Perceptions and effects of the acoustic environment in quiet residential areas

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Many cities have historical areas clearly distinguished from the rest because of the architecture, urban planning, and functionality. In many cases, these aspects give one the possibility of finding a characteristic acoustic environment and also developing quiet areas. Through an examination of sound levels and surveys, the perception of residents and passers-by concerning the acoustic environment of the old town of Cáceres and its relation with the characteristics of the urban environment were analysed. In addition, the perception and the effects of noise pollution of low intensity were studied. The results indicate that absence of daytime noise is the most influential environmental characteristic on the overall perception of the urban environment studied, even surpassing the feeling of security. The absence of daytime noise was also the most valued characteristic of the urban environment according to respondents. The most annoying noise source proved to be the road traffic. However, for similar levels of sound exposure, the percentages of people who were annoyed and whose sleep was disturbed were lower than those found in previous studies. Bells and birds, both soundmarks of the soundscape of this urban environment, were among the most annoying to passers-by. © *2017 Acoustical Society of America*. [http://dx.doi.org/10.1121/1.4979335]

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I. INTRODUCTION

Cities have preserved historic buildings and monuments that are parts of their identities and are some of their main tourist attractions. In many European cities, these historical elements are located in a limited region. These places have urban characteristics and a functionality clearly distinguishing them from the rest of the city: the construction characteristics and the functionality of buildings (museums, churches, etc.), the structure of streets (narrow and cobbled), the economic activity based on the service sector (trade, tourism, and leisure),[1] road traffic restrictions,[2] etc. All these urban features influence the environmental characteristics, including the acoustic environment.[3]

International organisations indicate that noise pollution is a major environmental problem affecting a large part of the world population and represents a risk to our health and quality of life.[4] Previous research has shown the positive influence of quiet urban areas as a possible mitigating measure of the effect of noise.[5] "Quiet areas" or "areas of high acoustic quality," as is proposed by Brown,[6] are among the objectives of the European noise policy.[7] However, despite the heritage of old towns being an important part of the urban landscape and is potentially interesting for the development of quiet areas, at present little information exists about the acoustic environment in old towns.

In the last decade, researchers have conducted some study of quiet areas in urban parks or rural areas[8,9] but very few have focussed on historical centres. Some historical centres have noise problems because of the excessive weight of economic activities in the service sector.[10] However, previous studies showed that the old town of Cáceres is a quiet area.[11] This area is characterised by differences in the typologies of its most important sound sources and its periodicity.[12] Moreover, in assessing quiet areas, it is important to analyse the reactions of people living in or visiting the areas. Some research shows that reducing noise level does not necessarily lead to better acoustic comfort in urban areas.[13] Consequently, a study about the perception of urban and environmental characteristics of the historic centre of Cáceres was performed. For this purpose, in a first stage, the resident population was interviewed to investigate the relationship between the acoustic environment and the characteristics of the urban environment and the effect of the noise of low intensity in people. In a second stage, a sociological study focussed on passers-by. The results obtained in both surveys were compared. The objectives were

(1) to analyse the relationships between the acoustic environment and the characteristics of the urban environment;
(2) to study the contribution of the different sound sources to the perception of the acoustic environment; and
(3) to investigate and quantify the perception and intensity of the effects of noise pollution of low intensity and strategies to combat it.

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II. METHODOLOGY

A. Study area

In this work, the old town of Cáceres was the study area. This old town was built at the top of a hill and is located in the urban centre of Cáceres city. Its surface area is approximately 0.13 km^2 (1% of the total surface of the city). Cáceres is located in the west of Spain and is one of the most important cities in the region. The old town of Cáceres was declared a Third Monumental Ensemble of Europe in 1968 by the Council of Europe and a "World Cultural Heritage Site" in 1986 by UNESCO.[14] Cáceres has one of the most complete Middle Age and Renaissance urban centres in the world. As was common in the Middle Ages in Spain, walls surround the old town. The streets of the old part of Cáceres are short and narrow, some with steep slopes and stairs. Also, vehicular traffic is limited to taxis, delivery vehicles, and the cars of people who live in the old town or who are staying in the hotels. Another important element of the area is the presence of squares generally associated with the presence of temples. Previous work offer photographs.[11]

The population of Cáceres has increased by 1.7% in the last five years, reaching a population of 95 855 inhabitants in 2014.[15] However, the population in the old town in the same period has decreased by 9.1%, and stands at 351 residents. Therefore, a population loss is taking place in this historical site. Figure 1(a) shows the age distribution of both places: Cáceres city and the old town. We can note a higher percentage of the population in the old town at the older intervals.

B. Survey and subject selection

Two surveys were used to analyse the residents' and the passers'-by perception of the acoustic environment. Previous studies[16,17] have validated both surveys. First, a survey of the resident population was conducted, analysing the following points:

(1) Satisfaction and assessment of urban environment.
(2) Contribution of the sound sources on the perception of the acoustic environment.
(3) Effects caused by noise.

The procedure followed was door-to-door interviews. A total of 70 surveys were carried out randomly in the different buildings in the old town. The survey population is approximately 20% of the resident population and with a similar age structure to the old town population, as Fig. 1(a) shows. Both age distributions were compared by a Q-Q plot [see Fig. 1(b)] and a *p*-value of 0.28 was obtained in the Kolmogorov-Smirnov test. Therefore, both age distributions do not have significant differences.

In a second stage, a survey with a structure similar to the previous one was performed with passers-by during daytime. This survey considered only the aspects of the outside environment and some questions were deleted to reduce the duration of the survey to fewer than 10 min and also to achieve a higher cooperation and dedication to the questions.

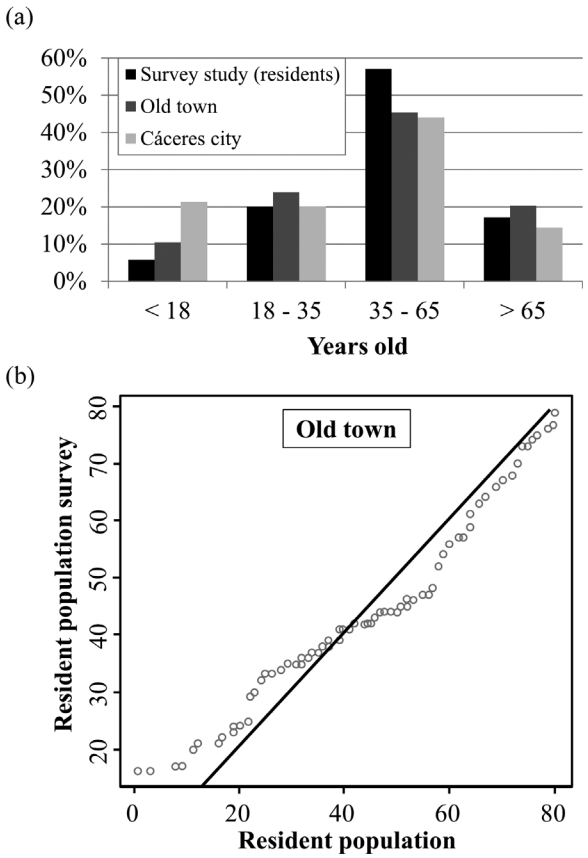

FIG. 1. Age structure of the resident population in the city of Cáceres, in the old town and in the study of surveys carried out with old town residents (a). Q-Q plot of the age distribution of the resident population and population surveyed in the old town (b).

A total of 50 surveys were carried out randomly in different places of the old town.

C. Sound measurements

This study contained two measurement campaigns. First, 21 sampling points were selected in the streets or squares where the survey population resided (see Fig. 2). At each sampling point, ten 15-min measurements were randomly performed in the following time-intervals: diurnal (from 07.00 to 19.00), evening (from 19.00 to 23.00), and nocturnal (from 23.00 to 07.00). The A-weighted equivalent sound level [L_{eq} (dBA)] was recorded at different time-intervals of the day. The noise descriptor L_{den} (dBA) was calculated following the guidelines of the European Noise Directive.[7] Second, the representative locations frequented by passers-by were selected to carry out the surveys and the sound measurements (see Fig. 2). Surveys and sound measurements happened simultaneously at each sampling point during the daytime. Thirty-one sampling points were selected in the area and also the A-weighted equivalent sound level was recorded at the different measurements.

The sound measurements were carried out with a type-I sound level meter (2238 Brüel & Kjaer). It was placed at a height of 1.5 and 2 m away from the nearest vertical surface when urban features allowed it.[18]

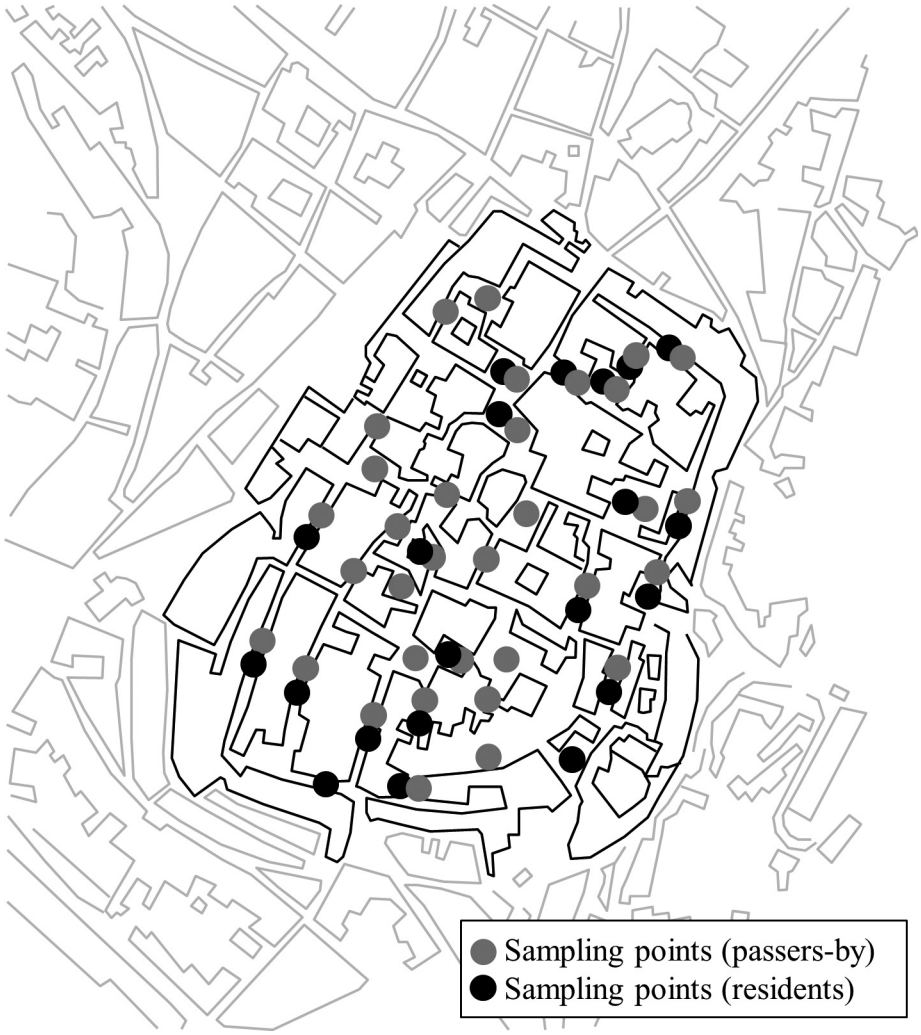

FIG. 2. Map of the old town of Cáceres and location of the sampling points.

III. RESULTS AND DISCUSSION

A. Satisfaction and assessment of the urban environment

In a first group of questions, the satisfaction of people with the community infrastructures and characteristics of this urban environment were evaluated. Survey participants were asked to choose which of the infrastructures and which of the characteristics were the most important from their point of view. Subsequently, these aspects were related to the overall perception of the environment and to the sociological characteristics (age, gender, and educational level). The age ranges used were: 16–30, 30–40, 40–50, 50–60, and >60 and the level of study was divided into the following categories: no education, primary school, high school or vocational training, and university degree.

1. Satisfaction with the community infrastructure

This study shows residents perceive "a little" satisfaction with the infrastructures associated with basic community services: schools, health centres, public transportation, parks, cultural centres, food shops, etc. [Fig. 3(a)]. In a hierarchical cluster analysis, these community infrastructures are located in the same group [Fig. 3(b)]. However, some of these community infrastructures obtained a significant percentage of people who valued them as the most important infrastructure of the urban environment [Fig. 3(a)]. This problem of lack of basic services is present in other old towns of other Spanish cities[19] and is one of the causes of their depopulation.[20] Instead, the streetlights and walkways obtained a moderate satisfaction and the temples and restaurants obtained a satisfaction between "moderately" and "quite" [Fig. 3(a)]. The streets have dim lights at night and stone pavement; however, residents are moderately satisfied with this community infrastructure and it is considered the most valued community infrastructure for the highest percentage of residents. These three community infrastructures, according to cluster analysis, constitute a differentiated group [Fig. 3(b)]. This result is interesting because these aspects are often typical elements of these urban environments, as historical elements (temples), as tourist elements (restaurants) or as a way to create an old urban aesthetic (dim lights at night and cobbled surfaces).

Finally, the relation between sociological aspects and the satisfaction with community infrastructures were analysed. The results show that age has a significant positive correlation with the assessment of food shops (a Kendall's tau coefficient of 0.36 with a p-value lower than 0.01). In addition, those aged between 40 and 60 yr old have a significantly lower satisfaction level to parks (a Pearson Chi-

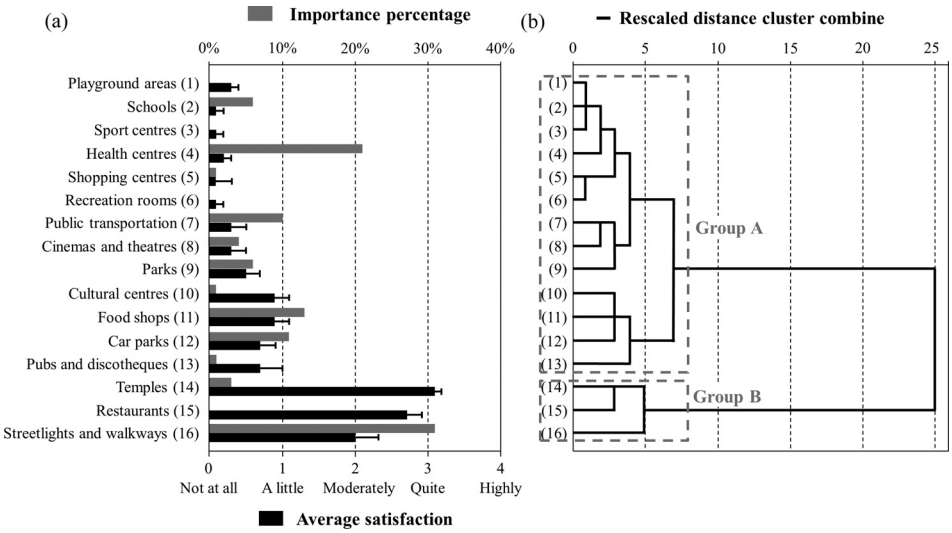

FIG. 3. Bar chart with the average satisfaction of the community infrastructures and the percentage of residents that considers what community infrastructure is the most important of the urban environment (a) and the cluster results calculated by the Euclidean Distance with Ward's method (b).

square value of 24.6 with a p-value lower than 0.05). This result is related to the necessity for middle-aged people to have parks for their children. These aspects should be taken into account in the management of these areas to avoid depopulation and ageing.

Depopulation and ageing represent a risk to the preservation of certain soundscapes. The resident's daily habits constitute an important element of the soundscape. If the urban environments are depopulated, this element is lost and it will be replaced by the "artificial" soundscape created by tourists or passers-by. In this sense, the results obtained in this study made it possible to detect some causes and guide us towards possible solutions.

2. Satisfaction with the environmental characteristics

When residents indicated their satisfaction with the characteristics of the environment, most of the characteristics presented a satisfaction level between "moderately" to "quite" [see Fig. 4(a)]. Note the difference in relation with the satisfaction with the community infrastructures. The environmental aesthetic is the characteristic with a greater satisfaction. Different studies show how the aesthetic plays an important role in environmental assessment.[21] By contrast, only three characteristics have a satisfaction between a little and moderately (street width, street condition, and family closeness). In other studies in historic centres, residents perceived cleaning problems and poor accessibility of these areas.[19] However, in this study both characteristics are valued with a satisfaction between moderately to quite.

Regarding the most valued characteristics in an urban environment, the highest percentage of residents considers that they are: the absence of daytime noise, cleanliness, safety, and the absence of nocturnal noise [see Fig. 4(a)]. Therefore, the characteristic of low sound levels in the area, registered in previous studies,[11] is detected and assessed by residents above other environmental and urban characteristics.

Passers-by could not evaluate easily the community infrastructures; this is the reason why the satisfaction of passers-by was analysed regarding the environmental characteristics [see Fig. 4(b)]. The passers-by have a higher average satisfaction to the environmental characteristics than residents do. Passers-by are quite or "highly" satisfied with the environmental characteristics (except for the security characteristic, which shows a satisfaction level between moderately and quite). Also, the characteristic with the highest average satisfaction for passers-by is the aesthetic of the environment. The most valued characteristics by passers-by, just as by residents, are the absence of daytime noise, safety, and cleanliness.

If we compare the satisfaction of residents and passers-by with the environmental characteristics, passers-by have a

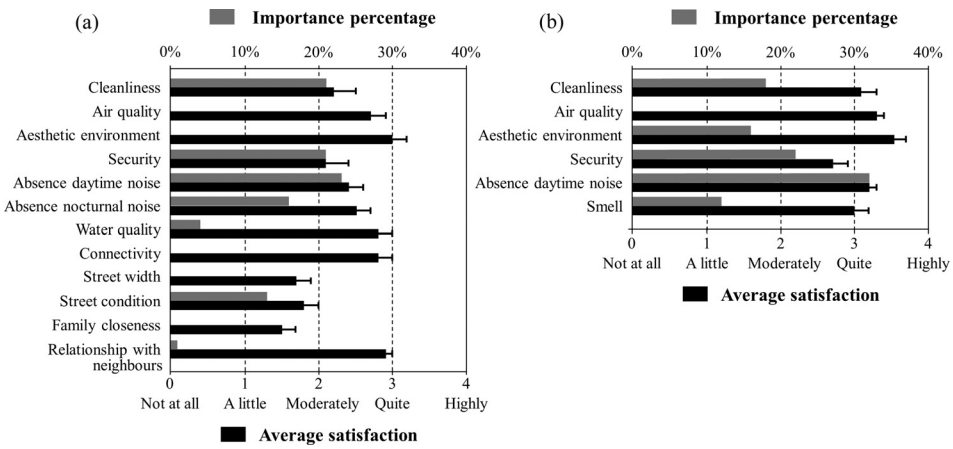

FIG. 4. Bar chart with the average value of the satisfaction of environmental characteristics and the percentage of people who consider which characteristic is the most important of the urban environment. Results of the resident survey (a). Results of the passers-by survey (b).

significantly higher satisfaction than residents (Table I). Other authors also found these differences.[22,23]

Next, the relation between sociological aspects and environmental characteristics were analysed. Regarding residents, respondents between 30 and 60 years old have a significantly higher satisfaction related to the absence of daytime noise compared to younger and older respondents (a Pearson Chi-square value of 37.7 with a p-value lower than 0.01). Age is the sociological aspect that frequently shows significant relations with the noise perception.[24] Then, concerning the assessment of the environmental characteristics, a significant positive correlation exists between age and street cleanliness and security (Kendall's tau coefficients of 0.31 and 0.22 with a p-value lower than 0.01 and lower than 0.05, respectively). Next, gender has a significantly higher percentage in women when analysing security. Women value more the security in the area than men (a Pearson Chi-square value of 14.7 with a p-value lower than 0.001 and a contingency coefficient of 0.470 with a p-value lower than 0.001). Another study performed in a World Heritage Site[25] produced a similar result.

Concerning passers-by, the most assessed characteristic, the aesthetic, has a significantly higher value for the age ranges between 16–30 and >60. The lower and higher age ranges valued more the aesthetics of the place. Afterwards, the education level is negatively correlated with the "absence of daytime noise" satisfaction and the "safety" assessment (Kendall's tau coefficients of −0.28 and −0.30 with a p-value lower than 0.05). Just as with age, previous studies show how the education level has a significant relation with the noise satisfaction or annoyance.[24,26]

3. Relation between environmental characteristics/ community infrastructures satisfaction and overall environmental satisfaction

In addition, residents and passers-by were asked about the overall satisfaction with the environmental characteristics and community infrastructures. Residents have an overall average satisfaction of 2.8 (moderately–quite) and passers-by have an average of 3.7 (quite–highly). The average satisfaction of passers-by is significantly higher than residents (p-value lower than 0.001 by the Mann-Whitney test).

Then, whether the value of the satisfaction given to each community infrastructure or to each environmental characteristic had a relation to the value of overall satisfaction was analysed. The value of overall satisfaction is independent of the residents' satisfaction with the different environmental characteristics and community infrastructures in the area. Nevertheless, if the level of satisfaction of passers-by to the environmental characteristics is related to the overall satisfaction level of the area, the different pairs of variables analysed show significant correlations. The results are shown in Fig. 5.

TABLE I. Results of the Mann-Whitney test applied to satisfaction of environmental characteristics by residents and passers-by.

Environmental characteristics	Average satisfaction		Mann-Whitney test P-value
	Residents	Passers-by	
Cleanliness	2.2	3.1	<0.001
Air quality	2.7	3.3	<0.001
Aesthetic environment	3.0	3.5	<0.001
Security	2.1	2.7	<0.001
Absence of daytime noise	2.4	3.2	<0.001

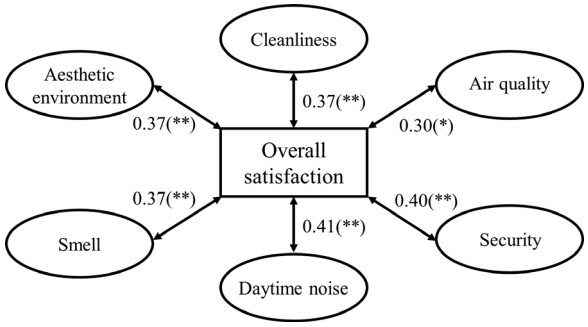

FIG. 5. Kendall's tau_b between the satisfaction of passers-by to different environmental characteristics and the overall satisfaction in the area. (**) Correlation is significant at the 0.01 level (2-tailed). (*) Correlation is significant at the 0.05 level (2-tailed).

As Fig. 5 shows, the absence of daytime noise shows the highest correlation with the overall environmental satisfaction. Even a partial correlation of the absence of diurnal noise showed the highest correlation with the overall satisfaction (a Kendall's tau coefficient of 0.36 with a p-value lower than 0.001). Therefore, it seems that noise management is important for appropriate tourism management of such environments. Note, for example, despite the importance of an appropriate air quality, the air quality is the worst related to overall environmental satisfaction.

Then, combinations of characteristics (independent variables) that explained significantly the variation of the overall assessment (dependent variable) were analysed. For that, a multinomial logistic regression whose parameter estimation was performed using a likelihood ratio test was carried out.

As shown in the multiple regression model obtained (Fig. 6), the characteristics of noise, safety, and aesthetics contribute significantly to the explanation of the variability of the overall satisfaction. The coefficient of determination (R^2) indicates the model explains 65% of variability. It is interesting to point out that these overall assessments were independent of age, gender, and educational level.

Residents and passers-by agree the absence of noise is one of the environmental characteristics that gives more

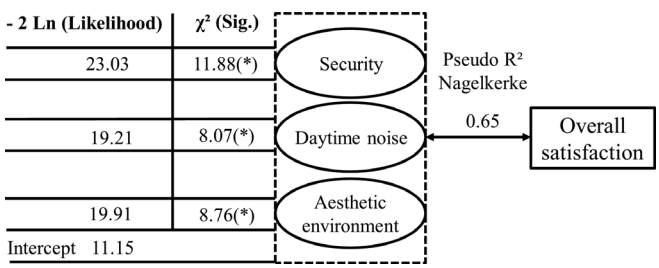

FIG. 6. Multinomial logistic regression model obtained from the relation between the satisfaction of different environmental characteristics and the overall satisfaction by passers-by.

value to the area; but it is also one of the environmental characteristics that has a higher level of satisfaction, especially among passers-by. Also, studies in other urban areas show noise is also one of the environmental factors with a higher percentage of valuation, even over environmental factors: security, view, and air quality.[26]

Therefore, our results indicate that noise is an important environmental characteristic in the overall perception of an urban environment. The importance of the acoustic environment in the assessment of this cultural world heritage site has encouraged us to analyse the contribution of the sound sources in the perception of environmental sounds and the study of their possible effects.

B. Contribution of the sound sources in the perception of the environmental sound

Previous studies in the old town of Cáceres detected the importance of other sound sources, besides those caused by traffic.[12] The aim at this stage was to analyse the perception of residents and passers-by to these sound sources. Because the study is a perception analysis of the different sound sources and because this perception will be related to levels of sound exposure, the study focused on the annoyance characteristic. Recent studies show annoyance as a characteristic with one of the highest coefficients of correlation regarding different acoustical descriptors.[27]

Figure 7 shows the levels of annoyance of passers-by and tourists because of internal and external sound sources. First, the levels of annoyance caused by both external and internal sources are between the ranges 0 (not at all) to 1 (a little). This result is a specific characteristic of the studied urban environment and allows for carrying out a specific study of the annoyance caused by low environmental noise and low impacts perceived. In the case of the resident population, the main source of annoyance, although it was little, is external sound sources.

External sources with a higher level of annoyance (a little) for residents are: construction works, nightlife, and road traffic [see Fig. 7(a)]. However, as Fig. 8 shows, despite the restricted traffic situation, road traffic is the most annoying source during the daytime (62%) and also considering the 24-h situation (52%). The nightlife is the most annoying source at nighttime (40%).

Regarding passers-by, the most annoying sources, with a value of 1 (a little), are road traffic, bells, and birds [see Fig. 7(a)]. As in the opinion of residents, road traffic is the main noise source of this environment perceived as annoying by passers-by. Despite its status as a restricted traffic area, road traffic remains as a significant contribution to the transformation of the soundscape of the environment. An important observation is that bells and birds are among the most annoying sound sources to passers-by. The annoyance of passers-by because of these sound sources is significantly higher than the annoyance of residents (p-value lower than 0.05 in the case of the bells and p-value lower than 0.001 in the case of birds according to the Mann-Whitney test). In addition, the annoyance because of bells has a significant negative correlation with the ages of passers-by (a Kendall's tau coefficient of -0.39 with a p-value lower than 0.01). Perhaps this is because these sources have been gradually disappearing from the urban environment and younger people have a more negative reaction to them. At this point, it should be noted that the sound of the bells and the song of the birds can be seen as marks of their soundscape. If these sound sources can get to be perceived as annoying, essential

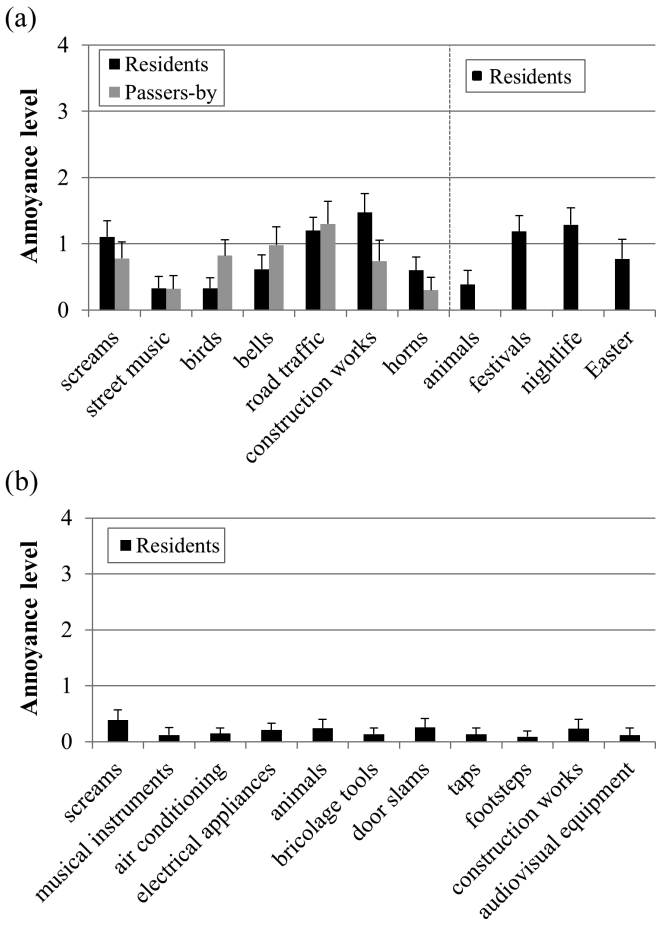

FIG. 7. Levels of annoyance (0: not at all; 1: a little; 2: moderately; 3: quite; 4: highly) of residents and passers-by to external sound sources (a) and levels of annoyance of residents to internal sources of their housing (b).

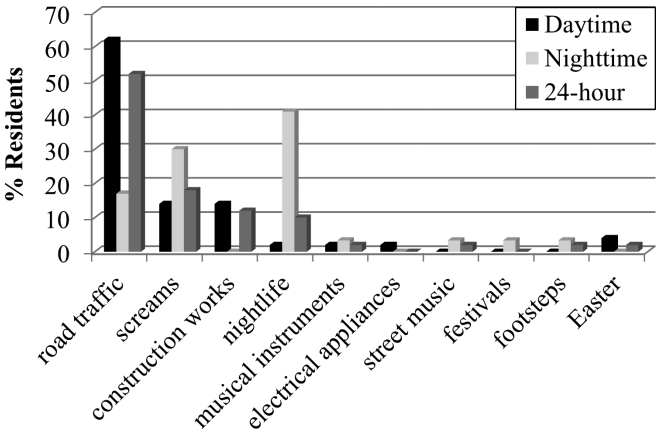

FIG. 8. Percentage of residents that select a sound source as the most annoying during daytime, nighttime, and 24 h.

aspects in the soundscape of certain urban environments could be lost.

Then, residents and passers-by are asked about how they considered the noise in this area compared to the rest of the city. Eighty percent of residents and ninety-four percent of passers-by considered this area quieter than the rest of the city. The opinion of residents and passers-by coincides with the differences in sound levels in this area compared to the rest of the city of Cáceres, as a previous study[11] found.

Parallel to this sociological study, sound measurements were performed. Coinciding with the opinions of residents, the main source of noise was road traffic during the sound measurements. Because of the importance of this sound source, the relation between L_{den} (dBA) registered in streets and squares of the old town (21 sampling points) and the average level of annoyance shown by residents to road traffic on these sampling points was analysed. The result is shown in Fig. 9.

The linear function shown in Fig. 9 shows a correlation coefficient of 0.87 (p-value lower than 0.001). In the range of 54–60 dBA, there are low levels of annoyance that would better fit using a logistic model. Recent studies have used a logistic regression to estimate the percentage of the highly annoyed population (% HA) by aircraft, rail, and road traffic noise.[28,29] However, the correlation coefficient was similar. Despite the low level of annoyance to road traffic indicated by the residents, it has a statistically significant relation with respect to sound values registered in their streets. In studies carried out by Della Crociata *et al.*[30] about the assessment of environmental quality, the acoustic satisfaction showed one of the highest coefficients of determination with regard to overall satisfaction, compared to the satisfaction of other environmental characteristics. Also, the A-weighted equivalent sound pressure level was one of the indexes that better describe the subjective sensations in the analysis of acoustic comfort.

Then, levels of annoyance from road traffic from residents were analysed to prove if the levels were similar to those registered in other studies for similar levels of sound exposure. For this purpose, the expressions proposed by Miedema and Oudshoorn,[31] which are also in the international standard ISO 1996-1,[32] were used. Through L_{den} (dBA) and with these expressions, the percentages of the annoyed population (% A) and the highly annoyed population (% HA) were calculated. These percentages were compared with those registered in the surveys. Because of the small size of the study area, the number of surveys carried out and the range of sound levels measured in the area, the study was divided into two groups of noise annoyance and the level of 60 dBA was the cut-off value. The results are shown in Fig. 10.

Figure 10 shows that the percentages of the annoyed population (% A) and the highly annoyed population (% HA) registered with the surveys are lower than those obtained through L_{den} (dBA).[31] Also, the % HA is lower than the Community Tolerance Level obtained by Shomer *et al.* from a set of road traffic noise data from 34 studies.[29] The resident population in the old town does not have a % HA and the % A is 6% for those locations that recorded a L_{den} from 60 to 67 dBA. The registered noise levels correspond to those registered in neighbourhood streets (Categories 4 and 5 according to the categorisation method).[33–35] However, although residents consider road traffic to be the main source of annoyance because of characteristics of the area, the levels of annoyance are lower than those reported in other areas of the city and in other cities.[36–38]

Regarding passers-by, as indicated in the methodology, the sound measurements and the surveys were registered at the same time. Figure 11 shows the results of relating sound levels with the annoyance of passers-by to different sound sources and overall noise annoyance.

Based on the results shown in Fig. 11, the overall noise annoyance had a significant relation with sound levels. Also, the overall noise annoyance had a significant relation with the annoyance from the sound sources: road traffic, screams, construction work, and horns. However, bells and birds as sound sources, which are characteristic sources of this place, had no relation to the overall annoyance. Road traffic annoyance is the main cause of the overall noise annoyance. Even, with a partial correlation, road traffic annoyance shows the highest significant correlation with the overall noise annoyance (a Kendall's tau coefficient of 0.44 with a p-value lower than 0.001). This result coincides with the opinions of

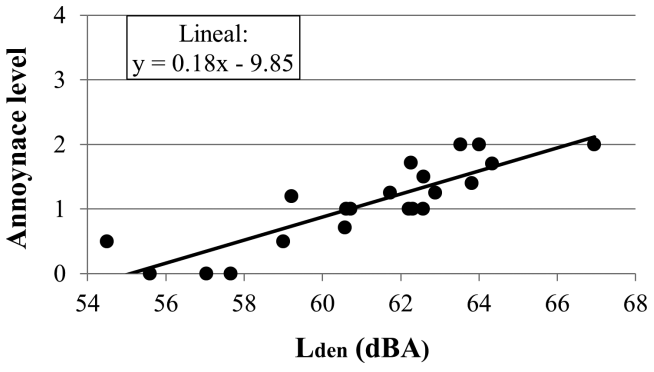

FIG. 9. Relation of L_{den} (dBA) and annoyance level (0: not at all; 1: a little; 2: moderately; 3: quite; 4: highly) to road traffic in the sampling points of the old town.

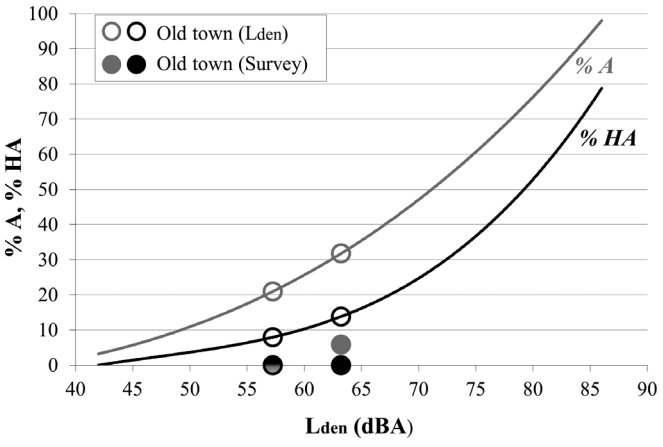

FIG. 10. Percentage of the annoyed population (% A) and the highly annoyed population (% HA) obtained through L_{den} (dBA) (Refs. 31 and 32) and registered with the surveys carried out in the old town of Cáceres.

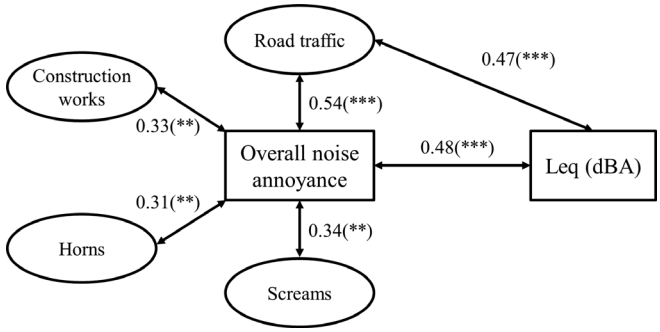

FIG. 11. Kendall's tau_b among the overall noise annoyance for passers-by, the annoyance from different sound sources and the A-weighted equivalent sound pressure levels. (**) Correlation is significant at the 0.01 level (2-tailed). (***) Correlation is significant at the 0.001 level (2-tailed).

passers-by, as Fig. 7(a) shows. In addition, road traffic annoyance was the only sound source with a significant relation to the sound levels registered.

Then, the relation between the average annoyance levels from the road traffic of passers-by and the L_{eq} (dBA) registered in streets and squares of the old town (31 sampling points) was analysed. The linear model has the best fitting compared with other mathematical models (see Fig. 12). The correlation coefficient was 0.76 (p-value lower than 0.001) and the Akaike's Information Criterion (AIC) was −16.5.

The level of annoyance of passers-by and residents caused by road traffic shows a significant relation to sound exposure levels. However, these sound levels have lower values than those registered in other areas of the city because of the peculiarity of the areas.

C. Effects caused by noise

In addition to analysing the effects of noise considering the level of noise exposure and the level of noise annoyance, the impacts of environmental noise may be evaluated by assessing its interference with social behaviour and other human activities. For many communities, noise interference with such activities as sleep, the ability to carry on conversations, or watch TV, for example, seems to have the most significant impact.[39]

Then, the frequency of activities affected by noise in the case of residents and passers-by and the actions and attitudes caused by noise in the case of residents were analysed. The results are shown in Table II.

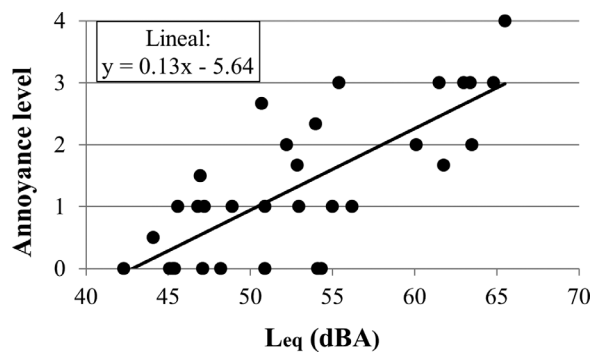

FIG. 12. Relation between the A-weighted equivalent sound pressure level and the annoyance level of passers-by to road traffic registered in the sampling points of the old town.

Predictably, as the level of annoyance registered in the previous analysis is low, the frequency of variation in different activities because of noise is between "never" and "rarely" for residents and is between rarely and "sometimes" for passers-by. In the case of residents, the affected activity with a higher assessment is night sleep, the induced action with a higher assessment is "close windows" and the attitude triggered with a higher assessment is "scared." Previous studies have found a significant relation between these activities and actions regarding sound exposure levels.[39] However, these studies had higher noise levels and greater variability than those recorded in this area.[11] Then, the sound exposure levels were related to the frequency of the activities, actions, and attitudes of residents and passers-by. Thus, L_{den} (dBA) had a significant relation regarding the action close windows and the attitude scared in residents (Kendall's tau coefficients of 0.47 with a p-value lower than 0.01 and of −0.49 with a p-value lower than 0.01, respectively). Therefore, the higher L_{den} is, the higher is the frequency to close the windows and the lower is the frequency of being scared. López Barrios[40] registered in urban environments with low noise levels a perception of insecurity of citizens. Regarding passers-by, the three analysed activities (Table II) showed a significant correlation with regard to the L_{eq} (dBA) registered during the development of the survey (Kendall's tau coefficients of 0.32 with a p-value lower than 0.01, of 0.34 with a p-value lower than 0.01 and of 0.26 with a p-value lower than 0.05, respectively).

TABLE II. Average frequency (0: never, 1: rarely, 2: sometimes; 3: often, 4: very often) in activities affected by noise in the case of residents and passers-by and in actions and attitudes caused by noise in the case of residents.

Residents		Average frequency (Scale 0–4)
Activity	Listening audiovisual equipment	0.8
	Night sleep	1.0
	Nap	0.4
	Conversations	0.7
	Intellectual activity	0.4
	Ability to concentrate	0.4
Action	Close windows	1.1
	Increase volume	0.9
	Pause conversation	0.4
Attitude	Irritability	0.2
	Anxiety	0.0
	Disorientation	0.2
	Decreased intellectual performance	0.1
	Scared	0.5
	Lack of relaxation	0.4
	Accident	0.0
Passers-by		**Average frequency (Scale 0–4)**
Activity	Thoughts	1.4
	Conversation	1.6
	Visual attention	1.2

Night sleep, the activity most affected by noise on residents, is an aspect with a high importance in current research because of its relation with other important diseases, like obesity,[41] diabetes or cardiovascular disease.[42] Then, the relation of the level of nocturnal sound exposure [L_n (dBA)] with the frequency of sleep disturbance by residents was analysed. The results are shown in Fig. 13.

In Fig. 13, the mathematical model that describes better the relation between L_n (dBA) and the sleep disturbed frequency is the logistic model. This model showed a correlation coefficient of 0.65 (p-value lower than 0.001) and an AIC value of −28.57. Previous studies have also used these models to correlate the sound annoyance with the sound exposure level.[43]

As done previously, sleep disturbance levels were compared with those obtained in previous studies.[36,38,44] Miedema *et al*. proposes several expressions that relate the level of nocturnal exposure, L_n (dBA), and the percentages of sleep disturbed obtained in European cities.[44] Considering the expressions proposed by Miedema *et al*., the population percentages with sleep disturbed obtained through L_n (dBA) registered in this enclave and those obtained in the surveys were compared. In this comparison, a similar procedure to the one used in Fig. 10 was carried out and the study was divided in two groups, with the level of 50 dBA as the cut off value. The results are shown in Fig. 14.

Figure 14 shows that, although the values obtained for percentages of little sleep disturbed (% LSD) are close to those expected, those obtained for sleep disturbed (% SD) and highly sleep disturbed (% HSD) are lower than those estimated from L_n (dBA).[44] However, these differences are lower for the first group analysed, with an average of 46 dBA. The average sound exposure levels [L_n (dBA)] registered in the two groups analysed are similar to the levels registered in neighbourhood streets (Category 5) and to those registered in service streets (Category 3) of the city of Cáceres,[36] respectively. However, % LSD, % SD, and % HSD registered in the surveys in the area with a lower noise exposure are much lower than those registered in the neighbourhood streets and % LSD, % SD, and % HSD registered in the area with the highest noise exposure are similar to

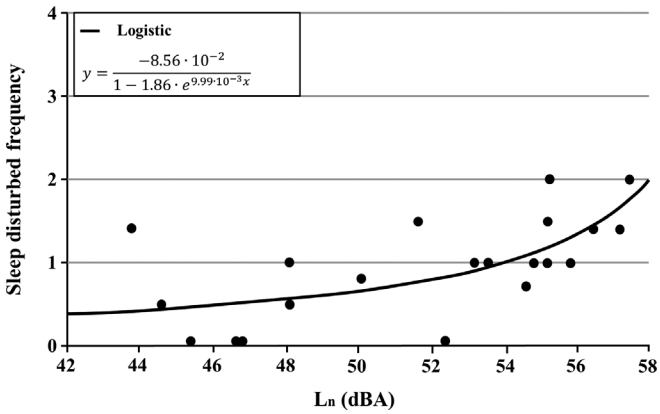

FIG. 13. Relation between L_n (dBA) and the sleep disturbed frequency (0: never; 1: rarely; 2: sometimes; 3: often; 4: very often) in the residents of the old town.

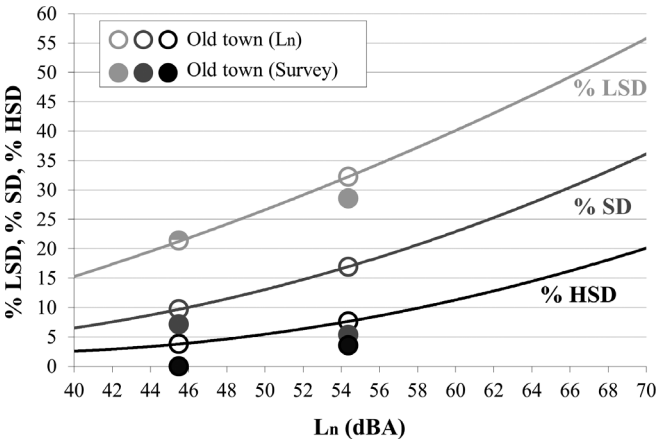

FIG. 14. Percentages of little sleep disturbed (% LSD), sleep disturbed (% SD), and highly sleep disturbed (% HSD) populations obtained from the proposed equations (Ref. 43) and from the answers to the surveys.

those registered in service streets.[36] Therefore, the disturbance caused by noise during night sleep is, in these areas, less than in other areas without these special characteristics for the same values of sound levels.

Also, another important aspect that can influence satisfaction and assessment of the urban environment and the effects caused by noise is the satisfaction of residents to the characteristics of their housing. In addition, dissatisfaction with the characteristics of their housing can be a reason to attempt to change their places of residence. Considering this, residents were asked about satisfaction with the characteristics of their housing. The results are shown in Table III.

Most of the satisfaction levels of the different characteristics of housing is quite average. Therefore, the characteristics of housing should not be the reasons for their depopulation. The characteristic with a lower average satisfaction was the soundproofing to outside noise. Again, noise is an environmental characteristic to consider. The architectural characteristics of housing located in this unique place are similar, made up of large walls of stones and tapial. However, the type of windows and their location are important aspects because they can influence the noise propagation. The great majority of resident respondents said that their windows were simple. However, regarding the location of windows in bedrooms and living rooms, some were located in the street and others in the courtyard. This aspect could perhaps relate to the effects of noise presented in residents. For this reason, the location of windows was examined to consider if they influence the average value residents

TABLE III. Satisfaction of residents to the characteristics of housing.

Building characteristics	Average satisfaction (Scale 0–4)
Location with respect to the city	3.0
Size	2.9
Building quality	3.0
Aesthetics	3.0
Soundproofing to outside noise	2.5
Soundproofing to inside noise	2.8
Air conditioning system	2.8

assign to the different effects of noise. In none of them, neither in bedrooms nor in the living room, did the location of the windows show significant differences in annoyance or in the frequency of activities or actions (p-value >0.05 by the Mann-Whitney test).

Finally, the frequency of the activities affected was related to personal characteristics of residents: age, education, and gender. "Night sleep" and scared have a significant positive relation with age (a Tau-b of Kendall of 0.21 and of 0.30, respectively, with a p-value lower than 0.05). Sleep problems and the frequency of waking up increase with age. Exposure to high sound levels can aggravate these problems. Studies show a relation between sleep disturbance caused by environmental noise and age.[45] In this study, despite the low sound levels found and the low frequency of sleep disturbance in the area analysed, also a significant relation with age is found.

IV. CONCLUSIONS

The old town of Cáceres is an example of the urban style of the ancient cities. Because of its location and its urban characteristics, the old town has some differences in environmental characteristics. These environmental and urban characteristics were analysed through individual surveys conducted with residents and passers-by and the results lead to the following conclusions:

(1) Residents perceive "none" or "a little" satisfaction with most of the infrastructure associated with basic community services. Perhaps this is one reason why in this area its population has decreased by 9.1% in the past five years. The depopulation of urban environments leads to the loss of essential elements of the soundscape.
(2) The environmental characteristics are positively perceived by residents and passers-by, although passers-by have a satisfaction significantly higher than residents. Both groups of respondents give the highest satisfaction to the aesthetic but the absence of daytime noise is the most valued characteristic.
(3) In an overall assessment of the area, residents give a satisfaction value close to quite despite the low level of satisfaction for basic infrastructures. Passers-by give an overall assessment close to "much." In this overall assessment of passers-by, the variable "absence of diurnal noise" is the most influential environmental characteristic in the overall perception of the urban environment. Therefore, this environmental characteristic can become an essential element of management of these environments.

The importance of the acoustic environment residents and passers-by gave in the assessment of the old town was the reason for carrying out an analysis of the contribution of sound sources in the perception of the sound environment and the study of its possible effects. The analysis yielded the following conclusions:

(1) The sound of the bells and the song of the birds are soundmarks of this area. These sounds were identified by passers-by as the second and third most annoying sound sources. Nevertheless, these sources had no significant relation to noise levels registered and neither did they have a significant relation with the overall annoyance perceived.
(2) The road traffic remains a significant contribution to the transformation of the soundscape despite being a restricted traffic area.
(3) The level of annoyance of residents and passers-by from internal and external sound sources was between "nothing" and a little. As in most urban areas, the sound source indicated by a higher percentage of residents and passers-by as the most annoying is road traffic. For passers-by, this sound source also explains the higher variability of the overall noise annoyance. Although the level of annoyance by road traffic for passers-by and residents was low, this perception had a significant linear relation with the values of sound exposure registered on the streets of this area.
(4) The frequency of the noise influence in different activities ranges from never to rarely for residents and from rarely to sometimes for passers-by. In the case of residents, the activity affected with higher assessment is night sleep, the action induced with a higher assessment is to "close the windows" and the attitude triggered with higher assessment is scared. In the case of passers-by, the most affected activity is conversation. In the case of residents, the action of closing the windows and the scared attitude have a significant relation with the L_{den}(dBA) indicator and, in the case of passers-by, all the activities affected had a significant relation with the sound level registered during the surveys [L_{eq} (dBA)].
(5) The frequency of nocturnal sleep disturbance, despite being assessed as a little for residents, had a significant relation with the values of nocturnal sound exposure [L_n (dBA)]. The mathematical model that fit better the relation between both of these variables was a logistic model. Recent studies have used a similar mathematical model in urban areas where aircraft or rail was the main noise source.

Finally, comparing the results of this study with those obtained in other urban areas, the following conclusions emerge:

(1) Sound exposure levels registered in the 24-h period [L_{den}(dBA)] correspond to those recorded in neighbourhood streets (Categories 4 and 5) of other cities. However, the results of surveys on residents show a percentage of the annoyed population (% A) and the highly annoyed population (% HA) lower than that registered in the neighbourhood streets.
(2) The survey with residents has the percentage of a little sleep disturbed population (% LSD) similar to those shown in other cities for the same level of sound exposure. However, percentages of sleep disturbed (% SD) and highly sleep disturbed (% HSD) populations are lower.

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