Hz, 1.5 Hz, 2.0 Hz, 3.0 Hz, 4.0 Hz, 6.0 Hz, 8.0 Hz, 16.0 Hz.

For each modulation frequency F, analyse a measure of the square of the received signal in each frequency band f and determine the modulation index of this wave form. This index represents the value of the $M_{F,f}$ for the modulation frequency F and the octave band f.

	• *Position* *Microphone*: centre of the listener's head, the listener being absent; *Sound source*: position of the talker • *Level* listener's ears level • *Period/ Rate* long enough (typically eight periods of the modulation frequency) to obtain a stable estimate of the modulation index.	
Measurement **(procedure 2)**	Set the test signal level at the microphone to equal that of speech under normal operating conditions. The sound pressure level should be set using A-weighting and level should be 68 dB. If a maximum length sequence (MLS) analysis equipment is used, the test equipment should be set up to provide a sample length of at least 1 second and the speech shaping filter should be used. • *Conditions* Background noise does not vary substantially with time. • *Position* Set the source (artificial mouth or suitable test loudspeaker) on the axis of the appropriate microphone at the normal speaking distance (measured from the lip-circle for the artificial mouth) and direct in the normal speaking direction. • *Level* listener's ears level • *Period/ Rate* 10 s	IEC 60268-16:1998
Validity conditions		
Comfort limits		