Building and Environment 97 (2016) 96–110

Contents lists available at ScienceDirect

Building and Environment

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

The effect of street canyon design on traffic noise exposure along roads

Gemma Maria Echevarria Sanchez[*], Timothy Van Renterghem, Pieter Thomas,
Dick Botteldooren

Ghent University, Department of Information Technology, Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium

A R T I C L E   I N F O

Article history:
Received 30 June 2015
Received in revised form
14 November 2015
Accepted 26 November 2015
Available online 2 December 2015

Keywords:
Road traffic noise
Street design
Building envelope design
Urban geometry
Urban sound propagation
Noise reduction

A B S T R A C T

Abating road traffic noise pollution is one of the main urban environmental challenges nowadays. However, architects and urbanists take decisions on urban regulations that define the shape of streets and buildings without taking this aspect into account. Furthermore, there is little information about the influence of urban geometry on traffic noise exposure in streets. In this study, the effect of street canyon design on sound pressure level distribution is numerically studied in high detail with the full-wave finite-difference time-domain method (FDTD). The CNOSSOS equivalent source power spectra were used to approach road traffic noise sources along two traffic lanes. Receivers both along the façades and the sidewalks have been considered in 42 cases. Numerical results demonstrate that building shape, street geometry and the presence of street furniture can have a strong impact on people's noise exposure. Building shape can be responsible for variations of up to 7.0 dB(A) at pedestrians. Building-façade design can reduce the average exposure at windows with 12.9 dB(A). It was further predicted that street geometry can enhance the positive effect of low barriers to 11.3 dB(A) along sidewalks. It was therefore concluded that carefully designing building façades and street geometry could improve the sound climate for people living and walking along busy urban streets and should be considered in future urban street design.

1. Introduction

Road traffic noise problems are typically approached with corrective methods a posteriori. Besides traffic management (e.g. changing vehicle speed, traffic intensity or traffic composition), the application of perishable absorbing pavements and the insertion of unsightly noise barriers, generating visual disconnection in space, are common but unattractive solutions in the urban environment. On the other hand, increasing façade and window sound insulation is only part of the solution as dwellers open windows, while pedestrians in noisy streets will not benefit from this measure.

Nowadays, architects and city planners take decisions on the urban configuration without taking street acoustics into account. Furthermore, there is little knowledge on the architectonic approaches and façade alterations that could reduce noise levels along streets. In this work, it is studied how street design affects directly exposed persons like pedestrians and incident sound on windows facing the street.

In an urban street canyon, there are two mechanisms that can be exploited to reduce the overall sound pressure level: promoting diffusion in order to scatter sound towards the sky and thus leaving the street canyon, and increasing absorption leading to effective loss in acoustic energy. At specific locations sound can in addition be shielded provided that no reflecting or scattering elements provide secondary paths into the shadow zone.

The effect of the multiple reflections and the importance of scattering in the urban environment was first assessed by Lyon [1]. Many studies approach the effect of façade irregularities and thus analyse sound diffusion in streets [2–5]. Heutschi [6] compiled look-up tables to evaluate the increase of road traffic noise level due to buildings for a long straight street including gaps, taking into account the height of façades, the width of the gorge, the absorption coefficient of façades and the degree of diffusion.

Absorption is an effective means to reduce overall noise levels in a reverberant space like a street. Different studies looked at absorbing (and diffusely reflecting) materials to reduce the overall

---

[*] Corresponding author.
E-mail address: gemma.echevarria@intec.ugent.be (G.M. Echevarria Sanchez).

http://dx.doi.org/10.1016/j.buildenv.2015.11.033
0360-1323/

level along streets [7,8]. Hothersall studied in detail the sound field near balconies along tall buildings for different absorption scenarios [9].

Also vegetation could be used, as it provides both effective absorption and scattering of sound, and in addition, a pleasant urban space. Low-height noise barriers located close to the source could also be used to reduce traffic noise in urban streets to shield pedestrians or façades [8,10]. The introduction of low height noise barriers covered by vegetated wall substrate placed close to the source or receiver is discussed in Ref. [11]. Absorption on such low height noise barriers was found to be essential to have positive effects for pedestrians. Vertical greenery systems at building walls are acoustically analysed in Ref. [12] showing high absorption, compared with other building materials. A combination of different green elements is explored in Ref. [13] where wall vegetation systems, green roofs and vegetated low screens at roof edges were studied while combining different full-wave numerical methods. The influence of building and roof design on non-directly exposed façades has been studied in detail in Ref. [14–17,13], given the importance of quiet façades in the urban environment [18–20]. The study of different roof shapes on sound propagation [17] brings interesting conclusions to achieve quiet façades through architectural design. A green roof was shown to strongly decrease the shielded façade noise load caused by nearby road traffic [21].

Balconies are strongly diffusing elements in a street, and their presence and shape have been studied before. El Diem predicted the sound field along high-rise building façades as influenced by the parapet form and balcony depth, giving interesting conclusions that could be taken into account by architects [22,23]. Naish assessed nine balcony types to provide guidance on optimised acoustic treatment [24]. Janczur assessed the recess of façades and building position to reduce noise levels [25].

The main objective of this research is to provide a systematic overview of a number of architectonic solutions and the detection of influential design elements in a typical urban canyon. The reduction in noise exposure for people living and walking next to roads is of primary concern in this work. In total, 23 different cases of façade geometries are numerically studied and 19 cases of street geometry. Both sound pressure level reductions at pedestrians and along windows facing the street are compared.

2. Methods and calculation

2.1. Sound propagation model

The influence of urban canyon design is assessed through the pressure–velocity finite-difference time-domain (FDTD) method [26]. This numerical technique solves the sound propagation equations directly in the time-domain. The efficient staggered-in-space, staggered-in-time numerical discretisation scheme [26] is used.

Rigid surfaces like the street are modelled by setting the normal component of the particle velocity to zero. For the façades, a frequency-independent real-valued surface impedance is employed as proposed in Ref. [27]. The interaction between sound waves and vegetation substrate is modelled by a rigid-porous frame model [28]. Parameter fitting on substrate measurements in an impedance tube has been discussed earlier in Ref. [13] and the same parameters were used in this study. Perfectly matched layers are used as perfectly absorbing boundaries to truncate the infinite propagation domain (i.e. the sky) to a finite simulation domain. The calculations are limited to two dimensions to prevent excessive computational cost. A point source in such a simulation environment represents a coherent line source assuming a constant street canyon cross-section in the third dimension. Experimental validation of the sound propagation model in urban streets in provided in Section 2.6.

2.2. Street geometry

The cases calculated present different detailed geometries derived from a basic canyon section with a 20-m street width and a 25.6-m building height (8 floors) as shown in Fig. 1. The configurations are symmetrical relative to the centre of the street.

Two road traffic lanes are modelled forming a 7-m wide road 0.2 m below the sidewalks. Sources are positioned at 1.5 m distance from the centre and 0.05 m above street level. The street use is also symmetric in the following order (from the centre): 3.5 m for each lane, 2 m bike lane and 4.5 m pedestrian sidewalk. The body of the car is not modelled.

A horizontal line of receivers, separated each 0.06 m, is positioned along the street width at pedestrian ear height (1.5 m). Vertical lines of receivers are distributed along the façade at 0.01 m distance (pressure values are calculated in the centres of the cells).

42 different cases have been studied and are arranged in sequence groups and classified in façade cases (F) or in street cases (S). The cases analysed are summarized in Fig. 2.

The window heights are 1.5 m and are recessed by 0.2 m relative to the face of the façade. The windows in balcony cases (F3) are 2.5 m high corresponding to a glazing giving access to a balcony. The position of low barriers on the sidewalks edge is at 3.5 m from the centre of the canyon except in depressed roads with inclined walls cases (S5.4 and S5.5) where barriers are placed at 4.5 m from the centre and in the two level street with inclined walls cases (S6.4 and S6.5) placed at 4.7 m from the centre. Geometries of additional elements are defined for each sequence in the next Table 1.

2.3. Simulation parameters

A spatial discretisation step of 0.02 m is employed (square cells), allowing to perform accurate calculations up to a sound frequency of 1700 Hz assuming that 10 computational cells per wavelength are sufficient for accuracy reasons (with a speed of sound of 340 m/s). The temporal discretisation is 20 μs leading to a Courant number of 1 in the current simulation setup; this choice minimizes phase errors, guarantees numerical stability and minimum computing time [26]. A Gaussian pulse is emitted with a centre frequency of 850 Hz and a time delay of 0.004 s. Each simulation took 30000 time steps, meaning 0.6 s real propagation time in the street canyon. This corresponds to 20 reflections at façades. Ground and roads are assigned a perfectly reflective material. Bricks along façades and additional elements are modelled by a frequency-independent impedance of 4080 kg s m^{-2} following ISO 9613-2 [27] and glazings with 31416 kg s m^{-2} [29]. A detailed description of the green-wall substrate properties can be found in Ref. [13].

2.4. Road traffic source model

Immission levels are calculated using the CNOSSOS Equivalent source model [30]. Equivalent power spectra at 0.05 m height were used to approach road traffic noise sources along the traffic lanes. Category 1 (Light motor vehicles) at a speed of 50 km/h was considered. Traffic intensity is of no interest in the current study as absolute levels are of no concern. Sound frequencies higher than 1.7 kHz have been neglected given the interest in low-speed road traffic in urban street canyons. Their contribution to total A-weighted levels is limited.