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Abstract: When carrying out acoustical measurements in order to construct an urban noise map, the ISO 1996 international standard is usually taken as a reference. However, this standard does not determine the precise location where we should place the measuring equipment. Instead, in some cases the standard offers corrections for the measured sound pressure level to assure reproducibility and comparability in the results. In this paper, we have carried out simultaneous measurements with two sound-level meters to study the effect of varying the location of the measuring equipment in terms of its height and the distance to the rear façade.The results indicate the need to apply some corrections due to reflexions on the façade with lower values than those recommended by the standard. In addition, it has been found necessary to make corrections for the distance to the source. Discrepancies between the standard and the results could be explained by the existence of screening effects associated with the parking lanes.

The influence of microphone location on the results of urban noise measurements

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Abstract

When carrying out acoustical measurements in order to construct an urban noise map, the ISO 1996 international standard is usually taken as a reference. However, this standard does not determine the precise location where we should place the measuring equipment. Instead, in some cases the standard offers corrections for the measured sound pressure level to assure reproducibility and comparability in the results.

In this paper, we have carried out simultaneous measurements with two sound-level meters to study the effect of varying the location of the measuring equipment in terms of its height and the distance to the rear façade.

The results indicate the need to apply some corrections due to reflexions on the façade with lower values than those recommended by the standard. In addition, it has been found necessary to make corrections for the distance to the source. Discrepancies between the standard and the results could be explained by the existence of screening effects associated with the parking lanes.

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1. Introduction

In recent decades, society has become conscious of the drawbacks that modern development has introduced in the daily lives of its citizens. Among these is noise, which is a secondary effect of the important increase in the population of our cities and in the communications necessary between their citizens. Due to its known significant effects on population (Öhrström, 2004; Muzet, 2007; Fyhri and Aasvang, 2010; Gopinath et al., 2011) and considering that noise pollution affects a large part of the world population, noise represents a risk to our health and quality of life (EEA, 2009; WHO, 2011).

Thus, noise must be studied and characterized in order to assist the authorities in protecting the citizens. As the measurement methodology can have an important influence on the noise level measured, standards have been proposed to ensure reproducible and comparable results in the measurements carried out by different technicians or in different locations. In that way, the ISO 1996 standards (ISO 1996-1, 2003; ISO 1996-2, 2007) must be a clear reference. Many studies that use this international standard to measure and assess environmental noise can be found in the scientific literature (Murphy and King, 2010; Mato-Méndez and Sobreira-Seoane, 2011; Gómez Escobar et al., 2012a).

In the ISO 1996-2 standard (ISO 1996-2, 2007) some considerations referring to the location of the microphone relative to reflecting surfaces are included in Annex B. In the standard, no restrictions are given about the distance of the microphone from a reflecting surface. However, because the reflexion of noise from a surface can increase the noise level measured, some corrections in the measured noise levels are proposed as a function of the position of the microphone with respect to the façade of the buildings.

In previous research, some authors have made comparisons between these proposed corrections and the results obtained in actual measurement conditions (Hall, 1984; Quirt, 1985; Picaut et al., 2005; Memoli et al., 2008; Jagniatinskis and Fiks, 2014; Mateus et al., 2015).

First, Hall carried out a study (Hall et al., 1984) regarding the differences between sound pressure levels of traffic noise at 2.0 m from a façade and the sound levels at its surface, for a series of measurements at 33 different houses. It was suggested that a 3 dB correction between measurement locations was appropriate on average.

A subsequent study conducted by Quirt (Quirt, 1985) using two kinds of sound sources, road traffic noise (outdoors) and a loudspeaker (in anechoic room), indicated that in many practical measurement situations, the 3 dB and 6 dB approximations were not appropriated. However, the assumption of energy doubling at 2 m from a building's surface is a reasonable approximation for a distributed source, such as road traffic.

Recently, Memoli (Memoli et al., 2008) studied the corrections for reflections on a façade. The sound levels from microphones placed at distances of 0.5 m, 1.0 m and 2.0 m from the façade wall, mounted directly on the façade wall and placed in free field, were compared for road traffic noise. The differences between the average sound levels obtained from the microphones placed near from façade wall (0.5 m, 1.0 m and 2.0 m) or mounted directly on the façade was 3 dB. These results are similar to the results obtained in Jagniatinskis and Fiks' study (Jagniatinskis and Fiks, 2014) on long-term environmental noise assessment. In the study by Jagniatinskis and Fiks, the microphone near from façade was placed only two metres from the reflecting surface.

Also, in Memoli's study (Memoli et al., 2008), the sound levels obtained from the microphone mounted directly on the façade wall and from the microphone placed in the free field were compared. The façade correction was 5.8 ± 0.9 dB and the inferior limit of this confidence interval coincides with the results obtained in a similar study (Mateus et al., 2015). Mateus et al. indicated that, especially for large distances between the noise source and the receiver, the assumed value of 6 dB might introduce significant errors in the results.

The studies by Jagniatinskis (Jagniatinskis and Fiks, 2014) and Mateus (Mateus et al., 2015) only evaluate the corrections of a microphone mounted directly on the façade wall at distances of 150 m and 250 m from road traffic noise sources respectively. Relative to the urban forms of southern European cities (narrow streets, reflective façades, construction density, etc.), the façades are closer to road traffic noise sources, and this feature could influence the sound propagation in urban areas. In relation to this topic, Picaut analyses in an experimental work (Picaut et al., 2005) how the sound is propagated in an urban street using an impulsive sound source, reaching the conclusion that the sound field is uniform within a cross section of the street.

Moreover, the ISO 1996-2 standard (ISO 1996-2, 2007) provides different possibilities as to the height at which you can place the microphone to make noise maps. However, it makes no mention as to the corrections to be applied in each of these cases, nor does the European Directive (COM, 2002).

In connection with this issue, different studies (Rey Gozalo et al., 2013, 2014) use the corrections proposed by the French standard "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores" (CETUR, 1980) and ISO 9613-2 standard (ISO 9613-2, 1996) in order to normalise the acoustic long-term measurements performed on balconies of dwellings situated at higher altitudes to four metres.

The aim of the present work is to study the differences that may exist between the values of the sound levels measured outdoors with the measuring equipment in different positions with regard to the façade or the ground. Accordingly, we analyse the necessary corrections to ensure reproducible and comparable results in the urban noise measurements carried out by different technicians or in different locations.

For this work, six different locations were chosen in the city of Cáceres (Spain), all of them different with respect to the street and traffic flow characteristics. The measurements were carried out simultaneously with two sound-level meters to analyse the ISO 1996-2 corrections. To that end, measurements were performed at different distances from the façade (0 to 3.0 meters) and at different heights (1.2 to 6.0 meters) to study the effect of outdoor reflexion.

Section 2 describes the methods used. Section 3 presents the results and discussion. Finally, Section 4 gives the principal conclusions of the study.

2. – Methods

2.1.- Sampling points selection

For the purpose of the present study, sampling locations were selected throughout the city of Cáceres (Spain). In previous studies, information about the acoustical levels in both the historic centre and the entire city can be found (Barrigón Morillas et al., 2002; Barrigón Morillas et al., 2005; Gómez Escobar et al., 2012b; Rey Gozalo et al., 2014).

In the selection of the sampling points we pay special attention to the considerations of Annex B of the ISO 1996-2 standard (microphone positions from reflective surfaces) with regard to the following:

– Size and structural features of the façade: the objective is to prevent, among other problems, multiple reflexions and diffraction effects. The façade had to be flat for at least one metre around the microphone that was flush mounted on the reflecting façade (i.e., no balconies or wires, which can be found at a 4 m height in most buildings). Moreover, if the microphone is used without a mounting plate, the façade must be built of concrete, stone, glass, wood or other similar hard materials.

– Microphone position with respect to the reflecting surface: this Annex sets the minimum distance between the projection of the measuring point on the reflective surface and the edges thereof depending on the distance of the measuring point to the façade and the height at which the microphone is placed.

– Viewing angle over the sound source. In our case, being an extended source, the viewing angle was 60° or greater.

Additionally, other considerations were taken into account, such as the length of the pavement, the road traffic as the primary sound source, the variability in the urban structure, the number of lanes and the absence of panels.

It was not an easy task to keep in mind all of the above considerations when selecting the sampling points because of the shape of Mediterranean cities (narrow streets, density of construction, presence of large balconies, etc.) and the wide range of sound sources due to the great amount of human activity associated with good climatic conditions.

Considering all of the above factors, six different locations were chosen. Figure 1 shows the selected points on the map of Cáceres, and Figure 2 shows the sketch thereof. The façades where the measures were performed are flat, without protruding elements next to the microphones. These surfaces are built with different hard materials, such as concrete, stone, marble and bricks, and they meet the requirements established in Annex B of the ISO 1996-2 standard for features of façades.

2.2. - Measurement procedure and equipment

Three groups of measurements were carried out in each of the selected locations and two sound-level meters were simultaneously used in each measure group (Table 1). In the first two measurement groups, A and B, one of the sound-level meters stayed in a fixed position, the fixed sound-level meter (Sr), at two meters from the back façade (the limiting distance to consider correction in the measured levels according to the ISO 1996-2), whilst the position of the other, the mobile sound-level meter (Sm), varied perpendicularly to the façade and parallel to the fixed sound-level meter (Sr). Measurements were performed with the mobile sound-level meter at distances of 0, 0.5, 1.2 and 3.0 meters relative to the façade. Measurements were carried out at heights of 1.5 and 4.0 meters. Figure 3a shows the microphones location of the A and B measurement groups.

In the third measurement, group C, the fixed sound-level meter (Sr) remained at a distance of three meters from the back façade and at a height of four meters, whilst the height of the mobile sound-level meters (Sm) varied. Measurements were performed with the mobile sound-level meter at heights of 1.2, 1.5, 2.5 and 6.0 meters. Figure 3b shows the microphones location of the group C.

Taking into account the results of the work done by Memoli et al. (Memoli, et al., 2008) and the directionality diagrams of the microphone used (model 4950 Brüel&Kjaer), the measurements at a distance of zero meters were performed by placing the sound-level meter so that it leaned on and was parallel to the façade, but a plate was not used to affix the microphone to the façade.

Simultaneous measurements were carried out for a period of 15 minutes for each configuration, with an integration time of 1 second and 1/3 octave bands from 50 to 10000 Hz. For each measurement, the volume of traffic was visually determined and classified (cars, heavy vehicles, and motorcycles) during sampling. Other relevant information (noise sources, meteorological conditions, street dimensions, road surface type, condition of the road surface, etc.) was also noted.

All measurements were performed using two 2250L Brüel&Kjaer type I sound-level meters equipped with windshields and mounted on two tripods at heights of 1.5 and 4.0 meters. For measurements at a height of 6.0 metres an extension pole was used. Calibration was performed using a 4231 Brüel&Kjaer type I calibrator.

2.3.- Analysis methodology

As stated above, six locations were selected. As shown in Table 1 and Figure 3, the three measurement groups (A, B and C), with four configurations each, resulted in a total of 12 pairs of measurements (Sm and Sr) made at each location during each measurement campaign. Because 12 campaigns were performed, the study consists of 144 pairs of measurements, each for a duration of 15 minutes.

The equivalent sound level (broadband and third octave), recorded with an integration period of 1 second, showed differences between each of the two sound-level meters (Sm and Sr). For example, in Figure 4, the detection of this effect can be observed. Therefore, the main objective of this study was to analyse the differences among each of the configurations of groups A, B and C.

One aspect that is considered in the study is that the variation in the distance from the façade or the variation in the height at which the mobile sound-level meter (Sm) is placed is also a variation of the distance to the main source of noise, the road traffic, with respect to the fixed sound level meter (Sr). For this reason, even though the ISO 1996-2 standard (ISO 1996-2, 2007) or the European Directive (COM, 2002) do not come into consideration this fact, it was considered of interest to apply a correction due to the distance to the linear source (Harris, 1998). In this way, we aimed to eliminate the effect that varying the distance from the source has on the measured value. It is hoped that with this procedure, the cause of the differences that can be measured between the reference sound-level meter and the mobile one is only the reflexion of the sound wave from the back façade.

Considering the above information, the differences between each sound-level meter of the couple (Sm, Sr) in each of the configurations for groups A, B and C were analysed using two different methods:

1. Using the measured noise values (without normalization of distance to the sound source).
2. Correcting, by geometrical divergence, the values measured by mobile sound-level meter (Sm) to normalize them to the distance of the reference sound-level meter (Sr). In this study, it was considered that the linear sound source is located in the centre of the street´s set of lanes. The expression used to obtain the equivalent sound level with sound source normalisation was as follows (Embleton, 1996):

$$Leq\ (Sm)_n = Leq\ (Sm) + 10 \cdot log\left(\frac{r_2}{r_1}\right)\ [dB] \quad (1)$$

Where:

- $Leq\ (Sm)_n$ is the normalised equivalent sound level of the mobile sound-level meter.
- $Leq\ (Sm)$ is the measured equivalent sound level of the mobile sound-level meter.

– r_2 is the distance from the mobile sound-level meter to the sound source.

– r_1 is the distance from the fixed sound-level meter to the sound source.

Based on these differences (Sm, Sr), an average value was obtained for each of the configurations for each group. These mean values were compared with the corrections proposed by the ISO 1996-2 standard (ISO 1996-2, 2007) but were also analysed with inferential statistical procedures. For this, the Wilcoxon signed-rank test (Wilcox, 1945; Mann and Whitney, 1947) was applied. This nonparametric test was used instead of a parametric test, as the small number of samples meant that the normality of the data was doubtful. This test determines whether the average values of the Sm-Sr difference does not differ significantly from zero. If there is no significant difference, it is assumed that there is no significant effect of the reflected waves from the back façade on the sound values recorded by the mobile sound-level meter with respect to the fixed meter.

3. - Results and discussion

As stated below, the results are shown as a function of the measurement groups A, B and C. In each of these groups, we analysed first the differences in the mean values of the bandwidth equivalent sound level and then the differences in the mean values per octave bands frequency.

3.1. - Measurements made at 1.5 m height (Group A)

In Table 2 are shown, for each of the four measurement configurations, the mean values of the differences and the standard error obtained in the measurements performed with the two sound-level meters.

If we look at the column showing the differences without normalizing for distance from the sound-level meter to the sound source, we see that the values obtained contrast sharply with the corrections recommended in the ISO 1996-2 standard. In fact, even the sign of the correction, except for that of configuration 1, is different from that expected based on the existence of a reflexion effect of the sound field from the back façade.

However, if we analyse the results shown in the column in which we make the normalization, we see that the signs of all of the corrections are consistent with what one would expect of the existence of a reflexion effect from the façade, i.e., positive values for measurements performed with the mobile sound-level meter close to the façade (Conf. 1, 2 and 3) and negative values otherwise (Conf. 4). This result suggests the need to apply this type of normalization to obtain a measurement value relative to 2.0 m of the façade. However, even with this normalization, the results show corrections for reflexions from the façade that are very different from those recommended in the ISO 1996-2 standard.

Therefore, according to these results, if we try to show measured sound level values that are comparable between different measuring points whilst using 2.0 m as a reference distance, we must make corrections not only for reflexions from the façade but also for the distance to the sound source.

Next, we analysed the statistical significance of the differences obtained from the results of the measurements performed with the mobile and reference sound-level meters, in the case of both non-normalized and normalized data. For this, we used the Wilcoxon signed-rank test, in which we compare this difference with the null value.

We note in Table 2 how in the case of non-normalized measurements, there are significant differences in the results for the four configurations. However, we must emphasize that as we have explained before, not only do the values of the differences not match those specified in the standard, but these values are also not consistent with the existence of reflexion effects from the façade.

In contrast, consider the case of the normalized measurements, in which the results are consistent with the presence of reflexions from the rear façade. Here the differences are significantly different from zero only in the single configuration in which the mobile sound-level meter is placed at 0 m from the façade. In the other three configurations, the mean values of the differences are near the null value without significant differences.

Therefore, according to the results obtained when measuring actual conditions, on average, it is appropriate to apply corrections for reflexion from the back façade only when a measurement is made very close to a wall. In addition, the average value of the correction for façade reflexions obtained is 1.7 dB, which is much lower than the 6 dB specified in the standard.

To look for possible causes of these results, we made an analysis of the measurements in frequency octave bands. Table 3 shows the mean values of the differences between the measurements realized with the two sound-level meters in the four configurations and the significance of these mean values with respect to the null value, as determined using the Wilcoxon signed-rank test.

We see that in Table 3, for configurations 1 and 2, all octave bands show significant differences when we do not make corrections for the distance to the source, although in many of them, the signs of the corrections are not consistent with the existence of a reflexion effect from the façade. However, when we make a correction for the distance to the source, this does not happen. This is because the difference in these bands between the values measured by the mobile and reference sound-level meters is very close to the null value. It is interesting to see how, for configuration 1, in the bands 63 Hz, the difference between the sound-level meters has a value close to 5 dB, and until the band at 500 Hz, this difference approaches or exceeds 3 dB. Conversely, in configuration 2, in the bands of 63 Hz, the difference is approximately 4 dB, and from the 250 Hz band, the differences are close to zero and are not significant.

Furthermore, the overall results are not very conclusive for configurations 3 and 4. However, as seen in most of the bands, the possible corrections that can be made due to reflexions from the façade are close to null.

Thus, as shown in the ISO 1996-2 standard, the consideration of a reference distance to the façade is essential so that the results of the measurements under certain conditions may be comparable to those measured in other parts of a city or in different cities under other conditions. However, according to the results obtained, the correction values for reflexion, with a measurement height of 1.5 m and under actual measurement conditions in urban areas, are less important than those recommended. Additionally, to obtain comparable results between different conditions and measurement points, it has been found necessary to normalize the data with respect to the distance between the measuring point and the sound source.

Looking at the results for the octave bands analysis, the corrections for reflexion from the façade are close to those indicated by the standard only for the very low frequency of 63 Hz and for measurements at 0 m and 0.5 m. In contrast, for measurements at 1.2 m from the façade, even at a frequency of 63 Hz, the results are far removed from those recommended.

These results can be understood if we consider the possibility that under normal measurement situations in urban areas, a screening effect may occur that is associated with the presence of parking lanes in many of the streets of the city.

3.2. - Measurements made at 4.0 m height (Group B)

Table 2 shows the average values and the standard error for the differences between the measurements carried out with the two sound-level meters in four configurations at a height of 4.0 m.

If we look at the differences with and without normalization for the distance from the mobile sound-level meter to the sound source in Table 2, we observe that the values obtained contrast sharply with the corrections recommended in the ISO 1996-2 standard. In this case, in terms of the consistency of signs, only in configuration 4 for the measurements without normalization do we see an unexpected value. However, in all cases, normalization with respect to the distance to the source means an approach of the results to the recommendations of the standard. This fact, again, seems to indicate the need for this type of normalization in order to obtain a measurement value based on a reference distance of 2.0 m from the façade.

It is interesting to note in these results that the values obtained are clearly superior to those shown in the previous section for a measurement height of 1.5 m above the ground. Even if we analyse the significance of the differences between the results of the measurements with the mobile sound-level meter and the reference meter using the Wilcoxon signed-rank test, as shown in Table 3, we find new significant differences with respect to the null value for configurations 2 and 3 of the normalized data. Therefore, only in configuration 4 are the differences not significantly different with respect to the null value.

Thus, according to the results obtained under actual measurement conditions, on average, for a measurement height of 4 m, we find that for the three configurations of the measuring equipment, corrections are necessary for reflexion from the façade only within 2.0 m of the wall. The mean value of the correction for reflexion from the façade determined at 0 m is 2.6 dB, which is much lower than the 6 dB specified in the standard. The average values determined for 0.5 m and 1.2 m, respectively, are 1.1 and 0.5 dB. These are well below the 3 dB specified in the ISO 1996-2 standard.

However, if we compare the corrections found at heights of 4.0 m and 1.5 m, we see that in all cases in which the measurement is made closer to the façade, the corrections increase and are closer to the recommended in the ISO 1996-2 standard. Conversely, for the measurements at 3.0 m from the reflecting surface, the effect of the façade does not seem to indicate its detection. Thus, according to these results, measurements at 2.0 m of the façade are not significantly affected by reflexions.

Then, as was done for measurements at 1.5 m, this study of the differences between the sound-level meters was analysed in frequency octave bands. Table 3 shows the average values of the differences in octave bands between measurements carried out with the two sound-level meters in four configurations at a height of 4.0 m and the significance of these mean values with respect to the null value determined using the Wilcoxon signed-rank test.

If we look at configuration 1 in Table 3, we observe significant differences until we reach the 1 kHz band, with values of the differences between the mobile sound-level meter and the reference one close to or greater than 3 dB. Those bands without significant differences have values near zero for these differences. It is interesting to see how in the 63 Hz band, the difference between the sound-level meters has a value close to 6 dB, which is indicated by the ISO 1996-2 standard.

In configuration 2, significant differences appear in almost every band with values between 1 and 2 dB, while the value of the correction at 63 Hz band is close to 5 dB. This means that a coherent summation effect is detected at this frequency.

In configuration 3, we also observed significant differences in some octave bands, although these were generally lower than 1 dB. However, in the 63 Hz band, the difference is nearly 2 dB. This results, therefore, in a value relatively close to that indicated by the standard for broadband measurement.

In contrast, in configuration 4 it can be seen that, as in most bands, the corrections obtained due to reflexions from the façade are close to null.

Therefore, as we observed in the outcomes obtained for a measuring height of 1.5 m, considering a measurement height of 4.0 m and actual measurement conditions in urban areas, the values of the correction due to reflexions have values lower than recommended according to our results. Additionally, it has been found necessary to normalize the data with respect to the distance between the measuring point and the sound source just as in the case of measurements at 1.5 m. This is so we can achieve comparable results between different conditions and measurement points.

However, it is necessary to highlight the differences between the results obtained for the series of measurements carried out at 1.5 m and at 4.0 m. In broadband, as shown in Table 2, the results for configurations in which the mobile sound-level meter is at a distance of less than 2.0 m from the wall lead us to consider the need to make corrections by reflexions on the façade in all cases for measurements at a height of 4.0 m, even though the values are still lower than those indicated by the standard. If we consider the results by octave bands, as shown in Table 3, we observe that the corrections obtained for 4.0 m at low frequencies are quite close to those indicated by the standard for broadband, and we find a higher number of bands in the mid and high frequencies where significant differences from the null value appear.

These results are consistent with the assumption indicated in the previous section about the possible existence of screening effects due to vehicles parked on the streets. This screening effect should diminish as we approach the façade or as we increase the height of the measurement.

As we indicated at the beginning of the study, the ISO 1996-2 standard and the European Directive (COM, 2002, ISO 1996-2, 2007) offer the possibility of performing measurements at heights of 1.5 m and 4.0 m, but they do not indicate any necessary corrections. This suggests that there are no significant differences. In accordance with the differences obtained in the previous analysis of measurements at 1.5 m and 4.0 m, this does not seem to happen; therefore, a more detailed study was conducted to analyse the influence of height in sound level values. The results are shown in the following section.

3.3. - Measurements made at 3.0 m from the façade (Group C)

For this study on the influence of the values of noise levels with respect to the variation in height, the fixed and mobile sound-level meters were placed at a distance of 3.0 m from the façade. The fixed sound-level meter was placed at a height of 4.0 m, and the mobile meter was placed at heights of 1.2, 1.5, 2.0 and 6.0 m, corresponding to configurations 1 to 4 (Group C). Table 2 shows the average values and the standard error for the differences in bandwidth between the measurements made with the two sound-level meters in the four configurations at a distance of 3 m from the reflecting surface.

According to the results shown in Table 2, if we first consider the column of differences without any normalization with respect to the distance from the sound-level meter to the source, we observe that the obtained values have different signs than are expected if we consider only the proximity to the source as we decrease the measurement height. If we normalize the data with respect to the distance to the source, using 4 m as a reference height, this phenomenon not only remains unchanged but also increases. Let us recall that the measuring equipment, on average, has measured a higher value as the height increases, which means a greater distance to the source. Moreover, if we analyse the significance of these differences between the mobile and reference sound-level meters, as shown in Table 2, all of the differences are significant with respect to the null value in the case of the normalized results in terms of the distance to the source.

Then, to study in more detail the differences in broadband and to analyse the causes, we analysed the mean values of the differences and their significance in octave bands. The results are shown in Table 3.

Based on the results shown in Table 3, we observe that there is a transition frequency corresponding to the 250 Hz band. For frequencies below this value, the screening effect is expected to be of little importance. This is consistent with the results obtained. Notice that for these bands, the lowest sound-level meter shows corrections with signs matching those expected with physical phenomena associated with the greater effect of a reverberant field. However, for frequencies above 250 Hz, the screening effects are important, and the sound-level meter that is placed at a greater height registers higher values of sound levels. This fact is maintained even for the comparison between the measurement configuration at heights of 4.0 and 6.0 m, although for many of the bands, the differences between the two measuring devices are not significantly different from zero.

Therefore we believe that the increase in height results in a decrease in the possible screening effect associated with parking lanes that often exist in most of the streets of our cities. This effect, which we have shown in previous measurement groups to explain the results, seems to be confirmed in this section. Considering this fact, it implies the need for the design of a good measurement protocol in cities to obtain results that can be normalized with respect to a distance to the façade or that are comparable with those at different measuring points. It also indicates that it is quite possible that the results obtained by the simulation software did not take into account these effects.

To better understand the effects we observed, it would be necessary to make accurate simulations of the behaviour of the sound field using methods such as the boundary elements method (BEM) or the method of fundamental solutions (MFS).

4. - Conclusions

For normal measurement situations in urban areas, in terms of meeting the requirements specified by the ISO 1996-2 standard in Annex B, we have studied the necessary corrections that must be made in order for the measurements carried out at different equipment positions with respect to the façade to be comparable between different measurement points.

To study the effect of reflexion from the façade, a reference distance to the façade of 2.0 meters has been considered, and to study the effect of measuring at different heights above the ground, a reference height of 4.0 m has been considered. The obtained values were compared with the values of the sound levels recorded in the mobile sound-level meter, which was located at a distance between 0 m and 3.0 m from the façade and at a height between 1.2 m and 6.0 m. The mean values of the differences between broadband and octave bands noise levels registered in the two sound-level meters were analysed descriptively and inferentially using the Wilcoxon signed-rank test. These analyses have shown the following:

- The consideration of a reference distance to the façade, as indicated by the ISO 1996-2 standard, is essential so that the results of the measurements under certain conditions may be comparable to those measured in other places or under other conditions.
- To compare the results of noise measurements in different urban environments and at different distances from the façade, it is suitable to make corrections not only for reflexion on the façade but also due to the distance from the measuring equipment to the sound source.
- Even considering both effects, the values of correction for reflexion from the façade obtained for the heights of 1.5 m and 4.0 m are lower than those proposed by the ISO 1996-2 standard. It was verified that corrections are needed for distances from the measuring point to the façade below 2.0 m if the measurement height is 4.0 m, but for a height of 1.5 m, corrections are needed only for a measurement on the façade.
- The octave bands analysis of the mean values of the differences among noise levels demonstrates the existence of a screening effect for the sound waves with wavelengths approximately less than or equal to the characteristic size of a vehicle. This may be an important reason that the corrections that apply to façade reflexion in the measurements in the existing urban environment in a city

are lower than those indicated by the ISO 1996-2 standard. This screening effect decreases as we approach the façade and, significantly, the height increases.

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TABLE CAPTIONS

Table 1.- Summary of the different pairs of measurements performed.

Table 2.- Mean values, standard error and significance of mean values (Wilcoxon signed-rank test) for the differences in bandwidth between the measurements made with the two sound-level meters in four configurations at a height of 1.5 m and 4.0 m and at a distance of 3.0 m. The symbols (*), (**), (***) indicate the level of significance of the differences ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively). (n.s.) indicates a non-significant difference ($p > 0.05$).

Table 3.- Mean values of the differences in octave band frequency between the two sound-level meters in four configurations for three measurement group (A, B and C) and the significance of these mean values with respect to the null value, as determined using the Wilcoxon signed-rank test. The symbols (*), (**), (***) indicate the level of significance of the differences ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively). (n.s.) indicates a non-significant difference ($p > 0.05$).

	Group A		Group B		Group C	
	Height: 1.5 m		**Height: 4.0 m**		**Distance to façade: 3.0 m**	
	Distance to façade (m)		**Distance to façade (m)**		**Height (m)**	
Configuration	**Mobile (Sm)**	**Fixed (Sr)**	**Mobile (Sm)**	**Fixed (Sr)**	**Mobile (Sm)**	**Fixed (Sr)**
1	0	2.0	0	2.0	1.2	4.0
2	0.5	2.0	0.5	2.0	1.5	4.0
3	1.2	2.0	1.2	2.0	2.5	4.0
4	3.0	2.0	3.0	2.0	6.0	4.0

Table 1

Group	Configuration	Distance/ Height (m)		$\bar{x}\,[Leq(Sm) - Leq(Sr)] \pm \sigma_{\bar{x}}$ (dBA) (p-value)	
		Mobile (Sm)	Fixed (Sr)	Without sound source normalization	With sound source normalization
A (Height: 1.5 m)	1	0	2.0	1.1 ± 0.1 (***)	1.7 ± 0.1 (***)
	2	0.5	2.0	-0.4 ± 0.1 (***)	0.1 ± 0.1 (n.s.)
	3	1.2	2.0	-0.2 ± 0.0 (***)	0.1 ± 0.1 (n.s.)
	4	3.0	2.0	0.3 ± 0.1 (**)	-0.1 ± 0.1 (n.s.)
B (Height: 4.0 m)	1	0	2.0	2.0 ± 0.2 (***)	2.6 ± 0.2 (***)
	2	0.5	2.0	0.6 ± 0.2 (*)	1.1 ± 0.2 (**)
	3	1.2	2.0	0.3 ± 0.1 (**)	0.5 ± 0.1 (**)
	4	3.0	2.0	0.2 ± 0.0 (***)	-0.1 ± 0.0 (n.s.)
C (Distance to façade: 3.0 m)	1	1.2	4.0	-0.7 ± 0.2 (**)	-0.9 ± 0.2 (**)
	2	1.5	4.0	-0.8 ± 0.3 (*)	-1.0 ± 0.3 (**)
	3	2.5	4.0	-0.2 ± 0.1 (*)	-0.4 ± 0.1 (**)
	4	6.0	4.0	0.4 ± 0.2 (n.s.)	0.7 ± 0.2 (*)

Table 2

Group	Height (m)	Distance to façade (m)	Configuration		$\bar{x}[Leq(Sm) - Leq(Sr)]$ (dB) (p-value)							
					Frequency (Hz)							
					63	125	250	500	1000	2000	4000	8000
A	1.5	0	1	Without normalization	4.12 (***)	2.82 (***)	2.81 (***)	2.11 (***)	0.90 (*)	-0.89 (***)	-0.53 (**)	-1.88 (***)
				With normalization	4.76 (***)	3.46 (***)	3.45 (***)	2.75 (***)	1.53 (**)	-0.25 (n.s.)	0.11 (n.s.)	-1.24 (**)
		0.5	2	Without normalization	3.31 (***)	1.00 (***)	-0.88 (**)	-0.29 (*)	-0.35 (*)	-0.38 (**)	-0.67 (**)	-0.73 (**)
				With normalization	3.80 (***)	1.49 (***)	-0.39 (n.s.)	0.19 (n.s.)	0.13 (n.s.)	0.11 (n.s.)	-0.18 (n.s.)	-0.24 (n.s.)
		1.2	3	Without normalization	0.58 (n.s.)	-0.96 (*)	0.30 (n.s.)	-0.29 (***)	-0.24 (***)	-0.08 (n.s.)	-0.42 (**)	-0.60 (**)
				With normalization	0.85 (**)	-0.70 (n.s.)	0.57 (*)	-0.02 (n.s.)	0.03 (n.s.)	0.19 (**)	-0.15 (n.s.)	-0.33 (*)
		3.0	4	Without normalization	1.98 (***)	-0.52 (**)	0.37 (**)	0.15 (n.s.)	0.28 (**)	0.41 (**)	0.34 (**)	0.30 (n.s.)
				With normalization	1.61 (***)	-0.89 (***)	0.01 (n.s.)	-0.22 (*)	-0.08 (n.s.)	0.04 (n.s.)	-0.03 (n.s.)	-0.06 (n.s.)
B	4.0	0	1	Without normalization	5.12 (***)	3.21 (***)	3.71 (***)	3.27 (***)	2.18 (***)	-0.03 (n.s.)	-0.05 (n.s.)	-0.38 (n.s.)
				With normalization	5.70 (***)	3.80 (***)	4.30 (***)	3.86 (***)	2.77 (***)	0.56 (n.s.)	0.53 (n.s.)	0.21 (n.s.)
		0.5	2	Without normalization	4.23 (***)	1.03 (***)	-0.89 (***)	0.57 (n.s.)	0.48 (*)	0.93 (**)	0.33 (n.s.)	-0.20 (n.s.)
				With normalization	4.68 (***)	1.47 (***)	-0.44 (*)	1.02 (**)	0.93 (**)	1.38 (**)	0.77 (*)	0.25 (n.s.)
		1.2	3	Without normalization	1.55 (***)	-0.26 (n.s.)	-0.01 (n.s.)	0.12 (n.s.)	0.23 (*)	0.37 (**)	0.14 (n.s.)	-0.49 (n.s.)
				With normalization	1.80 (**)	-0.01 (n.s.)	0.23 (n.s.)	0.37 (*)	0.48 (**)	0.61 (**)	0.39 (**)	-0.24 (n.s.)
		3.0	4	Without normalization	1.99 (***)	0.14 (n.s.)	0.42 (**)	0.18 (**)	0.19 (***)	0.28 (***)	0.17 (*)	-0.12 (n.s.)
				With normalization	1.67 (***)	-0.19 (n.s.)	0.09 (n.s.)	-0.14 (**)	-0.14 (*)	-0.04 (n.s.)	-0.15 (*)	-0.45 (***)
	Distance to façade (m)	**Height (m)**	**Configuration**		**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
C	3.0	1.2	1	Without normalization	1.54 (***)	1.53 (***)	0.58 (n.s.)	-0.55 (**)	-0.80 (**)	-1.47 (***)	-1.22 (***)	-1.09 (n.s.)
				With normalization	1.32 (**)	1.31 (***)	0.36 (n.s.)	-0.77 (**)	-1.02 (***)	-1.69 (***)	-1.44 (***)	-1.31 (*)
		1.5	2	Without normalization	1.63 (***)	1.30 (***)	0.27 (n.s.)	-0.51 (*)	-1.09 (***)	-1.65 (***)	-1.23 (**)	-1.06 (n.s.)
				With normalization	1.42 (***)	1.09 (***)	0.06 (n.s.)	-0.72 (**)	-1.30 (***)	-1.86 (***)	-1.44 (***)	-1.27 (*)
		2.5	3	Without normalization	1.07 (***)	0.91 (***)	0.07 (n.s.)	-0.36 (**)	-0.36 (**)	-0.20 (n.s.)	-0.36 (*)	-0.59 (*)
				With normalization	0.92 (***)	0.76 (***)	-0.08 (n.s.)	-0.51 (***)	-0.51 (***)	-0.35 (*)	-0.51 (*)	-0.74 (*)
		6.0	4	Without normalization	-0.52 (*)	-0.03 (n.s.)	0.71 (n.s.)	0.27 (n.s.)	0.31 (n.s.)	0.35 (*)	0.07 (n.s.)	-0.60 (***)
				With normalization	-0.24 (n.s.)	0.26 (n.s.)	0.99 (*)	0.55 (n.s.)	0.59 (n.s.)	0.63 (***)	0.35 (*)	-0.31 (n.s.)

Table 3

FIGURE CAPTIONS

Figure 1.- Location of sampling points

Figure 2.- Sampling points (top view)

Figure 3.- Microphone location in the group A and B (a) and group C (b)

Figure 4.- Time sequence of values for sampling point 1, configuration 2 and group C

Figure 1

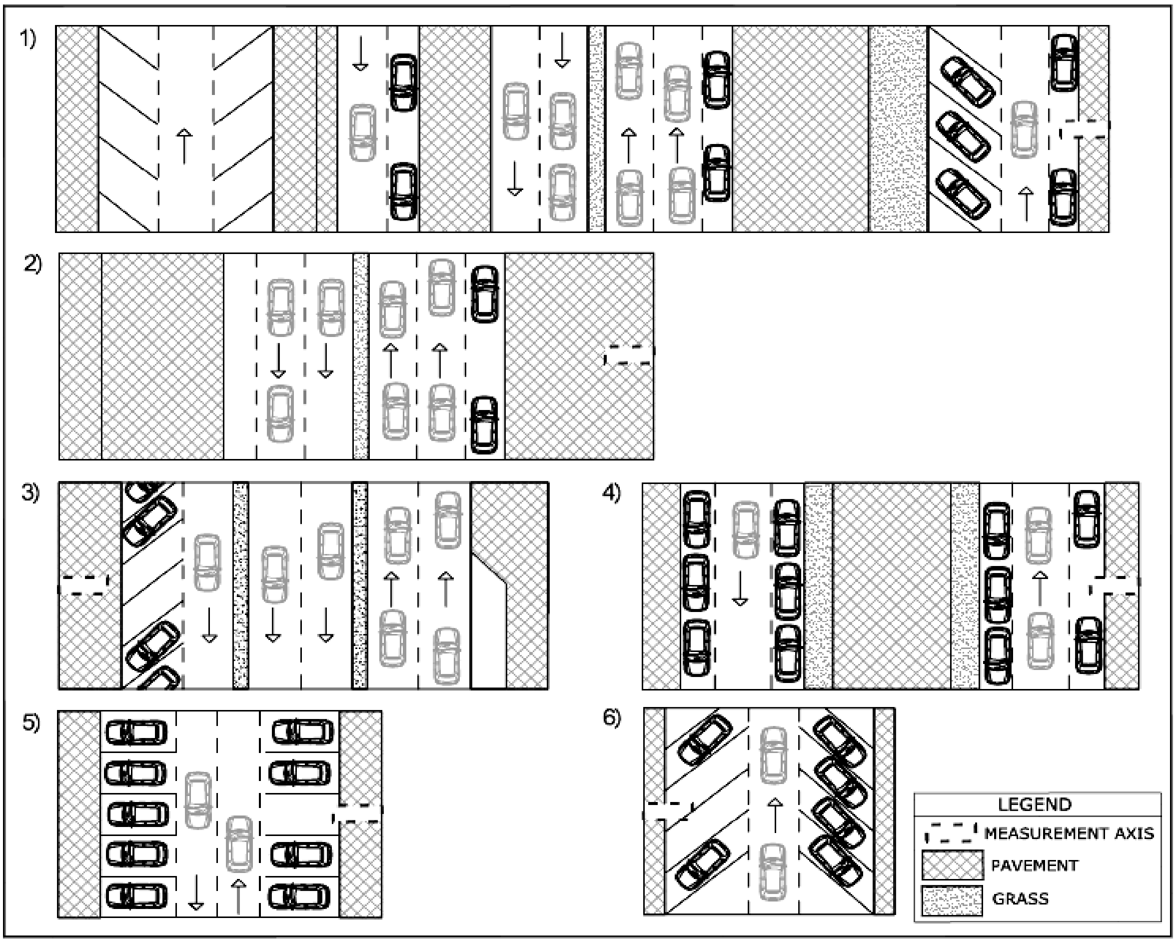
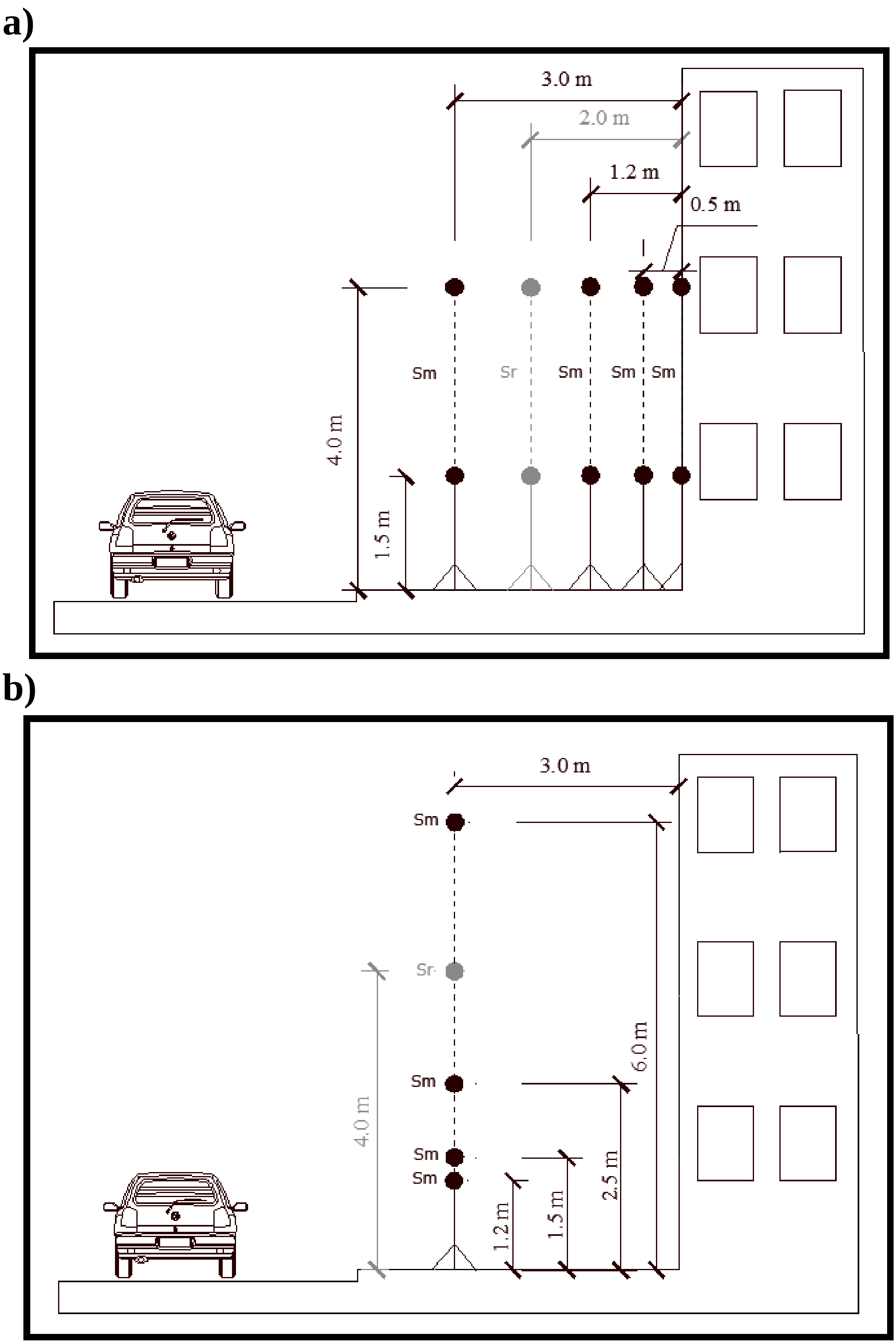


Figure 2


a)
3.0 m
2.0 m
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Sm
Sr
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b)
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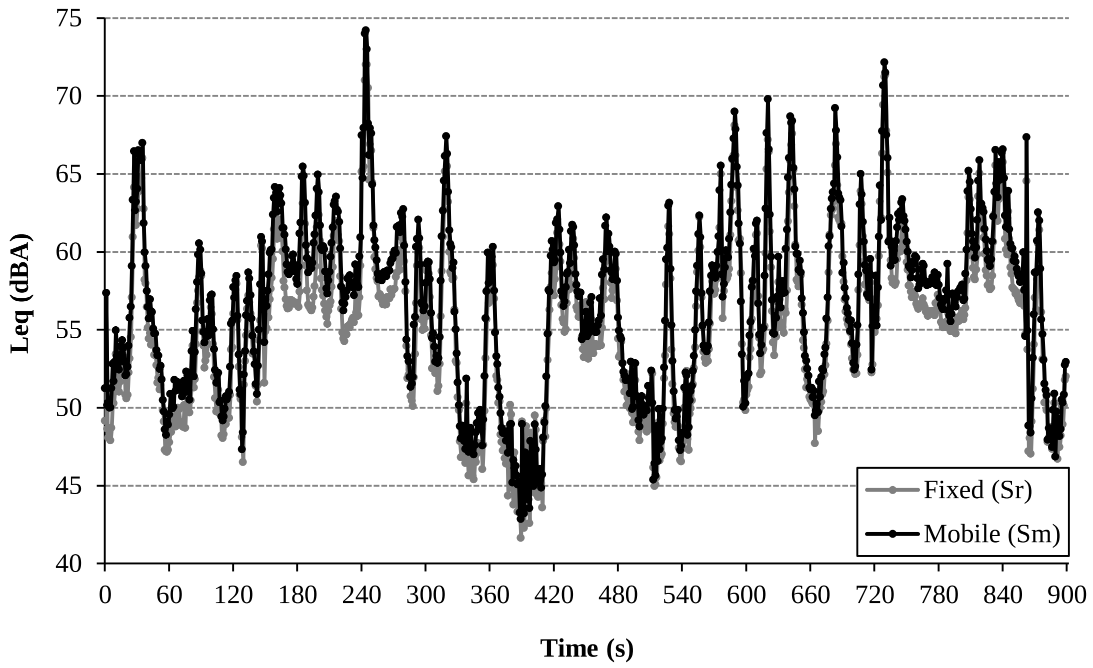
1.5 m
1.2 m

Figure 3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600
660
720
780
840
900
Time (s)
Fixed (Sr)
Mobile (Sm)

Figure 4