Applied Acoustics 74 (2013) 526–534

Contents lists available at SciVerse ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical Note

Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain)

J.M. Barrigón Morillas *, V. Gómez Escobar, G. Rey Gozalo

Laboratorio de Acústica, Departamento de Física Aplicada, Universidad de Extremadura, Avda. de la Universidad s/n, 10003 Cáceres, Spain

ARTICLE INFO

Article history:
Received 24 February 2012
Received in revised form 10 September 2012
Accepted 2 October 2012
Available online 5 December 2012

Keywords:
Urban noise
Architectural heritage
Soundscape
Noise sources
Urbanism

ABSTRACT

A study of the sound and noise sources was realised in the medieval historic centre of the city of Cáceres (Spain), which is a major site for tourism and has important restrictions on the use of vehicles. It was declared as World Heritage Site by UNESCO in 1986 and it is the third best-preserved monument in Europe.

A large number and a variety of noise sources were identified during fieldwork. Different source groups were defined based on the types and origins of the sources; noise sources with appearance frequencies lower than 10% were put in a unique group.

Descriptive and interferential analyses of the groups were performed to study the relative importance of the various sources. The analyses revealed that vehicles, passers-by, and people made a major contribution to the sound energy of the area. In addition, a masking effect by vehicles on other sound sources was detected.

1. Introduction

Traffic noise can be considered the major noise source disturbing the quality of urban life [22,19]. Although train and airplane noise sources can become more annoying than those produced by road traffic, as analysed by different authors [16,18], in the major parts of our cities, noise sources are related mainly to road traffic [24,26,15,27]. In previous studies, the authors' research group confirmed that road traffic is the main cause of the spatial variability of noise in towns for the range of size of the cities studied [3,4,6,7,13]. For the case of a large city with a major noise source, a reasonable option for noise mapping is calculation methods, which are recommended instead of measurement methods [25] although the accuracies of the estimates of the two methods can be considered equivalent [1].

However, there are wide areas and environments inside cities where, due to diverse causes, road traffic is controlled or is not the principal source of noise [5]. These areas are of great interest for carrying out different types of acoustic study [14,11].

If traffic is not the major noise source, the application of prediction models might not be useful for noise mapping or might require great effort for the characterisation of the noise sources. In this case, a measurement strategy for noise sampling might be reasonable for obtaining complete knowledge of the acoustical state of an area [12]. In this type of study, it is necessary to establish an adequate sampling strategy, both spatial and temporal, to determine the acoustical situation [10] and to acquire further knowledge of other aspects of acoustical pollution.

Besides, the control of road traffic implies an increase in the importance of other noise sources that could achieve, objectively or subjectively, an importance equal to or greater than that of traffic. To apply a noise control strategy in this case, previous identification of the noise sources and evaluation of their relative importance, both locally in the streets and globally over the whole area, are necessary.

Finally, if the studied area has a low level of noise pollution, in the sense indicated in several international references [23,26] and [27] it is an ideal environment for noise studies. Thus, the effect of low noise pollution on citizens with respect to their perception of noise as a contamination factor, the intensity of the noise disturbance that they are subjected to and the influence of noise in their daily activities could be studied and quantified [10].

In this paper, a study of the historical part of the city of Cáceres is presented. The city of Cáceres, with approximately 90,000 inhabitants, is located in the west of Spain. It is one of the most important cities in the region and has a constant flow of tourists due especially to its historic centre, which is a UNESCO World Heritage Site [28]. This part of the city, surrounded by an ancient wall and with limited traffic and high cultural and touristic value, was the subject of this study. Traffic is limited by means of bollards to taxis and to the cars of the people who live in the old part of the city or who are staying in the state-run hotel that is located there.

* Corresponding author. Tel.: +34 927 257234; fax: +34 927 257203.
E-mail addresses: barrigon@unex.es (J.M. Barrigón Morillas), valentin@unex.es (V. Gómez Escobar), guille@unex.es (G. Rey Gozalo).

0003-682X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apacoust.2012.10.001

Moreover, there are assigned hours for goods delivery to the restaurants and pubs and for free access in the morning. Maintenance and cleaning services are also allowed.

The main objective of the present study is the identification of the main noise sources which are present in the area, the evaluation of their absolute and relative influences on the noise level of the area and the study of the possible existence of interferences between these sources.

The second section of this paper presents the noise source analyses, the third present proposals for improvement and the last section presents the conclusions.

2. Noise source analyses

2.1. Introduction

The studied area has elements that make it a special environment with acoustical characteristics essentially different from those of locations where noise impact studies are usually performed.

The urban design and architectural characteristics of the area are exceptional due to the extraordinary conservational grade of the historic centre. As mentioned, this part of the city is walled, and for this reason, a reduced number of entrances and exits are present. It is located on the top of a hill, and the streets are short and narrow, some with steep slopes and stairs, and thus vehicles cannot transit through them. Throughout the old part of the city, squares with palaces and other ancient buildings are present. This area can be considered an acoustical island inside a modern city (although not officially delimited for noise protection but for preservation of the heritage, similar to the concept of "quiet area in an agglomeration' given by the [9]); photographs and maps of the area can be found in a previous work [10].

The kinds of noise source present in this area (Section 2.2), are very specific and variable with respect to their geometric characteristics, mobility, spatial distribution, temporal characteristics and relative intensity. Moreover, the noise sources are not generally isolated, and different combinations of them (with different emission powers and distances to the receiver) can be observed throughout the area.

All of these characteristics imply a high acoustical complexity in the area and, as a consequence, in its analysis. However, they increase the interest in the study of the area using an adequate method and in the results of this study. Different works have been done in the field of automatic recognition of sources [8,2,21]. It is not the aim of this study to propose a working method for the recognition of sources, but once identified by a technician, to use a systematic method to assess the importance of each source in the environment.

To obtain adequate information about the spatial and temporal acoustical situation of the area, forty sampling points were chosen. These covered all the representative locations of the historic centre of Cáceres. After a detailed analysis of the uses of the area, we concluded that there was a temporal structure associated with four time intervals. Thus, in each sampling point, ten 15-min measurements were performed at the following time intervals: 7:00 to 14:00, 14:00 to 17:00, 17:00 to 21:00, and 21:00 to 7:00. More information about sampling methodology can be found in a previous work [10].

2.2. Description of the noise source study method

From the noise levels measured and from the annotations written for each measurement, the influences of the sources on the sound environment of this part of the city were studied. The following procedure was used:

First, considering the high variability of the noise sources and the different circumstances in which they were present, the noise sources were grouped according to their types of sound and their characteristics. The groups established for the study were:

2.2.1. Vehicles

Cars, motorcycles and vans passing opposite the sampling point.

2.2.2. Passers-by

Passers-by walking opposite the sampling point.

2.2.3. Birds

White storks (*Ciconia ciconia*) generally, but also pigeons, jackdaws, blackbirds, thrushes, swifts, sparrows, etc. (*Columba livia, Corvus monedula, Turdus merula, Turdus philomelos, Apus apus, Passer domesticus,* etc.).

2.2.4. Bells

Bells of the churches of the old part indicating time for mass or the just the time.

2.2.5. Works

Temporary works to improve the street pavement or rehabilitation on the houses.

2.2.6. People

People not just passing by; for example, groups of persons talking, people playing music, or laughing, etc.

2.2.7. Animals

Animals not considered previously, such as cats, dogs, and crickets.

2.2.8. Other

Other noise sources not having a sufficient number of samples to be grouped independently (appearing in less than 10% of the measurements). Included in this group were sources such as refrigerator devices, stopped delivery trucks, vehicles passing by other streets near the sampling points, and door slams.

In Table 1, the results from these source groups are presented. Also in this table, the results for the absences of these source groups are presented. A measurement that was not included for a particular noise source group was considered as being in the absence group for this noise source.

Complementary to these groups, noise sources were also grouped as countable sources (e.g., *vehicles* and *passers-by*) and uncountable sources (those that were impossible or very difficult to count, such as *birds*, and those with small variations in number, such as *animals*, and *works*). For countable sources, the variability of noise levels as a function of the number of noise sources was analysed.

2.3. Preliminary analysis

Once the noise sources were grouped, statistical variables of the measured sound levels (L_{eq} for this analysis) for each group were calculated (Table 1) and the appearance frequency of each noise source was determined (Table 2).

The appearance frequency of each noise source was considered first. *Vehicles* and *passers-by* appeared in more than the half of the measurements (53% and 80%, respectively), independently of the analysed noise source (Table 2).

These results provided relevant initial information about the importance of the presence of noise sources. According to the sampling strategy, they indicated that both passers-by and vehicles had a wide presence in this part of the city, both spatially and tem-