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Evaluation of exposure to road traffic noise: Effects of microphone height and urban configuration

David Montes González [a,b], Juan Miguel Barrigón Morillas [b], Guillermo Rey Gozalo [b,*], Luís Godinho [a]

[a] *ISISE, Departamento de Engenharia Civil, Universidade de Coimbra, Luis Reis Dos Santos 290, Coimbra, Portugal*
[b] *INTERRA, Lambda, Departamento de Física Aplicada, Universidad de Extremadura, Cáceres, Spain*

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ABSTRACT

Noise pollution is a major environmental problem due to its impact on human health and implications for other spheres of society. Since road traffic is the main source of noise pollution, the use of measurement methodologies to accurately determine the environmental noise levels to which the façades of buildings in cities are exposed is an important issue. This paper presents an experimental study in urban environments that uses different configurations to evaluate the influence of the position of the microphone and the parking lanes on the levels of road traffic noise to which the population is exposed. In urban settings in which sound waves propagate without obstacles between the lanes of traffic and the receivers, broadband results for the differences between noise levels measured by microphones placed at heights of 4.0 and 1.5 m showed a significant increase with an increase in the distance between the microphone and sound source of between −0.8 and 0.9 dBA over a range from 2 to 8 m. This difference between the two microphones was greater at points where a lane of parked vehicles was located between the road traffic lanes and the receivers were placed near the façades of building. At the same heights, the broadband difference in sound levels ranged from 2.7 to 4.5 dBA. This acoustic shielding effect due to the presence of parked vehicles started to be relevant in the 250 Hz band and increased progressively with frequency. Taking into account these experimental results and the recommendations in the European Noise Directive, it would be important to apply corrections to sound indicators for road traffic noise that are related to the height of the microphone. Making a distinction between urban configurations with and without lines of parked vehicles between the microphone and the road traffic lanes would be advisable.

1. Introduction

The impact of environmental noise on human health has been widely reported by the World Health Organisation (WHO) (WHO, 2018). The scientific literature shows that this pollutant has harmful health effects on respiratory, nervous, metabolic and cardiovascular systems (Recio et al., 2016; Tobías et al., 2015; Roswall et al., 2017; Daiber et al., 2019; Barceló et al., 2016). The European Noise Directive (END) (COM, 2012) is the legislative reference in Europe for assessing how much population is exposed to environmental noise. The European Environment Agency (EEA) has indicated that noise pollution remains a major environmental health problem in Europe (EEA, 2017), and transport infrastructures such as roads, railways, airports and ports play an important role in this environmental problem (EEA, 2014). However, environmental noise also has relevant implications for other spheres of society, for example urban planning (Khomenko et al., 2020), economics (Zheng et al., 2020) and wildlife conservation (Alquezar and Macedo, 2019).

The use of experimental measurements offers a way to obtain real data in order to calculate human exposure to noise pollution. Long-term measurements have been performed in cities of different sizes, such as Madrid, Málaga and Cáceres (Spain) and Talca (Chile), to monitor environmental noise levels due to road traffic (Barrigón Morillas et al., 2015; PrietoGajardo et al., 2016; Rey Gozalo et al., 2015). Short- and long-term measurements were also used in Livorno (Italy) for the acoustic characterisation of the many different small boats that travel daily in all types of ports (Bernardini et al., 2019; Fredianelli et al., 2020). An experimental procedure using field measurements was also followed in Guangzhou (China) to study the noise level produced by moving subway trains in a three-storey building, where recorded vibration and noise levels were greater than the allowable values of criteria (Zou et al., 2015). On-site measurements were used in the annual assessment of noise around airports with different flight intensities in Vilnius (Lithuania) and Madrid (Spain) (Jagniatinskis et al., 2016). Lechner et al. (2019) also studied the combined effects of aircraft, rail and road traffic noise on total noise annoyance in Inns-

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* Corresponding author.
E-mail address: guille@unex.es (G. Rey Gozalo)

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bruck (Austria). There is has also been a line of research involving the use of mobile stations mounted on bicycles to measure environmental noise in cities (Guillaume et al., 2019; Quintero et al., 2019). Other investigations have combined simultaneous measurements of road traffic noise and gas particles in the areas surrounding roads to establish relationships between noise and air pollution (Perez-Prada and Monzon, 2017), and measurements have also been made to evaluate the quality of noise in quiet areas and green spaces (EEA, 2016; Rey Gozalo et al., 2019a; BarrigónMorillas et al., 2013).

The use of *in situ* measurements also plays a very important role in the production and validation of strategic noise maps developed by computational methods (WG-AEN, 2007; COM, 2012). Noise maps are very useful for estimating the proportion of a population that is exposed to a certain level of environmental noise and in planning actions to mitigate the impact on people's health (Thacher et al., 2020; Ögren et al., 2018). In this regard, there is a domain of research that proposes an alternative to traditional static maps by creating dynamic noise maps based on *in situ* measurements, which makes it possible to continuously update the values of the sound indicators shown in these maps (Benocci et al., 2019; Zambon et al., 2017). The development of dynamic noise models has also been proposed to determine the instantaneous sound power of each vehicle (Can et al., 2009, 2010).

Around 100 million people are exposed to levels above 55 dB L_{den} in European Union countries, where road traffic is the main source of annoyance (EEA, 2017). When assessing the impact of this source of noise on the façades of residential, working and sensitive (educational, medical, etc.) buildings through measurements, the position of the microphone is an important issue (Barrigón Morillas et al., 2016). ISO 1996-2 (ISO 1996-2, 2017) is used as a reference for the measurement procedure (Rey Gozalo et al., 2019b). In order to determine the sound level incident on the façade, it provides some corrections to the measured sound level due to reflections of sound on the surface as a function of the distance between the microphone and the façade (Mateus et al., 2015; Montes González et al., 2018a; Flores et al., 2019). It also states that a microphone height of 4.0 ± 0.2 m should be used for general mapping, unless otherwise specified. In accordance with this standard, END (COM, 2012) stated that evaluation points should be placed at height of 4.0 m ± 0.2 m when measurements are carried out near buildings. But it also stipulates that other heights equal to or greater than 1.5 m could be chosen, in which case the results should be corrected for an equivalent height of 4.0 m, although it does not specify the way in which this correction should be done. Moreover, the Guide du Bruit des Transports Terrestrial: Prevision des Niveaux Sonores (CETUR) (CETUR, 1980) proposed that no correction should be applied between the microphone locations at heights of 1.5 and 4.0 m for U-profile streets. This aspect may be relevant in measuring the noise levels to which residential buildings in cities are exposed, due to the urban and architectural configuration of the streets and the presence of obstacles such as lines of parked vehicles (Montes González et al., 2018b, Montes González et al., 2020a). Some recent research is also particularly focused on traffic noise exposure of high-rise residential buildings in urban areas (Wu et al., 2019; Benocci et al., 2020; Jeon and Jo, 2019).

Considering all these aspects, this paper presents an experimental study of urban environments with different characteristics, in order to evaluate the influence of the microphone position in the determination of levels of road traffic noise to which the population is exposed. It could be important in different current methodologies used to assess noise pollution. On the one hand, to ensure a correct verification of the strategic noise maps. Secondly, for an adequate elaboration of the noise maps based on mobile measurements. Moreover, for an accurate *in situ* assessment of the levels of exposure to urban noise. In short, this study should allow a more precise evaluation of the number of people exposed to undesirable noise levels.

2. Methodology

Streets in which road traffic was the main source of noise and with different architectural, urban and vehicle flow characteristics were selected within Coimbra, a city with approximately 146,000 inhabitants (Statistics Portugal,) located in the central region of Portugal. In each street (S), two different sets of measuring points (P) were considered: one in an urban configuration where there were no obstacles between the microphone and the sound source, and a second in which there was a lane of parked vehicles between the receiver and the traffic lanes. In the first case, the ground distance between the microphone and the closest point to the sound source (d_{MS}) was considered when selecting the points, while in the second, the ground distance between the microphone and the nearest point of the line of parked vehicles (d_{MV}) was taken into account. As detailed in Table 1, measurement points were selected in streets 1 (S1), 2 (S2), 3 (S3) and 4 (S4) for cases without and with obstacles between the microphone and the sound source as a function of d_{MS} and d_{MV}, respectively. However, in streets 5 (S5) and 6 (S6), measurements in only one of the two previously specified urban configurations could be carried out. Fig. 1 shows a graphical diagram of the measuring points in each of the streets. For streets 2 and 4, two schemes are shown, since two different sections of each street were considered in order to include scenarios with and without parked vehicles. As can be seen, streets with different characteristics were chosen to develop the tests. Aspects such as the number of traffic lines, the orientation of parked vehicles, and the width and profile (L or U) of the street were considered for this purpose. Average traffic flows greater than 600 vehicles/h were recorded on all streets, including heavy vehicles corresponding to urban bus lines.

Ten measurements of 10 min each were conducted during daytime and evening periods (7:00–19:00 and 19:00–23:00) at each point; to take these measurements, the microphones of two class 1 analysers according to IEC 61672–1 (IEC 61672–1, 2013) were simultaneously placed at heights of 4.0 and 1.5 m above the ground. Verification of the calibration of the instruments was carried out before and after the measurement sessions, using a Brüel and Kjær 4231 sound calibrator. The equivalent sound level (L_{Aeq}) was recorded by the microphones at 4.0 and 1.5 m in broadband and frequency octave bands between 63 Hz and 8 kHz (Montes González et al., 2018a; Yang et al., 2020). Fig. 2 shows the position of the microphone at some of the measurement points on the streets considered in the study. In cases where the microphones were located in front of a building façade, a distance of at least 0.5 m was maintained from the surface in order to avoid complex reflection effects (Memoli et al., 2008; Montes González et al., 2020b). On streets with a line of vehicles parked between the microphones and the sound source, one of the aims was to assess how the acoustic shielding effect varied as a function of the distance d_{MV} whenever possible, according to the urban configuration. In this regard, the number of parked vehicles and their positions were sufficient to ensure the screening of microphones with a minimum horizontal viewing angle of 60° with respect to the linear sound source, according to

Table 1
Measurement points (P) in each street (S).

	Without parked vehicles				With parked vehicles		
	P1	P2	P3	P4	P5	P6	P7
	d_{MS} (m)				d_{MV} (m)		
Street 1 (S1)	2.0	4.0	6.0	8.0	1.0	2.0	3.0
Street 2 (S2)	2.0	4.0	6.0	8.0	1.0	2.0	3.0
Street 3 (S3)	2.1	–	–	–	2.4	–	–
Street 4 (S4)	1.5	–	–	–	1.2	–	–
Street 5 (S5)	–	–	–	–	1.0	–	–
Street 6 (S6)	2.3	–	–	–	–	–	–

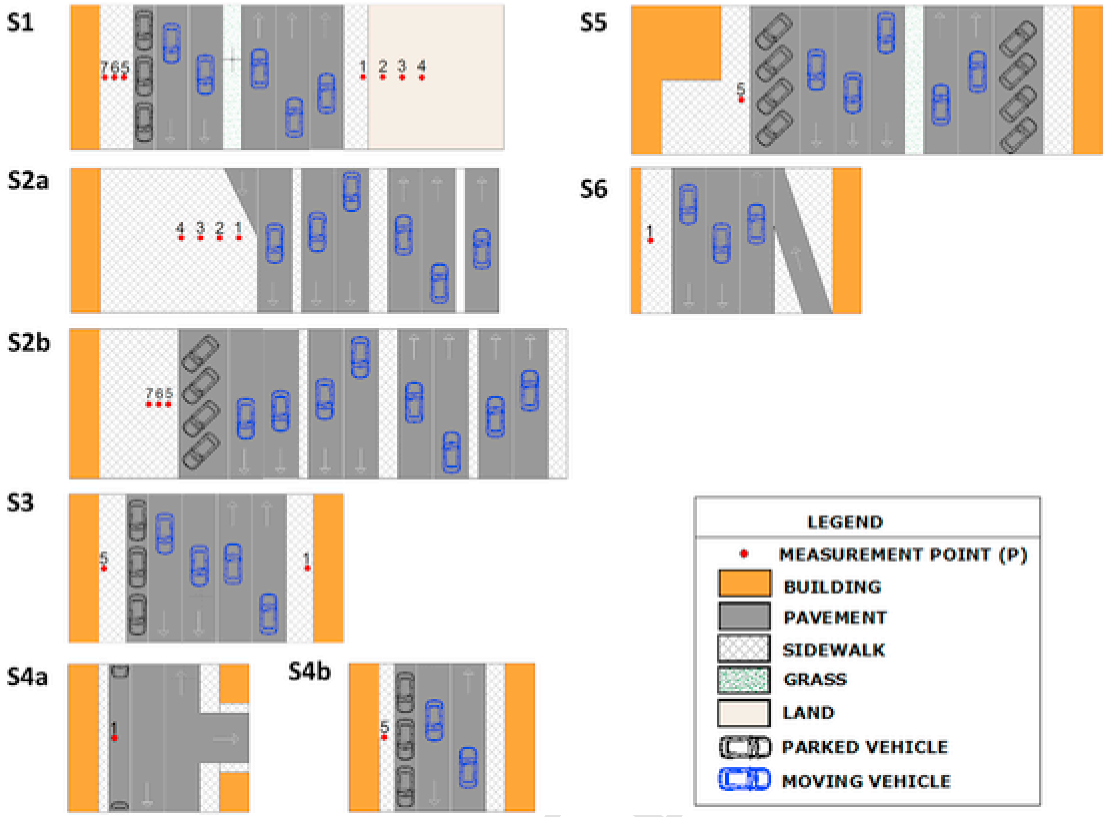


Fig. 1. Layout of the measurement points in the streets.

the guidelines of the ISO 1996-2 standard for considering an extended source (ISO 1996-2, 2017).

3. Results

3.1. Measurement configurations without parking lanes

In this section, the effect of the variation in the distance between the microphone and the sound source (d_{MS}) on the difference in sound level between microphones located at 4.0 and 1.5 m above the ground is evaluated in urban configurations without parking lanes. As can be seen in Fig. 1, the features of streets 1 and 2 allowed several measurement points to be selected in order to assess the influence of the variable d_{MS} in each of these streets.

Fig. 3 shows the average values of the difference in the broadband equivalent sound level between both microphones ($\Delta Leq_{4m-1.5m}$) in the different selected streets and the corresponding 95% confidence intervals. At the measuring points in the different streets, where the distance between the microphone and the traffic lanes (d_{MS}) was in the range 1.5–2.25 m, the average differences in the equivalent sound level between the microphones at 4.0 and 1.5 m ranged from −0.8 to 0.3 dBA. On the one hand, negative values for the difference in sound levels were obtained in streets 1, 2, 4 and 6, indicating that the receiver placed at a height of 1.5 m recorded the highest values of the equivalent sound level. In the case of street 3, the positive sign of the difference in levels indicates that a higher sound level was recorded by the microphone located at 4.0 m. This may have been due to the protrusions on the façade of the rear building, in such a way that a reflection effect could be generated near the microphone at 4 m, contributing to an increase in the measured level. As the averages of the differences between the values registered at 4.0 and 1.5 m in some cases were near zero (see Fig. 3), an analysis was carried out to check whether these averages differed from zero (pared-sampled *t*-test). The results showed that there were significant differences between the average sound values recorded at heights of 4.0 and 1.5 m ($p < 0.05$) at all points on the studied streets, except in the case of street 2 for $d_{MS} = 2$ m. Therefore, this indicates a significant bias as a function of microphone height.

It is also interesting to highlight in Fig. 3 that in streets 1 and 2, the average difference in sound levels increases significantly with the distance between the sound source and the microphone (d_{MS}) between 2 and 8 m (p-value < 0.05 according to *t*-test), and even reverses sign and reaches a maximum average value of 0.9 dBA in street 2 for $d_{MS} = 8$ m. Hence, in measurement configurations where the microphones are further away from the sound source, a higher sound level was recorded by the receiver located at 4.0 m. This value is similar to the results of another study carried out in front of a building with microphones placed at heights of 2.0 and 5.3 m, with a distance of approximately 11 m between the receivers and the nearest lane of traffic (Janczur et al., 2006).

Experimental results obtained on U- and L-profile streets with no obstacles between the traffic lanes and the microphones show variations of between −0.8 and 0.9 dBA for the average difference in equivalent sound level between receivers located at 4.0 and 1.5 m. However, the CETUR proposal (CETUR, 1980) is not to apply corrections for microphone heights equal to or lower than 4.0 m for U-shaped streets, even though END (COM, 2012) indicates the need to make corrections to levels measured at heights of between 1.5 and 4.0 m. Furthermore, when assessing the exposure of a building façade in an urban environment with no obstacles between the microphone and the traffic lanes, a significant relationship is found between the difference in sound levels between heights of 4.0 and 1.5 m and the distance between the receivers and the sound source (d_{MS}) (see Fig. 4).

Fig. 4 shows in red the adjustment curve for the relationship between the difference in the equivalent sound level and the corresponding distance between the microphones and sound source in these streets. This curve predicts that for a minimum value of $d_{MS} = 1$ m, the microphone placed at 1.5 m would register an equivalent sound

Fig. 2. Positions of microphones during *in situ* measurements.

level greater by 0.84 dBA than that placed at 4.0 m. It can also be seen that if the distance between the microphones and the sound source is increased to 10 m (an order of magnitude), the microphone at 4.0 m would then register a sound level higher by 1 dBA. Hence, for a range of distance of 1–10 m between the microphones and the sound source, a variation of around 1.8 dBA would result in the difference between the microphones at heights of 4.0 and 1.5 m. In addition, the coefficient of determination (R^2) indicates that the variable d_{MS} (the distance between microphone and sound source) is able to explain 60% of the variation in the difference in sound level between the two microphone heights.

This dependence on the sound level measured with microphones placed at heights of 4.0 and 1.5 m above the ground is not only relevant in determining the impact of environmental noise on the façade of buildings, but can also be of interest in on-site measurements according to ISO standards 11819-1 and 11819-4 (ISO 11819-1, 1997; ISO 11819-4, 2013) for measuring the influence of road surfaces on traffic noise (Czuka et al., 2016; Cho and Mun, 2008).

To allow for a detailed analysis of the effect of the distance between the microphone and the sound source, the broadband study was complemented by an octave band analysis. Fig. 5 presents the average difference in the measured equivalent sound level (Leq) between the microphones located at heights of 4.0 and 1.5 m in octave frequency bands and the corresponding 95% confidence interval. The results for the four measurement points (P1, P2, P3 and P4) on street 1 (S1) as a function of the distance between the microphone and the sound source (d_{MS}) are shown in Fig. 5a. In the frequency bands between 63 and 500 Hz, the difference in equivalent sound level between the microphones located at 4.0 and 1.5 m ($\Delta Leq_{\ 4m\text{–}1.5m}$) followed a fairly similar trend over the range of distances studied. This is stable at around −0.5 dB for points P2, P3 and P4, while at point P1 it has values closer to −1 dB that is, between 63 and 500 Hz, the microphone located at 1.5 m registers a higher sound level than that placed at 4.0 m over the whole range of distances between 2 and 8 m. Above 500 Hz, the results obtained at the different measuring points start to differ and have positive values, indicating that the microphone located at 4.0 m is recording a higher sound level value. In the 1 kHz band, the difference in sound level increases to between 1 and 1.7 dB depending on the point, reaching a maximum value at the four measurement points. At point P4 (d_{MS} = 8 m), the maximum value of 1.4 dB is detected, with a posi-

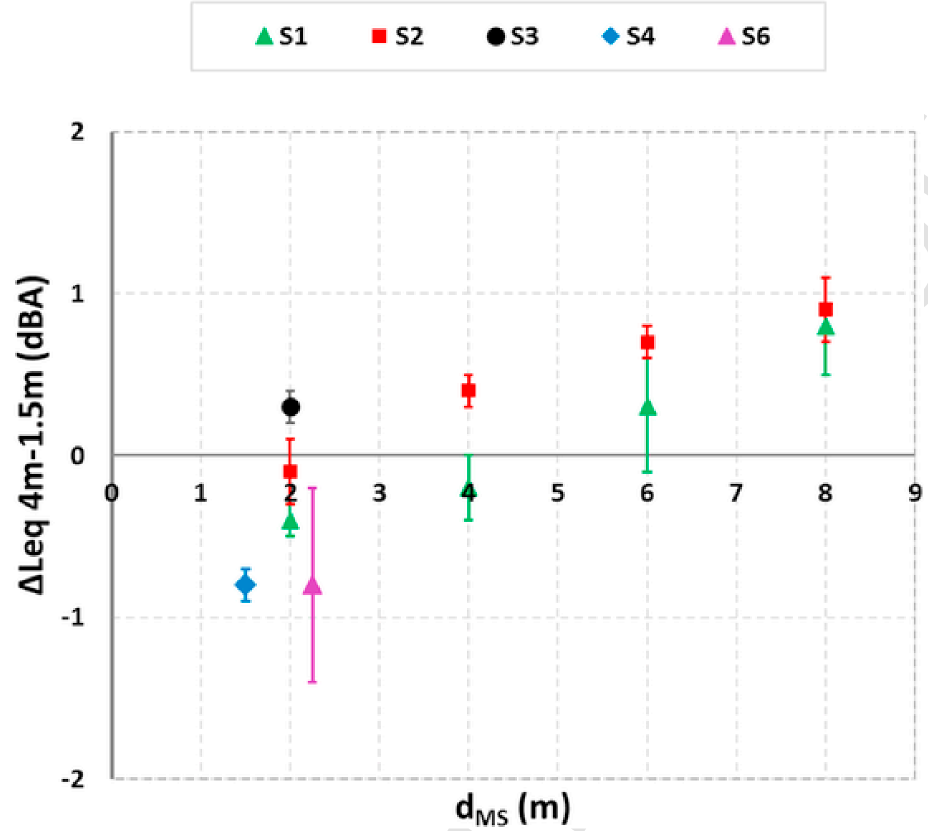


Fig. 3. Variation in ΔLeq between microphones at heights of 4.0 and 1.5 m with distance between the microphone and sound source (d_{MS}) without obstacles.

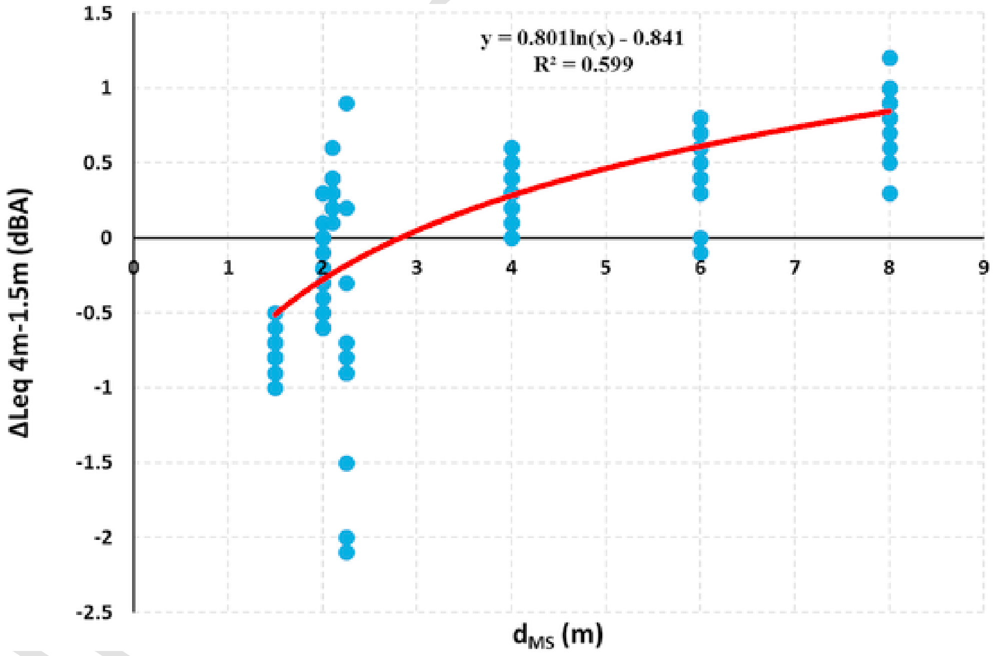
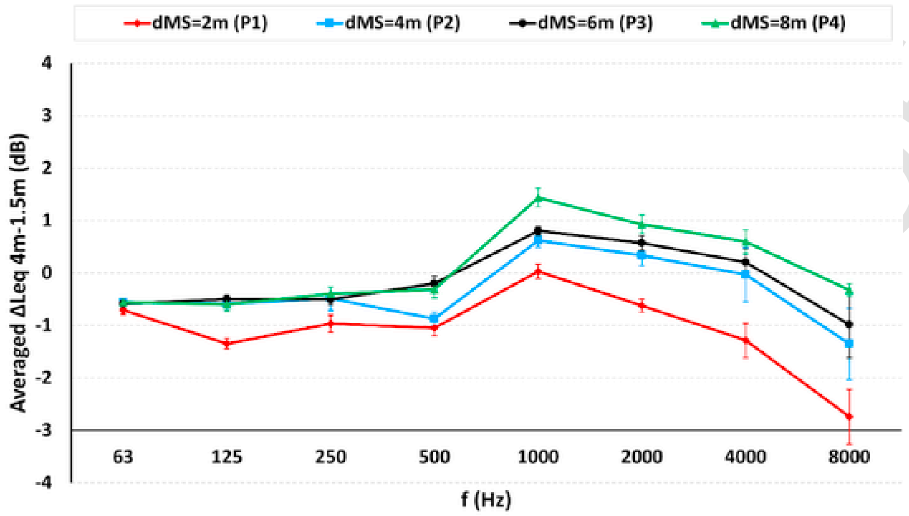


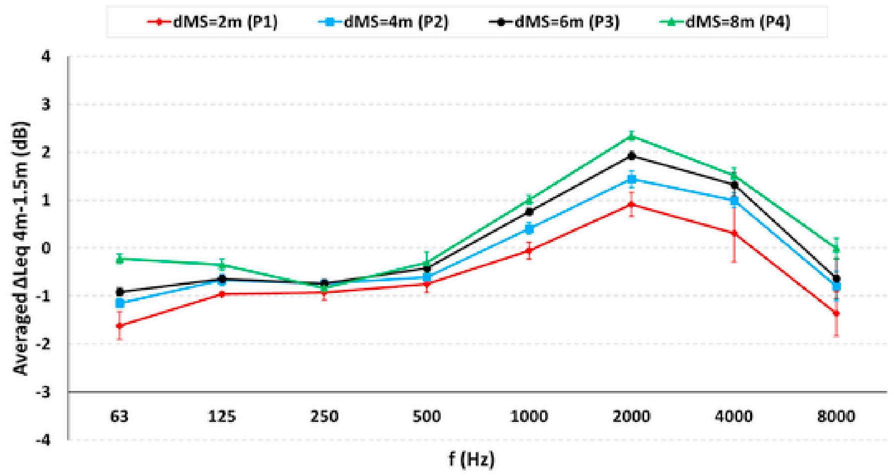
Fig. 4. Relationship between ΔLeq $_{4m-1.5m}$ and distance between the receivers and the sound source.

tive sign, while at point 1 (d_{MS} = 2 m), this maximum value is 0 dB. The difference in sound levels then starts to progressively decrease with frequency over the whole range of distances, remaining at positive values at points P2, P3 and P4 up to 4 kHz; however, at point P1, it has negative values up to 8 kHz, where it reaches the minimum value of −2.7 dB. In the case of street 2 (Fig. 5b), a general trend similar to that of street 1 is observed, although in this case, in the 63 and 125 Hz bands, values are detected for the sound level differences with negative sign that are higher than in street 1, reaching a minimum value of −1.6 dB at a distance of 2 m (P1). In addition, there is a significant variation in the results obtained in these frequency bands at the four measurement points. The differences observed between streets 1 and 2 at low frequencies may be related to the different urban configurations, since although in both cases these streets have an L profile, in

a) Street 1 (S1)



b) Street 2 (S2)



c) Streets 3, 4, 6 (S3, S4, S6)

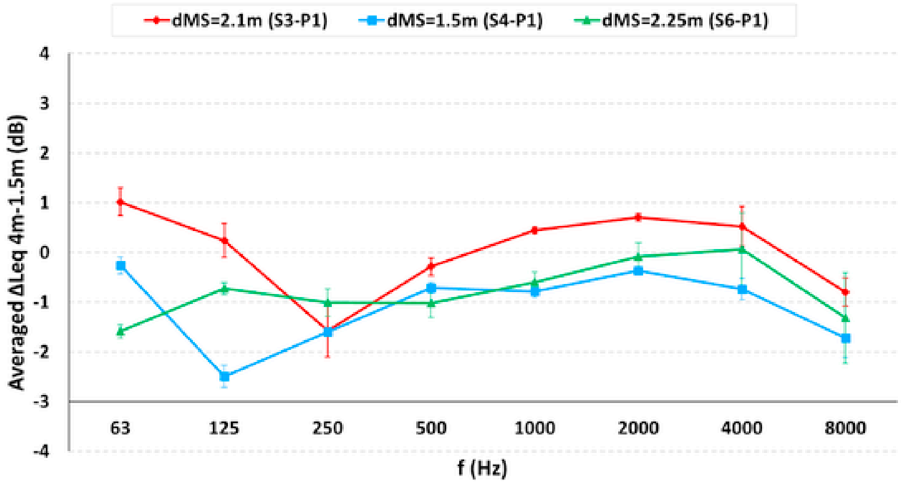


Fig. 5. Variation in the difference in measured equivalent sound level (Leq) between microphones located at heights of 4.0 and 1.5 m in octave frequency bands with distance from the microphone to the sound source (d_{MS}) without obstacles.

the case of street 2 there were buildings behind the measuring equipment, while in street 1 there were none. As in Fig. 5a for street 1, the values of the differences in street 2 remain stable above 125 Hz, with negative values up to the 500 Hz band. Above this frequency, there is a notable increase in the difference in the sound levels with increasing frequency until positive values are reached, when the microphone located at 4.0 m begins to record a higher sound level, in this case reaching a maximum value in the 2 kHz frequency octave band. The maximum value of 2.3 dB is obtained at point P4. Finally, the difference in the sound level decreases again over the whole range of distances (between 2 and 8 m) as the frequency increases to 8 kHz. Fig. 5c shows the results for streets 3, 4 and 6, where the measurement points were located at a range of distances of 1.5–2.25 m between the microphone and the traffic lanes. As can be seen, the difference in sound levels remains negative over the whole range of frequencies at points 4 and 6, unlike at point 3. In this case, it is interesting to highlight some of the interference phenomena that are generated between direct and reflected sound waves in bands between 63 and 250 Hz, depending on the distance of the microphones from the façade of the building (Montes González et al., 2020b).

3.2. Measurement configurations with parking lanes

The influence of the variation in the distance between the microphone and the parking lane (d_{MV}) on the difference in the sound level between microphones located at heights of 4.0 and 1.5 m near building façades was assessed using the points indicated in Table 1 and Fig. 1 in streets 1, 2, 3, 4 and 5 with parked vehicles.

Fig. 6 shows that the average difference in equivalent sound level between the receivers at heights of 4.0 and 1.5 m ($\Delta Leq_{4m-1.5m}$) ranges from 2.7 dBA at point P5 in street 4 (S4–P5) to 4.5 dBA at point P7 in street 2 (S2–P7). Similarly to Section 3.1, the average values of these differences differ from zero at all points according to pared-sampled *t*-test ($p < 0.001$). This means that the microphone located at 4.0 m recorded a significantly higher value for the sound level in all streets with a parking lane between the microphone and the traffic lanes. This acoustic shielding effect due to parked vehicles in urban environments reaches a magnitude that can be relevant in the process of validating strategic noise maps because computational models do not usually consider the presence of these obstacles when calculating noise indicators for building façades (Montes González et al., 2018b). It may also be important in the corrections to be applied to sound indicators calculated based on measurements in dynamic noise maps (Benocci et al., 2019) and mobile measurement stations in urban environments (Guillaume et al., 2019). Another interesting aspect of Fig. 6 is that no significant variation ($p > 0.05$ according to *t*-test) in the acoustic shielding effect was observed when the distance between the microphone and the line of parked vehicles (d_{MV}) was varied. This may be interesting considering the range of distances between the microphone and noise barriers used in the EN 1793-6 standard (EN 1793-6:2018, 2018) for *in situ* tests to determine the insertion loss of noise-reducing devices. Concerning the presence of other objects in urban environments that can also influence the propagation of sound, investigations of noise reduction by hedges in different European cities were carried out. Differences of between 1.1 and 3.6 dBA were found in experimental measurements made in configurations with and without bushes in front of microphones located 1.5 m above the ground (Van Renterghem et al., 2014).

To enable a detailed analysis of this shielding effect, Fig. 7 shows the difference in the measured equivalent sound level (Leq) between microphones located at heights of 4.0 and 1.5 m in octave frequency bands, with the corresponding 95% confidence intervals, for urban configurations with parking lanes in streets 1, 2, 3, 4 and 5. Similar spectral results are shown in Fig. 7a for the differences in sound levels at points P5, P6 and P7 on street 1, regardless of the distance between the microphone and parked vehicles (d_{MV}), except at octave fre-

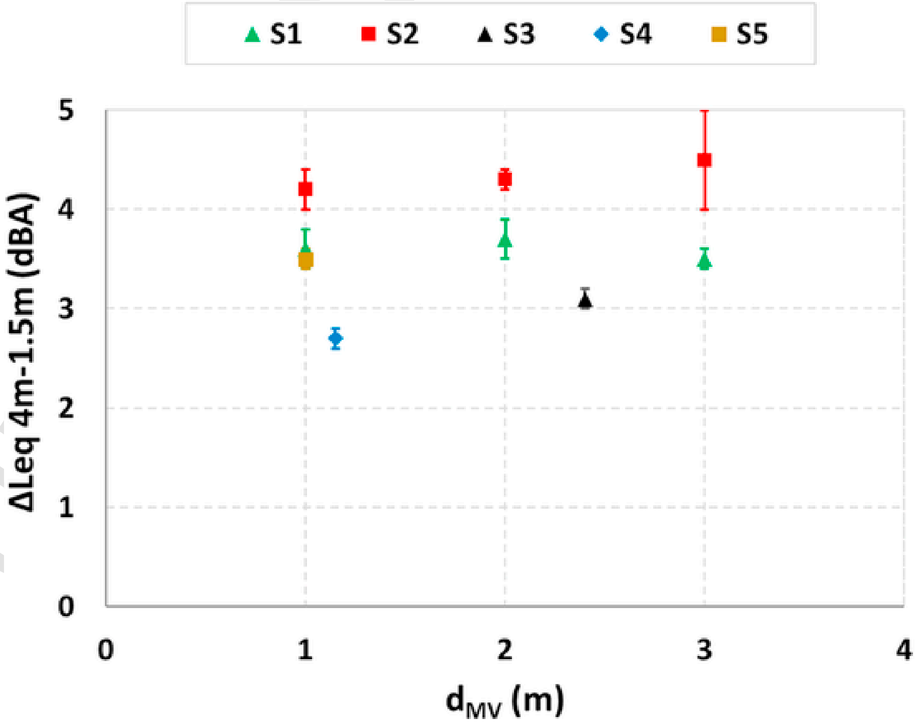
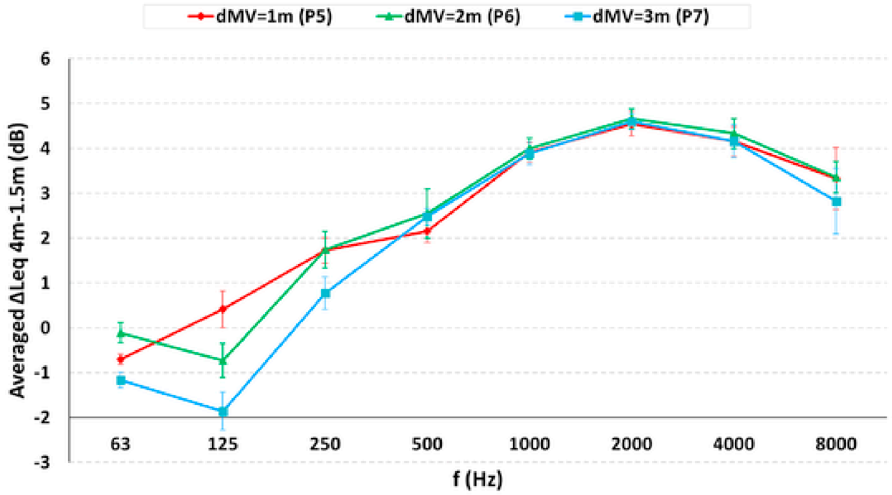
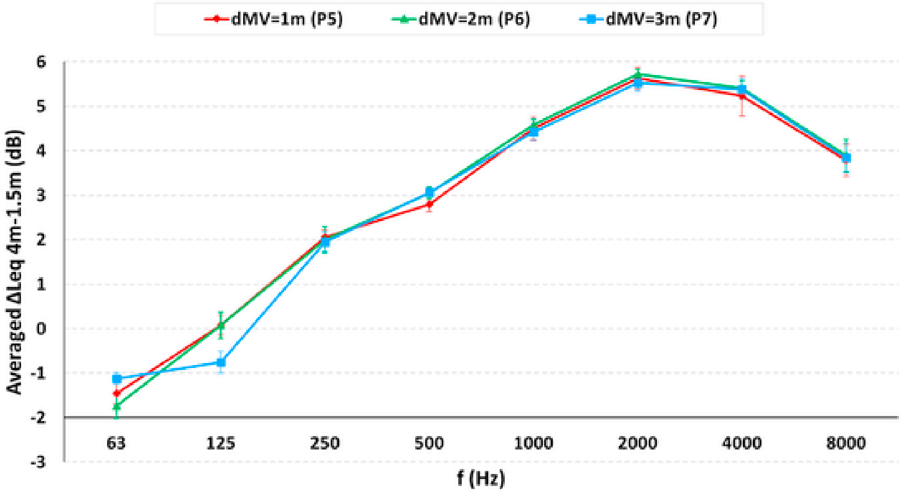


Fig. 6. Variation in ΔLeq between microphones at heights of 4.0 and 1.5 m with distance from microphone to parked vehicles (d_{MV}).



b) Street 2 (S2)



c) Streets 3, 4, 5 (S3, S4, S5)

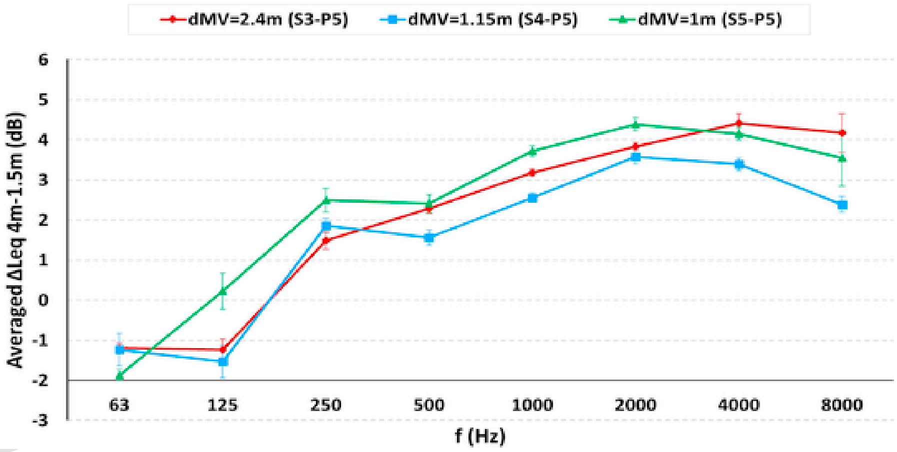


Fig. 7. Variation in the difference in measured equivalent sound level (Leq) between microphones located at heights of 4.0 and 1.5 m in octave frequency bands with distance from the microphone to parked vehicles (d_{MV}).

quency bands below 250 Hz. This may be due to the fact that as d_{MV} increases, the distance from the microphone to the façade (d_{MF}) decreases; wave interference phenomena may then appear at certain frequencies, which may vary as a function of d_{MF} (Montes González et al., 2020b). In general, an acoustic shielding effect is observed in street 1 due to the presence of vehicles parked parallel to the building's façade. This effect starts to become relevant in the 250 Hz band, and increases gradually with frequency until it reaches a maximum value of around 4.7 dB at 2 kHz. Subsequently, this acoustic shielding effect decreases slightly with frequency to values of around 3 dB in the 8 kHz band. In this case, the microphone at a height of 4.0 m detects a higher sound level than at 1.5 m. A similar trend to street 1 was found in street 2 (Fig. 7b) for the equivalent sound level difference. However, in this case, two significant aspects were observed. Firstly, the behaviour at measuring points P5, P6 and P7 in frequency bands below 250 Hz was quite similar, probably because in this section of the street the distance between the microphone and the building façade is greater than in street 1. This would lead to mitigation of the wave interference effect in these frequency bands. Secondly, a higher maximum value of the acoustic shielding effect is seen in this street in the 2 kHz band, with values of around 5.7 dB. Fig. 7c shows the differences in the frequency bands of sound levels measured in streets 3, 4 and 5. In accordance with the results for streets 1 (Figs. 7a) and 2 (Fig. 7b), an acoustic shielding effect is noted, which increases gradually with frequency up to the 2 kHz band. That is, the microphone at 4.0 m also records a higher sound level than at 1.5 m. In this case, there are some slight differences in the magnitude of the shielding effect between the three streets that may be related to the orientation of the parked vehicles. While in street 5 the vehicles are parked at an approximate angle of 45° with respect to the building façade, in streets 3 and 4, the line of parked vehicles is parallel to the surface. Hence, a discontinuous acoustic barrier is formed in street 5 with a greater thickness than in streets 3 and 4.

4. Conclusions

The effects of microphone height and urban configuration on the determination of noise indicators used to calculate the exposure level of a population to road traffic noise are evaluated in this paper. To achieve this, a series of *in situ* measurements were carried out in Coimbra (Portugal) with two microphones located at heights of 4.0 and 1.5 m above the ground, in urban settings with and without lines of parked vehicles between the sound source and the microphones.

In urban settings where the sound field propagates without obstacles between the traffic lanes and the receivers:

- Broadband results for the difference between the noise levels measured by microphones placed at heights of 4.0 and 1.5 m showed a significant increase with the distance between the microphone and sound source (d_{MS}) of between −0.8 and 0.9 dBA, over a range of distances from 2 to 8 m.
- At the closest distances to the source (approx. 2 m), the microphone at a height of 1.5 m measured higher noise levels than the one at 4 m, for all octave bands.
- However, for a range of distances between 4 and 8 m, the microphone located at 4 m recorded the highest noise levels in octave bands from 1 to 4 kHz.

However, in urban configurations with a lane of parked vehicles between the sound source and the receivers placed near building façades:

- The broadband difference in sound levels between microphones at heights of 4.0 and 1.5 m ranged from 2.7 to 4.5 dBA. This means that the microphone located at 4.0 m recorded significantly higher values for the noise level.
- This acoustic shielding effect due to the presence of parked vehicles became relevant in the 250 Hz band, and increased progressively with frequency until values of differences of between 3 and 5 dB were reached in the range 1–4 KHz.
- No significant changes were found in the differences in sound level obtained at the various distances studied between microphones and parked vehicles.

These findings are relevant for the verification of the strategic noise maps regulated by the END, since computational models do not usually consider the presence of these obstacles when calculating noise indicators at building façades. Furthermore, considering the magnitudes of the noise level variations recorded in these urban configurations and the 5 dB range used for noise indicators in strategic noise maps, these results could be important in calculating the numbers of people exposed to certain levels of noise. Taking into account these experimental results and the recommendations from END, it can be concluded that:

- It is important to make corrections to sound indicators for road traffic noise related to the height of the microphone.
- When applying these corrections, it is necessary to make a distinction between urban configurations with and without lines of parked vehicles.

This issue is also relevant to the application of corrections to sound indicators according to the heights of the microphones in on-site measurements related to lines of research involving dynamic noise maps and mobile stations using bicycles to measure environmental noise.

Author statements

David Montes González: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Funding acquisition. Juan Miguel Barrigón Morillas: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration, Funding acquisition. Guillermo Rey Gozalo: Validation, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Supervision, Funding acquisition. Luís Godinho: Investigation, Resources, Writing - Review & Editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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