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Noise spectra for calculation the speech transmission index in public address systems

Paweł Dziechciński

***Abstract*—To precision calculate the speech transmission index (STI), it is necessary to know the level and spectrum of the interfering noise. Simplified design methods used in public address systems are limited to obtaining an appropriate signal-to-noise ratio based on A weighted sound levels. For this reason, among others, guidelines for designers usually contain information on typical interfering noise levels and do not provide information on the noise spectrum. As shown in the paper, the effect of the noise spectrum on STI can be very high, and when such spectrum cannot be obtained by measurement or computation, standardised spectra appropriate for a given type of noise can be used for STI calculations.**

***Keywords*—speech transmission index; STIPA; public address system; interfering noise; noise spectra**

I. Introduction

To calculate the Speech Transmission Index for Public Address Systems (STIPA) [1] for the purposes of theoretical analyses or the design of public address systems, it is necessary to know the spectrum of interfering noise. Various noises have already been taken into account in the first publications on speech intelligibility. French and Steinberg assumed that interfering noise and speech had the same spectrum, used interfering noise in the signal chain and room [2]. Pollack and Picket investigated the effect of white noise with 0, +6, and -12 dB per octave spectral tilt [3], with a limited spectrum [4] and a low-frequency spectrum associated with weapon systems [5]. Houtgast and Steeneken also used speech [6] and traffic noise [7] as interfering noise in their studies to create a speech transmission index. Spectral-shaped noises were also used by Wijngaarden and Steeneken, among others, to simulate the noise of fans in a traffic tunnel [8]. In the analysis of speech intelligibility in communication channels, in addition to white noise, it is also quite common to use pink noise and its spectra, limited to the width of a given channel [9]. Jathar and Rao [10] used brown noise due to its spectral similarity to noise at the train station during peak hours. The influence of the spectrum of individual noise colours on the intelligibility of syllables determined by the CVC method as a function of the signal-to-noise ratio (*SNR)* was presented by Prodeus and others [11]. Dziechciński analysed the impact of various factors on *STIPA* for the traffic noise [12] to adapt to the specific case of interfering noise, and pink noise and male speech as the two cases determining the least and most favourable interfering noise spectrum, respectively, for typical cases [13],[14]. Sometimes pink noise is assumed to occur in a typical natural environment [15], but in this paper it will be shown that it is a rather special case.

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This paper focusses on objects where a public address system formally must provide sufficiently high speech intelligibility. These include voice alarm systems (VAS) [16],[17], railway passenger information systems [18],[19], and rooms designed for voice communication [19],[20]. In these objects, the main sources of noise can be crowd, technical installations, and transport. Dziechciński [22] showed that in the case of noise caused by people, speech spectra for vocal effort appropriately related to the noise level can be used to calculate STI. In this study, analogous analyses were performed for other important noise sources for public address systems. In the case of technical installations, mainly heating, ventilation, and air conditioning (HVAC) systems or television and audio equipment were analysed. In the case of railway infrastructure, various cases that may occur on railway platforms were analysed, and in the case of rolling stock, typical disturbances inside rail vehicles occurring both at a standstill and while travelling. The study aims to assign standardised spectra to individual noise sources for the purpose of calculating STIPA in the design of public address systems, in cases where it is not possible to obtain the spectrum by measurement or calculation methods.

II. Research design

The algorithm of the analyses performed in the work was analogous to the analyses in Dziechciński's work [22] for crowd noise. The effect of the interfering noise spectrum on STIPA was evaluated by determining the characteristics of $STIPA(SNR_A)$. SNR_A is defined as:

$$SNR_A = L_{Aeq,s} - L_{Aeq,n} \tag{1}$$

where $L_{Aeq,s}$ is the A-weighted equivalent continuous sound level of speech and $L_{Aeq,n}$ of interfering noise.

STIPA was determined by a statistical method with IEC 60268-16 [1], assuming that the reverberation time $T = 0$ s, corresponding to the greatest impact of SNR_A on $STIPA$. On this assumption, modulation transfer index m_k in the k-th 1/1 octave band in the range 125 Hz - 8 kHz is described by (2):

$$m_k = \frac{1}{1+10^{-SNR_k/10}} \tag{2}$$

The $STIPA(SNR_A)$ vectors were calculated for SNR_A in the range from 5 to 15 dB with 0.5 dB steps.

Typical occupational noise levels for a wide range of building area types are presented in the BS 5839-1 standard [16]. Beyond crowd noise, which is the subject of a separate publication [22] Typical sources of noise in buildings with BS 5839-1, which determine the highest levels of interference and are analysed in this paper, are fans, television and audio devices, and rail vehicles. The paper analyses those cases of sources for which typical interference spectra can be expected. On the other hand, buildings for which the spectra of interference can be very diverse, e.g. factories and plant rooms, have been omitted. It should also be remembered that unusual sources of noise may appear in public facilities (e.g. a fountain in a shopping mall).

Brown and pink noise were used as reference interfering spectra for each type of source. In addition, other spectra characteristic of a given source, standardised or used as a reference in the literature, were selected for noise sources. In the context of interference used for speech intelligibility analyses in sound systems, white noise is unlikely to be used and will not be taken into account in this study. The spectra of the reference noise normalised to L_{Aeq} = 0 dB are shown in Table I.

TABLE I
REFERENCE NOISE SPECTRA NORMALISED TO L_{AEQ} = 0 DB

Reference spectra	L_{Zeq} [dB]						
f [Hz]	125	250	500	1000	2000	4000	8000
Pink noise	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0
Brown noise [10]	3.2	0.2	-2.8	-5.8	-8.8	-11.8	-14.8
AES75 [23]	-3.5	-3.5	-3.6	-5.2	-7.5	-9.7	-12.0
EIA-426-B [24]	-4.2	-4.2	-4.2	-4.5	-7.2	-10.2	-14.0
IEC 60268 [25]	-5.7	-5.2	-5.1	-5.3	-6.2	-8.8	-14.1
NR25 [26]	10.5	2.0	-4.0	-8.2	-11.3	-13.7	-15.5
NR45 [26]	8.8	1.3	-3.7	-7.3	-10.1	-12.3	-14.0
NR85 [26]	4.6	-0.3	-3.7	-6.3	-8.5	-10.3	-11.8
-5 dB/octave [27]	7.8	2.8	-2.2	-7.2	-12.2	-17.2	-22.2
Railway noise [28]	-4.2	-5.7	-5.5	-5.4	-5.6	-9.0	-17.7
Traffic noise [29]	1.6	-1.7	-4.2	-4.1	-7.8	-12.7	-18.1

The tested noise spectra were taken from the literature and the results of measurements carried out by the Acoustic Testing Laboratory of the Wrocław University of Technology and Sciences (spectra given in tables without literature references). These spectra are presented in the chapter with analysis results. Detailed information on test spectra can be found in the reference literature.

III. RESULTS

A. *Television and audio equipment*

In the case of voice alarm systems, television and audio equipment can be the main source of interfering noise, e.g. in hotel rooms. Activation of a voice alarm in a VAS usually involves disconnecting the standard mains power supply supplied to the rooms, but some of these devices are battery powered, so they can also be active when messages are emitted. The reference spectra are signals used to test the power of loudspeaker devices. The most commonly used signals of this type are the simulated programme signal (IEC 60268-1) [25], the signal from EIA-426-B [24], Music-Noise (AES75) [23] and the signal from ANSI/CTA2034-A [30] (in the 1/1 octave bands 125 Hz – 8 kHz practically compliant with IEC 60268-1). The reference signals spectra after normalisation to L_{Aeq} = 0 dB are shown in Fig. 1. The analyses for television and audio equipment were limited to the reference spectra and the selection of the spectrum providing the lowest STIPA values. The results of the analyses are presented in Fig. 2.

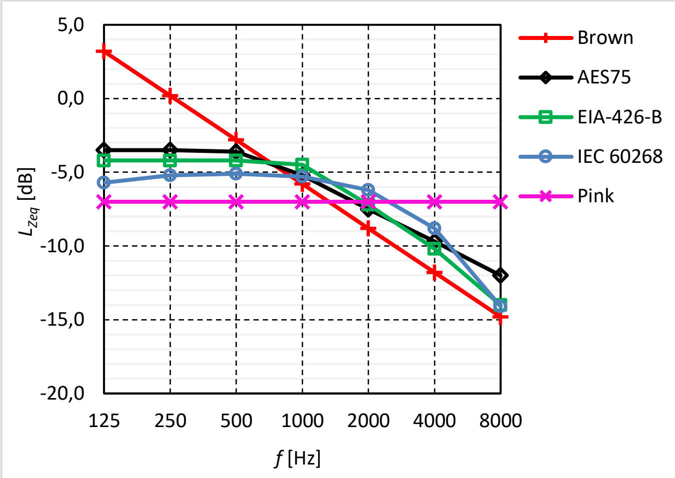

Fig. 1. Television and audio equipment reference noise spectra normalized to L_{Aeq} = 0 dB.

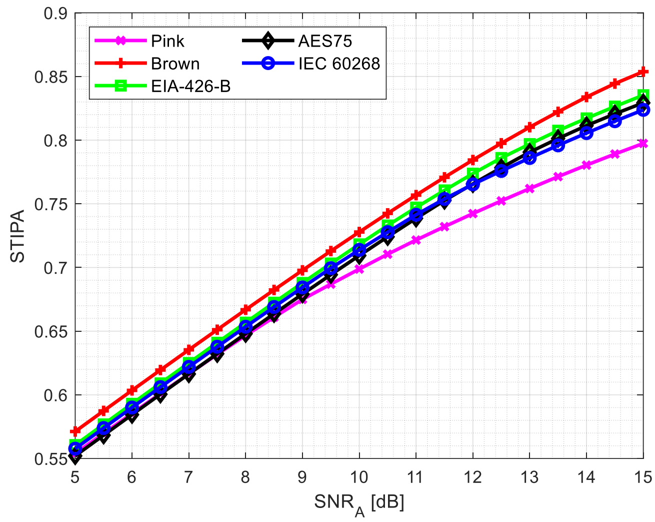

Fig. 2. *STIPA*(SNR_A) for television and audio equipment reference noise spectra, $L_{Aeq,n}$ = 65 dB.

B. *Fan, blowers and HVAC systems*

One of the most important sources of noise from technical installations are fans and blowers. Indoors, these are mainly fans used in HVAC systems. In the case of vehicles, these are additionally fans used, for example, to cool engines.

A facilitation in the design of PA systems in rooms may be the fact that the sound power levels of ventilation systems in the 1/1 octave bands are usually possible to obtain from their designers. A simple approach may be to use curves such as NR, NC, RC, NCB, or RNC where they have been used to determine the requirements for HVAC systems. However, at the conceptual design stage and for other systems that use fans, such data may not be available.

In addition to colour noises, the NR25, NR45, and NR85 curves were used as reference spectra for HVAC systems [26], and a -5dB/oct line (Fig. 3). The use of NR (noise rating) is widespread in Europe. NR25 is the maximum required value for venues such as concert halls, broadcasting and recording studios, NR45 for department stores, supermarkets, canteens, general office, and NR85 is the limit value used for road tunnel ventilation noise [31]. The spectrum line -5dB/octave has been used in older publications as a good approximation to ventilation-type noises [27]. The effect on the STIPA of the individual reference spectra is significantly different (Fig. 4) and therefore each of them will be used in subsequent analyses.

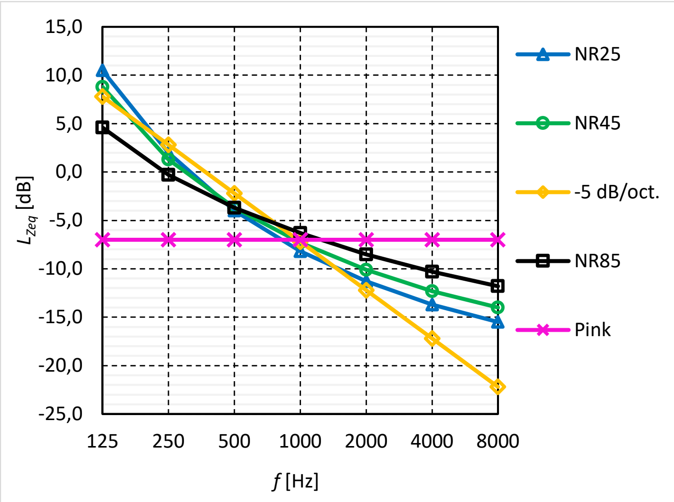

Fig. 3. Reference noise spectra for fans, blowers, and HVAC systems normalised to L_{Aeq} = 0 dB.

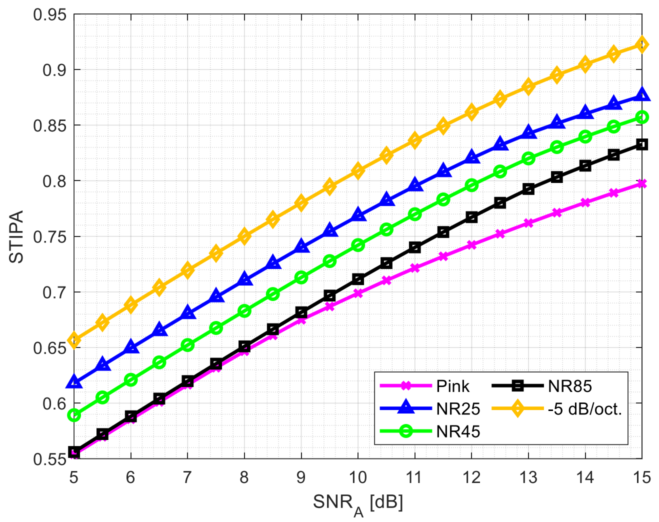

Fig. 4. $STIPA(SNR_A)$ for fans, blowers and HVAC systems - reference noise spectra, $L_{Aeq,n}$ = 65 dB.

The noise spectrum of fans and blowers depends mainly on their design, while the noise level additionally depends on factors such as the rated motor power and the volume discharged. Typical fan noise spectra from Lauchle paper [32] (not including the fix for the blade pass frequency) after normalisation to L_{Aeq} = 0 dB are presented in the Tab. II and Fig. 5. The results of the analyses are presented in Fig. 6.

The noise spectrum emitted by an HVAC system can differ from that of fans, especially in ducted systems, due to the use of silencers, among other things. Furthermore, in the medium and high frequency range, the source of noise can be ventilation grilles and diffuser systems, especially in the case of air conditioning pumps and chillers [33].

TABLE II
NOISE SPECTRA FOR A VARIETY OF AXIAL AND CENTRIFUGAL FANS [32] NORMALISED TO L_{AEQ} = 0 DB

			L_{Zeq} [dB]							L_{Aeq}
Sym-bol	Fan type	f [Hz]	125	250	500	1k	2k	4K	8k	[dB]
F1	Centrifugal BC1		4.0	3.0	-2.0	-6.0	-13.0	-17.0	-19.0	0
F2	Centrifugal BC2		4.6	2.6	-1.4	-6.4	-12.4	-16.4	-21.4	0
F3	Centrifugal FC		11.0	1.0	-6.0	-6.0	-11.0	-16.0	-21.0	0
F4	Radial Low p >1		4.9	0.9	-3.1	-5.1	-10.1	-13.1	-16.1	0
F5	Radial Low p <1		9.6	3.6	-6.4	-7.4	-10.4	-15.4	-18.4	0
F6	Radial Mid p >1		9.5	0.5	-2.5	-6.5	-11.5	-15.5	-18.5	0
F7	Radial Mid p <1		10.9	-1.1	-4.1	-6.1	-11.1	-15.1	-18.1	0
F8	Radial High p >1		5.8	0.8	-4.2	-6.2	-8.2	-11.2	-14.2	0
F9	Radial High p <1		7.3	-0.7	-5.7	-5.7	-7.7	-10.7	-13.7	0
F10	Vaneaxial 1		-8.3	-8.3	-3.3	-4.3	-6.3	-13.3	-17.3	0
F11	Vaneaxial 2		-2.5	0.5	-2.5	-4.5	-9.5	-15.5	-17.5	0
F12	Vaneaxial 3		-2.1	-3.1	-3.1	-5.1	-7.1	-11.1	-14.1	0
F13	Tubeaxial $d<1$		-6.1	-5.1	-3.1	-5.1	-6.1	-13.1	-15.1	0
F14	Tubeaxial $d>1$		-9.7	-7.7	-3.7	-4.7	-5.7	-13.7	-16.7	0
F15	Propeller		-8.4	-1.4	-3.4	-4.4	-7.4	-13.4	-17.4	0

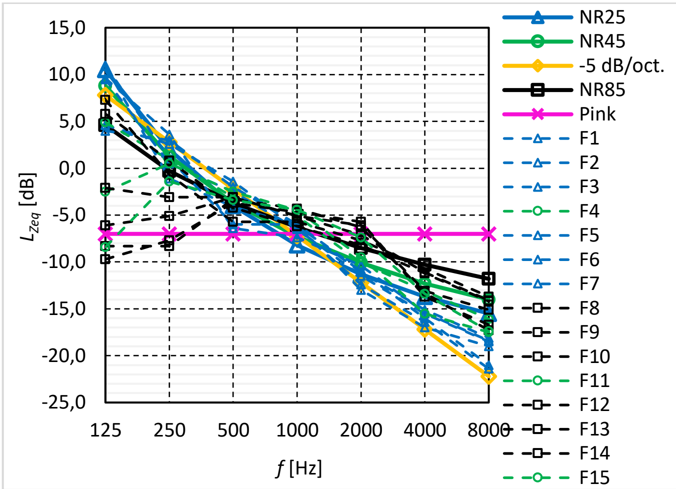

Fig. 5. Noise spectra for a variety of axial and centrifugal fans [32] normalised to L_{Aeq} = 0 dB.

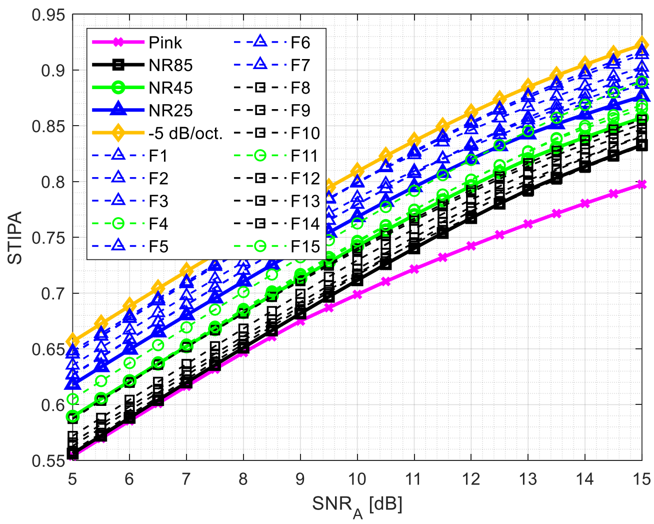

Fig. 6. $STIPA(SNR_A)$ for a variety of axial and centrifugal fans, $L_{Aeq,n}$ = 65 dB.

The first group of devices for which the analyses were performed are tunnel fans, as well as smoke exhaust ventilation. The interfering noise spectra for these systems are shown in Tab. III and in Fig. 7. Detailed information on individual objects can be found in the source literature. The results of the analyses are presented in Fig. 8.

TABLE III
TESTED NOISE SPECTRA OF TUNNEL AND SMOKE EXTRACTION FANS

Symbol	Object	f [Hz]	L_{Zeq} [dB] 125	250	500	1k	2k	4K	8k	L_{Aeq} [dB]
T1	Tunnel #1, without attenuators [34]		99	96	104	111	97	91	81	111.7
T2	Tunnel #2 - jet fans [35]		85.3	91.3	87.6	85	78.3	70.9	60.8	89.5
T3	Tunnel #3, [36]		80	85	82	80	76	70	62	84.6
T4	Tunnel #1, with attenuators [34]		81.1	79.3	80.1	82.3	77.8	72	64.8	85.3
T5	Tunnel #4 – ventilation fans [37]		79	77	76	74	69	65	60	78.3
T6	Tunnel #5 – jet fans [38]		87	91	81	79	90	77	74	92.4
T7	Shopping mall – smoke exhaust		78	63.8	65.2	69.3	66.4	60.7	53	72.9
T8	Tunnel #4 – emergency fans [37]		63	69	73	73	67	64	63	76.2
T9	Tunnel #6 –fans with deflectors [39]		94	94	94	91	84	85	82	95.7
T10	Tunnel #6 –fans without deflectors [39]		89	86	86	82	81	85	83	90.6

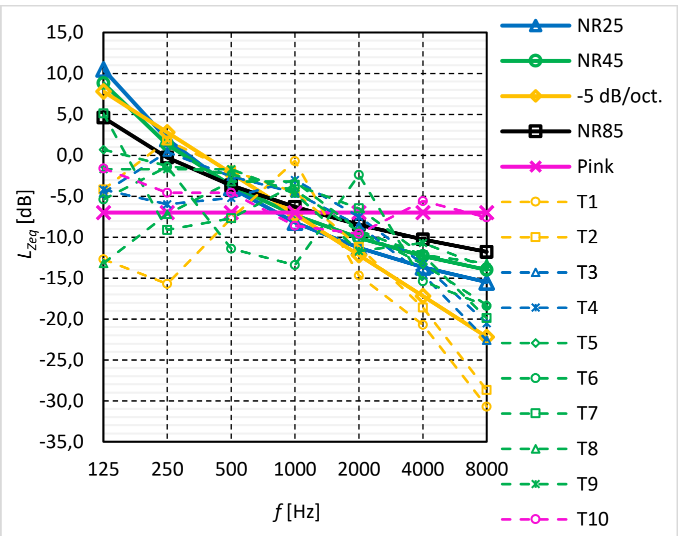

Fig. 7. Noise spectra of the tunnel and smoke extraction fans normalised to L_{Aeq} = 0 dB.

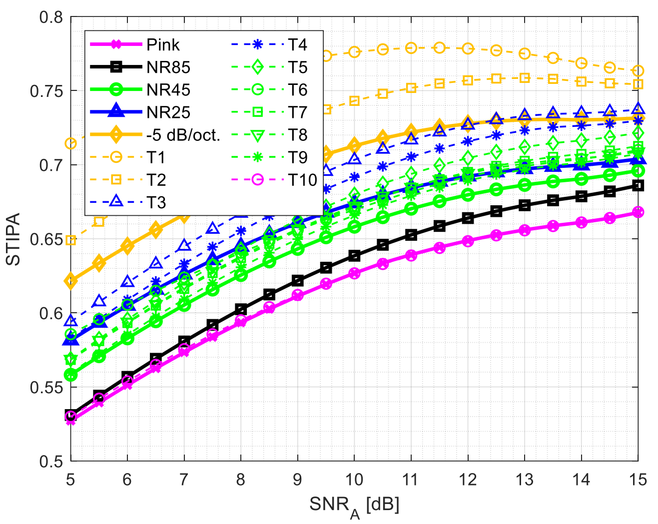

Fig. 8. *STIPA*(SNR_A) for tunnel and smoke extraction fans, $L_{Aeq,n}$ = 85 dB.

On the other hand, the lowest noise levels are generated by HVAC systems used in rooms intended for direct communication, such as classrooms, meeting rooms, and offices. The interfering noise spectra for these systems are shown in Table IV and in Fig. 9. The results of the analyses are presented in Fig. 10.

TABLE IV
TESTED NOISE SPECTRA OF HVAC SYSTEMS IN CLASSROOMS, MEETING ROOMS AND OFFICES

Symbol	Object	f [Hz]	L_{Zeq} [dB] 125	250	500	1k	2k	4K	8k	L_{Aeq} [dB]
OF1	Meeting rooms - cooler, refrigerator [27]		62.3	52.7	53.9	47.4	33.5	27.8	26.9	53.9
OF2	Meeting rooms - ventilation [27]		58.5	50.2	43.5	40.3	36.7	30.1	23.4	47.8
OF3	Classroom #1		46.7	48.6	49.6	47.5	42.3	33.9	26.4	51.4
OF4	Classroom #2		44.5	45.6	45.2	42.8	37.4	29.9	24.0	46.9
OF5	Office #1		53.0	51.2	45.0	41.6	38.2	33.4	25.2	48.1
OF6	Classroom #3 - ventilation [40]		48.9	47.1	44.4	41.8	39.1	32.6	23.3	47.0
OF7	Office #2 – variable air volume [41]		55.1	59.2	55.6	55.8	50.7	48.1	42.6	59.7
OF8	Office #3 [42] (Fig. 1c)		44	46	43	42.5	39	35	30.5	46.9
OF9	Office #2 – constant air volume [41]		53.0	50.0	47.5	43.9	41.1	39.1	36.3	50.0
OF10	Office #3 [42] (Fig. 1a)		49	49	46	42.5	41	38	35	48.9
OF11	Office #3 [42] (Fig. 1d)		50	49	48.5	45	43	41	38	51.0
OF12	Office #2 – fan coil unit [41]		53.8	52.3	49.1	47.0	45.0	43.1	39.6	52.9

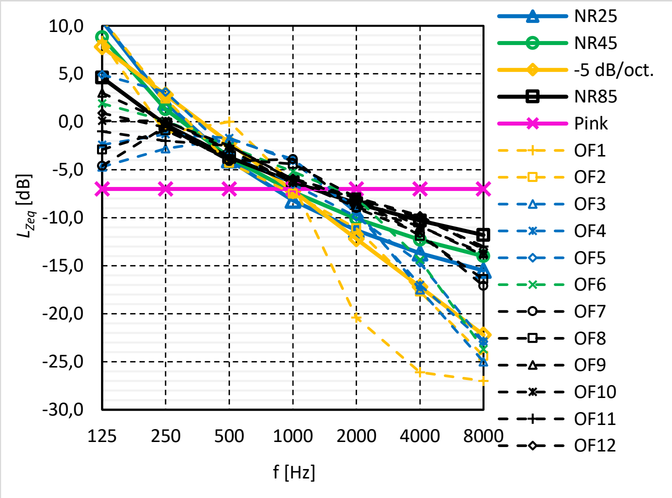

Fig. 9. Noise spectra of HVAC systems in classrooms, meeting rooms, and offices normalised to L_{Aeq} = 0 dB.

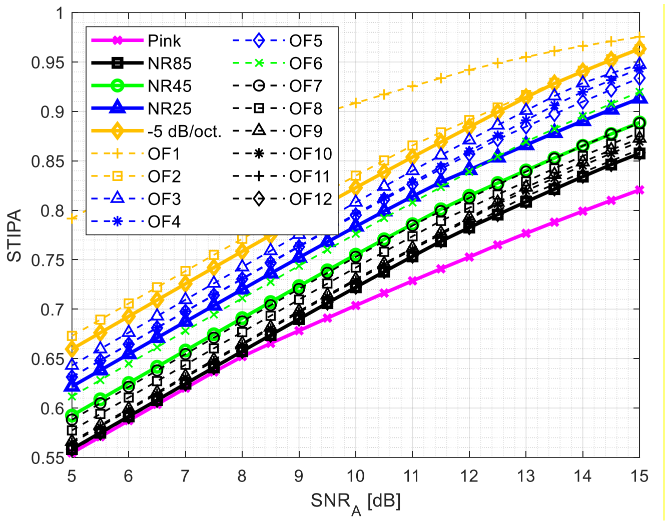

Fig. 10. *STIPA*(*SNR$_A$*) for HVAC systems in classrooms and meeting rooms, $L_{Aeq,n}$ = 55 dB.

C. *Railway noise*

In the rail system, the required STIPA values must be ensured in terms of infrastructure and rolling stock, i.e., inside vehicles. Different interfering noise spectra can also be expected in both of these areas.

In the case of railway infrastructure, the noise emitted by rail vehicles is often the main source of interfering noise. This noise depends on the train operations on nearby platforms. Engines, fans, and compressors can always be the source of noise, and brake noise can play an major role in the global noise level when a vehicle enters the platform. In the first stage of the research, standardised rail and road noise spectra (platforms are sometimes localised near roads) noise spectra, pink noise (the most difficult case), brown noise (referring to Jathar and Rao [10]), and the NR85 curve (fans as possible source of noise) were used as reference noise spectra. The reference noise spectra for the railway noise normalised to L_{Aeq} = 0 dB are shown in Fig. 11. The normalised railway noise spectrum are not defined for the 1/1 octave band of 8 kHz. This value was determined by reducing the level in the 4 kHz band by -8.7 dB. The correction of -8.7 dB was calculated as the mean value of the coefficients of traction noise from the EU Directive 2015/996 [43]. In Poland, a noise level of L_A = 85 dB is recommended for platforms for calculation purposes [19]. In view of the results obtained, *STIPA*(*SNR$_A$*) shown in Fig. 12, traffic noise was not used in further analyses.

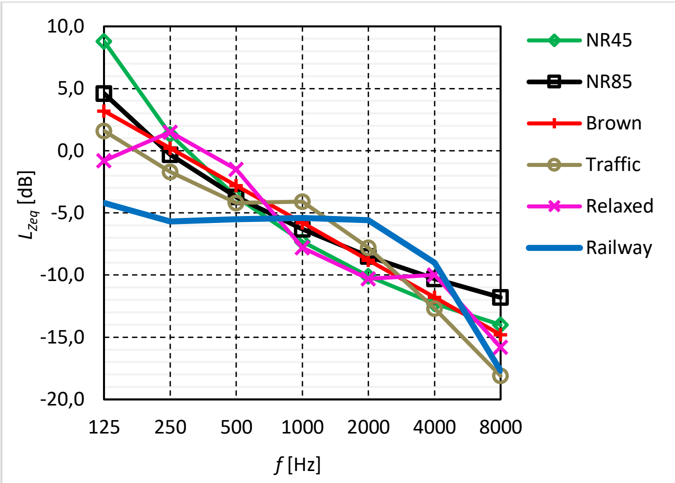

Fig. 11. Reference noise spectra for railway noise normalised to L_{Aeq} = 0 dB.

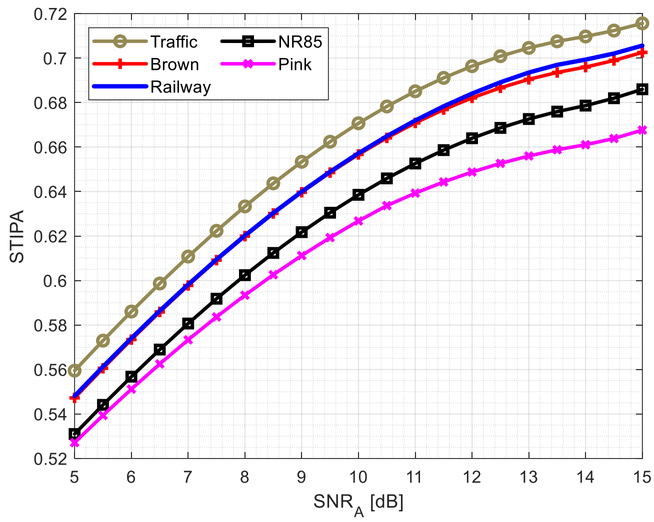

Fig. 12. *STIPA*(*SNR$_A$*) for railway noise - reference noise spectra for rail platforms, $L_{Aeq,n}$ = 85 dB.

The tested spectra were obtained for various platforms and rail vehicles. Measurements were made for nine diesel vehicles (D01-D09), 11 electric vehicles (E01-E11), independently or jointly for different vehicle operations (A - arrival, D - departure, P - passing, S - standstill) and for different objects or events. The interfering noise spectra for these systems are shown in Table V. The results of the analyses are presented in Fig. 13.

The speech intelligibility requirements for rolling stock must be met at standstill and 80 km/h open track [44]. Tested interfering noise spectra were obtained by measurement for these two cases (S – standstill, and P - 80 km/h open track).

Sources of noise in rail vehicles can include noise from HVAC systems, conversations (which were not included in the measurements of the test spectra) and other vehicle systems (e.g. engines) and, while driving, additionally rolling noise. For high-speed rails, aerodynamic noise is an additional component, which can be ignored in the range of analysed speeds. The NR45 and NR85 curves, the brown noise, the railway noise, and the "relaxed" speech spectrum were used as reference noise spectra (Fig. 11). The "relaxed" speech spectrum (male speech spectrum for "hashed" vocal effort [45]), was considered a representative crowd noise spectrum for sound levels up to 70 dB [22]. The interfering noise spectra inside rolling stock are shown in Table VI. The results of the analyses are presented in Fig. 14.

TABLE V
TESTED NOISE SPECTRA OF RAILWAY TRANSPORT ON PLATFORMS

	L_{Zeq} [dB]							L_{Aeq}
Symbol f [Hz]	125	250	500	1k	2k	4K	8k	[dB]
D01a S	57.6	56.6	58.0	59.2	55.9	54.2	53.3	63.5
D01b S	63.7	57.3	60.5	62.6	60.0	58.2	53.8	66.8
D02 P	73.1	72.5	79.3	82.4	77.8	70.6	59.7	84.9
D03 A	55.6	53.9	55.0	52.2	56.1	43.3	38.4	59.7
D04 P	84.0	84.8	85.0	80.1	80.5	86.3	86.0	91.1
D05 P	77.5	85.3	85.5	82.7	83.8	79.3	73.1	89.3
D06 P	74.5	86.5	87.5	85.1	80.7	75.0	66.9	89.3
D07 S	66.9	54.3	57.8	60.5	51.6	45.7	39.1	62.6
D08 A	70.3	73.5	62.3	59.6	57.6	51.6	50.3	67.9
D08a S	65.3	67.0	61.8	57.3	52.9	54.7	53.3	64.5
D08b S	60.6	64.0	62.5	66.0	61.2	52.8	45.2	68.6
D08c S	71.9	76.0	70.8	70.2	65.4	60.0	57.1	74.5
D09a S	58.0	54.6	59.1	61.2	59.4	49.4	44.8	64.8
D09b S	64.6	59.3	67.4	72.5	70.7	57.9	45.5	75.7
E01 S	56.9	59.5	46.3	42.9	43.0	42.3	34.8	53.5
E02 ASD	69.4	77.2	78.8	74.2	72.3	65.5	56.4	79.9
E02 SD	62.8	64.5	58.7	60.4	57.5	54.9	55.4	65.2
E03 ASD	71.4	70.7	71.2	68.1	73.1	71.5	56.4	77.8
E04 ASD	59.1	60.9	64.0	60.5	59.8	56.6	44.0	66.4
E05 ASD	64.9	67.7	64.7	60.8	56.0	50.1	43.2	66.2
E06 A	77.7	76.8	75.4	76.2	75.5	84.8	68.1	87.0
E07 AS	62.1	63.8	58.4	53.0	60.2	47.9	44.2	63.8
E07 SD	67.3	64.8	55.6	53.3	52.0	50.8	40.2	61.2
E07a S	58.0	58.7	51.6	48.5	44.4	41.2	33.6	54.9
E07b S	68.7	69.9	60.0	57.3	56.3	54.1	49.9	65.5
E08 P	66.5	71.0	71.1	66.8	63.1	51.3	49.3	72.0
E09 P	54.8	60.1	65.1	68.1	65.3	59.2	47.3	71.4
E10 P	58.3	62.1	67.1	69.6	63.4	56.0	47.4	71.8
E11 A	69.6	68.3	64.7	61.9	57.9	52.5	50.1	67.2
E11 D	51.4	49.7	45.2	47.1	40.1	31.7	23.0	50.0
E11 S	52.8	56.1	48.4	48.8	42.2	40.4	34.6	53.2

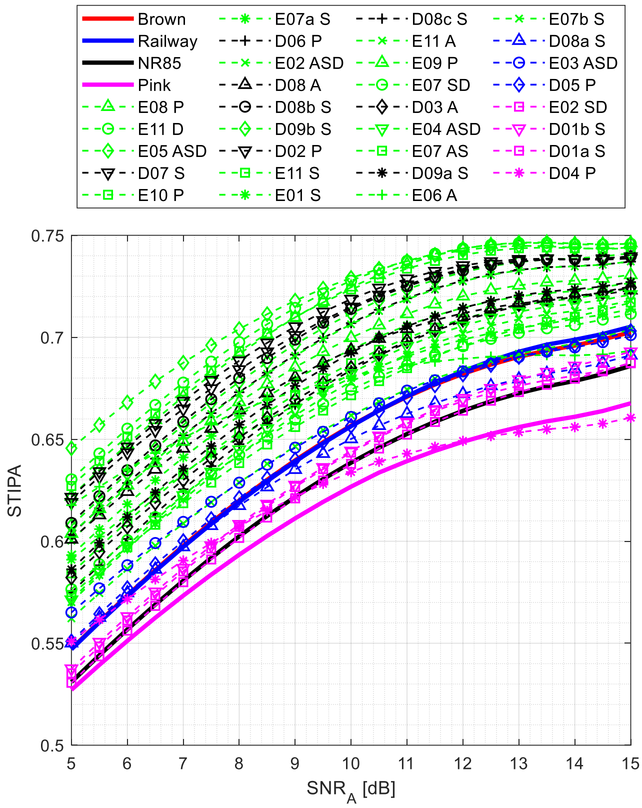

Fig. 13. *STIPA*(SNR_A) for tested railway noise spectra on platforms, $L_{Aeq,n}$ = 85 dB.

TABLE VI
TESTED NOISE SPECTRA OF NOISE INSIDE ROLLING STOCK

	L_{Zeq} [dB]							L_{Aeq}
Symbol f [Hz]	125	250	500	1k	2k	4K	8k	[dB]
D1 P	73.9	69.0	66.4	60.2	59.4	53.0	45.3	68.0
D1 S	67.5	64.4	59.8	56.0	52.2	46.2	35.9	62.2
D2 P	74.7	68.3	65.7	60.4	54.6	50.5	49.4	67.1
D2 S	63.4	66.5	64.9	56.4	50.0	46.3	41.4	64.4
D3 P	71.5	66.3	59.9	56.9	47.5	43.4	38.4	63.0
D3 S	60.5	61.4	53.8	51.4	47.5	40.9	31.8	57.5
D4 P	71.3	71.0	65.7	63.5	59.3	53.2	43.1	68.7
D4 S	66.2	70.1	63.3	61.6	58.3	51.9	42.0	67.1
D5 P	69.5	69.1	65.0	62.8	59.0	52.3	42.9	67.8
D5 S	66.9	68.4	62.3	60.4	55.1	46.7	36.8	65.4
D6 P	72.7	70.4	65.3	63.9	59.8	53.6	47.3	68.8
D6 S	68.0	69.1	65.2	63.4	60.3	54.0	44.9	68.3
E1 P	74.9	70.5	67.4	61.6	54.7	50.5	43.9	68.4
E1 S	58.5	54.1	46.6	44.7	42.4	38.6	28.8	51.4
E2 P	75.9	73.4	70.6	64.9	58.5	51.6	44.8	71.4
E2 S	60.1	53.3	44.1	38.5	34.6	28.1	24.2	49.0
E3 P	75.6	70.1	67.3	61.8	56.2	50.2	41.7	68.5
E3 S	63.8	58.2	57.2	55.4	51.7	45.3	34.0	59.9
E4 S	61.9	56.3	53.7	52.1	45.4	38.1	30.9	56.3

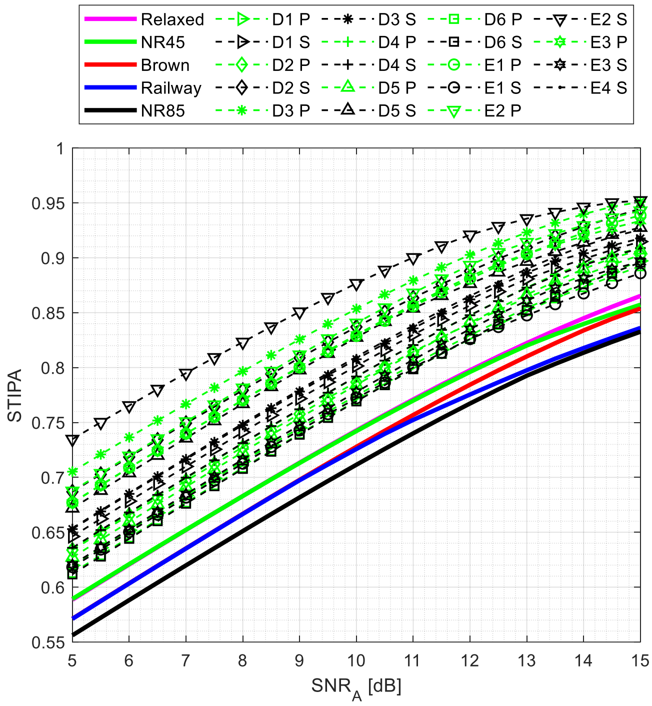

Fig. 14. *STIPA*(*SNR$_A$*) for tested spectra of noise inside rolling stock, $L_{Aeq,n}$ = 65 dB.

IV. Discussion

The first source of interfering noise analysed were television and audio equipment. The spectra of signals emitted by such sources have been developed for the purpose of testing the power parameters of loudspeaker devices. The tested spectra gave similar *STIPA*(*SNR$_A$*) values, but on average the lowest *STIPA* value was obtained for the Music-Noise spectrum (AES75) [22] and this spectrum is recommended for use as an interfering noise spectrum of television and audio equipment in the design of public address systems.

In the case of noise caused by fans (including HVAC systems), it is recommended to use the spectrum for this case, for which the public address system is designed. If it is not possible to determine these spectra by measurement, the calculation methods in this area are well documented, and it is usually possible to obtain the spectrum and noise levels from the HVAC designer. However, if this is not possible, then for STIPA calculations in public address systems for noise generated by fans or HVAC systems, the spectrum with the shape described by the NR85 curve met the requirements in the vast majority of cases. For the fifteen spectra analysed, typical of different fan designs, this spectrum always met the requirements. If the design of the fan is known, based on the results presented in the paper, the spectral shapes described by the NR45 or NR25 curve can be used, which will provide greater accuracy in the calculations. It is not recommended to use the 5dB/oct. curve, as it met the requirements only in a few cases.

The NR85 curve also worked well in 9 out of 10 tunnel fans tested. In the case of the tenth spectra tested, the NR85 curve depending on the SNRA value gave a STIPA overestimate of 0.00 to 0.02, which can be considered a satisfactory result. However, a safe approach for this case was to adopt a pink noise spectrum.

For classrooms and conference rooms, although the noise levels emitted by HVAC systems are much lower, the shape of the spectrum described by the NR85 curve also met the requirements for each of the cases analysed.

For noise on railway platforms, 27 of the 31 interfering noise spectra tested were met by the reference rail spectrum. Brown noise used by Jathar and Rao [10] gave results similar to railway noise, but with an indication of the latter. For three of the four cases for which it did not meet the requirements, depending on the value of the *SNRA* the STIPA revaluation ranged from 0.00 to 0.015, which can be considered a satisfactory result. The fourth case, for which the STIPA revaluation was as high as 0.03, concerned the passage through the platform of a train for which a L_{Aeq} = 89 dB, so this vehicle probably did not meet the TSI noise requirements [46]. Therefore, it can be considered that the railway noise spectrum is suitable as an interfering noise spectrum in the design of sound systems on railway platforms.

Noise spectra measured while driving and at a standstill were used as test spectra for rail vehicles. In both of these cases, the vehicle's systems (including HVAC) were active. However, interfering noise emitted by passengers is not taken into account. Taking this into account and the results of the analyses, Used for the calculation of sound systems in rail vehicles, it is recommended to use the spectrum marked in the work as "relaxed". It is the spectrum of male speech for "hashed” vocal effort [45], which was considered a representative spectrum of crowd noise for sound levels up to 70 dB [22].

Conclusion

The analyses carried out as part of the study show that for the purposes of designing public address systems, the Music-Noise spectrum defined in the standard AES75 [23] can be used as an interfering noise spectrum for TV and audio equipment. For interfering noise generated by fans and HVAC systems, in most cases, a spectrum with the shape described by the NR85 curve will work [26]. When designing sound systems on rail platforms, the rail noise spectrum will work in most cases [28]. For sound systems inside rail vehicles, the appropriate interfering noise spectrum is the spectrum of male speech for "hashed” vocal effort [45], which has also been recognised as a representative crowd noise spectrum for sound levels up to 70 dB [22].

Pink noise, which is often used as an interfering noise spectrum in the design of sound systems and set as the default interfering noise spectrum in some computer programmes for the design of sound systems, is a very unfavourable case. Its use in most common cases can lead to an underestimation of the STIPA value.

For the calculation of the STI, it is recommended to use the noise spectrum present in the area under consideration whenever possible. For existing buildings, it is best to obtain them by measurement. In the case of designed buildings, if there is such a possibility, interfering noise can be measured in acoustically similar objects, or when the spectrum of sound power levels of noise sources is known, it can be determined by calculation. The spectra specified in the paper should be used when such possibilities do not exist or for the purposes of theoretical analyses.

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