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Abstract

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Keywords ISO 1996; measurement configurations; façade; ISO 11819-4; backing board.

Taxonomy Environmental Acoustics, Acoustic Reflection, Outdoor Propagation of Sound

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ACOUSTIC BEHAVIOUR OF PLATES MADE OF DIFFERENT MATERIALS FOR MEASUREMENTS WITH THE MICROPHONE FLUSH MOUNTED

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Abstract

Different possibilities for the location of the microphone are provided when it is desired to determine the sound levels outdoors. With regard to this topic, the ISO 1996-2 standard proposes a series of corrections depending on the distance to the façade of the buildings to evaluate the incident sound field, thus correcting the effect of reflections. In this regard, in the case of the microphone located on a reflecting surface, the standard establishes two options: on the one hand, to place the microphone directly on the façade, and on the other hand, to use a plate on the surface. This work shows a comparative study of the acoustic behaviour of two plates with identical geometries through in situ measurements, both in broadband and frequency bands. One of them is made of aluminium, following the explicit recommendation of the ISO 1996-2 standard. The other plate is made of methacrylate to look for a less dense material and, consequently, to obtain a plate that is more easily transportable. Different measurement conditions have been considered to evaluate the differences and similarities between the two plates. The results obtained in different measurement configurations show an equivalent acoustic behaviour of both plates. Consequently, the alternative use of a methacrylate plate instead of an aluminium plate could be considered adequate according to the indications of the ISO 1996-2 standard.

Keywords: ISO 1996; measurement configurations; façade; ISO 11819-4; backing board.

1. Introduction

Noise is considered an important factor of environmental pollution [1,2]. Although this issue mainly affects urban environments [3,4], natural environments are also disturbed [5,6]. Noise is generated by different types of sources; however, road traffic is the most dominant source of environmental noise [7]. In fact, the World Health Organization ranked traffic noise as second among some environmental stressors for the public health impact in a selection of European countries [8].

To evaluate noise doses received by citizens or sound levels that affect natural environments, it is essential to carry out measurements, either as an evaluation system or as a way to verify the adequacy of the calculation models developed in each specific environment.

The series of ISO 1996 standards [9,10,11] is one of the most used references for the elaboration of legislation concerning the evaluation of the impact of urban noise. In fact, the ISO 1996-2 standard is considered in many research studies [12,13,14] because it is recommended as a reference for noise mapping in the European Noise Directive [2]. A new version of this standard was recently published [11], but this study was carried out while the previous version [10] was valid. In addition, in the aspects analyzed in this work, the new version does not add differences that must be considered. Among other aspects, this standard provides different possibilities for the location of the microphone when it is desired to determine the sound levels outdoors. It also proposes some corrections depending on the selected location with the purpose of considering the reflections of sound and, in its Annex B, includes some conditions for the verification of the proposed corrections. Reflections on façades of buildings are also considered in standards related to acoustic insulation [15, 16].

Because of the complex geometric configuration of real urban environment in cities streets, some difficulties are found in the actual measurement conditions to verify the stipulations stated in Annex B [17]. In fact, Barrigón Morillas et al. [18] analysed the relationship between the distances façade–microphone and façade–sound source (a) and the relationship between the distances microphone–sound source and façade–sound source (b) for the verification of the proposed corrections. That study revealed that considering these relationships, the position of the microphone flush mounted on the reflecting surface is the case where the above mentioned conditions are more easily met. In this regard, the ISO 1996-2 standard considers two options in Annex B when the microphone is placed on the reflecting surface. On the one hand, the microphone can be placed directly on the façade. On the other hand, a plate must be used to place the microphone on the façade. In this case, the ISO 1996-2 standard states that the microphone can be mounted parallel to the plate or with the microphone membrane flush with the surface of the mounting plate. Following the guidelines of the cited standard, the plate should not be thicker than 25 mm and its dimensions not less than 0.5 m × 0.7 m. In addition, the plate should be of an acoustically hard and stiff material, such as painted chipboard thicker than approximately 19 mm or 5 mm aluminium plate.

A similar measurement configuration with the microphone mounted on a backing board instead of a microphone in free-field conditions is considered in the ISO 11819-4 standard [19] for a modified version of the statistical pass-by method. It is applicable to measurements taken in an urban, built-up, environment or in the presence of safety barriers, noise barriers, embankments or road cuttings.

Many research studies use this measurement configuration with the microphone placed on a plate to validate noise maps and study the variation in sound level in front of reflecting surfaces [20-28]. Quirt [20] conducted a study about the behaviour of the sound field near the façades of buildings. Some measurements were made outdoors and in a semi-anechoic acoustic chamber to check the predictions of sound levels made using a mathematical model. In these tests, a 7.2 x 4.8 m panel of 19 mm thick plywood was used in the anechoic room as a reflecting wall, on which the microphones were placed.

Recently, Fégeant [21] conducted a study about the generation and the scattering of acoustical waves using a theoretical diffraction model and measurements. To assess diffraction effects and provide a simple way to locate the minima and maxima of deviation from pressure doubling, some plywood plates of 15 mm thickness and dimensions of 0.9 x 0.75 m and 1.8 x 1.5 m were used in free field conditions to place the microphones.

Bojola et al. [22] and Memoli et al. [23] conducted similar works to test the acoustic corrections due to reflections on the façade, as established in the ISO 1996-2 standard. Therefore, they used some microphones to simultaneously measure the sound level in free field, on the façade of buildings and near the reflecting surfaces. In the first case, Bojola et al. used a steel plate of 50 x 80 cm to mount the microphone flush on the reflecting surface, while Memoli et al. used a 5 mm thick aluminium plate of 60 x 90 cm (effective dimensions, not including space used by the support).

Hopkins et al. [24] studied the variations in sound level using a microphone mounted on a reflecting surface and the other microphone placed at a location between 0.1 and 2.0 m from it. To this end, measurements of sound pressure level were performed in a scale model into a semi-anechoic chamber using reflectors made of 30 mm thick varnished board with dimensions between 2 x 2 m and 6 x 6 m.

With regard to this topic, Jagniatinskis et al. [25] and Mateus et al. [26] also researched to check the acoustic corrections due to the distance to the reflecting façade by performing long duration measurements. To achieve this objective, they used some microphones in different configurations. First, Jagniatinskis et al. placed a microphone on a window of the façade using a metal plate with 160 mm diameter. In the second case, Mateus et al. constructed a 5 mm thick aluminium plate of 60 x 90 cm to mount the microphone flush on the reflecting wall.

This 'backing board' technique was also used by researchers involved in noise mapping. In this way, Mioduszewski et al. [27] and Szczodrak et al. [28] produced metal plates to place the microphones on the façade of dwellings to develop strategic noise maps according to the European Noise Directive.

Therefore, the use of plates to place the microphone in the sphere of the evaluation of the impact of noise on the population is an aspect of interest. Even as indicated in some studies, the use of plates could be a way to minimise sources of uncertainty in the measurement of sound levels [29].

Considering all the cited works, it can be noted that plates for this measurement configuration are made of different materials and dimensions. These plates can weigh more than 10 kg such as the aluminium plate used by Memoli (similar to other cases [13,22,27,28]). Some plates made of wood or similar materials are also used [20,21,24]. However, for making outdoor measurements for noise mapping [2,30] with the microphone placed on the reflecting surface using a plate, it would be ideal to use a light and resistant material whose acoustic behaviour could be similar to that recommended in ISO 1996-2. Thus, it would be very helpful that the plate could be light and easy to drive for been placed on the façades of buildings and, at the same time, tough for not been damaged because of the weather conditions when it is used for long duration measures.

This work shows a comparative study of the acoustic behaviour of two plates with identical geometries through 'in situ' measurements, both in broadband and frequency bands. One of them was made of aluminium, following the explicit recommendation of the ISO 1996-2 standard. However, a methacrylate plate was constructed with the aim of searching for a less dense and tough material.

2. Methods

2.1 Materials and acoustic equipment

In order to approach the problem, two plates of different and acoustically hard materials were designed according to the instructions of the ISO 1996-2 standard regarding the dimensions and thickness. They were made of aluminium and methacrylate, respectively, and had a thickness of 6 mm each. Both plates had effective dimensions (not including space used by the support) of 50 x 70 cm (Fig. 1).

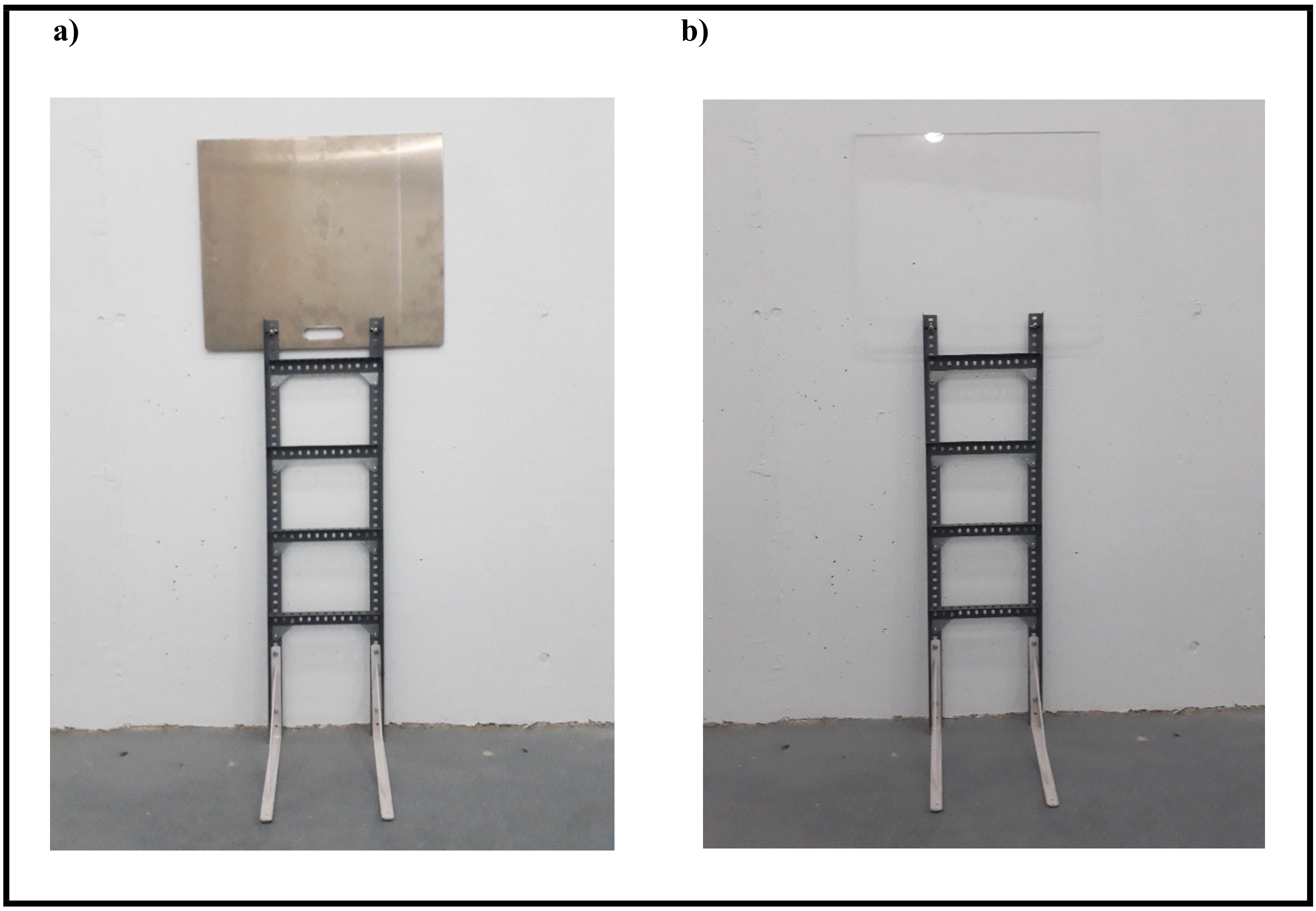


Figure 1: Designed plates of a) aluminium and b) methacrylate

2250L Brüel & Kjær type 1 analyzers were used for carrying out the measures. In connection with this matter, according to the indications of Annex B of the ISO 1996-2 standard for measurements directly on the surfaces for a frequency range whose upper limit is 4 kHz, microphones of 13 mm diameter (4950 Brüel & Kjær) were selected.

2.2 Measurement procedure

Four sampling points were selected to conduct a comparative study of the acoustic behaviour of these plates. In connection with this topic, different settings were considered with the purpose of assessing the plates with and without a reflecting surface behind them and also with varying ground conditions (see Fig. 2).

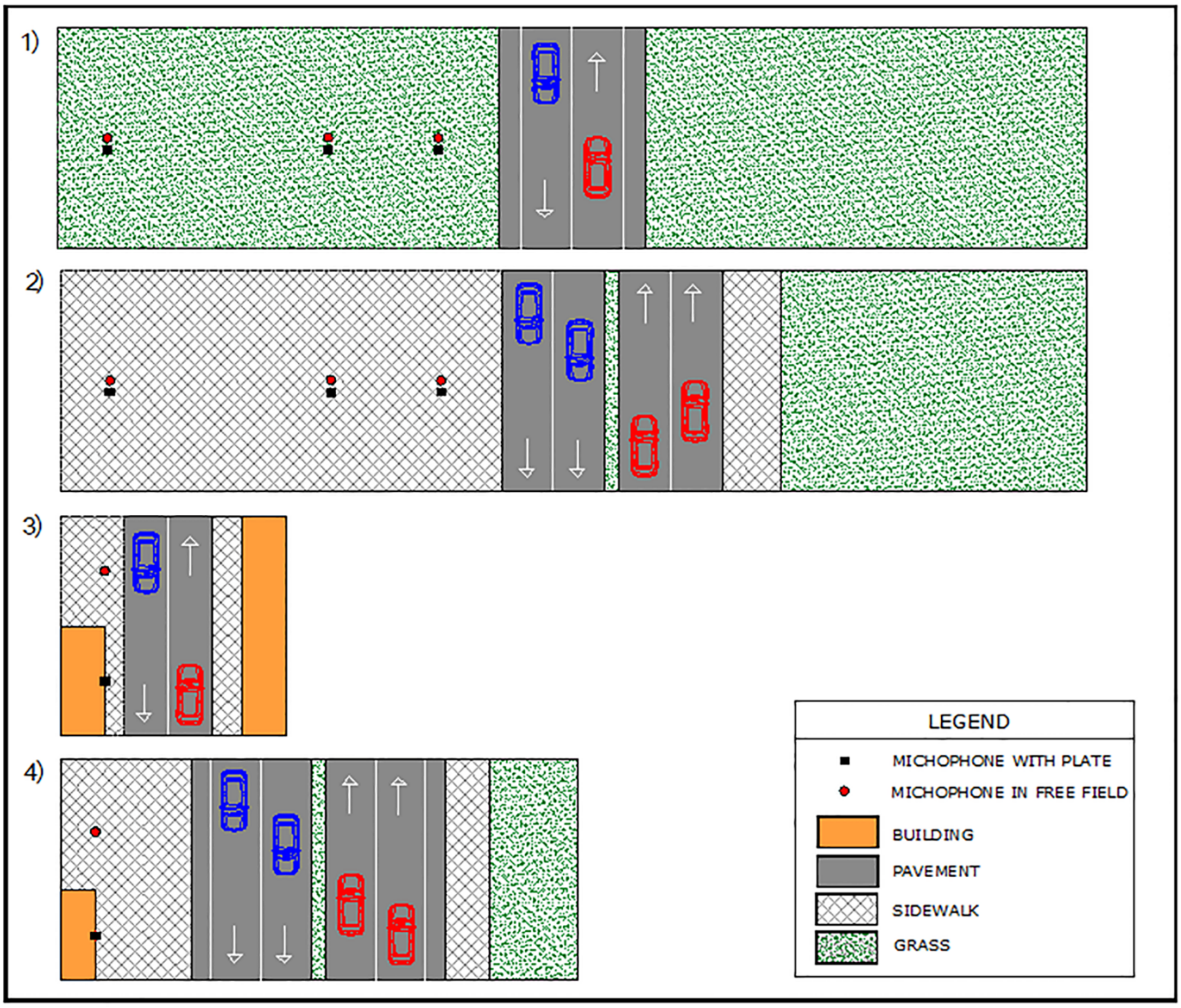


Figure 2: Location of microphones in configurations 1, 2, 3 and 4

In the selection of the measuring points, two additional aspects were considered. First, the screening effects associated with the parking lanes [31]. In this regard, points without reflective obstacles (such as parked cars) between the sound source and the microphone were chosen. Second, we considered those environments that allowed to conduct the study with the plates located at different distances from the sound source, considering the centre of the closest lane to the microphone as the reference point in this sense [32].

Taking into account the conditions included in Annex B of the ISO 1996-2 standard for measurements on reflecting surfaces, the plates were placed on the façades of buildings at points 3 and 4 (Fig. 2.3 and 2.4). Using this measurement configuration, five measurements of Leq with a duration of 10 min were made with one microphone placed at 1.5 m over the ground in free field and the other placed on the plate. This procedure was followed for both the aluminium and the methacrylate plates. The same method was used at points 1 and 2 (Fig. 2.1 and 2.2), but in this case, the plates were situated in free field conditions considering the measurement configurations established in the ISO 11819-4 standard and other research works [29, 33]. Three measurement configurations were considered at points 1 and 2 depending on the distance between the sound source and the microphone: 1 (d=7.5 m), 2 (d=15 m) and 3 (d=30 m). In all measurements, the total vehicle flow was greater than 100.

2.3 Statistical analysis

First, a descriptive analysis was performed. The mean values of the differences between the equivalent sound level recorded by the microphone located on the plate and the one located in free field and 95% confidence intervals for mean were analysed. This study was performed in broadband and one-third octave bands.

The differences between the aluminium and methacrylate plates were then compared by inferential statistics. On the one hand, an analysis of the variance (ANOVA) was performed to compare broadband sound levels obtained for both the cases. On the other hand, a multivariate analysis of variance (MANOVA) was performed for the comparison of one-third octave band sound levels.

3. Results and Discussion

In this section, results obtained through 'in situ' measurements in the four measuring points are provided.

3.1 Urban areas without buildings

3.1.1 Absorbent ground

First, an open urban area without buildings and absorbent ground near the traffic lanes was considered (see Fig. 2.1) to perform the research. The outcomes obtained for broadband at measuring point 1 (Table 1) showed that the difference in equivalent sound levels obtained between microphones placed on plates and in free field conditions was close to 6 dB correction. It can be verified that the value of the differences is similar to that indicated by ISO 1996-2, despite the absence of a rear façade.

	$\Delta L_{EQ\ PLATE-\ FREE\ FIELD}$ (dBA)		
Measure	**Config. 1**	**Config. 2**	**Config. 3**

		(d = 7.5 m)	(d = 15 m)	(d = 30 m)
Aluminium	1	6.03	6.19	5.58
	2	6.08	6.20	5.74
	3	6.15	6.10	5.62
	4	6.03	6.18	5.85
	5	6.10	6.14	5.76
Methacrylate	1	6.01	6.14	5.57
	2	6.04	6.15	5.62
	3	6.02	6.10	5.52
	4	6.06	6.58	5.41
	5	6.09	6.19	5.48

Table 1: Equivalent sound level values measured at point 1

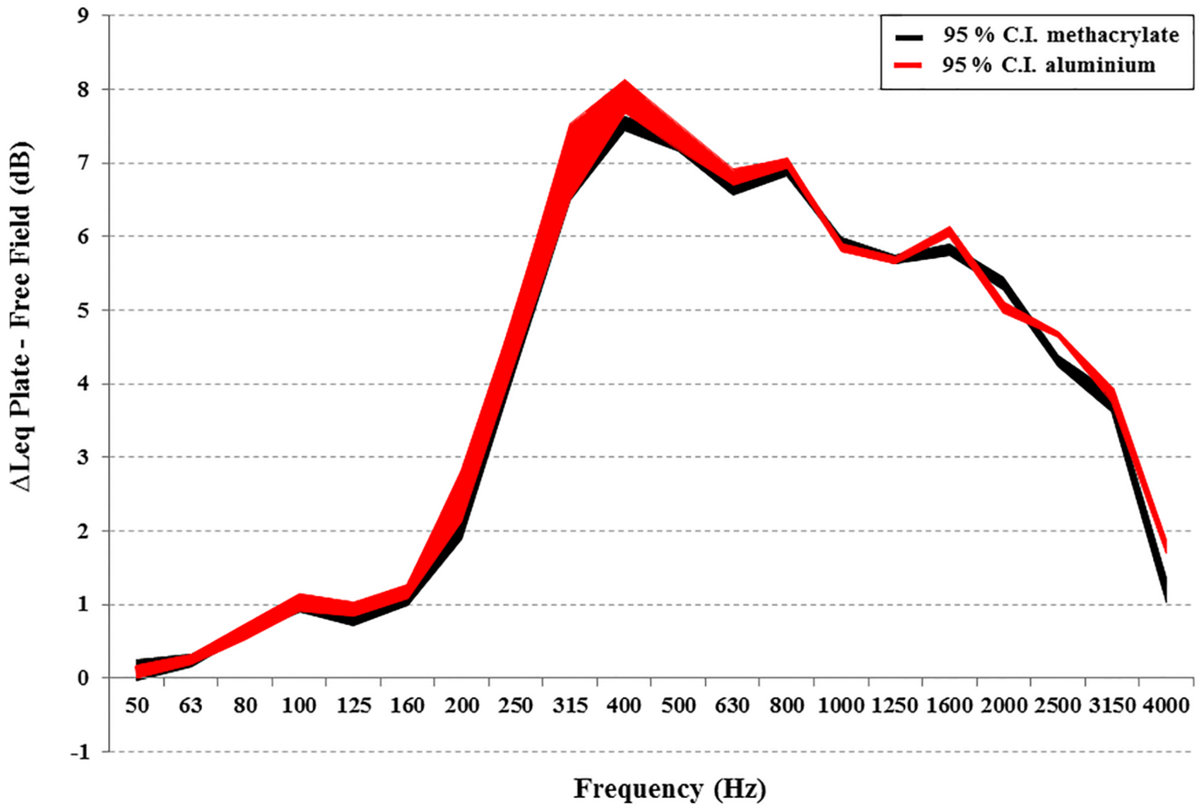
An inferential analysis was performed to compare the differences in equivalent sound level between both the cases (Table 2). Configurations 1 and 2 did not show significant differences between the aluminium and methacrylate plates, while the third configuration presented significant differences. Although in one of the configurations statistically significant differences were found, the value of the differences is very small (0.19 dB). The authors consider that, given the results found in the other two configurations, it does not appear to be an aspect associated with the material but with specific measurement conditions or statistical fluctuations. In fact, despite the significance of this difference, when we analysed the confidence intervals (95%), as indicated in ISO 1996-2, the values of the differences overlapped. May be that this statistical differentiation could disappear with a greater number of measures.

Configuration	**Average ΔLeq ± 95% C.I.**		**T test**	**P-value**
	Methacrylate	**Aluminium**		
1	6.04 ± 0.04	6.08 ± 0.06	- 1.27	> 0.05
2	6.23 ± 0.24	6.16 ± 0.05	0.78	> 0.05
3	5.52 ± 0.10	5.71 ± 0.14	- 3.12	< 0.05

Table 2. Comparison of the average differences for both the materials at point 1.

Annex B of the ISO 1996-2 standard indicates the use of a microphone of 13 mm diameter for measurements directly on the surfaces for a frequency range whose upper limit is 4 kHz. If the frequency exceeded 4 kHz, a 6 mm microphone should be used. Considering that 13 mm microphone was used in the measurements, the spectral results obtained for the three measurement configurations in one-third octave bands between 50 Hz and 4 kHz with a 95% confidence interval are shown in Fig. 3. The values obtained for the difference in equivalent sound level with plates made of methacrylate and aluminium were quite similar. This difference takes values around 6 dB in an approximate range of one-third octave bands between 250 and 3150 Hz. As was expected for low frequencies taking into account the size of the plates, a decrease in the values of differences was observed, as shown in Fig. 3. Although the averaged differences of equivalent sound level obtained in configuration 3 in the methacrylate plate in all frequencies over 1000Hz tend to be lower than in the aluminium plate, in configurations 1 and 2 of this point this only happens above 2500 or 3150 Hz. Furthermore, considering that this behaviour is not noted in any other measurement points and the results of multivariate analysis (Table 3), it does not appear to be associated with the material but with specific measurement conditions or statistical fluctuations.

a)



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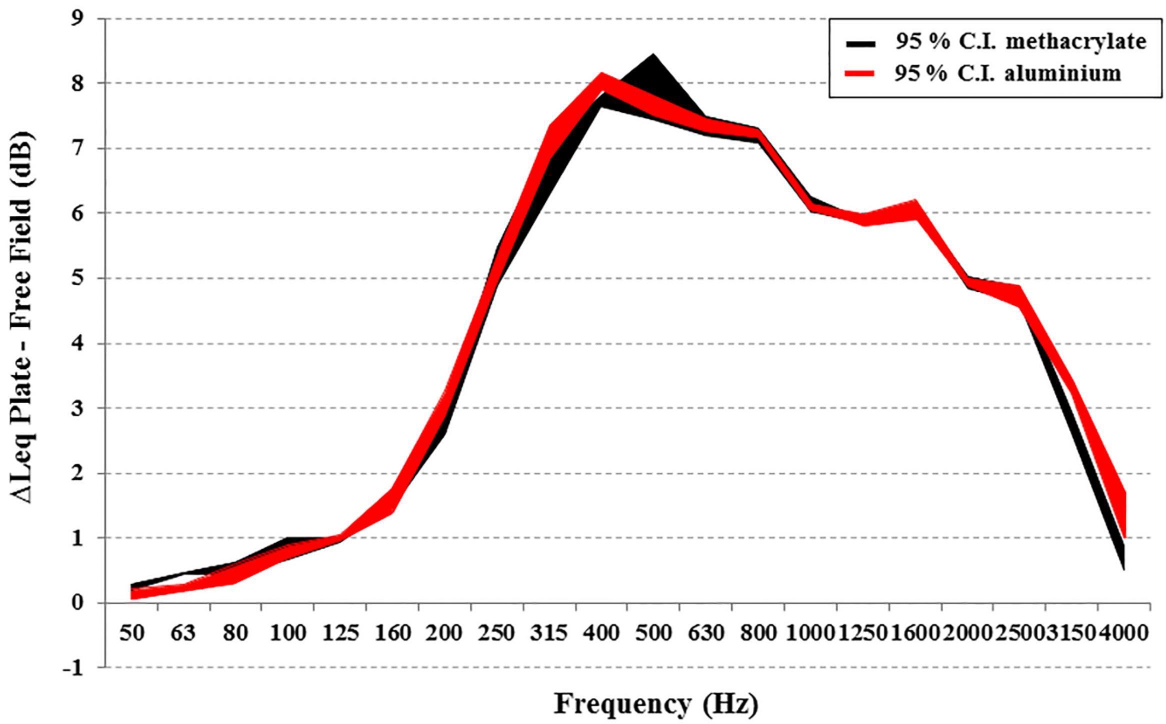
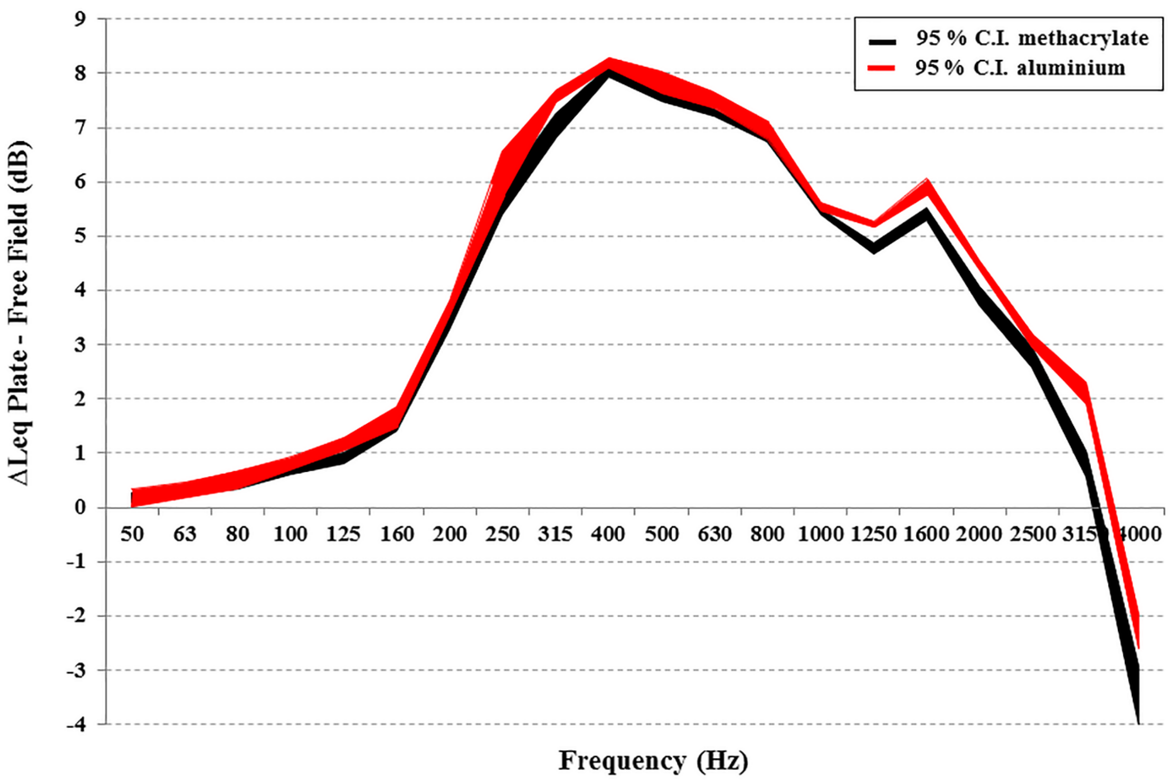


95 % C.I. methacrylate
95 % C.I. aluminium
ΔLeq Plate - Free Field (dB)
9
8
7
6
5
4
3
2
1
0
-1
50 63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000
Frequency (Hz)

c)



95 % C.I. methacrylate
95 % C.I. aluminium
ΔLeq Plate - Free Field (dB)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
50 63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 4000
Frequency (Hz)

Figure 3: Averaged differences of equivalent sound level with 95% confidence interval in one-third octave frequency bands between one microphone placed in free field conditions and the other positioned on a plate made of aluminium or methacrylate at distances of a) 7.5, b) 15 and c) 30 m from the sound source.

Considering a 95% confidence interval, the results obtained with the plates made of methacrylate and aluminium showed an overlap in most of the one-third octave bands, as shown in Fig. 3. In addition, taking into account the multivariate analysis (MANOVA) results shown in Table 3 for the set of the one-third octave bands between 50 Hz and 4 kHz, no significant differences between the two materials were observed.

Configuration	Pillai's value	F	P-value
1	0.96	3.00	> 0.05
2	0.99	17.71	> 0.05
3	0.97	4.71	> 0.05

Table 3. MANOVA of averaged differences in one-third octave bands of both the materials at point 1.

3.1.2 Reflecting ground

At the measuring point with reflecting ground near traffic lanes (see Fig. 2.2), results obtained for a broadband analysis showed values close to 6 dB for the difference in equivalent sound level between microphones placed in free field conditions and directly on the plates made of aluminium and methacrylate in configurations 1, 2 and 3 (Table 4). However, for distances of 15 and 30 m between the sound source and the microphones, a greater variability in the values than that in the previous case was observed (see Table 5).

	Measure	$\Delta L_{EQ\ PLATE-\ FREE\ FIELD}$ (dBA)		
		Config. 1 (d = 7.5 m)	Config. 2 (d = 15 m)	Config. 3 (d = 30 m)
Aluminium	1	5.52	6.67	5.32
	2	5.53	5.59	5.11
	3	5.81	5.97	5.23
	4	6.16	5.69	5.03
	5	5.58	5.81	5.85
Methacrylate	1	5.74	5.78	5.46
	2	5.69	6.75	5.91
	3	5.90	5.97	5.75
	4	5.62	5.84	5.87
	5	5.65	6.00	5.33

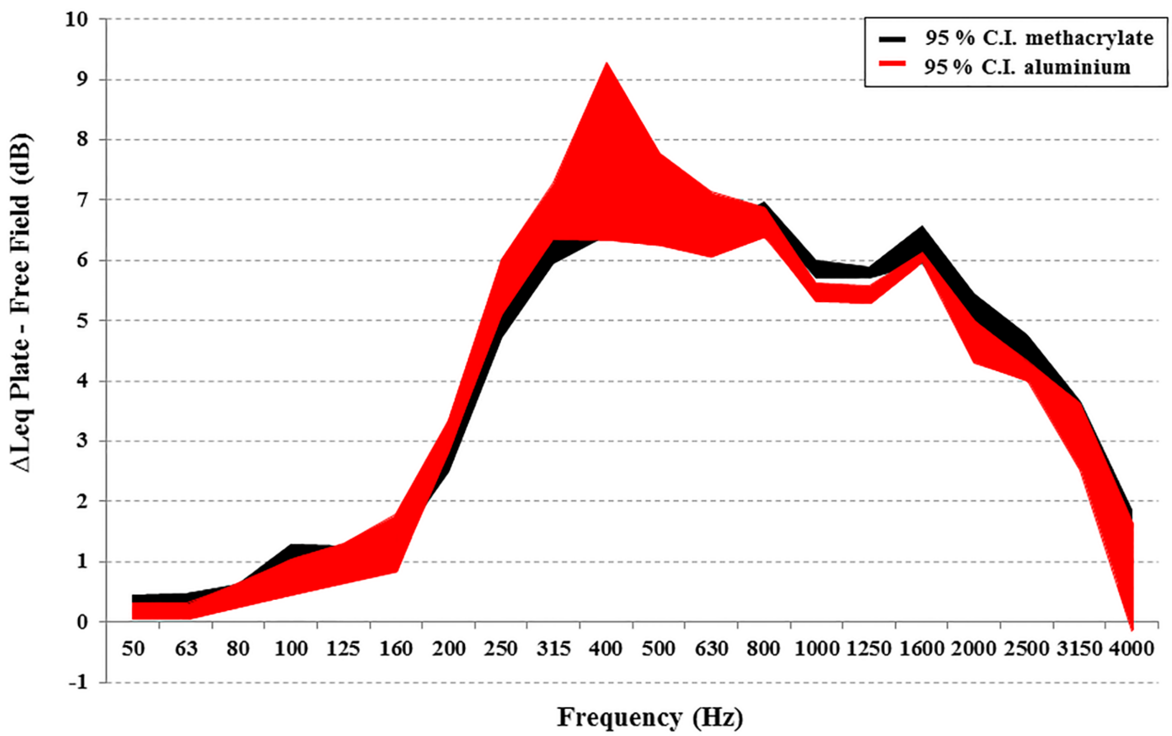
Table 4: Differences in equivalent sound level in broadband at point 2

The results of a descriptive analysis performed for both the materials are shown in Table 5. The table shows that the confidence intervals (95%) for the values of the differences overlap for configurations 1, 2 and 3. In addition, the inferential analysis performed, whose results are presented in Table 5, to compare the differences in equivalent sound level between both the cases did not show significant differences between the aluminium and methacrylate plates. On the other hand, if results of Tables 5 and 2 are compared, a greater variability in the values in point 2 are noted. This fact can be explained because the complexity of an urban environment as point 2 in terms of traffic variability and the presence of other secondary characteristic sound sources of urban environments, whose temporal-spatial location is variable, may introduce a higher variability factor than in an peri-urban environment as point 1 [34,35].

Configuration	Average ΔLeq ± 95% C.I.		T test	P-value
	Methacrylate	Aluminium		
1	5.72 ± 0.14	5.72 ± 0.34	0.00	> 0.05
2	6.07 ± 0.49	5.95 ± 0.53	0.47	> 0.05
3	5.66 ± 0.32	5.31 ± 0.40	1.93	> 0.05

Table 5. Comparison of the average differences for both the materials at point 2.

a)



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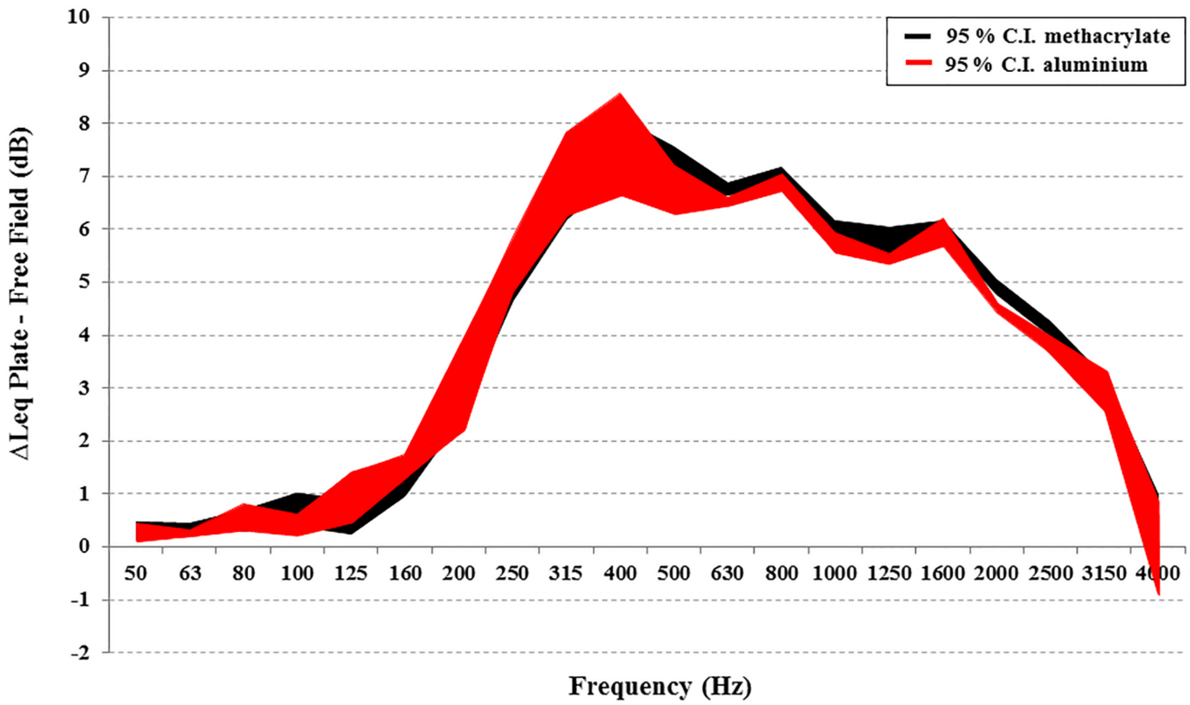

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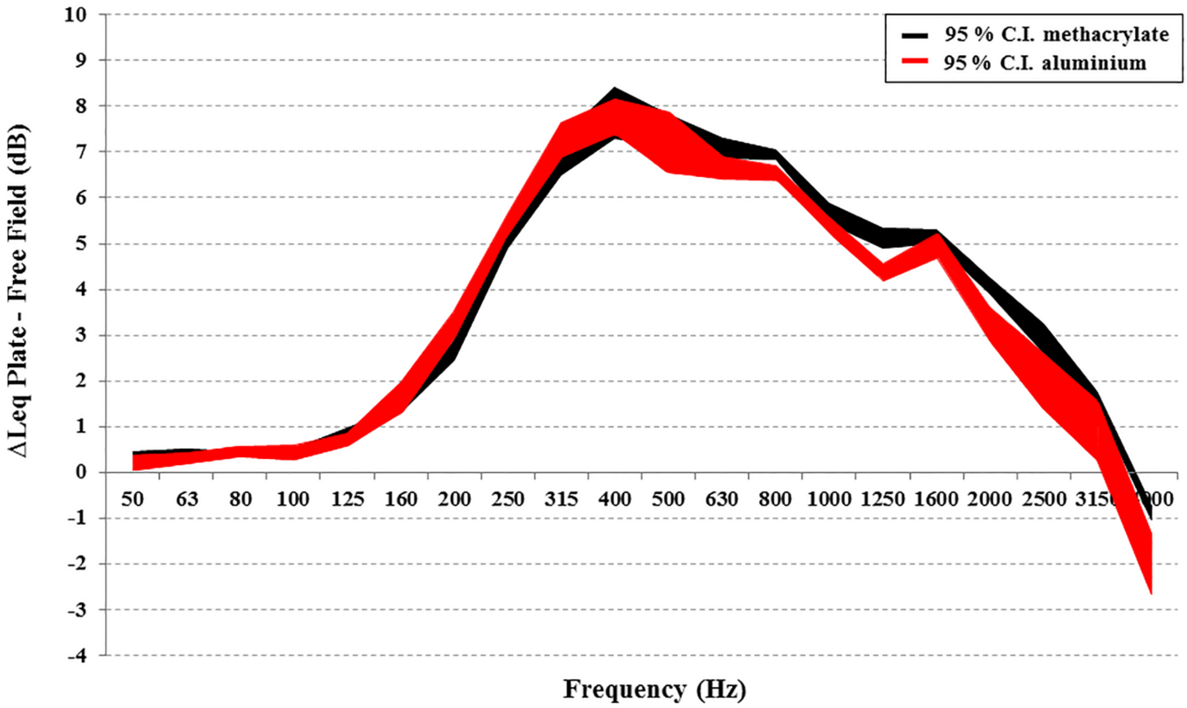


Figure 4: Averaged differences in equivalent sound level with 95% confidence interval in one-third octave frequency bands between one microphone placed in free field conditions and the other positioned on a plate made of aluminium or methacrylate at distances of a) 7.5, b) 15 and c) 30 m from the sound source.

As shown in Fig. 4, the spectral results for the frequency range of 50 Hz to 4 kHz in configurations 1, 2 and 3 had a quite similar shape to those obtained in previous section. They also showed an overlap for both the materials in most of one-third octave bands if a 95% confidence interval is considered. In a similar way, the MANOVA performed for the set of frequency bands showed no significant differences between the two materials (Table 6).

Configuration	Pillai's value	F	P-value
1	1.00	99.70	> 0.05
2	0.99	13.64	> 0.05
3	0.98	4.87	> 0.05

Table 6. MANOVA of averaged differences in one-third octave bands of both the materials at point 2.

3.2 Urban areas with buildings

Streets with urban configurations different from those of points 1 and 2 were considered in this section. As can be seen in Fig. 2.3 and Fig. 2.4, the urban environments at points 3 and 4 contain buildings near the traffic lanes. In this regard, only one measurement configuration was possible at each point (Table 7).

		$\Delta L_{EQ\ PLATE-\ FREE\ FIELD}$ (dBA)	
	Measure	**Point 3** **d = 2.8 m**	**Point 4** **d = 9.6 m**
Aluminium	1	5.15	5.78
	2	5.41	5.60
	3	5.41	5.87
	4	4.97	5.83
	5	5.46	5.77
Methacrylate	1	5.21	5.67
	2	4.78	5.74
	3	5.33	5.85
	4	5.36	5.64
	5	5.13	5.66

Table 7: Differences in equivalent sound level in broadband at points 3 and 4

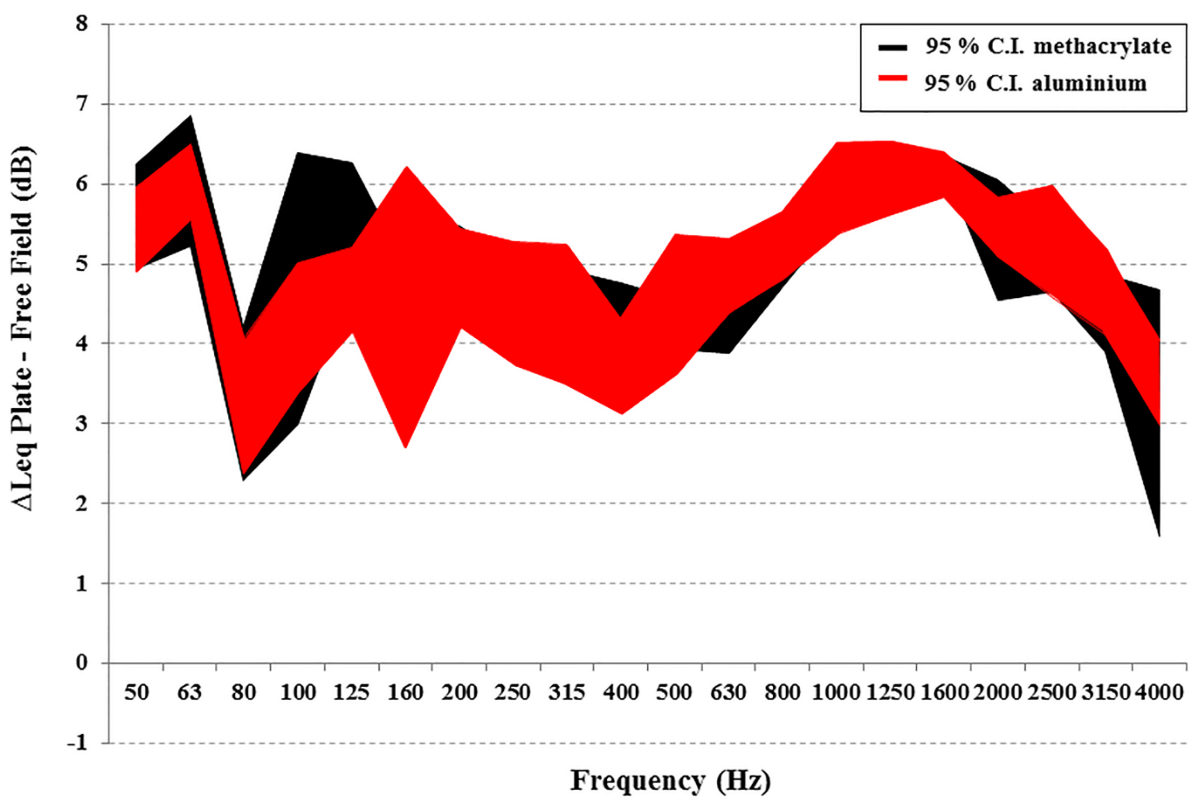
In this case, where the aluminium and methacrylate plates were placed on the façade of building, the confidence intervals (95%) for the values of the broadband differences overlapped for both the materials at points 3 and 4 (see Table 8). In addition, the inferential analysis performed, whose results are presented in Table 8, to compare the differences in equivalent sound level between both the cases did not show significant differences between the aluminium and methacrylate plates.

It is also interesting to note from the descriptive analysis results, as presented in Table 8, that values obtained for the difference in sound levels in broadband differed slightly from the correction of 6 dB proposed by the ISO 1996-2 standard, especially at point 3 where the distance between the sound source and the microphone was smaller. In this regard, it must also be considered that the street of point 3 has buildings on both sides, being an environment in which many reflections of sound waves are generated. Values for differences between approximately 3 and 7 dB were obtained in the range of 50–3150 Hz (Fig. 5). They also seem to show the existence of interference effects between direct and reflected sound waves.

Point	Average ΔLeq ± 95% C.I.		T test	P-value
	Methacrylate	Aluminium		
3	5.16 ± 0.29	5.28 ± 0.26	-0.84	> 0.05
4	5.71 ± 0.11	5.77 ± 0.13	-0.97	> 0.05

Table 8. Comparison of the average differences for both the materials at points 3 and 4.

a)



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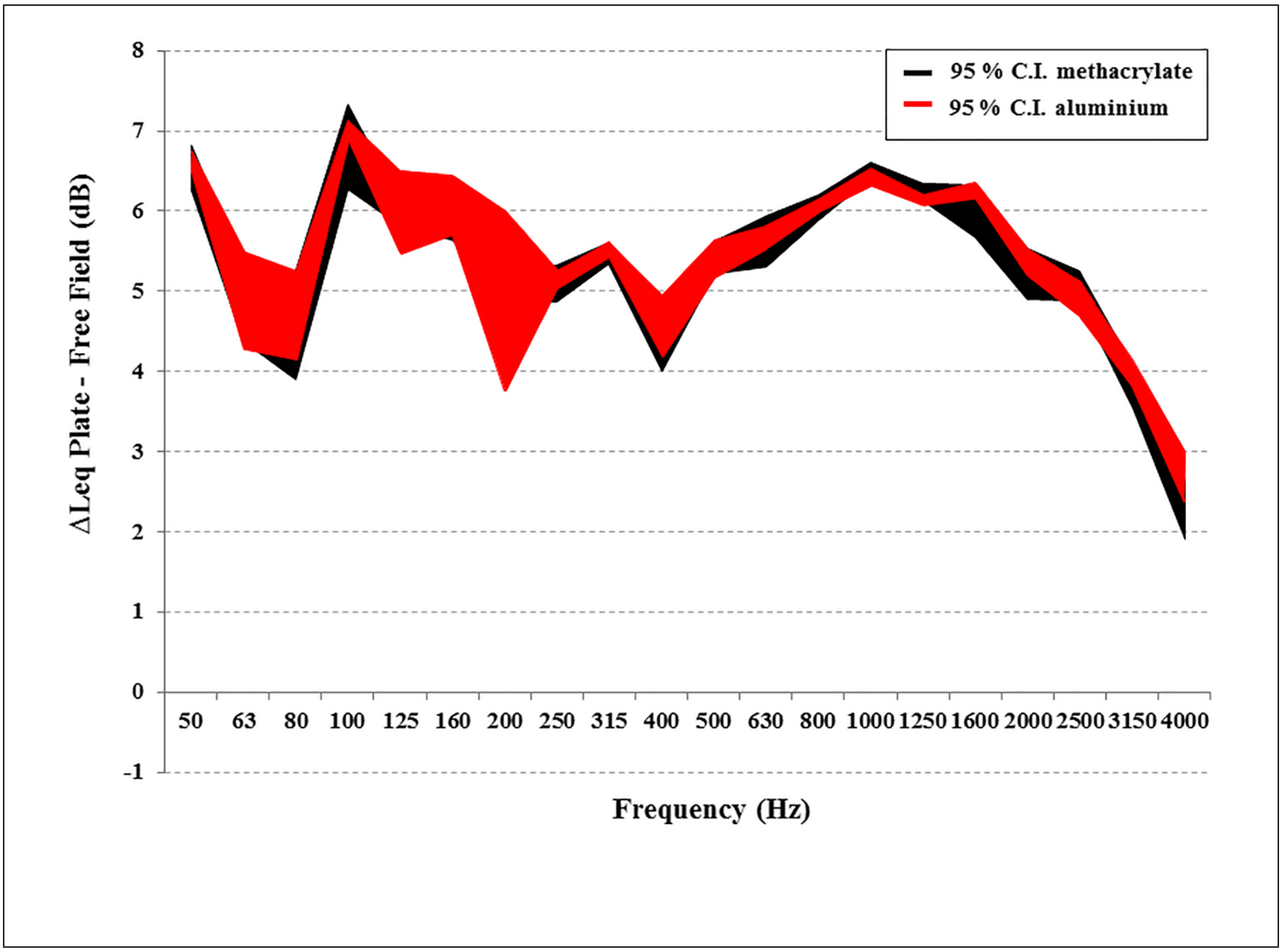

Figure 5: Averaged differences in equivalent sound level with 95% confidence interval in one-third octave frequency bands, with one microphone placed in free field conditions and the other positioned on a plate (on the façade of building) made of aluminium or methacrylate at distances of a) 2.8 and b) 9.6 m from the sound source.

Considering the multivariate analysis results shown in Table 9 that was performed for the set of the one-third octave bands, no significant differences between the two materials were detected.

Configuration	Pillai's value	F	P-value
3	0.99	30.34	> 0.05
4	0.89	1.00	> 0.05

Table 9. MANOVA of averaged differences in one-third octave bands of both the materials at points 3 and 4.

Finally, a comparison of the outcomes obtained for one-third octave frequency bands between those cases where the plate was placed on the façade of a building (points 3 and 4) and those in which it was not (points 1 and 2) showed that there was a significant difference in the values of difference of sound levels for frequencies below 250 Hz. These results agree with the conclusions obtained by Hopkins et al. [24] through measurements in a scale model into a semi-anechoic chamber using a point source. They indicated that the sound pressure level measured in front reflective surfaces varies depending on their size, particularly at frequencies below 300 Hz.

4. Conclusions

A detailed study was conducted on the behaviour of two plates, which were geometrically identical but made of different materials: aluminium, according to the indications of the ISO 1996-2 standard, and methacrylate, much easier to handle, given the important difference in density between both the materials.

The research was developed in two basic and different configurations. In the first one, the behaviour of both plates was studied, with respect to the free field, without the existence of a rear facade. Although these configurations are not included in ISO 1996-2, it is useful for the study of the raised problem and is also a type of configuration used in the ISO 11819-4 standard. Second, all the recommendations of ISO 1996-2 have been strictly followed, both in their normative part and the recommendations contained in Annex B.

Considering the conditions specified in this paper, the results obtained in different measurement configurations show an equivalent acoustic behaviour of plates made of aluminium and methacrylate both in broadband and one-third octave bands. Consequently, the alternative use of a methacrylate plate instead of an aluminium plate for measurements could be considered adequate according to the indications of the ISO 1996-2 standard.

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