Chapter

Noise Profile Categorization for Noise Mapping in Cities: The Case of Cuenca (Spain)

José A. Ballesteros, María Jesús Ballesteros, Samuel Quintana and Marcos D. Fernandez

Abstract

According to the European Law, noise maps in cities have to be worked out and updated every 5 years. Because of this, it is interesting to establish new methodologies to develop and update the noise maps in a more efficient way. Although there are specific standards to carry out noise maps and a good practice guide was defined, there is not a common procedure in the definition of the noise map. In each research, a specific methodology is defined based on the experience of the researchers and the characteristics of the town. In this work, a methodology based on a street typology classification is proposed to be applied to noise maps. This methodology allows allocation of the mean power and the temporal behavior to each street from its characteristics and the time profiles measured with semi-permanent noise monitoring systems. The methodology was developed, tested, and validated in the city of Cuenca (Spain) and the results obtained are shown in this chapter.

Keywords: urban noise, noise mapping, noise profiles, street typologies, monitoring system

1. Introduction

The European Law [1], developed in Spain by the Royal Decrees [2, 3], states that noise maps in cities with a population in excess of 100,000 individuals need to be developed and updated every 5 years.

A noise map can be done just based on a prediction model, that is, without any kind of empirical measurement; but to achieve a minimum accuracy level, a calibration of the model is required through a selected number of in-situ measurement points, which increases the budget to carry out the noise map. Moreover, although specific standards and a good practice guide [4] have been defined to be used in noise maps, each research group defines its own methodology based on its experience and the characteristics of the town. Therefore, a proper balance must be found among the cost of the noise map, its accuracy, and the number of measurement points; that balance can be improved with the use of a road categorization system to achieve representative measurements of all the types of roads to minimize the cost without losing accuracy in the model.

Classically, four sampling methods have been considered: to select the sampling points by laying a grid over a map of the target zone, to define a source-oriented sampling where measurement locations are selected arbitrarily to represent different road and traffic conditions, to define a receptor-oriented sampling in which the noise exposure of a particular class of receptors is investigated, and to select the sampling points using a prior classification of the urban noise [5].

In [6] sampling points were selected, covering all of the representative locations and all of the streets in the area. The sampling points were always in the middle of the street or location-specific. This methodology for selecting sampling points and locations allows performing a detailed study of the area and it is not based on a previous categorization of the streets, but neither is similar to the commonly used grid method.

Preliminary studies of three towns [7–9] served to adapt and optimize the definition of the categories established in [10]. This definition consisted of six categories:

- Class 1: national roads
- Class 2: streets that provide access to the major distribution nodes of the town
- Class 3: streets that lead to regional roads
- Class 4: streets that allow clear communication among the previous types of streets
- Class 5: the rest of the streets of the town except walking streets
- Class 6: walking streets

The categorization method was later applied in [11] to five medium-sized Spanish towns with populations ranging from 218,000 down to 50,000, and later in [12] to 20 towns with sizes ranging from 2200 to 700,000 inhabitants, and with areas between 0.57 and 59 km^2.

In this work, a methodology based on a street typology classification is proposed to carry out noise maps. This methodology, recently validated in [13, 14] allows allocating the mean power and the temporal behavior to each street from its characteristics and the time profiles measured with semi-permanent noise monitoring systems. Because of this, as the streets are classified a priori in different typologies, the number of measurement points is reduced maintaining the accuracy of the noise map and reducing the measurement cost. The proposed methodology has been applied to the noise map of Cuenca.

2. Methodology

2.1 The town of Cuenca

Cuenca is a Spanish town in the Castilla-La Mancha region, capital of the province of the same name. The town's mean altitude is 946 m above sea level (a.s.l.). The area of the municipality is 911.06 km^2, and the total population of the city is 54,898 inhabitants (year 2018) [15].

The town has two different areas: the old town and the new one. The first one is located in the high part of the town, bordered by rivers Júcar in the north and Huécar in the south. The new part of the town is located at the west-south of the old town towards north-south.

Cuenca has an important historical and architectural heritage and many museums in the old town, been considered World Heritage City since 1996.

2.2 Road type definition

To define the street typologies in the town of Cuenca, the following road and urban characteristics (all of them with influence from the acoustic point of view) were taken into account:

- Road characteristics:
  - Number of lanes of the street.
  - Average daily traffic (ADT)
  - Average daily speed (ADS)
- Urban characteristics:
  - Road width
  - Pavements
  - Main use of the street.

Based on the aforementioned characteristics, seven street typologies were established in this research:

- Type 1 (class 1): Motorway.
- Type 2 (class 2): Main distribution streets in the town.
- Type 3 (class 4): Secondary distribution streets in the town.
- Type 4 (class 3): Main distribution streets in a neighborhood. These streets are used for traffic distribution in a neighborhood and are connected with bigger streets.
- Type 5 (class 4): Residential distribution streets. These streets are used by people to arrive in a completely residential street (types 6 and 7).
- Type 6 (class 5): Residential streets in the town and residential distribution streets in new neighborhoods.

- Type 7 (class 5): Completely residential streets. Only the people who live in these areas use these streets.

This street classification allows performing a categorization of the streets in a town based on their acoustics characteristics. Thus, measurements only in some streets of each category are needed, being possible to apply the noise profile obtained for each category to the rest of the streets in the same category during the noise map simulation phase. According to [16] these procedures only generate little deviations from strictly using only real measurement data for all the sampling points.

2.3 Long time measurements

To carry out long measurements, three noise monitoring equipment have been placed in fixed locations during 11 months, and another one has been moved among different locations. This hybrid procedure is quite common to increase the temporal and spatial resolution [17].

The location of two of these fixed equipments has been chosen to take into account the main areas of the town: Old town and Carretería Street. The third has been located to characterize the residential noise of the town (Acacia Uceta Street).

The moving equipment has been located in different places in order to characterize the noise in different kinds of streets in the town. The locations of this equipment were: República Argentina Avenue, 16 (3 months), Mediterráneo Avenue (4 months), Hermanos Valdés Street, 4 (2 months).

The location of each monitoring equipment can be observed in **Figure 1**, and their accurate location is in **Table 1**.

Figure 1.
Monitoring equipment locations.

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Equipment label	X coord. [m]	Y coord. [m]
Old Town	574,163.64	4,436,764.68
Carretería Street	573,634.63	4,436,174.01
República Argentina Avenue	573,414.85	4,436,005.10
Acacia Uceta Street	572,681.20	4,436,180.54
Mediterráneo Avenue	574,127.48	4,435,221.37
Hermanos Valdés Street	573,619.63	4,436,365.07

Table 1.
Monitoring equipment locations.

The equipment has been installed at 4 m height and 2 m from the facade according to the regulations [18]. For that, a bracket fixed to the facade has been used with an outdoor microphone. In **Figure 2** the microphone installation can be observed.

The microphone calibration was checked manually when the equipment was installed when it was removed, and at least once a week. If there was an error, the equipment was repaired or replaced. Moreover, four automatic CIC calibrations per day were configured at 00, 10, 14, and 19 h, which were permanently monitored and checked.

The main acoustic parameters that have been measured were:

- L_{Aeq}: A-weighed equivalent level.
- L_d: Day equivalent level.

Figure 2.
Microphone installation.

- L_e: Evening equivalent level.
- L_n: Night equivalent level.
- L_{den}: Day-evening-night equivalent level.
- L_N: Percentile levels.

After taking the measurements for a whole month, a validation process was carried out. First of all the automatic calibrations were checked. If there was any error, data between the last correct calibration and the first one (the wrong calibration would be in the middle) were removed because it is not possible to know when the equipment failed. For instance, if calibrations at 10 h and at 19 h were right, and calibration at 14 h was wrong, data from 10 to 19 h were removed.

Then, the meteorological conditions were checked [18]. If it was raining, data for this period of time were removed. Moreover, if the average speed of the wind during a certain day was higher than 4 m/s (it is more restrictive than the regulations −5 m/s-), data for this day were also removed.

After these validations, a more detailed analysis of the L_{Aeq} parameter was done. Analyzing the time profile and the audio files, anomalous events have also been removed, for instance, if events in the street that are not representative of the typical behavior of the area took place (parades, parties, etc.).

With this, all the data considered for the studio could be assessed as correct.

Once the data have been validated, three different hour profiles have been obtained each month, the whole month profile, the working day profile, and the non-working day profile. To obtain these profiles, data for each hour have been averaged. The profiles obtained for all the months during the period of time when the equipment was in a certain location were similar. With this, all the hour profiles were also averaged to obtain the typical hour profile of the area.

2.4 Road simulation process

The aim of the noise map simulation is to make up a digital model of the town to obtain the noise propagation levels due to the traffic. The digital model is composed of: a ground digital model with the level curves (**Figure 3a**); obstacles, mainly buildings (**Figure 3b**); roads (**Figure 3c**), and receivers (**Figure 3d**) to evaluate the noise parameters.

When the digital model has been carried out, the next step consists of defining the characteristics of each one of the layers stated. Concerning roads, the data to define in the model are the ADT and ADS for light and heavy vehicles during the 3 day periods (day, evening, night).

To make this process easier, all the roads in the town have been classified according to the typologies defined in Section 2.2. The map in **Figure 4** shows the classification carried out. Then, the simulation results are obtained and compared with those from long time measurements and short-time measurements, and the noise map is adjusted.

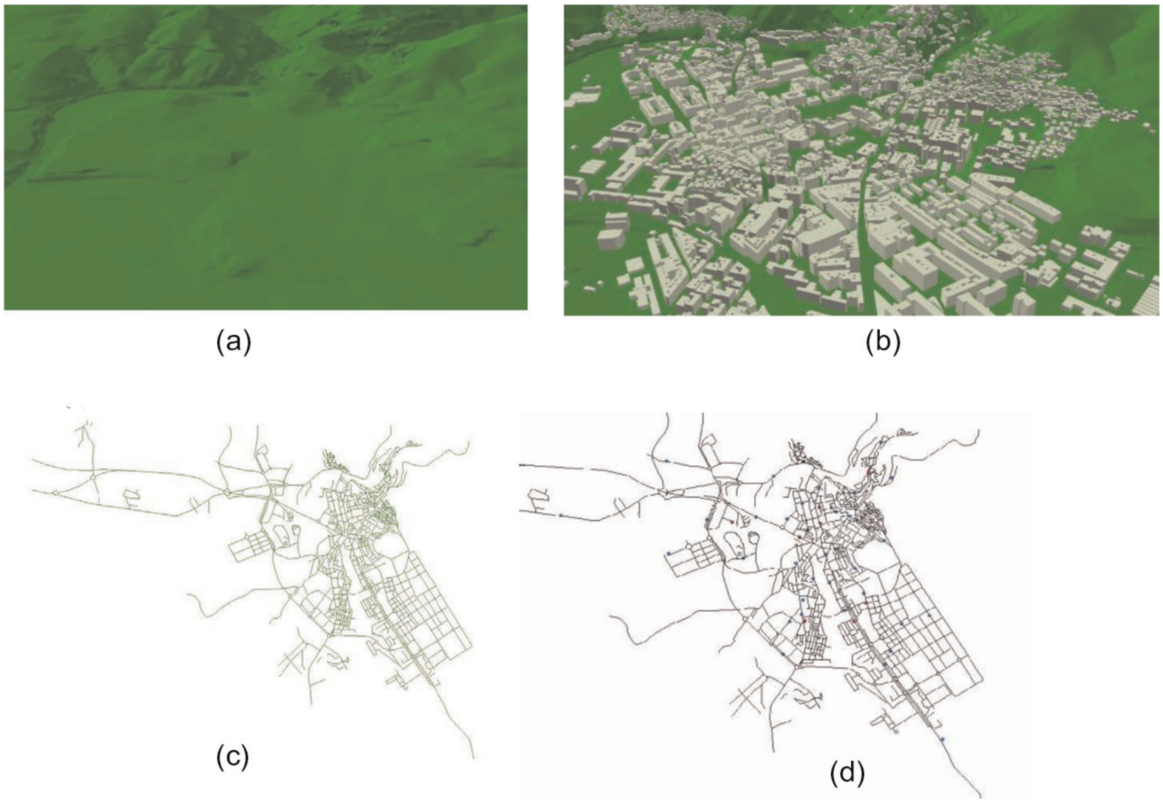

Figure 3.
Noise map process. (a) Ground layer. (b) Building layer. (c) Road layer. (d) Receivers.

Figure 4.
Road classification.

3. Results

In this section, results obtained for the measurements carried out with the noise monitoring systems in each one of the chosen locations are shown, together with the discussion of the whole results.

The street typologies defined in Section 2.2 have been checked out with short time measurements before the installation of the monitoring systems in the proposed locations (type 1 roads are not set, as there were no people living near a motorway). Accordingly, the measurement points can be classified as follows:

- República Argentina Avenue: Type 2.
- Carretería Street: Type 3.
- Old Town: Type 4.
- Mediterráneo Avenue: Type 5.
- Hermanos Valdés Street: Type 6.
- Acacia Uceta Street: Type 7.

As there are very few differences among the measurements for every month, only the averages for the whole measurement time are shown. **Figures 5** and **6** illustrate, respectively, the weighed equivalent levels for day and night periods (results for the evening period are almost identical to those of the day period). **Figure 7** shows the mean L_{Aeq} level in dB(A) for each one of the measurements points. **Figures 8** and **9** show the mean L_{Aeq} levels during working days (Monday to Friday) and non-working days (weekends and festivities), respectively. Finally, **Figure 10** represents the noise climate (L_{10}–L_{90}) and **Figure 11** the singular noise events (L_1).

According to all these results, general and specific statements can be done that prove and justify the approach of using road typologies to simplify noise maps.

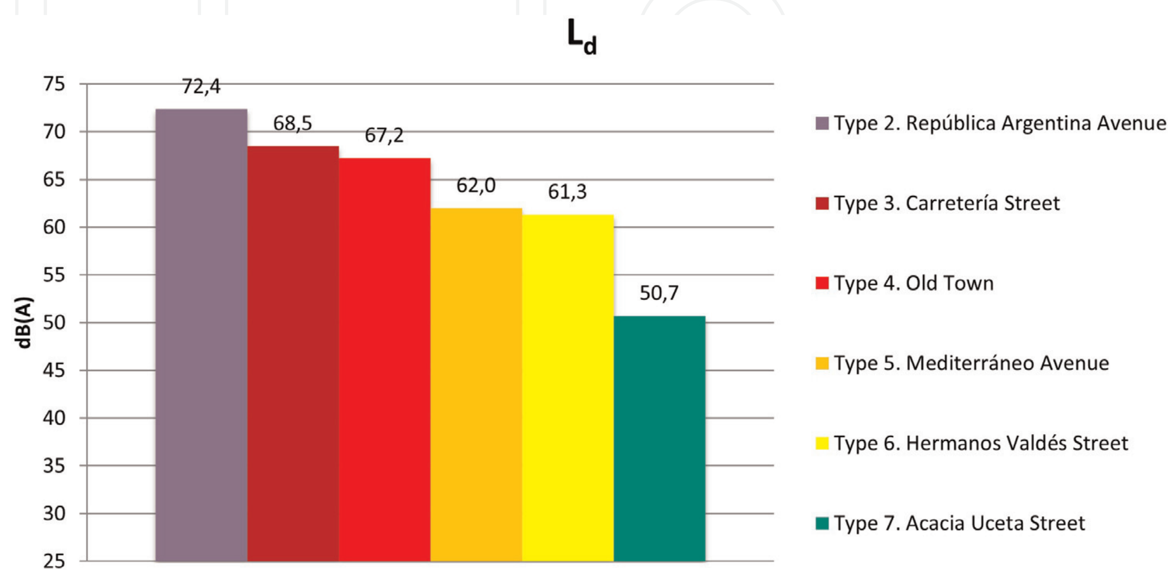

Figure 5.
L_{day} results.

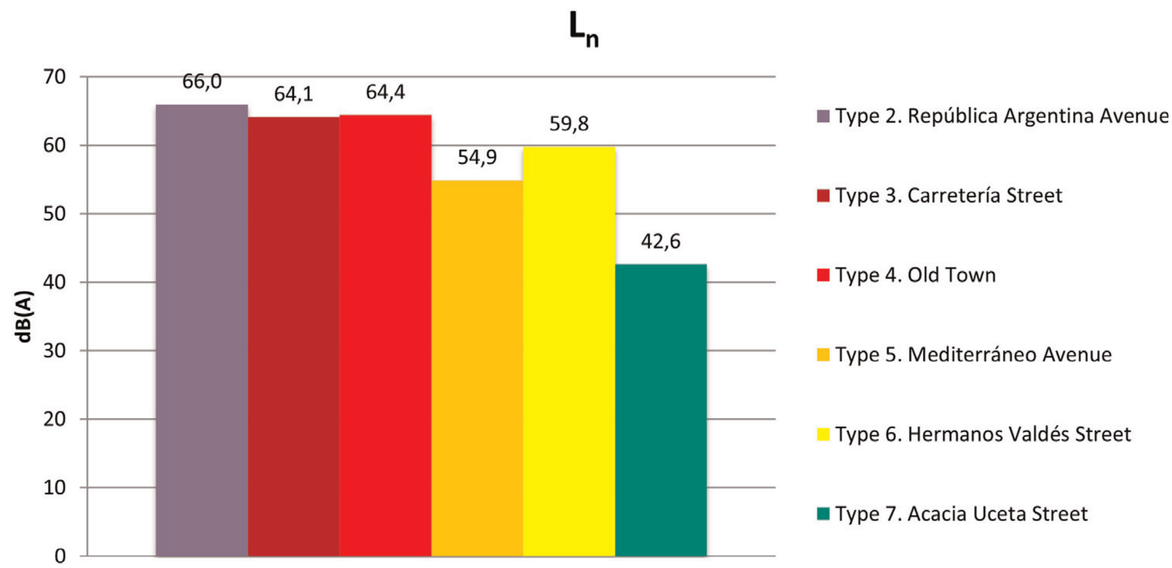

Figure 6.
L_{night} results.

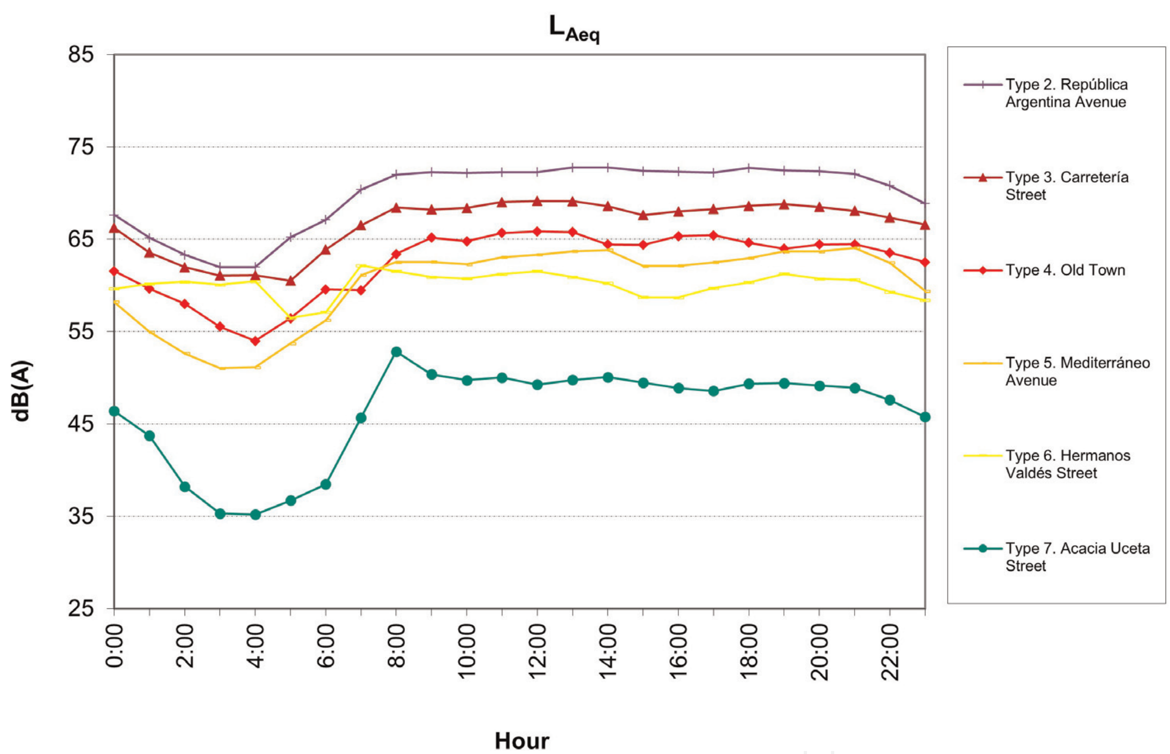

Figure 7.
L_{Aeq} results.

Firstly, specific noise profiles can be derived for each road typology, that can be described as follows:

- In roads of type 2, the L_{Aeq} is almost constant around 72 dB(A) during the day. At 22 h this level starts to decrease, being minimum from 3 to 4 h with 62 dB(A). At this time the noise level starts to increase up to 8 h. Observing the L_{Aeq} during working days, a similar trend with levels around 73 dB(A) during the day and a minimum of 60 dB(A) at 3 h can be found out. On non-working days, the level is around 72 dB(A) during the day and the minimum of 64 dB(A) is reached at 4 h.

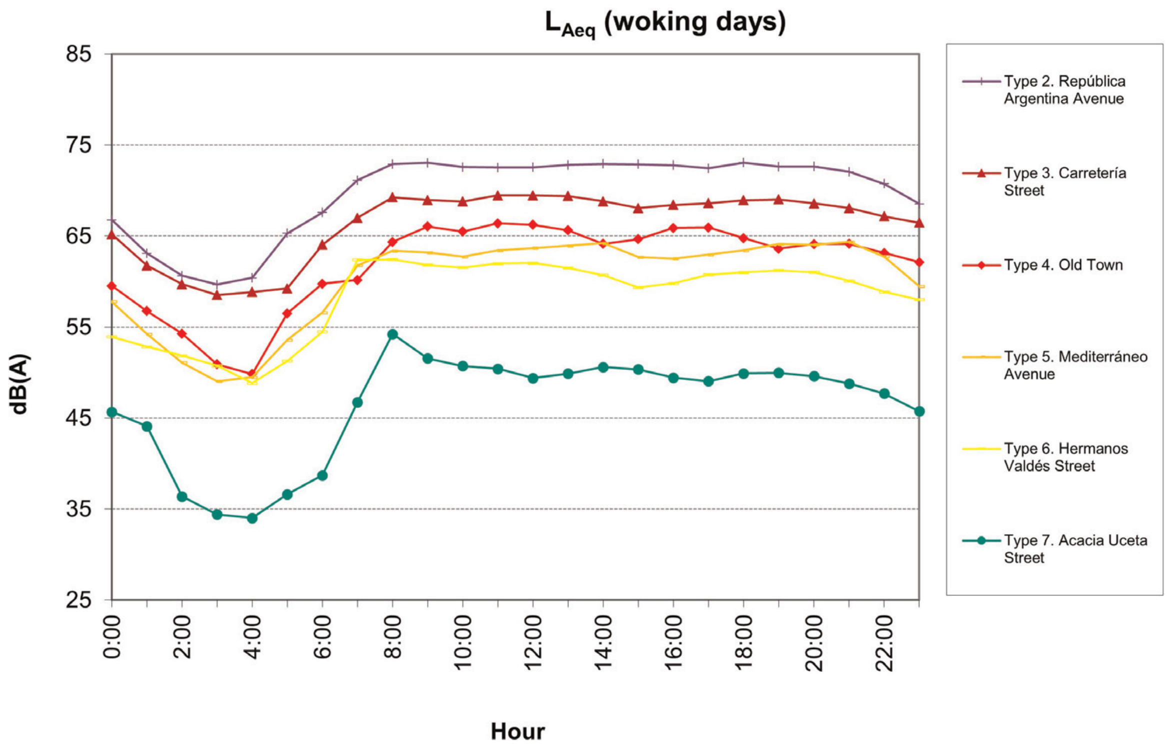

Figure 8.
L_{Aeq} results during working days.

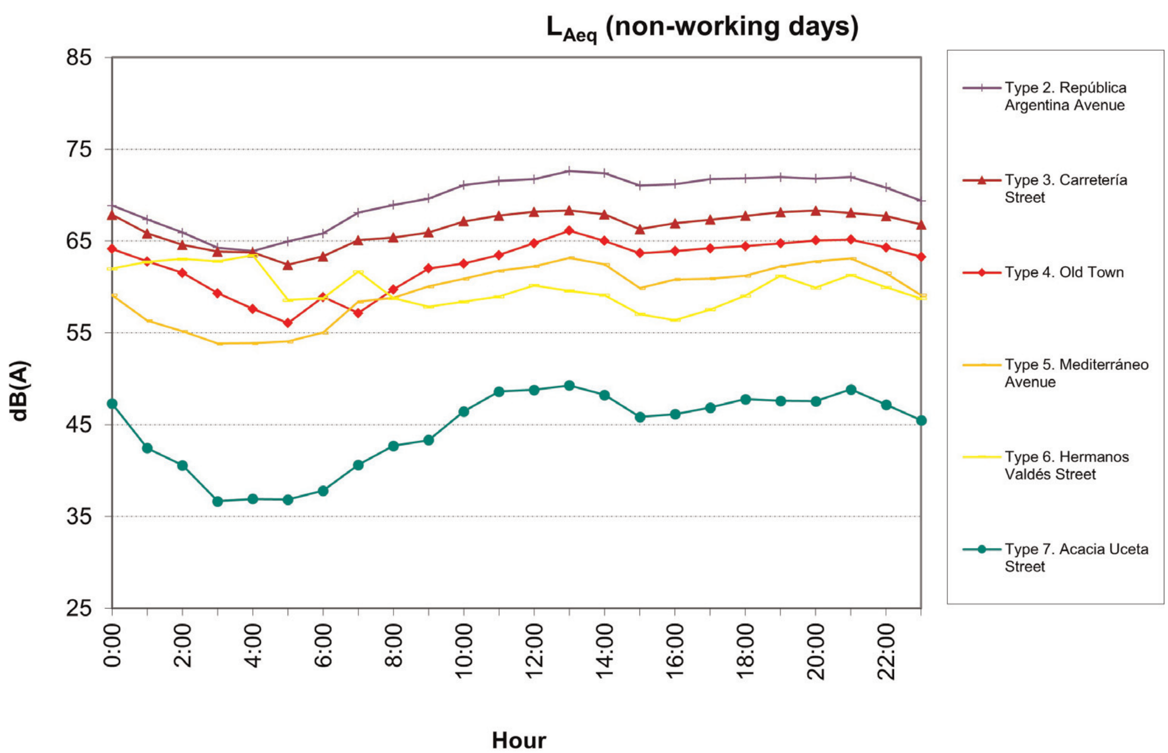

Figure 9.
L_{Aeq} results during non-working days.

- In type 3 roads, the L_{Aeq} is again almost constant close to 70 dB(A) during the day. At 22 h the level starts to go down with the minimum L_{Aeq} (60 dB(A)) at 5 h when the level starts to increase. During working days, the same trend can be

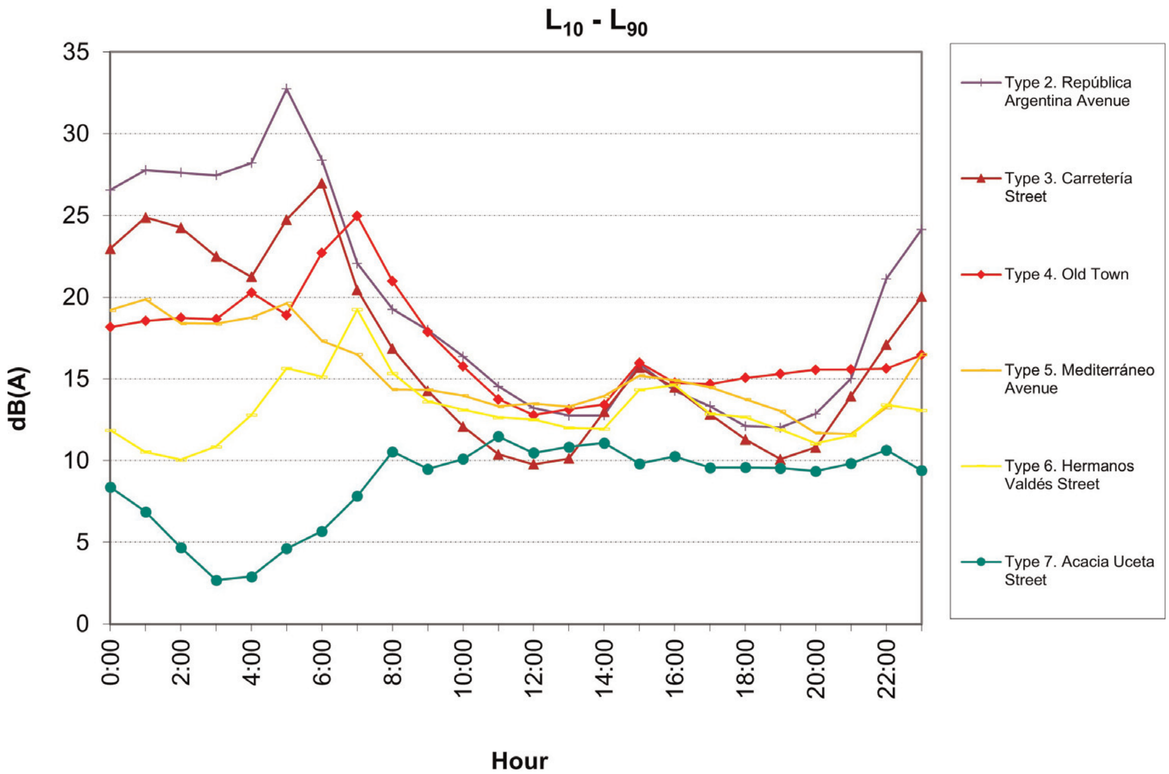

Figure 10.
Noise climate (L_{10}–L_{90}) results.

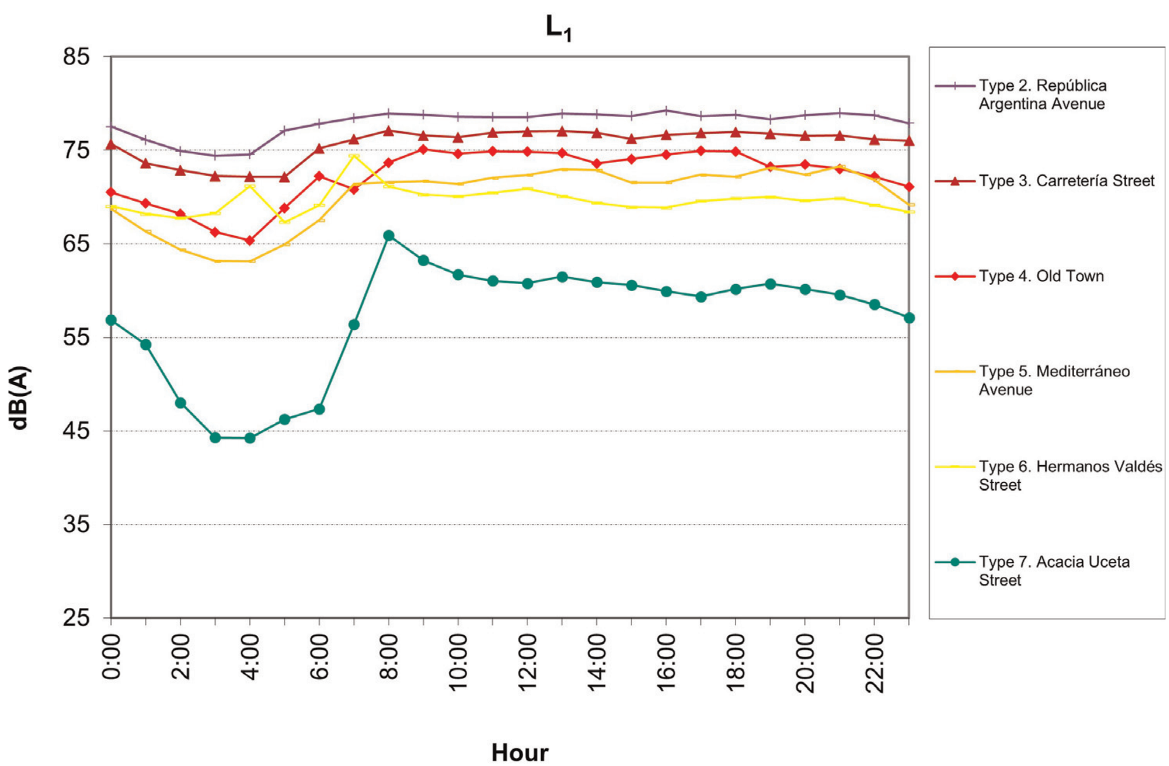

Figure 11.
Singular noise events (L_1) results.

observed, with levels around 70 dB(A) during the day and a minimum of 58 dB (A) from 3 to 4 h. Concerning non-working days, a more constant profile is obtained, with levels around 67 dB(A) during the day and a minimum of 62 dB (A) at 5 h.

- In roads of type 4, the L_{Aeq} is around 65 dB(A) from 9 to 21 h. At this time the level decreases to 54 dB(A) at 4 h, increasing from this time to 9 h. On working days, the day levels are around 66 dB(A) from 9 to 17 h, being 50 dB(A) the minimum L_{Aeq} at 4 h. Non-working days have an L_{Aeq} around 64 dB(A) during the day and a minimum of 56 dB(A) at 5 h.

- Type 5 roads show a L_{Aeq} between 62 and 64 dB(A) from 8 to 22 h with a minimum during this period from 15 to 16 h. From 22 to 4 h the level diminishes to 51 dB(A), moment when it starts to go up to 8 h. Concerning working days, similar levels are observed from 8 to 22 h, being the minimum of 49 dB(A) at 3 h. Levels during non-working days are lower during the day, with a L_{Aeq} from 60 to 63 dB(A) from 9 to 22 h, and higher during the night with a minimum of 54 dB (A) from 3 to 5 h.

- The level in type 6 roads is almost constant during the whole day with a L_{Aeq} around 61 dB(A). The level decrement is observed from 5 to 6 h with 57 dB(A). Working days have more differences between day and night with a level around 62 dB(A) in the morning (from 7 to 13 h) and around 60 dB(A) in the evening (from 13 to 21 h). At night the L_{Aeq} decreases to 49 dB(A) at 4 h. Non-working days have higher levels during the night, around 63 dB(A) than during the day, with levels from 58 to 62 dB(A). This behavior is due to the leisure activities during the night on non-working days.

- The level during the day in the 7th type of road is almost constant around 50 dB (A). The maximum level is at 8 h (53 dB(A)) because it is the moment when people go out to work. At night the levels decrease down to 35 dB(A) from 3 to 4 h. Working days have a similar profile, being the minimum L_{Aeq} of 34 dB(A) at 4 h. About non-working days, the level decreases during the day and it is more variable (from 43 to 49 dB(A)). At night, the level is higher than during working days with a minimum of 37 dB(A) from 3 to 5 h.

Globally speaking, it is possible to see that the higher the typology of the road, the lower the noise level is, with almost non-existent overlaps among them. In all the types, noise levels are almost constant during the day and start to decrease around 22:00 h, being the quietest hour between 3:00 and 4:00 h. The level at 8:00 and 9:00 h (entrance to works and schools) is almost constant for the whole day and evening.

Therefore, according to the results of Cuenca, its day period embraces from 8:00 to 21:00 h and night period from 21:00 to 8:00 h. Furthermore, it can be stated that the more residential the street is, the higher the noise reduction during the night is. This behavior is due to the fact that in residential areas the traffic during the night is almost non-existent, whereas in other streets there is some more traffic during the night. This fact is also reinforced by the differences in the noise climate between day and night periods.

If working and non-working days are compared, it is possible to state that during the day the L_{Aeq} is generally lower during non-working days. At night the noise level in non-working days is increased. This increase in level is due to the increment in traffic because of leisure activities, which many times take place directly in the street.

Noise climate, shows a higher variability during the night period, being quite homogeneous for the day period. This fact, together with the higher noise levels during the day, indicates that there may be a significant number of similar noise sources that contribute to the noise pollution; meanwhile, during the night the number of noise sources is lower but more heterogeneous. Some differences also stand out if the road typology is considered, as those with a heavier traffic intensity (types 2–5) present values for the noise climate higher during the night period than during the day period; on the other hand, the trend is the opposite for the residential road types (6 and 7).

The singular noise events indicator (L_1) shows that in the surroundings of Cuenca there are no noise sources with emissions of high noise intensity within a short period of time (aircraft overflights, high-speed trains, booming sources, etc.). Nevertheless, it is stated that for the measurement points with lower L_{Aeq} and lower traffic intensity (for instance Acacia Uceta Street—type 7) there is a very significant variation of L_1 during the quietest hour (3:00–4:00 h); it means that in residential areas a single noise source can appear as extremely noisy, whereas for areas with more traffic intensity a single noise source is masked among all the noise sources.

Correlating the life in the city of Cuenca with the results, it can be set that the main cause of environmental noise is traffic [19]. The intensity of the traffic and its composition depends on the road typology. Taking into account the proposed road typology, the review of principal traffic noise models of [20] and the traffic intensity massively measured in Cuenca, a finite set of traffic intensity categories could be defined to refine, even more, the prediction model by assigning to each road not only its typology but also its traffic category.

4. Conclusions

In this paper, a road type classification has been developed taking into account road and urban characteristics. With this, seven types of roads have been defined: motorway, main distribution streets in the town, secondary distribution streets in the town, main distribution streets in a neighborhood, residential distribution streets, residential streets, and completely residential streets.

The long-time measurement results showed an almost constant level during the day, which decreases during the night. The more residential the road is, the more the level decrease during the night. Moreover, it can be observed higher level differences between day and night during working days than during non-working days.

This classification has been applied to the noise map of the World Heritage City of Cuenca. For that, a digital model was performed and adjusted with long time measurements carried out in roads classified inside different categories and with short-time measurements.

The methodology proposed allows allocating mean power and temporal behavior to each street from semi-permanent noise monitoring systems, and with this, the measurement cost of the noise map could be lowered, while maintaining a high level of accuracy.

This strategic tool may help to derive action plans to fight against the noise and reduce the number of people exposed to heavy noise.

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Conflict of 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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References

[1] European Commission. Directiva 2002/49/CE del Parlamento Europeo y del Consejo, de 25 de junio de 2002 sobre evaluación y gestión del ruido ambiental (Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise)

[2] BOE. Real Decreto 1513/2005 de 16 de diciembre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del Ruido, en lo referente a la evaluación y gestión del ruido ambiental (Royal Decree 1513/2005 of December 16th to develop the Law 37/2003, of November 17th, about the noise regarding the assessment and management of the environmental noise)

[3] BOE. Real Decreto 1367/2007 de 19 de octubre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del Ruido, en lo referente a zonificación acústica, objetivos de calidad y emisiones acústicas (Royal Decree 1367/2007 of October 19th to develop the Law 37/2003, of November 17th, about the noise regarding the acoustic zoning, quality objectives and acoustic emissions)

[4] E. C. W. G. A. of Exposure to Noise (WG-AEN). Good practice guide for strategic noise mapping and the production of associated data on noise exposure

[5] Brown A, Lam K. Urban noise surveys. Applied Acoustics. 1987;**20**(1):23-39

[6] Gómez V, Barrigón JM, Gozalo GR, Vaquero J, Sierra JM, Vílchez-Gómez R, et al. Acoustical environment of the medieval centre of Cáceres (Spain). Applied Acoustics. 2012;**73**(6):673-685

[7] Barrigón JM, Gómez V, Gutiérrez P, Méndez J. Study of Vitoria-Gasteiz by categorizing roadway characteristics. In: Proceedings of Internoise, Nice, France. 2000. p. 292

[8] Barrigón JM, Gómez V, Gutiérrez P, Alejandre L. Study of medium-sized cities of Extremadura by categorizing roadway characteristics. In: Proceedings of the 7th International Congress on Sound and Vibration (ICSV7), Garmisch-Partenkirchen, Germany. 2000. pp. 2413-2420

[9] Barrigón JM, Gómez V, Méndez JA, Vílchez-Gómez R, Trujillo J. An environmental noise study in the city of Cáceres (Spain). Applied Acoustics. 2002;**63**(10):1061-1070

[10] Gómez V, Barrigón JM, Méndez J, Vílchez-Gómez R, Vaquero J. Noise study of Salamanca (Spain) by means of a categorization method. In: Proceedings of Forum Acusticum, Seville, Spain. 2002. pp. 84-87985

[11] Barrigón JM, Gómez V, Méndez JA, Vílchez-Gómez R, Vaquero JM, Trujillo J. A categorization method applied to the study of urban road traffic noise. The Journal of the Acoustical Society of America. 2005;**117**(5):2844-2852

[12] Barrigón JM, Gómez V, Gozalo GR, Vílchez-Gómez R. Possible relation of noise levels in streets to the population of the municipalities in which they are located. The Journal of the Acoustical Society of America. 2010;**128**(2):EL86-EL92

[13] Bastián-Monarca N, Suárez E, Arenas JP. Assessment of methods for simplified traffic noise mapping of small

cities: Casework of the city of Valdivia (Chile). Science of the Total Environment. 2016;**550**:439-448

[14] Barrigón JM, Montes D, Gómez V, Gozalo GR, Vílchez-Gómez R. A proposal for producing calculated noise mapping defining the sound power levels of roads by street stratification. Environmental Pollution. 2021;**270**: 116080

[15] INE. National Institute of Statistics (Instituto Nacional de Estadística) [Internet]. 2018. Available from: http://www.ine.es/ [Accessed: February 18, 2022]

[16] De Coensel B, Brown AL, Tomerini D. A road traffic noise pattern simulation model that includes distributions of vehicle sound power levels. Applied Acoustics. 2016;**111**: 170-178

[17] De Coensel B, Sun K, Wei W, van Renterghem T, Sineau M, et al. Dynamic noise mapping based on fixed and mobile sound measurements. In: EURONOISE 2015, Maastricht, France. 2015. p. 6

[18] ISO 1996-1:2016. Acoustics— Description, measurement and assessment of environmental noise— Part 1: Basic quantities and assessment procedures

[19] SICA. Information System about Noise Pollution (Sistema de Información sobre Contaminación Acústica) [Internet]. 2022. Available from: https://sicaweb.cedex.es [Accessed: February 22, 2022]

[20] Garg N, Maji S. A critical review of principal traffic noise models: Strategies and implications. Environmental Impact Assessment Review. 2014;**46**:68-81. DOI: 10.1016/j.eiar.2014.02.001