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A review of the measurement procedure of the ISO 1996 standard. Relationship with the European Noise Directive

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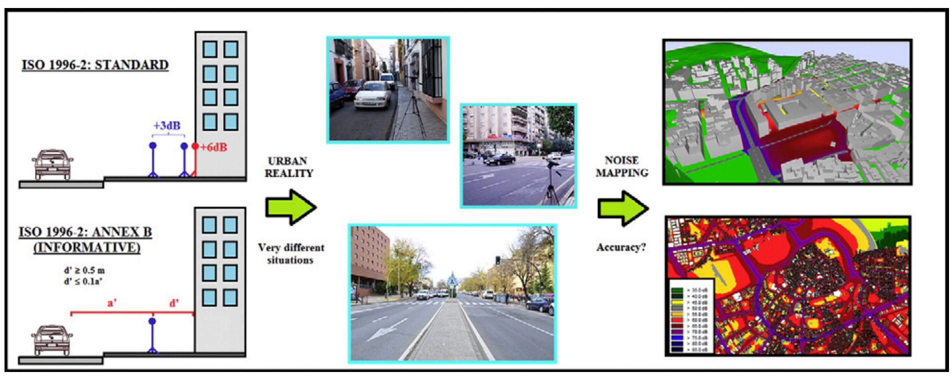
HIGHLIGHTS

- ISO 1996-2 standard and the accuracy of estimations of noise doses were reviewed.
- A wide variation among standard corrections and experimental results was published.
- Unexpected increases of sound level with height have been reported in literature.
- Detailed studies regarding the standard and its Annex B (informative) are necessary.
- Results of the application of the European Noise Directive could be being affected.

GRAPHICAL ABSTRACT



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ABSTRACT

Accuracy in the knowledge of the sound field incident on a façade is essential for proper planning of control actions. Independently of the chosen method for noise mapping, if we wish to know the exposed population, it is essential to measure the incident noise level on the façade. Regarding the geometry of the measuring point in relation to the façade and other elements of the environment, the normative part of the ISO 1996-2 standard only makes reference to the distance between the microphone and the façade. The rest of the geometric aspects that could influence the result of a measurement are not considered in the standard. Although some of these aspects are considered in Annex B, the annex is only informative. The ISO 1996 standard is considered in the European Noise Directive as a reference in the elaboration of strategic noise maps, the main tool for assessing the exposure of the population to noise pollution.

This work presents a detailed review of the literature and proposes research strategies in order to study the relationships between the ISO 1996-2 standard measurements procedure and the accuracy of the estimations of noise doses received by people obtained by the application of the European Noise Directive. The published results show significant relative differences with respect to the values proposed by the standard for the corrections and indicate the possibility of the influence of these results on the accurate development of strategic maps.

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Contents

1. Introduction

Worldwide economic and social development occurred over the last decades. Among other consequences, this has led to a significant increase in the number of people living in cities (Buhaug and Urdal, 2013; Henderson and Gun, 2007; Mulligan and Crampton, 2005) and in the use of transport infrastructure. As a result, a progressive increase in noise levels in economically developing countries (Zannin and Sant'Ana, 2011), and, possibly in other related environmental problems (Can et al., 2011; Fernández-Camacho et al., 2015) has taken place. In developed countries, the situation can be considered stabilized, as in case of Europe, where estimations indicate that more than 125 million people could actually be exposed to road traffic noise above 55 dB L_{den} (day-evening-night–level indicator), including more than 37 million exposed to noise levels above 65 dB L_{den} (EEA, 2014).

In the 1990s, some studies detailed the harmful effect of acoustic pollution on the health of human beings (Passchier-Vermeer and Passchier, 2000). This includes annoyance (Arana and García, 1998; Fidell et al., 1991; Fields, 1998; Guski, 1999) and sleep disturbance (Carter, 1996; Öhrström, 1990, 1991, 1995; Thiessen, 1988). Such feelings of displeasure show a relation with adverse effects on human emotions, leading to anger, disappointment (Fields, 1998) and even stress (Evans et al., 1995, 2001). Stress hormones have the potential to increase the incidence risk of cardiovascular diseases (Babisch et al., 1990, 1994; Ising et al., 1999). Also, in the same years, the first studies were published that disclosed the approximate percentages of the European population who are exposed to day and night levels higher than 55 dBA (Berglund et al., 1999; Lambert and Vallet, 1994). In the margins of uncertainty of these studies, they indicate that about 40% of the population in the European Union is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dBA daytime; and 20% is exposed to levels exceeding 65 dBA. More than 30% are exposed at night to L_{eq} exceeding 55 dBA which are disturbing to sleep. The emergence of this large number of studies in different countries allowed carrying out a meta-analysis and some synthesis curves emerged, which can be used for the prediction of the percentage of annoyed subjects (Miedema and Oudshoorn, 2001; Miedema and Vos, 1998). According to these curves, the estimations indicated approximately 23%, 18% and 10% of highly annoyed receivers for L_{den} of 65 dB in the cases of aircraft, road traffic and railway respectively.

Taking into account the evident adverse effects of environmental noise, the European Commission recognized community noise as an environmental problem, and an international focus on the problem was initiated. Therefore, environmental noise emerged as a major issue in environmental legislation and policy (EC, 1996).

The establishment of the European Noise Directive (EC, 2002) represented a significant improvement in awareness among the general public and policymakers about the knowledge of the acoustic situation in the cities of the member states (Murphy and King, 2010). Nevertheless, the European Noise Directive has not only had an impact in European countries (D'Alessandro and Schiavoni, 2015; Licitra and Ascari, 2014; Kephalopoulos et al., 2014; Vogiatzis and Remy, 2014) but has also been used as a reference by various studies made in cities around the world (Chang et al., 2012; Suárez and Barros, 2014; Zuo et al., 2014).

Accuracy in the knowledge of the acoustic situation is essential for the identification of the sites concerned. And, as a consequence, it is also very relevant for proper planning of control actions for each situation. Moreover, this knowledge of the acoustic situation can help us to fight other serious environmental problems because of the relationship of sound levels with other atmospheric pollutants (Allen et al., 2009; Morelli et al., 2015; Vlachokostas et al., 2012). In order to conduct studies of the acoustic situation and its effects on the inhabitants of cities and for the planning of possible solutions, an important option to consider is noise mapping. In this

direction, according to the European Noise Directive, noise mapping is the main tool for the assessment of human exposure to environmental noise pollution. Consequently, searching for the obtention of better noise maps means better assessments of exposed population and, therefore, an improving in the design of action plans.

To obtain a noise map, different methods or strategies can be considered. Generally, we can differentiate between computerized methods based on models of sound field propagation and studies carried out with "in situ" measurements. These methods differ largely from each other in methodological aspects associated with the selection of sampling points. However, even when a computerized method is used, "in situ" measurements are necessary for calibration or validation (WG-AEN, 2007). In connection with this topic, the ISO 1996 international standard (ISO 1996-1, 2003; ISO 1996-2, 2007) describes aspects related to the calculation and measurement procedure of the sound pressure level outdoors, and it is used as a reference for noise mapping by the European Noise Directive. Although this paper focuses on the study of the application of the corrections proposed in ISO 1996 standard, similar considerations for traffic noise measurements are included in NT ACOU 039 (NT ACOU 039, 2002). In addition, some standards (ISO 140-5, 1998; ISO 16283-3, 2016; EN 12354-3, 2000) and papers (Berardi, 2013; Berardi et al., 2011) take into consideration the reflections on the building surface for façade sound insulation measurements.

Independently of the chosen method for noise mapping, if we wish to know the population exposed to noise, the fundamental question is to evaluate the incident noise level on the façade to the desired height. It is known that the incident sound level depends on many factors, both temporal and spatial. Therefore, to get a suitable assessment, it is important to consider not only the characteristics of the sound source but also the situation of the evaluation point regarding the source and the specific urban environment of each street or façade that we intend to evaluate. In this way, for each configuration, the sound energy incident on the façade of the building under consideration is evaluated as accurately as possible.

ISO 1996-2 guidelines are often followed to obtain measurement noise mapping or for the calibration and validation of calculated noise maps. But what is the level of accuracy that we can obtain with the use of the recommendations provided by the standard? Does the standard consider the variability that exists in urban environments? These aspects are essential if we wish to obtain accurate noise maps and effectively reduce the impact of noise pollution on the population. Note that a recent publication by the World Health Organisation (WHO, 2011) ranked noise pollution as second among a series of environmental stressors for the public health impact in a selection of European countries. Indeed, contrary to the trend for other environmental stressors, which are declining, noise exposure is actually increasing in Europe (WHO, 2011).

In this way, some essential aspects, which could be interrelated, must be taken into account, and they should be considered when the measuring point is chosen and at the time of applying any corrections to the value of the measured noise level:

1. The geometry of the measurement point in relation to the different elements of the surroundings:
   a. With respect to the façade, both in height and distance to it.
   b. With respect to the sound source (distance, viewing angle…).
   c. With respect to the different elements of the urban environment (street width, building height, terrain features, reflecting surfaces…).
   d. With respect to the geometry and the characteristics of the façade (angle in relation to the source, building materials, irregularities or presence of arcades, balconies…).

2. The characteristics of the sound source under evaluation (source type, spectrum, temporality, intensity, geometry…).

In the following sections, how these aspects are considered in the ISO 1996-2 standard will be analysed. And a review of the literature will be made to show the studies that different authors carried out in relation to these issues in real measurement conditions and the conclusions that have been reached. Section 2 discusses the corrections proposed by the ISO 1996-2 standard in its normative part for acoustic measurements in urban environments and the conditions stipulated in Annex B (informative). In Section 3, each of the cases of the corrections proposed by the standard is studied. A literature review is carried out about the works related to these topics. In Section 4, the possible relation between the corrections to be applied and the distance between the microphone and the sound source is analysed. Finally, Section 5 deals with a study about the effect of the height of the microphone on the value of the noise level.

2. The ISO 1996-2 standard and the measurement of noise pollution in urban environments

Regarding the geometry of the measuring point in relation to the façade and other elements of the environment, the normative part of the ISO 1996-2 standard only makes reference to the distance between the microphone and the façade. The rest of the previously mentioned geometric aspects that could have an influence on the result of a measurement are not considered in the standard. Also, it does not determine the distance at which the microphone must be located in respect to the building façade in a clear way, leaving this choice to scientific and technical criteria. In relation to this issue, in order to take into account the effects of reflection for the building façade, the standard proposes some corrections to be applied to the values of the measured noise levels. The ISO 1996-2 standard makes a distinction between three cases:

a) A position with the microphone flush mounted on the reflecting surface: −6 dB.
b) A position with the microphone located between 0.5 and 2 m in front of the reflecting surface: −3 dB.
c) A free field position (reference condition): 0 dB.

Note that, in this proposal for corrections, there may be some doubts since:

- There is only one value, −3 dB, for a wide area of distance from the façade, between 0.5 and 2 m.
- It is not clear what must be done if the measurement is performed further than 2 m because the standard does not propose any correction. Do these distances to the façade correspond to a free field?

In order for a proper understanding of these three issues, it is necessary to consult Annex B of the standard. This appendix does not belong to the normative part of ISO 1996-2; it is included in the standard with an informative character. For the first case, some conditions are described for which the indicated value is expected, and some situations are mentioned for which it is not appropriate to measure this whole range of distances. And, for the second case, some conditions for which the measurement point can be considered in a free field are specified, but this range of distances to the evaluated building façade cannot be considered as included in the standard.

Secondly, the standard points out that the proposed corrections may not match the results in real measurement conditions in an urban environment. Lower or higher deviations from the values indicated can be obtained in practice. Again, although the normative part of ISO 1996-2 makes some references to the conditions for which the proposed corrections are verified, in Annex B (informative), various considerations that should be taken into account are listed in detail. However, as will be shown, in many cases, these conditions cannot be verified in a real urban environment.

In these areas, it is of great interest to conduct a detailed review of the literature and to propose research strategies that allow to delimit these uncertainties in order to improve the accuracy of the estimations of noise doses received by people in their homes and workplaces and in hospitals, nursing homes, schools, etc.

On the other hand, in connection with the characteristics of the sound source under evaluation, ISO 1996-2 establishes, in its normative part, some aspects to be considered, but all of them concern the representativeness of the measure regarding the average conditions of the source in the environment and the variations in weather conditions. Nothing is indicated about the possibility that the corrections depend on the features of the source. As we will see later, there are studies that suggest a dependency in this regard.

It may also be of interest to note that, so far, the possibility of an interaction between geometric and temporal aspects has not been raised. This means that some geometrical elements influential on the final value of the incident sound level on the façade may have significant variations over time. These elements must also be considered for the measurements or calculations to be representative of the average situation of the environment under evaluation.

Different sources of uncertainty should be considered in assessing the exposure of the population to noise pollution. ISO 1996-2 standard estimates a minimum uncertainty of 2 dB for measured noise levels, which is associated with factors such as instrumentation, operating conditions (repeatability), weather and terrain conditions and residual sound. In the case of computerized noise maps, those uncertainties due to the digital terrain model (Arana et al., 2011), the software used (Arana et al., 2009), etc. will be added.

This paper focuses on the aspects related to the geometry of the measurement point and road traffic as a sound source. Aspects associated with the temporality of the sound source represent an independent and wide ranging line of work. For example, spatial and temporal patterns of noise exposure due to road traffic in a city of a developing country (Pakistan) were studied by Mehdi et al. (2011). A measurement methodology to know the evolution of daytime building façade noise levels by road traffic in a city of a developed country (Belgium) was investigated by Van Renterghem et al. (2012). The effects of singular noisy events on long-term noise indicators were studied by Prieto Gajardo et al. (2014). The relation between categorisation method and the temporal variability of urban noise was studied by Rey Gozalo et al. (2015). A model for estimating annual levels of urban traffic based on Fourier analysis noise was proposed by Barrigón Morillas et al. (2015). The pilot project on the establishment of National Ambient Noise Monitoring Network across some cities in a developing country (India) is described by Garg et al. (2016).

In this field of work ISO 1996 standard, parts 1 and 2, are currently under revision. Draft ISO 1996-2 (ISO 1996-2, 2011) recommend a methodology for the calculation of uncertainty. Following the guidelines of draft ISO 1996-2, Alves and Waddington (2014) indicates that, in their field measurements, the magnitude of the uncertainty associated with a short term measurement of $L_{Aeq,1h}$ is 4.2 dB for road traffic noise (95% confidence). In connection with this topic, the influence of short-term sampling parameters on the uncertainty of the L_{den} environmental noise indicator is studied according with draft ISO 1996-2 in other work (Mateus et al., 2015a), which indicates that it is possible to derive a two variable power law representing the uncertainty of the determined values as a function of the two sampling parameters: duration of sampling episode and number of episodes.

3. The microphone location with respect to the building façade

The ISO 1996-2 standard proposes corrections to be applied to the values of the measured noise levels. These corrections are determined depending on the distance between the microphone and the back surface, as indicated in Section 2.

The aim of this proposal is to correct the effects of increased noise levels due to sound reflections on the surface. In this way, the real value of the incident sound field on the façade (free field) is obtained.

These corrections have been analysed by some authors in urban environments by "in situ" measurements or simulations. It is interesting to indicate that the different papers published in this respect, in general, have focused on studying the corrections, depending on the distance to the building façade. But they have not carried out a detailed study of whether the indications of Annex B (informative) are verified or not.

3.1. The position with the microphone flush mounted on the reflecting surface

Although the standard establishes a correction of −6 dB between a microphone flush mounted on the façade and a microphone in a free field, it also indicates that this is an ideal case, so lower deviations from this value do occur in practice.

In respect of the mounting of the microphone on the reflective surface, only what is previously indicated appears in the normative part. It is necessary to look over Annex B (informative) to find two basic options to place the microphone:

a) On a plate placed on the surface.
b) On the surface itself.

In the first option, a microphone with a 13 mm (1/2 in.) diameter should be used in the case of road traffic noise and broadband. The microphone can be mounted parallel to the plate or with the microphone membrane flush with the surface of the mounting plate. For assembly, certain conditions relating to the characteristics of the plate and the mounting must be respected. In relation to the façade, it must be flat, within 1.0 m of the microphone and with a tolerance of ±0.05 m, and the distance from the microphone to the edges of the surface must be higher than 1.0 m.

In the second case, it is indicated that the surface must be made of concrete, stone, glass, wood or a similar hard material. In addition, the reflecting surface must be flat, within 1.0 m of microphone and with a tolerance of ±0.01 m. Annex B also states that, in this case, for octave-band measurements, a microphone of 13 mm diameter or smaller should be used. If the frequency range is expanded above 4 kHz, a 6 mm microphone should be used.

The indicated correction of −6 dB was analysed by different papers in urban environments.

In the work done by Memoli et al. (2008), acoustic measurements were carried out for a period of 15 min for streets with different geometries: five urban roads with type U and two urban roads with type L. Road traffic was considered as the sound source and four microphones were used. They were placed at a 4.0 m height to simultaneously measure different distances from the façade. A range of distances from 6.6 m to 34.0 m between the source and the façade was used. In this paper, a difference of 5.7 dB ± 0.8 (95% confidence) is obtained between the measured sound level with one of the microphones placed on the reflective surface on a plate and the measured sound level with one of the microphones placed in free field conditions. Although the resulting difference is globally consistent with the correction proposed by the ISO 1996-2 standard, within the range indicated by the authors, differences higher than 1 dB between what it is indicated in the standard and the measured values can be observed.

In connection with this topic, Mateus et al. (2015b) conducted simultaneous measurements for 47 months with three microphones: one of them in a free field (3.5 m above the cornice of the building), another flush mounted on the façade using a metal plate and the last one placed on the glass of a window of the same wall. The distance between the microphone in the free field and the horizontal line connecting the other two devices on the façade was 6.3 m. In this case, an urban street with an L profile was selected, and road traffic was taken into account as the sound source. The distance between the source and the sound level meters was 150 m. Therefore, the results of two options to place the microphone flush mounted on the façade as indicated by ISO 1996-2 were analysed in this paper. The results show that, if the microphone is mounted directly on the window, the difference between the sound levels varies from 4.0 dB to 4.4 dB, whereas, if a plate of reflective material is used, the difference is 4.9 dB. Based on these results, it is stated that if a −6 dB correction is applied following the standard guidelines, significant errors could be introduced in some cases.

Therefore, studies that analyse the differences between the sound levels measured in free field conditions and with the microphone located on a reflective surface show disparity values that, depending on the case, may involve differences of up to 2 dB regarding the correction of −6 dB established by the ISO 1996-2 standard, as shown in Table 1. These results may have an important impact on the results obtained to date under the application of the European Noise Directive. As this configuration is usually used to locate the receptors in simulated strategic noise maps, it is important to know what geometrical factors are causing these results and whether these experimental results are being considered or not in the application of the propagation models. Consequently, it is essential to increase the number of studies in this line of work by taking into account the urban reality of European cities.

Table 1
Differences between the sound levels measured in free field conditions and with the microphone located on a reflective surface in case of an extended source (see Fig. 1).

Reference	Microphone	RO (m)	d′ (m)	a′ (m)	h (m)	Correction (dB)
Memoli et al. (2008)	Façade Free	6.6–34	0 –	6.6–34	4.0	5.7 ± 0.8
Mateus et al. (2015b)	Façade Free	150	0 –	150	15.2	4.9
Mateus et al. (2015b)	Glass Free	150	0 –	150	15.2	4.0–4.4

3.2. The position with the microphone located in front of the reflecting surface

The normative part of the ISO 1996-2 standard excludes measures in the range of distances from the façade up to 0.5 m. However, some researchers have studied this range of distances. For instance, Memoli et al. (2008) conducted a study that analysed the differences in sound levels obtained between a microphone located on the façade and another one situated at very small distances from it. For this purpose, a speaker with an MLS signal was used as a sound source. The results show that the correction near the metal plate at distances between 0.01 and 0.02 m from it changes very quickly with distance, variations of up to approximately 0.6 dB are obtained. In an analogous way, a study was conducted where the range of distances to the façade was 0.25 to 0.5 m and in which two distances between the sound source and the façade were considered: 10.1 and 13.1 m. When the sound source was located at a distance of 10.1 m, sound level differences between the two microphones were about 1.0 dB at 0.25 m and 0.4 dB at 0.5 m, whereas, for a distance of 13.1 m, the results were approximately 1.9 dB at 0.25 m and 1.3 dB at 0.5 m.

In another work by Hopkins and Lam (2009) the range between 0.1 and 0.5 m for the distance between the microphone and the reflective surface is analysed. A comparison of the variation of sound pressure level predicted by the method of the integral equation (IEM) and that measured in a scale model 1:5 in a semi-anechoic chamber with a point source for different sizes of reflective surface is shown. Differences between the finite and semi-infinite reflectors are most noticeable at frequencies below 300 Hz.

In this respect, the ISO 1996-2 standard states, "The difference between the sound pressure level at a microphone placed 2 m in front of the façade and at a free-field microphone is close to 3 dB in an ideal case where no other vertical reflecting obstacle influences sound propagation to the studied receiver. In complex situations, e.g. high building density on the site, canyon street, etc., this difference can be much higher." Therefore, the standard itself indicates the difficulty of accurately knowing the value of the difference between the incident sound field on the façade and the one effectively measured in these conditions. Consequently, it indirectly indicates the need to develop research in this line. The importance of this measurement configuration must be considered. It is quite used in the assessment of noise exposure in urban areas and, also, as a reference to validate noise maps at selected sites.

Annex B (informative) of the ISO 1996-2 standard lists a series of specifications regarding the distances among the microphone, reflecting surface and sound source for which a correction of −3 dB would be applied:

- The façade should be flat with a tolerance of ±0.3 m.
- In order to avoid the edge effects, minimum distances between the image of the microphone on the reflective surface (point 0) and the closest edges of the reflecting surface are set up: b (horizontal distance) and c (vertical distance) (see Fig. 1). These distances must satisfy some conditions:

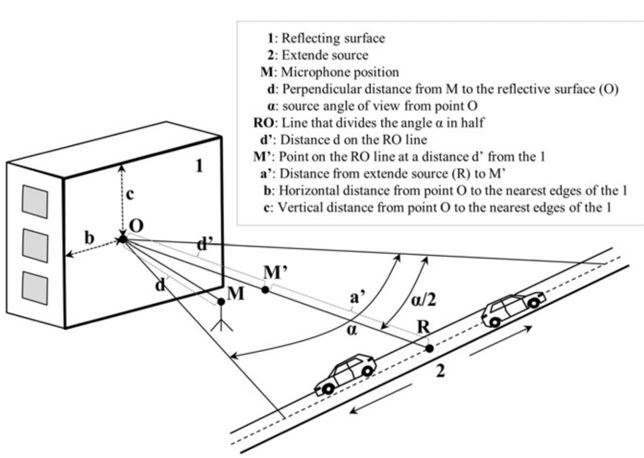

Fig. 1. Microphone near the reflecting surface (ISO 1996-2, 2007).

$$b \geq 4d \quad (1)$$

$$c \geq 2d \quad (2)$$

where d is the perpendicular distance from the microphone to the façade.

- To guarantee that the incident and reflected sounds have the same magnitude, in the case of the extended source (road traffic), the criterion of Eq. (3) must be satisfied. This equation relates the distances a′ and d′, taken along the dividing line of viewing angle α as shown in Fig. 1. Assuming that M' is the point on the dividing line of angle α at a distance d from the façade, d′ can be defined as the distance between M′ and the façade, and a' can be defined as the distance between M' and the sound source.

$$d\prime \leq 0.1a\prime \quad (3)$$

- To ensure that the microphone is placed at an enough distance from the area of the correction of −6 dB near the façade in the case of an extended source (road traffic), Eq. (4) should be taken into consideration when an analysis is performed on broadband, and Eq. (5) should be taken into consideration when an analysis is performed on octave bands.

$$d\prime \geq 0.5\text{m} \quad (4)$$

$$d\prime \geq 1.6 \text{ m} \quad (5)$$

- To guarantee that the microphone is in a free field, Eq. (6) should be considered:

$$d\prime \geq 2a\prime. \quad (6)$$

Taking into account these considerations included in the informative part of the standard, the distance between the façade and the sound source limits the possibilities to place the microphone with respect to the evaluated façade. In Fig. 2, different options for the microphone location are presented for the distances façade-microphone and microphone-sound source depending on the total distance between the façade and the sound source. To develop these figures, a minimum distance of 2.0 m between the microphone and the sound source (the reference point of the sound source is the nearest vehicle wheel (Jonasson, 2006)) has been considered.

In Fig. 2:

- The solid line just on the axis X in Fig. 2 (a) represents the measurement position on the façade, d′ = 0 m. This measurement position is represented by the solid line of the unit slope in Fig. 2(b).
- The shaded area at the bottom of Fig. 2(a) represents the options for measuring from 0.5 to 2 m, which corresponds to the shaded area at the top of Fig. 2(b).
- The shaded area at the top of Fig. 2(a) represents the measurements in free field conditions. The measurements are also represented by the shaded area at the bottom of Fig. 2(b).

Considering equations 3, 4 and 6, whose implications are shown in Fig. 2, it is deduced that:

- The measurement at distances lower than 0.5 m from the façade is explicitly excluded.

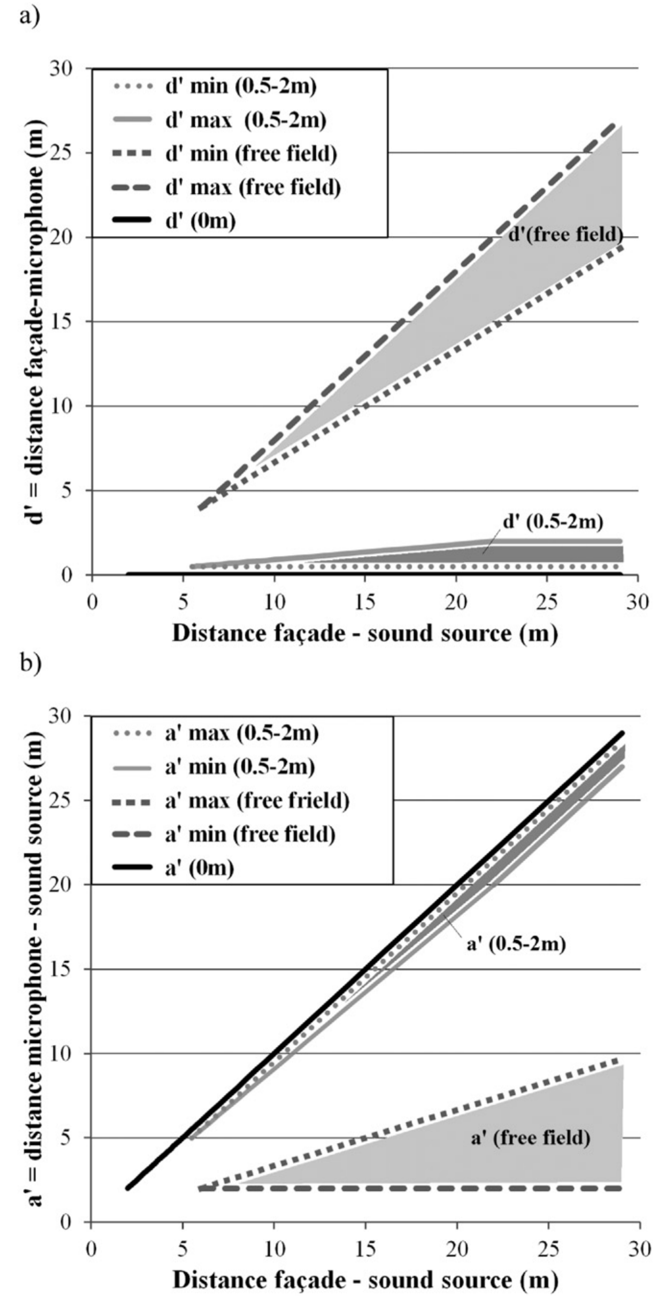

Fig. 2. Relationship between the distances façade-microphone and façade-sound source (a) and relationship between the distances microphone-sound source and façade sound-source (b) according to the measurement areas regulated in Annex B (informative) of ISO 1996-2 standard.

– For distances from the façade to the sound source below 5.5 m, only the option for measuring with the microphone flush mounted on the façade guarantees that the correction indicated by the standard, in this case of −6 dB, will be verified.
– For distances of between 5.5 m and 22 m from the façade to the traffic line, in addition to the option for measuring on the façade, the effective range of distance from the façade to place the microphone in the area of 0.5 to 2 m increases. However, only for a distance of 22 m or higher from the façade to the sound source, a measurement carried out with a microphone located 2 m of the façade ensure the correction of −3 dB indicated by the standard. For greater distances than 22 m between the façade and the sound source being evaluated, any option provided by the standard could be used to place the microphone to guarantee the corrections indicated by the standard. In this respect, it should be observed that, for the range of distances from 0.5 to 2 m from the façade to the microphone, in the work made by Memoli et al. (2008), a dependence of the correction due to reflection on the façade with respect to the distance between the sound source and the façade is found.
– For the distance between the microphone and the sound source indicated, to find an area for measurements that verifies the free field condition, it is necessary that the sound source is located at least 6 m from the façade or other influential reflective surface behind the microphone. It must be clarified that this area for measurements is not valid in the ISO 1996-2 standard approach to assess the incident sound field on the building façade, but it is valid on a façade near the measuring point and placed at an equal distance from the sound source. Naturally, in free field conditions, for distances further than 4 m from the microphone to the building façade being evaluated, the value of the measured sound field does not correspond to the value of the incident field on the façade because an attenuation by geometric divergence would take place in the propagation from the measuring point to the reflecting surface.

Just as with the previous correction, this correction of 3 dB has been analysed by different authors in urban environments.

Considering vehicles as a sound source on highways and main streets of Toronto, Hall et al. (1984) conducted a study of the differences among the sound pressure levels measured on the outside of 33 dwellings. To this end, a comparison of the measurements performed at 2.0 m from the façades and the surfaces was made, so the microphone was placed directly on the windows in the last case. The results show that, on average, a correction of 3 dB between the two measuring points is appropriate, except at low frequencies. In this work, there is no indication about the possible variability detected in this mean value. But it is specified that, for frequencies below 200 Hz, the obtained values fluctuate significantly above and below the 3 dB indicated, reaching values of 1.7 dB and 7.3 dB at the third octave bands of 40 Hz and 50 Hz respectively.

Quirt (1985) carried out a study to investigate the behaviour of the sound field near the exterior surfaces of buildings. For this purpose, he used a mathematical model to predict noise levels. In the verification, a series of measurements was made in a semi-anechoic acoustic chamber with a controlled sound source and another series of "in situ" measurements were made with a controlled sound source and road traffic noise. In this study, it is indicated that the assumption that the energy is doubled (+3 dB) at 2 m from the surface of the building is a reasonable approximation for an extended source such as road traffic and for third octave bands above 100 Hz. This result is consistent with that specified by the ISO 1996-2 standard in Annex B (informative) with regard to the appearance of coherence effects at low frequencies and the indication of a minimum distance of 1.6 m for measurements in octave bands (Eq. (5)).

Both the studies of Hall et al. (1984) and Quirt (1985) were performed before the development of the ISO 1996-2 standard (ISO 1996-2, 1987), but they agree that, on average, a correction of −3 dB in the range between 0.5 and 2 m in front of the reflecting surface is suitable.

After the development of the latest version of the ISO 1996-2 standard (ISO 1996-2, 2007), Memoli et al. (2008) tested the acoustic corrections due to reflections from the back wall. In each of the measuring points, the distance from the microphone to the façade (d) was varied, establishing at least three values: 0.5, 1 and 2 m. The objective was to compare the average of the values obtained in the range of 0.5 to 2 m from the façade and the value established in ISO 1996-2 standard. Using road traffic as a sound source, some values in the range of 6.6 to 34.0 m were used for the distance from the source to the façade (D). However, the values of the distance between the microphone and the sound source (D-d) for each measurement point are not explicitly stated. The results shown in the study are those obtained for the total streets studied, and there is no breakdown to distinguish the partial values for roads with U and L typologies or to distinguish different values of the distance between the sound source and the microphone. In this study, a difference of 3.0 ± 0.8 dB (95% confidence) is obtained between the microphone located in the range 0.5–2.0 m and another microphone placed in a free field. There is a difference of 2.7 ± 0.6 dB (95% confidence) between the microphone located in the range 0.5–2.0 m and a receiver flush mounted on the reflecting surface. On average, the results show a match with those values proposed by the ISO 1996-2 standard. But it can be observed that there is a certain variability in the experimental values for the measurement conditions used in this study involving deviations of up to 1 dB with respect to the proposed value. In fact, in this work, using an MLS point source, it is found that, until distances greater than 1.0 m, there are not differences of 3.0 dB between the microphone flush mounted on the façade and the microphone located at some distance from the surface.

Hopkins and Lam (2009) also study the effects of diffraction on the sound field in front of finite size reflectors in the range between 1 and 2 m for the distance between the microphone and the reflective surface. Important fluctuations can be reached in connection with different source-reflector-receiver geometry. The effects are significant until 100 Hz if reflector is larger than 4 × 4 m, but even up to 630 Hz for 2 × 2 m reflector.

In another study, Jagniatinskis and Fiks (2014) realized noise measurements for a year. In this case, as in the previous one, road traffic was used as a sound source. A location with a high flow of vehicles was selected where the distance between the microphone and the sound source was 250 m. Two microphones were used to measure simultaneously and were connected to the same station. One of them was located 2 m from the façade, and the other one was placed on a plate in one window of the wall. The first of the conclusions drawn from this study is that, in overall terms, the difference between the annual values of the day-evening-night (L_{den}) sound level registered by both microphones is about −3 dB. In this way, the result matches the correction proposed by the ISO 1996-2 standard in the case of a microphone located between 0.5 and 2 m in front of a reflective surface. Another finding of this work is that the average difference in measured sound levels between both sound level meters is up to 2 dB lower at night than in the daytime. This fact could be related to the flow of vehicles in both periods and, therefore, the characteristics of the studied source.

Another paper that is of interest in this regard is the work of Montes González et al. (2015) in which the effect of varying the distance between the microphone and the building reflective surface is studied in urban environments. The work was carried out in different parts of a city in a range of distances from 8.2 m to 28.4 m between the façade and the centre of a set of traffic lanes (reference sound source). Two microphones were used to measure simultaneously. The reference microphone was located 2 m from the building façade, and mobile microphone was placed at different distances from it (0 m, 0.5 m, 1.2 m and 3.0 m). Analyses were conducted with microphones situated at the heights that the ISO 1996-2 standard established for noise mapping: 1.5 m and 4.0 m. In the paper, an explicit reference is made to Annex B (informative) of the standard and to compliance with some of the aspects mentioned in Annex. Also, the effect of the distance between the microphone and the noise source is analysed. The results show that the correction values for reflection in real measurement conditions in urban areas are lower than those recommended by the ISO 1996-2 standard. In the case of microphones located at a 1.5 m height, the differences between sound levels obtained on the façade and 2.0 m from it are 1.1 dB if a correction due to the distance to the sound source is not applied and 1.7 dB if the correction is applied. In the case of the microphone located 4.0 m high, these differences are 2.0 dB and 2.6 dB respectively. Therefore, the results obtained in this study show significant differences between the corrections indicated in the standard and the measured differences. Furthermore, in this range of façade-microphone distances, an appreciable influence is observed on the outcome associated with the distance between the sound source and the façade under evaluation. In addition, this study indicates the possibility that inevitable urban configurations (parking lines) in the streets of our cities could have a not insignificant effect on the results of the measurements and, consequently, could have a result not considered at present in noise maps elaborated under the European Noise Directive. It should be noted that, if this effect exists, it could involve a variability factor in time on the setting of the calculation model.

The differences between the sound levels measured with the microphone located on a reflective surface and near façade in the case of an extended source are summarized in Table 2.

Another situation of a lack of definition that arises in the application of the corrections proposed by the ISO 1996-2 standard is the existence of a single correction value for a very wide area between the distances of 0.5 and 2 m. Perhaps, this is the reason why most of the above mentioned studies compare only the mean values obtained in this range of distances. Although, for example, in the study of Memoli et al. (2008), the average correction of the positions of 0.5, 1 and 2 m show a coefficient of variation of approximately 22%. In the work of Montes González et al. (2015), a comparison is made between the sound values obtained at 0.5 and 1.2 m from the reflecting surface with respect to those registered at 2 m. The most significant differences were found at a height of 4.0 m. At this point, in the measurements performed between 0.5 and 2 m from the façade, differences of 0.6 ± 0.2 dB (without correction for distance from the source) and 1.1 ± 0.2 dB (with correction for distance from the source) were obtained.

Accordingly, for the results obtained in different studies, a wide variation was found regarding the correction that would correspond when the measurement is made between 0.5 and 2 m from the façade under evaluation. This variation could be motivated by very diverse circumstances, and it seems to be associated with the complex urban environment of our cities. This can be caused because the urban environment implies the existence of distances between source and façade that, for certain measurement configurations, does not allow compliance with the recommendations of ISO 1996-2, or the sound field can be influenced in its propagation by urban configurations (size and shape of the façades) or by urban elements (parking lanes) that, in some cases, could become variable in time. The sound source might be rather close to the façade under evaluation or be influenced in its propagation by urban configurations. And, in some cases, it could become variable in time. Both aspects can have repercussions on the accuracy of the noise maps developed up to now under the European Noise Directive.

Therefore, it is concluded that it is necessary to increase the number of studies, which check the correction to be made in the case of

Table 2
Differences between the sound levels measured with the microphone located on a reflective surface and near façade in case of an extended source (see Fig. 1).

Reference	Microphone	RO (m)	d′ (m)	a′ (m)	h (m)	Correction (dB)
Hall et al. (1984)	Near façade Façade	No data	2 0	No data No data	No data	3.2 ± 0.2
Memoli et al. (2008)	Near façade	6.6–34	0.5, 1.0, 2.0	4.6–33.5	4.0	3.0 ± 0.8
	Free		–	6.6–34		
Memoli et al. (2008)	Near façade	6.6–34	0.5, 1.0, 2.0	4.6–33.5	4.0	2.7 ± 0.6
	Façade		0	6.6–34		
Jagniatinskis and Fiks (2014)	Glass Near façade	250	0 2	250 248	No data	≈3
Montes González et al. (2015)	Near façade Façade	8.2–28.4	2 0	6.2–26.4 8.2–28.4	1.5	1.1–1.7 (±0.2)
Montes González et al. (2015)	Near façade Façade	8.2–28.4	2 0	6.2–26.4 8.2–28.4	4.0	2.0–2.6 (±0.4)

measurements performed at a distance from the façade between 0.5 and 2 m depending on the variety of urban configurations and distances to the sound source that can be found. It is very necessary that, if analysing the specific effects of different geometric urban configurations is wanted, new studies analyse and indicate results independently for the different configurations of the environment and the different microphone positions, which have been used.

Finally, situations that may be of interest is what must be done if the measurement is made more than 2 m from the building façade but fails to fulfil the free field condition (Eq. (6)). This area is not considered in the ISO 1996 standard and has not been previously studied in detail. However, it can be of great interest to measure noise levels in urban environments. Since this area does not meet the free field condition, it is still influenced by the building façade. So, perhaps some correction term will allow evaluating the free sound field incident on a façade. Therefore, it is of interest to conduct studies in this new line of work. This possibility has been analysed by Montes Gonzalez et al. (2015) in a study of the differences between two microphones located 2 and 3 m from the façade, using road traffic as the reference noise source. The results show a slight increase in the sound level in the microphone situated at 3 m, although it becomes negligible when applying a correction due to the difference in distance to the source between these two positions. These results may indicate the possibility of using distances between the façade under evaluation and a measuring point larger than 2 m to evaluate the incident sound field on the façade.

4. The position of the microphone with respect to the sound source

Annex B (informative) of the ISO 1996-2 standard, as has been mentioned above, in the case of a microphone in a free field (Eq. (6)), as when it is positioned at a distance between 0.5 and 2 m from a reflective surface (Eq. (3)), established relations between the distances microphone-sound source and microphone-reflective surface (see Fig. 2). In this regard, the standard does not take into account any kind of dependence of the proposed corrections on the distance between the microphone and the sound source, probably because it considered an effective compliance with the conditions indicated by these equations. However, due to the great variability in the geometry of streets in real conditions, it is not possible to verify the condition stated in Eq. (3). For this reason, it is interesting to analyse the effect that the distance between the façade and the sound source has on the corrections to be applied. This would provide checks of the calculation models that are made through measures in this range of distances.

In relation to this aspect, Memoli et al. (2008) refers to the importance of registering the distance between the sound source and microphone as well as the distance between the façade and the sound source (parameter D). The variation of parameter D is associated with a variation in the distance between the sound source and the microphone, and, due to the different distances between sound sources and dwellings that exist between northern Europe and southern Europe, it is considered necessary to take it into account in these types of studies.

In this way, Memoli et al. (2008), using a loudspeaker with an MLS signal as a sound source, check the differences of 3.0 dB with respect to a microphone located on the façade. A very interesting aspect was found, the dependence of these differences on the distance between the sound source and the measurement point. Differences of 3.0 dB were found when the sound source was located at a distance of 13.1 m from the reflecting surface. However, if the source was placed at a distance of 10.1 m, the average difference did not exceed 2.5 dB.

Picaut et al. (2005) analyse the sound propagation in urban areas in an experimental study. They use an impulsive sound source and an array of microphones located at heights between 1.2 and 6.0 m on a street with a U profile whose buildings are approximately 18 m high. The obtained values during testing indicate a decrease in sound level as the distance between the source and the array increases, reaching approximately 11 dB at the 1 kHz octave band between the microphone positions located 6 and 50 m from the source.

Lee and Kang (2015) conducted a simulation work in order to study the behaviour of the sound field in urban streets. In particular, they used a technique based on a calculation method that combines ray tracing and modelling by source image. The results show, for the case of a point source, an attenuation of the sound pressure level as the distance between the source and receiver increases. It is more significant in a near field, especially in the case of narrow streets. However, in the case of a line source, for representing road traffic noise, the obtained values of sound pressure level are relatively constant as the distance between source and receiver increases, both in narrow and wide streets.

In the study of Montes González et al. (2015), a correction due to the distance to the sound source is applied in the analysis of each of the blocks of acoustic measurements (Harris, 1991). These normalized sound values due to the distance to the sound source were compared with those sound values not normalized. Overall, it appears that normalized sound values show a qualitative behaviour according to expectations and are closer to the results indicated in the ISO 1996-2 standard.

Therefore, no detailed study of the impact that the distance between the source and façade has on the correction to apply has been made, whether complying with the conditions established in Annex B or omitting them. But, according to results published so far, the existence of an effect due to distance on these corrections seems to be detected. Owing to normal urban configurations that exist in Europe, this fact could have significant effects on the assessment of noise impact on the population in the application of the European Noise Directive if the calibration process of the simulated results with the measured sound levels is considered.

5. The height of the microphone

The ISO 1996-2 standard provides that, for noise mapping, the following microphone heights must be used:

a) 4.0 ± 0.5 m in residential areas with multistorey buildings.
b) 1.2 ± 0.1 m or 1.5 ± 0.1 in residential areas with one floor buildings and recreational areas.

In relation to this topic, the European Noise Directive states that, when calculations are carried out for developing strategic noise maps in relation to noise exposure, the assessment points must be 4.0 m $\pm$ 0.2 m in height above ground level. Similarly, it states that, when measurements for noise mapping are made, other heights may be chosen, but they must not be lower than 1.5 m above the ground, and results should be corrected in accordance with an equivalent height of 4.0 m. However, no correction method is proposed in this regard.

In this way, the ANSI S12.18. (1994) standard proposes a microphone height between 1.2 and 1.8 m above ground level to perform acoustic measurements outdoors while the ANSI S12.9-3 (1993) standard establishes a height between 1.0 and 2.0 m. On the other hand, the FHWA-PD-96-046 (1996) report of the US Department of Transportation proposes a microphone height of 1.5 m as a preferred position, establishing other possible options of from between 4.5 m and 7.5 m for areas of multistorey buildings.

The actual measurement conditions in an urban environment do not always allow placing the measuring device at the height of 4.0 m as specified by the ISO 1996-2 standard. Therefore, as neither the European Noise Directive nor the ISO 1996-2 standard make any mention of the use of possible corrections if the measures are carried out at different heights, this is considered an area to investigate and analyse that is of great interest.

In connection with this aspect, the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores" (CETUR, 1980) fixes the following corrections (K_h) for U profile streets:

$$k_h = -\frac{2\,(h-4)}{l} \text{ if } h>4\ m \tag{7}$$

$$k_h = 0 \text{ if } h\leq 4\ m \tag{8}$$

where "l" is the distance between the façades of both sides of the street, and "h" is the height above ground at which the measuring microphone is located.

The corrections proposed by the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores", which provide a decrease in sound level as the microphone height increases above 4.0 m, have been taken, among others, as a reference in different studies (Rey Gozalo et al., 2013, 2014) to normalize the long-term sound measurements made on balconies of apartments located higher than 4.0 m. However, this guide does not propose any corrections for microphones situated between 1.5 and 4.0 m.

In relation to this matter, in Nicol and Wilson (2004), the vertical variation of the noise level is analysed in urban streets with a U profile. To do this, taking road traffic as the reference sound source, several streets of the city of Athens were selected with different relationships between the average height of buildings and the width of the street. Simultaneous measurements of 15 min were made with three microphones at a distance of 1 m from the building façade. One of the microphones was placed on the street and the others, with different configurations, were placed on two floors of the building. The results show a decrease in sound level as the height increases. Based on the data reported in this study, an average was made of the obtained differences among the sound value registered by the microphone located at street level and those registered by microphones located on different floors of the building at heights of 8, 11.5, 15, 18.5 and 22 m. The results show a decrease of 2.3 dB, 3.1 dB, 3.5 dB, 2.1 dB and 7.8 respectively with height, so the trend is in line with what is established in the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores" in relation with a decrease of sound level as height increase above 4 m although the measured decrease in this paper is results greater than that proposed in the standard. The results found by the authors for two of the streets studied in this work are shown in Fig. 3.

Shortly after the publication of the work of Nicol and Wilson (2004), Soler Rocasalbas et al. (2005) focused their analysis on the differences of microphones located at heights between 1.5 and 4.0 m. They assessed noise levels in different circumstances based on the slope of the street, the distance from the building façade and traffic flow. The results show that, on average, the microphone situated at 1.5 m registered 0.2 dB more than the microphone at 4.0 m (see Fig. 3). So, the difference is very small between the two locations according to what is indicated in the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores" (CETUR, 1980).

Also, in the same direction, some studies have been conducted by combining simulation software and experimental measurements in order to study the behaviour of the sound level on the façade in streets with road traffic conditions (Janczur et al. 2006a, 2006b, 2009; Walerian et al., 2011). Generally, in these works, the field test confirmed the validation software for the range of higher floors. However, for the range of lowest floors, an overestimation of the sound level is observed.

Firstly, Janczur et al. (2006a) conducted a study to predict the distribution of noise levels on the façade of buildings by simulation software (PROP11), and these estimates were experimentally verified (Janczur et al., 2006b). The agreement between measurement and simulation results was tested for different directivity characteristics of an equivalent point source representing the vehicles. The study was made in an urban street with a width of 43.4 m with buildings on both sides with heights of 25.8 and 32.4 m. The microphones were placed at heights of 2.0, 5.3, 8.6, 14.6, 19.1, 22.4 and 25.7 m and at a distance of 0.5 m from the façade of the highest building. The experimental results due to current traffic show that, between 2.0 and 5.3 m, there is an average increase of noise levels of 0.5 dB. This increase, not foreseen in the standard, could have an influence on noise mapping. For heights between 5.3 and 8.6 m and 8.6 and 14.6 m, there are mean decreases of 0.5 and 0.4 dB respectively, which are in line with the estimates of Eq. (7) (see Fig. 3).

In an analogous way to the previous work, Janczur et al. (2009) analysed a new urban environment by carrying out a comparison of the data obtained through simulation and acoustic measurements. In this case, a series of microphones were placed in each of the 10 floors of the façade of a 34 m high building located in the vicinity of a road in a street with an L typology. Measurements of 10 min were performed to determine the equivalent noise level by a four channel digital analyser. The measurements were divided into three groups of

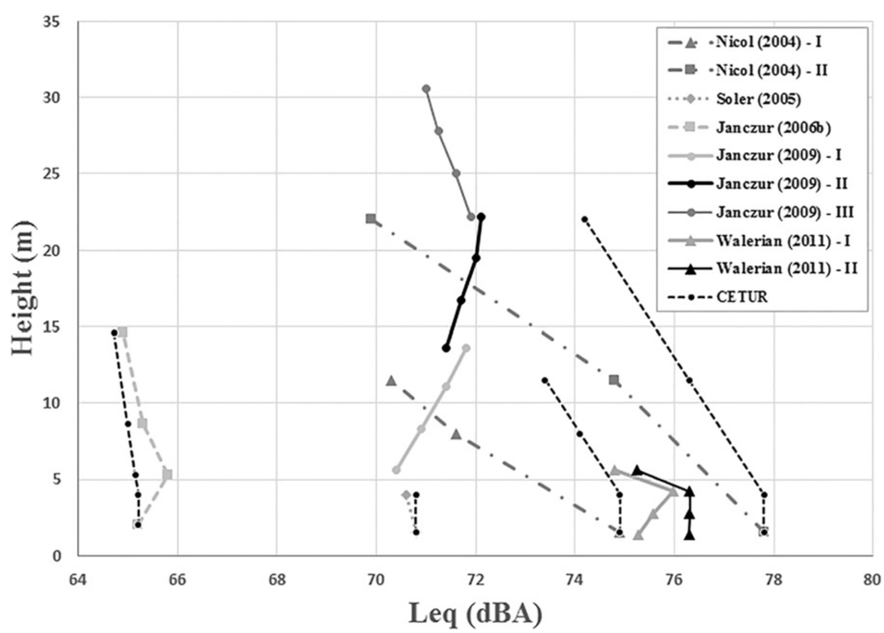

Fig. 3. Sound level variation depending on the height of microphone.

simultaneous measures. In the first one, receivers in floors 1 to 4 are included; in the second one, floors 4 to 7 are included and, in the third one, receivers in floors 7 to 10 are included. To this end, the microphones were placed 1 m from the building façade and 1.5 m above the corresponding floor. The experimental results show an increase in noise levels of approximately 1.5 dB between the heights of 5.6 and 13.9 m and 0.7 dB between the heights of 13.9 and 22.2 m. This increase in sound level is opposite what is expected, even just for reasons of geometrical divergence. Above 22.2 m, sound levels begin to decrease as altitude increases (see Fig. 3).

Walerian et al. (2011) carried out a new study similar to the prior one. In this instance, the urban environment is the same as that used in the work of Janczur et al. (2009), but, instead of placing the microphones next to the façade of the building, they were located in a zone near the road. In this study, four microphones were situated at the respective heights of 1.4, 2.8, 4.2 and 5.6 m in two vertical lines next to a pedestrian bridge, one on each side of the road. Measurements of 10 min were performed to determine the equivalent noise level by a four channel digital analyser and were divided into two groups of simultaneous measurements, one on each vertical line. The experimental results show that, for one of the vertical lines, the measured noise level increases with height from 1.4 m to 4.2 m for a total of 0.5 dB, decreasing by about 1.0 dB between 4.2 and 5.6 m. However, for the second line, located 1 m closer to the road (5.95 m), the sound level values remain nearly constant from 1.4 m to 4.2 m high, showing a fall of 1.0 dB between 4.2 and 5.6 m (see Fig. 3).

In this respect, the work of Montes González et al. (2015) studies the effect of varying the height of the microphone at different points in a city with two sound level meters using simultaneous measurements. For this purpose, a reference microphone was placed 4.0 m high and another microphone was placing at different heights (1.2 m, 1.5 m, 2.5 m and 6.0 m), performing measurements of 15 min. In all cases, the microphones were placed at 3.0 m from the building façade. The values obtained in broadband for the differences of sound levels measured by both microphones, with and without the application of a correction due to the distance to the sound source (Harris, 1991), indicate that, just considering the proximity to the source as the height of measurements decreases, the obtained values have different signs. The results achieved for the differences of sound level between the mobile microphone located at heights of 1.2 m, 1.5 m, 2.5 m and 6.0 m and the reference microphone located at 4.0 m are −0.7 dB, −0.8 dB, −0.2 dB and 0.4 dB respectively. Therefore, the microphone registered, on average, higher sound values as the height increased in spite of being at a greater distance from the source. In the case of applying a correction due to the distance to the source, the values obtained are −0.9 dB, −1.0 dB, −0.4 dB and 0.7 dB respectively. Thus, the sound level increase with height is kept. As this paper does not show measured sound levels, the results cannot be included in Fig. 3.

In addition to variation of sound level depending on the height of microphone in analysed studies, the correction proposed in the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores" in case of U profile streets are shown in Fig. 3.

The fact that recent studies show an increase in noise levels between 1.5 and 4.0 m can lead to underestimations of sound exposure levels represented in the strategic noise maps of cities around the world following the instructions of the European Noise Directive and the ISO-1996-2 standard. Furthermore, this trend appears to exceed 4.0 m, which would contradict the corrections due to the height of the microphone proposed by the "Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores".

6. Conclusions

This work presents a detailed review of the literature and proposes research strategies in order to study the relationships between the ISO 1996-2 standard measurements procedure and the accuracy of the estimations of noise doses received by people obtained by the application of the European Noise Directive.

The ISO 1996-2 standard proposes corrections to be applied to the values of the measured noise levels. The aim of this proposal is to correct the effects of increased noise levels due to sound reflections on surfaces. In this way, the real value of the incident sound field on the façade (free field) is obtained. These corrections have been analysed by some authors in urban environments using "in situ" measurements or simulations.

The different papers published in this respect, in general, have focused on studying the corrections depending on the distance to the building façade, but they have not carried out a detailed study regarding to what extent the indications of Annex B (informative) are verified or not.

The most relevant results published, which may have a significant impact on the results obtained up to now for the implementation of the European Noise Directive, are summarized below:

- The studies conducted to analyse the differences between the measured sound level in the free field and with the microphone located on the reflective surface present a disparity in values. Depending on the case, this may involve differences of up to 2 dB relative to the −6 dB correction indicated by the ISO 1996-2 standard. It should be remembered that this configuration is usually employed in the realization of strategy noise maps through simulation to locate receivers.
- In the studies realized for analysing the correction, which would be applied when the measurement is made between 0.5 and 2 m from the façade under evaluation, the results of different works have a wide variation. This variation can be greater than 1 dB relative to the −3 dB proposed in the standard.
- The studies carried out with respect to the sound level variation depending on the height of the microphone also show quite different results. In some cases, they correspond with that expected, and, in other cases, increases of sound level with height have been detected, which would directly contradict the expected results considering the geometric divergence of the sound wave.

Besides the mentioned results, some possibilities are not considered until the moment arises. On the one hand, the corrections applied could be related to the flow of vehicles and, therefore, to the characteristics of the sound source to be studied. On the other hand, it may be that the incident sound field in the façade can be studied directly by measurements at larger distances than 2 m.

The differences found between the corrections proposed by the standard and the experimental results could be caused by very diverse circumstances, and they seem to be associated with the quite complex configuration of the urban environment of our cities. The sound source can be rather close to the façade under evaluation or influenced in its propagation by urban configurations. It could even, in some cases, become variable in time. Therefore, considering the results shown above, different lines of research arise:

- It is of great importance to know what geometric factors cause the differences found between the correction values proposed by the standard and the experimental results and to what extent these experimental results are being considered in the application of the propagation models.
- It is essential to increase the number of studies in this line of work by taking into account the urban reality of European cities, that is, the wide variety of urban configurations and distances to the sound source that can be found.
- It is necessary that, if analysing the specific effects of different geometric urban configurations is wanted, that new studies analyse and indicate results independently for the different configurations

of the environment and the different microphone positions, which have been used.

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