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Indoor Noise Reduction Index with an open window (Part II)

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Abstract

An index to evaluate indoor noise level reduction with an open window Noise Reduction Index (NRI) was proposed [Buratti C. Indoor Noise Reduction Index with open window. Appl Acoust 2002;63(4):431–51]. The reduction was due to the installation of a false ceiling in the room, thus reducing the contribution of the reverberant field. Experimental data related to two different kinds of false ceiling were compared to the results obtained by an original calculation model. Good agreement was found between experiments with two different materials and predictions. The present paper examines six different kinds of false ceiling and arrives at a new validation of the model. Calculations of NRI show good agreement with experimental data: a maximum difference of −1.2 dB(A) was found with a mean difference of 0.5 dB(A) for a wide range of absorption coefficient values. Hence the model represents a reliable instrument for indoor NRI prediction, if the acoustic absorption characteristics of materials are known.

Keywords: Noise Reduction Index (NRI); Buildings acoustic insulation; Open window; Road; Spectrum and $L_{eq(A)}$ measurements; Model validation

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Nomenclature

a	absorption coefficient (–)
A	absorption units (m^2), defined as $A = \sum_{i=1}^{n} a_i S_i$ (Sabine)
$\Delta L_{eq(A)}$	weighted A continuum equivalent level variation (dBA)
ETD	experimental theoretical difference (dBA)
f	frequency (Hz)
L	sound pressure level (dB, dBA)
$L_{eq(A)}$	weighted A continuum equivalent level (dBA)
NRC	noise reduction coefficient (–)
NRI	Noise Reduction Index (dBA)
S	area of a surface (m^2)
v	train velocity (km/h)

Subscripts

0	without false ceiling
1–6	false ceiling with sample nos. 1–6
250	at 250 Hz
500	at 500 Hz
1000	at 1000 Hz
2000	at 2000 Hz
(A)	weighted A
C	ceiling
e	experimental
f	final
t	theoretical

1. Introduction

Technological progress of society caused in the last decades a significant improvement of noise pollution, the fifth environmental emergency in Europe after traffic, air pollution, landscape and waste. Traffic is the main source of noise, also because of its diffusion.

Acoustic comfort could be related to different conditions:

- noise source characteristics, in terms of sound power, acoustic spectrum, directional properties, time, collocation;
- noise propagation, in terms of indoor and outdoor sound field characteristics (direct and reverberating), materials and building elements transmission of sound;
- indoor and outdoor users activity.

Noise control could be directly carried out on source, along the transmission path or through passive protection of the receiver. Best control systems are on source, but good results could be obtained also reducing indoor reverberating field due to internal or external noise sources.

The present paper is Part II of a previous work [1], where an index to evaluate indoor noise level reduction with open window (NRI) was proposed: reduction was due to the installation of a false ceiling in the room, in order to reduce the contribution of reverberating field; the influence of different materials on the indoor pressure level with open windows was also considered. Experimental data related to two different kind of false ceiling were compared to the results obtained with an original calculation model; a good agreement was found between experimental and theoretical data, but the model was validated on only two different materials. The present paper examines six different kind of false ceiling and a new validation of the model is proposed. All measurements were carried out at the Acoustic Laboratory of the University of Perugia, in compliance with International Standards [2–5]. The single numbered index NRI (Noise Reduction Index) represents the arithmetical average of the weighted A continuum equivalent level reduction ($\Delta L_{eq(A)}$) in the central frequency bands 250, 500, 1000 and 2000 Hz, with respect to the situation without false ceiling, as defined in [1]. Noise reduction was calculated both for road and railway traffic noise, reproduced through normalized spectra [6–8].

In the present paper measurements and calculations were repeated with the methodology described in [1], considering six different kind of false ceiling. Results were then compared with those obtained by the theoretical model developed in [1], in order to validate the model; the model calculates the open window noise reduction, due to indoor false ceiling installation, from the absorption coefficient of the materials vs. frequencies.

An evaluation of panel costs per square meter was finally carried out, in order to relate costs to acoustics performances.

2. Experimental facility and methodology

The experimental facility consists of (see Fig. 1):

- coupled reverberating rooms: boxed structures with reinforced concrete walls of 0.40 m width, mechanically insulated from outdoor and from one another and built in compliance with ISO 140-1 [2]; the emission room has a net volume of 53.36 m^3, while the receiving room has a net volume of 62.79 m^3; walls and ceiling of both rooms are plastered, floor is covered with ceramic tiles; doors are made of boxed metal filled with sand while the sealing gasket is of silicon rubber. Opening between the two rooms has 4.20×2.50 m dimensions, a total area of 10.50 m^2 and it is closed during testing by a wall made of two layers of bricks (0.18 m width), with in between a layer of rock wool of 0.03 m width; walls are externally coated with reflecting plaster. The dividing wall presents also a window with $H \times L = 1.25 \times 1.50$ m dimensions.

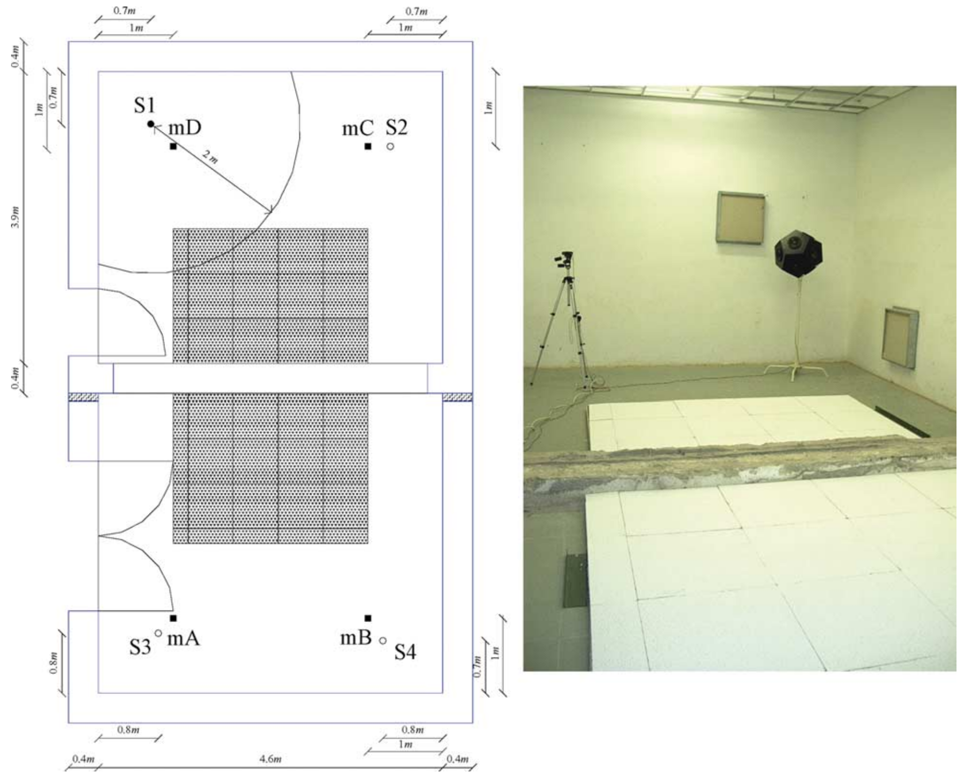

Fig. 1. Sample disposition in the absorption coefficient measurements (S1, S2, S3, S4: source positions and mA, mB, mC, mD: microphone positions in the reverberation time measurements).

The measuring system consists of:

- an omni-directional noise source with dodecahedral shape, verified at emission uniformity as established by ISO 140/3 [3] and powered by a SU-A900 amplifier linked to a digital tape recorder DAT (Digital Audio Tape-Corder) SONY model TCD-D7;
- two capacitor microphones (model 40AR by GRAS) equipped with PRE12H pre-amplifiers by 01 dB;
- acquisition and elaboration system SYMPHONIE by 01 dB.

The measuring system is in Class 1 and complies with technical norms IEC 225/1966, IEC 225/1979 and IEC 804/1995.

Noise reduction evaluation due to installation of sound absorbent ceilings inside the receiving room was carried out as in [1] considering only the open window because measurements with closed and open window gave the same results in [1]. Therefore the situations investigated in the present paper are the following:

(A) Measurements with open window

- (Al) road traffic;
- (A2) low speed railway traffic;
- (A3) high speed railway traffic.

The same noise sources as in [1] were employed; their spectra were recorded along the main roads and railways in the city of Perugia and in the outskirts and then reproduced in Laboratory. At the same time, a Literature research was carried out on the spectra established by European Norms; several rules try to define a normalized spectrum of road and railway traffic [6–8], where all spectra are defined in A pondered band levels and are normalized at 0 dB(A), therefore a global reference level needs to be defined. The following sources were chosen:

- *road traffic*: normalized spectrum proposed by prEN 1793-3 European Norm [7], global level (A) proposed by Società Autostrade S.p.A. (Italian Motorways Company) fixed at 83.8 dB(A); a spectrum of road traffic was measured in Via Mario Angeloni, one of the heaviest loaded roads in the city of Perugia, a one-way straight road with three lanes and at a constant slope of 5%;
- *railway traffic*: normalized spectra of the Swedish NT ACOU 062 Norm [6], global (A) level found in Literature fixed in $L_{g(A)} = 86.3$ dB(A) for low speed railway (90 km/h) and in $L_{g(A)} = 92$ dB(A) for high speed railway (140 km/h). The real noise produced by a train was recorded along the Terontola-Chiusi line, at Ferretto, near Perugia, where four perfectly horizontal bolted tracks are present.

A comparison between the recorded spectra and the ones reproduced in the emission room shows a good agreement; reference spectra for road and railway traffic chosen for laboratory reproduction are reported in Fig. 2.

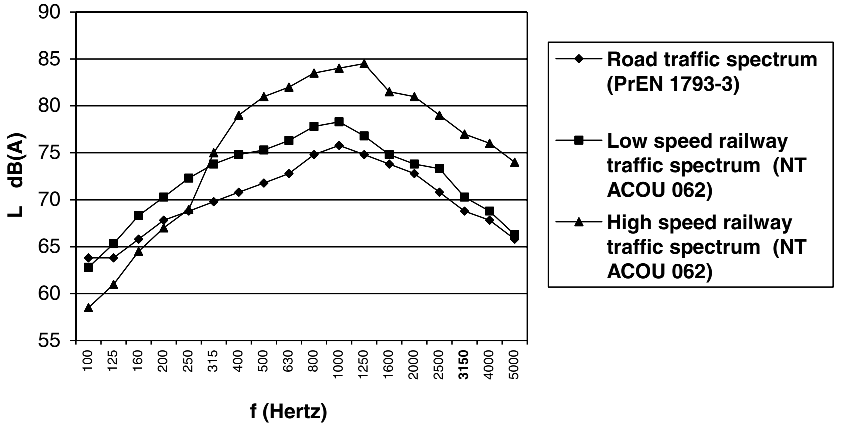

Fig. 2. Road and railway noise spectra.

Sound pressure levels and noise spectra in the receiving room without false ceiling, measured in [1], were used in order to have the same reference state; all measurements were then carried out six times, for six different kind of false ceiling.

The following measurements were carried out:

- acoustic absorption coefficient of the six samples;
- L_{eq}(A) and spectrum in the emission room (point E in Fig. 3);
- L_{eq}(A) in 38 points of the receiving room (see Fig. 3);
- spectrum in 1, 16, 28, 42 and 55 points of the receiving room (see Fig. 3).

The acoustic absorption coefficients of the six samples of false ceiling were measured in compliance with EN ISO 354, using the Sabine equation [9]. Sample was put on the floor of both the rooms without the separation wall (Fig. 1); a 50 mm thickness plenum between sample and floor was realized to reproduce average mounting conditions. To

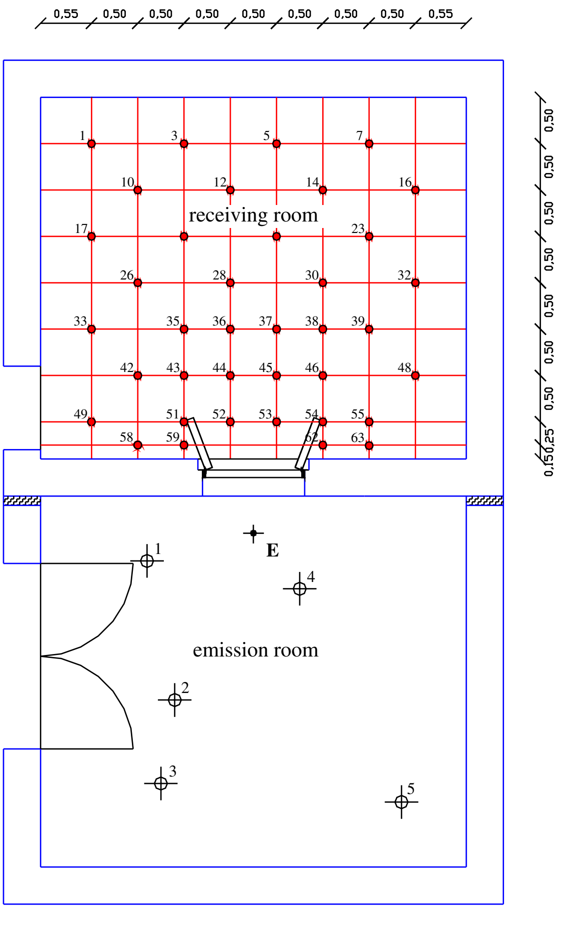

Fig. 3. Measurements points in the receiving room and source points in the emission room.

consider the influence of the area of the floor covered by the sample during the test, as suggested by EN ISO 354 [9], a correction for measured absorbed units was carried out.

For L_{eq}(A) and spectra measurements, the same methodology as in [1] was used: source emits noise transmitted by a DAT digital recorder in each of the five positions established in compliance with UNI EN ISO 140-3 [3]. $L_{eq(A)}$ is measured in point E of the emission room (see Fig. 3) and in each point of the measurement grid, at an height of 1.50 m (human ear height). A spectrum analysis is carried out in points E, 1, 16, 28, 42, 55: the energy average of the spectra found in the five points gives the mean spectrum of the receiving room. Weighted A continuum equivalent level in each measurement point was referred to the following time periods:

- 30 s for road traffic;
- 15 s for low speed railway traffic;
- 10 s for high speed railway traffic.

Energy average of $L_{eq(A)}$, in the different positions of the source, is carried out for each point of the grid and a mapping is obtained in the receiving room. Procedure is repeated for the three different traffic spectra and for the six kind of false ceiling; finally energetic average of $L_{eq(A)}$ in all points of the grid gives a representative value of the receiving room.

For each sample of false ceiling, a testing time of about 24 h was necessary, including: the net measurements period (about 3 h), the time necessary to move and install the microphones and to assemble and disassemble the false ceiling.

3. Samples description

The six samples of false ceiling were assembled under the actual ceiling covering its entire surface (about 12 m^2).

The main characteristics of the examined samples are reported in Table 1; samples are shown in Fig. 4.

4. Measurement results

4.1. Absorption coefficients

The trend of sound absorption coefficient for the six kind of panels was obtained by calculating absorption units vs. frequency using Sabine equation; absorption coefficients vs. frequencies are reported in Table 2 and Fig. 5.

Sample 5 shows the best performance with a maximum value of 0.9 at 1000 Hz; values higher than 0.5 are obtained in the frequencies range 250–5000 Hz.

Samples 1 and 3, characterized by the presence of holes, have a similar behaviour, with maximum values of the absorption coefficient in the range 500–2000 Hz ($a = 0.5$–0.6 for sample 1 and 0.5–0.7 for sample 3); maximum value is at 1000 Hz.

Table 1
Characteristics of examined samples

No.	Model	Dimensions (mm)	Materials	Bores	f^*
1	CASOLA/Casoprano/ Multiform	$600 \times 600 \times 8$	White covered and pre-painted plaster	Circular, different diameter, passing through (8.15% surface)	Medium
2	CASOROC/Placo	$600 \times 600 \times 9.5$	Covered plaster smooth surface	–	Low
3	QUATTRO/Gyptone/ Multiform	$600 \times 600 \times 12.5$	Covered plaster back acoustic felt	Square, passing through (18% surface)	Medium
4	FREQUENCE 9544M4B/03/ Armstrong/Multiform	$600 \times 600 \times 18$	Mineral fibre porous media	–	Medium/high
5	OPTIMA 2000M4/16/ Armstrong/Multiform	$600 \times 600 \times 25$	Mineral fibre porous media	–	Medium/high
6	TERVOLFON 40/ Armstrong/Multiform	$600 \times 600 \times 40$	Hydro-repulsive rock wool, white painted textile surface	–	Medium/high

f^* = range of frequencies characterized by the higher absorption coefficients.

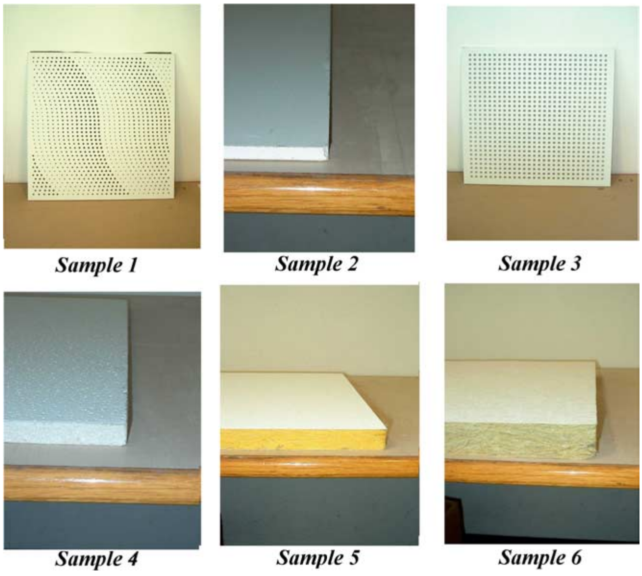

Fig. 4. Examined samples.

Table 2
Absorption coefficients of examined samples

f (Hz)	1	2	3	4	5	6
100	0.11	0.05	0.04	0.09	0.11	0.25
125	0.08	0.14	0.04	0.10	0.11	0.25
160	0.20	0.41	0.07	0.34	0.21	0.77
200	0.23	0.24	0.16	0.39	0.32	0.54
250	0.29	0.26	0.25	0.43	0.48	0.58
315	0.37	0.18	0.35	0.52	0.65	0.59
400	0.38	0.18	0.41	0.53	0.69	0.49
500	0.49	0.15	0.53	0.60	0.74	0.62
630	0.51	0.12	0.60	0.64	0.80	0.79
800	0.56	0.10	0.66	0.71	0.83	0.73
1000	0.59	0.08	0.69	0.68	0.92	0.72
1250	0.55	0.06	0.66	0.72	0.83	0.76
1600	0.48	0.07	0.59	0.65	0.75	0.63
2000	0.45	0.05	0.49	0.55	0.61	0.53
2500	0.38	0.06	0.43	0.53	0.57	0.48
3150	0.35	0.05	0.40	0.51	0.55	0.44
4000	0.37	0.10	0.42	0.44	0.55	0.37
5000	0.38	0.09	0.41	0.41	0.52	0.31
Global	0.45	0.10	0.50	0.60	0.70	0.55

Samples 4 and 6 have a similar behaviour in the frequencies range where they show the maximum absorption coefficient; they have a maximum value of about 0.75 at 1000 Hz and values higher than 0.5 in the frequencies range 250–4000 Hz.

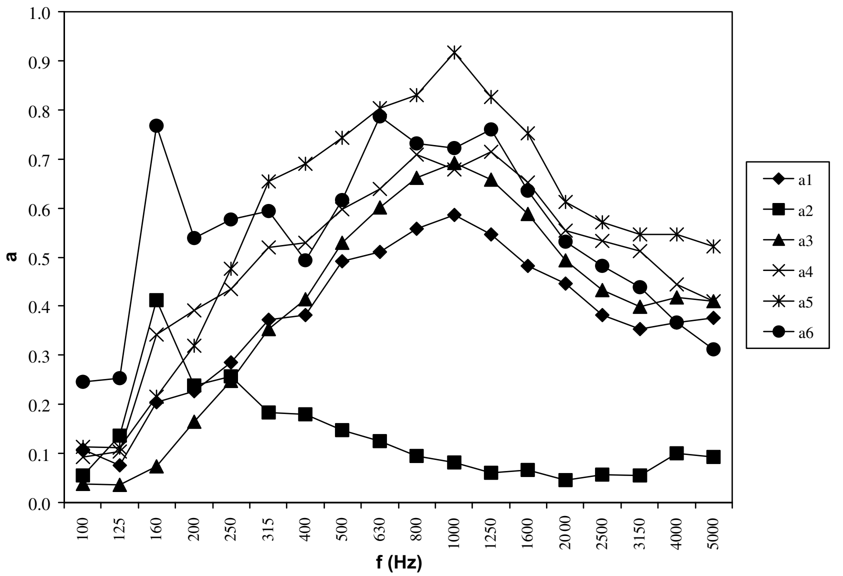

Fig. 5. Absorption coefficient of the six sample vs. frequencies.

Finally sample 2, characterized by a smooth not porous surface and without holes, shows low values of absorption coefficient, always in the range 0.05–0.15, as expected.

4.2. Spectra measurements and $L_{eq(A)}$ maps

Spectra and $L_{eq(A)}$ measurements were carried out in the receiving room, as described in ∫2; measurements without false ceiling obtained in [1] were compared to data obtained by measurements of the six kind of false ceiling described in ∫3, in order to evaluate noise abatement. Measurements were repeated three times: for road traffic, low speed railway traffic and high speed railway traffic. Results were analyzed and different noise maps were obtained:

(a) $L_{eq(A)}$ maps in the receiving room for each kind of false ceiling and each traffic condition;
(b) $L_{eq(A)}$ variation maps between the condition without false ceiling and the conditions in a).

$L_{eq(A)}$ variations vs. frequencies were also calculated employing the mean spectra measured in points 1, 16, 28, 42, 55 of Fig. 3; they were reported in Fig. 6 together with the absorption coefficients of the false ceiling. Results show, as in [1], that higher abatements are obtained at the frequencies where absorption coefficient is higher (except for low frequencies, where resonance phenomena are present).

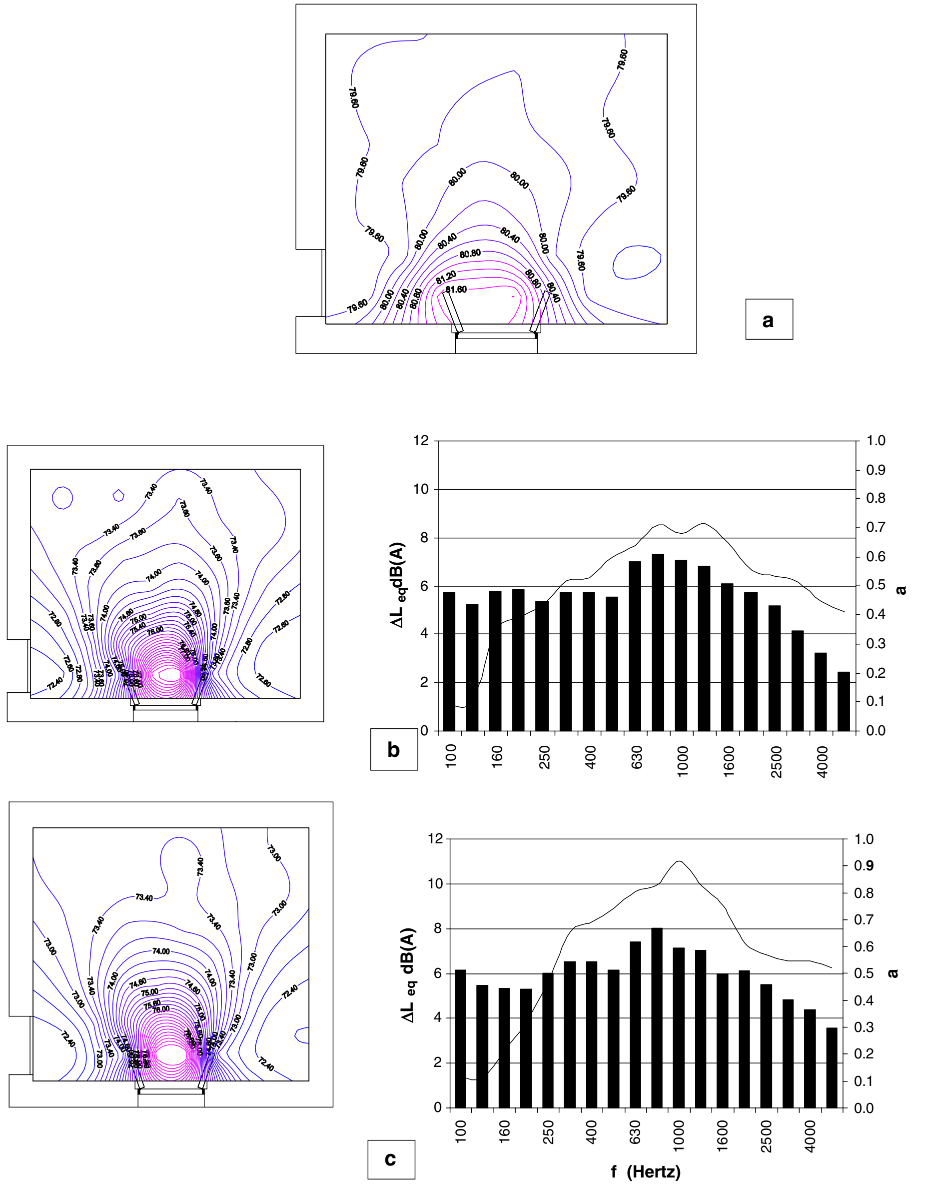

Fig. 6. Experimental results: (a) noise map without false ceiling; (b) noise map with sample 4, related $\Delta L_{eq(A)}$ and absorption coefficient; (c) noise map with sample 5, related $\Delta L_{eq(A)}$ and absorption coefficient.

18 maps for $L_{eq(A)}$, $L_{eq(A)}$ variations and spectral variations figures were obtained; as an example and for brevity, Fig. 6 shows results related to samples 4 and 5, characterized by the best performances.

Table 3
$L_{eq(A)}$ values and $L_{eq(A)}$ reductions in the receiving room with the six samples, in the three different traffic conditions

$L_{eq(A)}$ (E)	$L_{eq(A)}$ **0**	$L_{eq(A)}$ **1**	$L_{eq(A)}$ **2**	$L_{eq(A)}$ **3**	$L_{eq(A)}$ **4**	$L_{eq(A)}$ **5**	$L_{eq(A)}$ **6**
Road traffic							
85.1	79.7	75.6	79.5	74.3	73.5	73.3	73.7
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	ΔL4 = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		4.1	0.2	5.4	6.2	6.4	6.0
Low speed railway traffic (v = 90 km/h)							
86.1	81.0	76.3	80.8	76.0	75.8	75.3	76.0
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	ΔL4 = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		4.7	0.2	5.0	5.2	5.7	5.0
High speed railway traffic (v = 140 km/h)							
92.1	87.2	82.5	87.1	81.9	81.5	81.2	82.0
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	ΔL4 = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		4.7	0.1	5.3	5.7	6.0	5.2

Table 4
Theoretical and experimental Noise Reduction Index (NRI) and ETD values for the six samples plus the two samples A and B examined in [1], in the three traffic conditions and related mean values

	NRC	NRI(e) dB(A)	NRI(t) dB(A)	ETD dB(A)	NRC	NRI(e) dB(A)	NRI(t) dB(A)	ETD dB(A)
	Sample 1				Sample 2			
Road traffic		4.5	5.4	−0.9		0.9	1.9	−1.0
Low speed railway traffic	0.45	5.1	5.4	−0.3	0.13	0.9	1.9	−1.0
High speed railway traffic		4.9	5.4	−0.5		0.9	1.9	−1.0
Mean values		4.8	5.4	−0.6		0.9	1.9	−1.0
	Sample 3				Sample 4			
Road traffic		5.9	5.6	0.3		5.9	6.2	−0.3
Low speed railway traffic	0.49	5.3	5.6	−0.3	0.57	5.0	6.2	−1.2
High speed railway traffic		5.3	5.6	−0.3		5.3	6.2	−0.9
Mean values		5.5	5.6	−0.1		5.4	6.2	−0.8
	Sample 5				Sample 6			
Road traffic		6.4	6.9	−0.5		6.0	6.5	−0.5
Low speed railway traffic	0.69	5.6	6.9	−1.3	0.61	5.0	6.5	−1.5
High speed railway traffic		5.6	6.9	−1.3		5.0	6.5	−1.5
Mean values		5.9	6.9	−1.0		5.3	6.5	−1.2
	Sample A				Sample B			
Road traffic		1.2	1.0	0.2		3.1	3.1	0.0
Low speed railway traffic	0.15	1.1	1.0	0.1	0.4	3.9	3.1	0.8
High speed railway traffic		1.2	1.0	0.2		4.2	3.1	1.1
Mean values		1.2	1.0	0.2		3.7	3.1	0.6

All experimental results are synthesized in Table 3; they show that:

- samples 4–6 give $L_{eq(A)}$ variations in the range 6.0–6.4 dB(A) for road traffic;
- samples 3–6 give $L_{eq(A)}$ variations in the range 5.0–5.7 dB(A) for low speed railway traffic;
- samples 3–6 give $L_{eq(A)}$ variations in the range 5.2–6.0 dB(A) for high speed railway traffic.

Therefore, at least four samples show good performances.

4.3. Noise reduction index

The parameter NRI (Noise Reduction Index), introduced in [1] in order to characterize a material for its ability to reduce indoor noise with open window, was calculated with the following equation:

$$\mathrm{NRI(e)} = [\Delta L(\mathrm{e})_{250} + \Delta L(\mathrm{e})_{500} + \Delta L(\mathrm{e})_{1000} + \Delta L(\mathrm{e})_{2000}]/4. \tag{1}$$

Results are shown in Table 4. Experimental values of Noise Reduction Index (NRI), calculated for the three different traffic conditions, vary between a minimum mean value of 0.9 dB(A), related to sample 2, to a maximum of 5.9 dB(A), related to sample 5. Good values were obtained also for other samples (1, 3, 4 and 6), always comprised in the range 4.8–5.5 dB(A).

5. Calculation model application and results

The theoretical calculation model introduced in [1] was employed to predict the NRI value, defined as

$$\mathrm{NRI(t)} = [\Delta L(\mathrm{t})_{250} + \Delta L(\mathrm{t})_{500} + \Delta L(\mathrm{t})_{1000} + \Delta L(\mathrm{t})_{2000}]/4. \tag{2}$$

Pressure level values with the six false ceilings were calculated considering the absorption properties of materials; in particular, being acoustic power without false ceiling given by $W = D_0 A_0 c/4$ and final sound density with the false ceiling given by $D_\mathrm{f} = 4W/cA_\mathrm{f}$, the latest could be written as follows [1]:

$$D_\mathrm{f} = D_0 \frac{A_0}{A_\mathrm{f}} \tag{3}$$

and the relative sound level as

$$L_\mathrm{f} = L_0 + 10\log_{10}\frac{A_0}{A_\mathrm{f}}. \tag{4}$$

Therefore, considering $A_\mathrm{f} = A_0 + A_\mathrm{fC} - A_\mathrm{0C}$, the following is obtained:

$$L_\mathrm{f} = L_0 - 10\log_{10}\left(1 + \frac{A_\mathrm{fC}}{A_0} - \frac{A_\mathrm{0C}}{A_0}\right), \tag{5}$$

where A_0 and A_0C could be estimated or measured in situ.

Table 5
Theoretical $L_{eq(A)}$ values and $L_{eq(A)}$ reductions, for the six samples, in the three traffic conditions

$L_{eq(A)}$(E)	$L_{eq(A)}$ **0**	$L_{eq(A)}$ **1**	$L_{eq(A)}$ **2**	$L_{eq(A)}$ **3**	$L_{eq(A)}$ **4**	$L_{eq(A)}$ **5**	$L_{eq(A)}$ **6**
Road traffic							
85.1	79.7	74.4	79.0	73.9	73.5	73.0	73.7
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	ΔL4 = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		5.3	0.7	5.8	6.2	6.7	6.0
Low speed railway traffic (v = 90 Km/h)							
86.1	81.0	75.6	80.0	75.1	74.7	74.1	74.7
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	Δ*L4* = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		5.4	1.0	5.9	6.3	6.9	6.3
High speed railway traffic (v = 140 km/h)							
92.1	87.2	81.6	86.3	81.1	80.8	80.2	80.8
		ΔL1 = Leq0 − Leq1	ΔL2 = Leq0 − Leq2	ΔL3 = Leq0 − Leq3	ΔL4 = Leq0 − Leq4	ΔL5 = Leq0 − Leq5	ΔL6 = Leq0 − Leq6
		5.6	0.9	6.1	6.4	7.0	6.4

Eventually ΔL was calculated as

$$\Delta L = L_0 - L_f. \tag{6}$$

Results are reported in Table 5; they show that:

- samples 4–6 give $L_{eq(A)}$ variations in the range 6.2–6.7 dB(A) for road traffic;
- samples 3–6 give $L_{eq(A)}$ variations in the range 5.9–6.9 dB(A) for low speed railway traffic;
- samples 3–6 give $L_{eq(A)}$ variations in the range 6.1–7.0 dB(A) for high speed railway traffic.

The mean theoretical values of Noise Reduction Index (NRI) were also calculated for the three different traffic conditions; they are reported in Table 4 and vary between a minimum of 1.9 dB(A), related to sample 2, to a maximum of 6.9 dB(A), related to sample 5.

6. Comparison between measured and calculated data

In order to compare the experimental and the theoretical values obtained, the ETD parameter (experimental theoretical difference), defined in [1] as follows, was also calculated:

$$\text{ETD} = \text{NRI(e)} - \text{NRI(t)}. \tag{7}$$

Then NRI and ETD values were related to the NRC index, defined in the Literature [10] as the arithmetical average of sound absorption coefficients in the central frequency bands 250, 500, 1000, and 2000 Hz:

$$\text{NRC} = \frac{(a_{250} + a_{500} + a_{1000} + a_{2000})}{4}. \tag{8}$$

Results show that both theoretical and experimental values of NRI increase with NRC, so that the more sound absorbent is the material the higher is the noise reduction. Fig. 7 shows NRI values vs. NRC, considering also samples A and B investigated in the previous work [1]. A minimum value of NRI (1 dB(A)) is obtained for NRC = 0.1 both for theoretical and experimental data; a maximum value of NRI of about 6 dB(A) for experimental data and of about 7 dB(A) for theoretical data is obtained.

Finally the difference between experimental and theoretical data ETD was calculated and it is reported in Fig. 8; it varies (see also Table 4) between a minimum of −0.1 and a maximum of −1.2 dB(A); the mean value of ETD is about −0.5 dB(A).

Therefore theoretical model generally gives values of NRI higher than experimental data; nevertheless the difference is very low and it could be considered comprised in the experimental uncertainty.

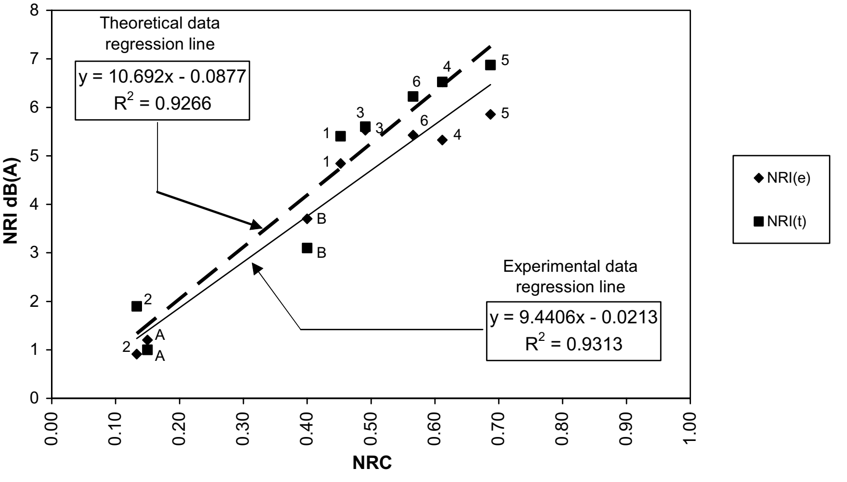

Fig. 7. NRI(e) (continuous line) and NRI(t) (dashed lines) vs. NRC.

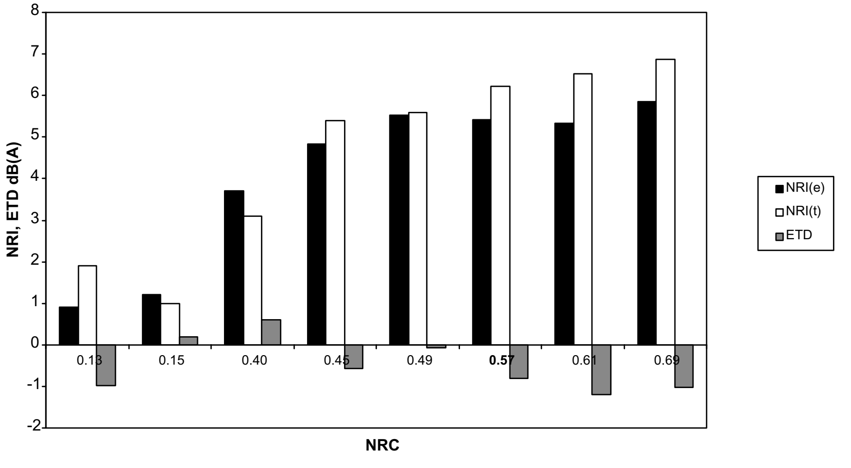

Fig. 8. NRI(e) (black), NRI(t) (white) and ETD (grey) vs. NRC.

6.1. Costs evaluation

An economic evaluation of the false ceiling installation was also carried out, considering costs per square meter of material, estimated for a supply of about 200 m^2. In Fig. 9 costs per square meter are reported vs. NRI experimental values: it is interesting to point out a general increasing of the costs with increasing noise abatement performances: a minimum of about 4 €/m^2 for NRI(e) = 1 dB(A) and a maximum of about 16 €/m^2 for NRI(e) = 6 dB(A) were found.

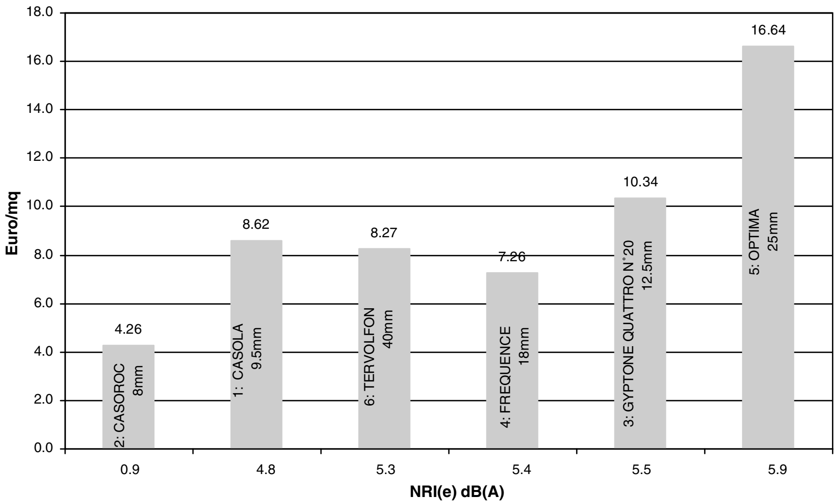

Fig. 9. Costs of materials (€/m^2) vs. NRI(e).

7. Conclusions

The present paper is Part II of a previous work [1], where the problem of indoor noise reduction with open window was considered. Such as in [1], road and railway traffic noise were considered and the influence of the indoor installation of false ceilings was theoretically and experimentally studied.

Experimental data found in [1] were not sufficient for the validation of the theoretical model, therefore an extension of the experimental campaign is proposed in the present paper, investigating six kind of different false ceiling with the same methodology as in [1]. All measurements were carried out at the Acoustics Laboratory of the University of Perugia.

Absorption coefficients of the six samples were preliminarily measured, in compliance with ISO 354 [9]: global values vary between 0.1 and 0.7, therefore a representative sample of materials, with low, medium and high absorption coefficients, was considered.

The mean experimental value of Noise Reduction Index (NRI) (for three different noise situations: road traffic, low speed railway traffic and high speed railway traffic) was in the range 0.9–5.9 dB(A); increasing values were found for increasing absorption properties of materials (NRC). Five of the six panels gave values of NRI > 4.5 dB(A), therefore all of them could be considered suitable for this application.

The theoretical evaluation of NRI with the model developed in [1] shows a good agreement between experimental and calculated data: a maximum difference ETD between experimental and theoretical data of −1.2 dB(A) was found; the mean value of ETD was −0.5 dB(A). Therefore, even if the model gives abatement values lower than experimental data, the difference is very low and it could be considered comprised in the experimental uncertainty, for a wide range of absorption coefficient values (0.1–0.7). Finally the model can be considered validated and represents a reliable instrument for indoor Noise Reduction Index prediction, knowing acoustic absorption characteristics of materials.

An economic analysis was also carried out and it showed an increasing cost of materials with acoustic performances in terms of NRI.

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References

[1] Buratti C. Indoor noise reduction index with open window. Appl Acoust 2002;63(4):431–51.
[2] ISO/FDIS 140-1: Acoustics. Measurements of sound insulation in buildings and of building elements. Requirements for laboratory test facilities with suppressed flancking transmission, 1999.
[3] EN ISO 140-3: Acoustics. Measurements of sound insulation in buildings and of building elements. Laboratory measurements of airborne sound insulation of building elements, 1997.
[4] UNI EN ISO 140-2: Acoustics. Measurements of sound insulation in buildings and of building elements. Determination, verification and application of precision data, 1994.
[5] UNI CEI EN 45001: Criteri generali per il funzionamento dei laboratori di prova, 1990.
[6] NORDTEST METHOD NT ACOU 062: Acoustics. Determination of sound power levels of noise sources. Survey method using a reference sound source, 1987.
[7] prEN 1793-3: Road traffic noise reducing devices. Test method for determining the acoustic performance. Normalized traffic noise spectrum, 1997.
[8] NF S 31-051: Mesure du pouvoir d'isolation acoustique des éléments de costruction et de l'isolement des immeubles. Mesure en laboratoire du puvoir d'isolation acoustique au bruit aérien deséléments de contruction. AFNOR, 1985.
[9] EN ISO 354: Acoustics. Measurement of sound absorption in a reverberation room, 1985.
[10] Barber A. Handbook of noise and vibration control. Elsevier Advanced Technology; 1992.