COVER PAGE

Document downloaded by @DAEL

Sat Oct 31 06:30:11 2026
For personal use

When automatic English translation is provided, only the original document is authentic.
The EAA cannot be held responsible of any translation error

Bibliographical reference

Façade Shaping as Local Means Protecting Against Traffic Noise, Ryszard Janczur, Elzbieta Walerian and Mieczyslaw Czechowicz, Acta Acustica **vol. 97** (Number 5), 2011, pp. 769-778

DOI
https://doi.org/10.3813/AAA.918457

Acta Acustica united with Acustica
Vol. 97 (2011) 769 – 778

DOI 10.3813/AAA.918457

Façade Shaping as Local Means Protecting Against Traffic Noise

Ryszard Janczur, Elzbieta Walerian, Mieczyslaw Czechowicz
Institute of Fundamental Technological Research, Polish Academy of Sciences Pawinskiego 5 B, 02-106 Warsaw, Poland. ewaler@ippt.gov.pl

Summary
Based on the simulation program, it is possible to modify a shape of a building façade to obtain favourable conditions of acoustical climate. The favourable conditions are searched for in a form of a recess in a building façade creating a vertical niche. Observing the recess parameters and the building position in relation to the road, the range of the total positive effect is defined. The applied simulation program considers a road structure and traffic composition as well as influence of surrounding objects. Adjusting the modelling accuracy, the simulation model validation range is defined. The comparison with the field measurements showed that the simulation model could be applied for upper floors of the high-rise building. For this range, the obtained results can be applied in designing of the noise abatement means.

PACS no. 43.50.Lj, 43.50.Rq

1. Introduction

Cities, due to inherited historical structure, are developed in a form of canyon streets. Modern architecture introduces high- rise buildings of shapes differing from a simple shoebox. In redeveloped area, canyon structure is frequently left to obtain interesting aesthetic effect of unique space arrangement. In built-up area, from a viewpoint of processes gathering the outdoor noise propagation, the different propagation spaces can be distinguished. The large distance propagation throughout weakly developed area creates a space, where the road can be reduced to a single line source and propagation can be assumed over an impedance ground, interaction with single obstacles including. In this situation, the propagation is strongly affected by atmospheric conditions. Contrary to this, in densely built-up area, with dominating traffic noise, the characteristic is the source proximity and the propagation, which involves interaction with surrounding buildings. The traditional cities structure, reduced to canyons as well as a modern space arrangement with buildings of different shapes and arbitrary positions in relation to the source, requires different approach in simulation procedure than in cases of large distance propagation.

For large distance outdoor propagation, where moving inhomogeneous medium has to be considered, the fluid dynamics equations, solved numerically, are applied [1]. Coupled with the Kirchhoff-Helmholtz integral equation for description of interaction with obstacle, the numerical schemes are developed and applied for consideration of a screen presence [2, 3, 4, 5] and noise transmission between city canyons [6, 7]. The numerical solutions requiring discretisation make the methods less efficient with growing frequency. Another applied method - ray tracing, contrary to the former ones, is based on high frequency approximation. The review of models combining these approaches, accompanied by discussion of their applicability, has been presented within the framework of the HARMONOISE Project [8, 9].

In road proximity, noise abatement is mostly possible basing on local protecting means. Prediction of their efficiency requires the enough accurate acoustical field description. For high-rise buildings, a façade shaping can be considered. Most frequently, the action is undertaken in the vertical direction by introduction of balconies or terraces, which play a role of screens parallel to a road. The early studies were based on the scale model experiments [10, 11]. Currently, the detailed analytical field description is applied to observe the benefits of introduced changes in the propagation process. The acoustical field is described with the use of the ray tracing [12, 13, 14] or boundary element methods [15, 16] and a method based on the Green's function application [17].

In the paper, action is proposed in the horizontal direction. Due to a recess in a building façade creating a kind of a niche, only vehicles over a limited road segment, just in front of a recess, emit noise to the space at a recess base, while vehicles further in lanes are screened by the recess wedges. As in the case of balconies, the reflection field limits positive effect. Despite this, the properly selected recess parameters could provide the acoustical climate improvement in space within a recess.

Received 30 December 2009,
accepted 12 July 2011.

© S. Hirzel Verlag · EAA

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

It is very frequent to present effects of modification in road surroundings in a form of an isolated physical effect for a single line source, which emits signal of a limited spectrum. It is not sufficient for evaluation of acoustical climate improvement. To this end, the obtained effect of an urban system modification has to be presented by the quantity recommended as the annoyance measure – the sound equivalent level at the defined receiver for the defined time interval. This means that the sound level requires presentation showing its spread over a building façade at successive floors.

For road proximity, from the above stems necessity of a road emission description with the adequate accuracy. It has to involve vehicle flow spreads over lanes and a model of noise emission by a vehicle, full spectrum including. An assumption of a line source, resulting in 2D sound field presentation, can be applied to systems of an axial symmetry like canyon streets. However, a whole road reduction to a single line source, which omits road lane structure with lane different positions and different flow rates over them, is misleading in assessment of a screening element efficiency [18]. The same concerns presentation of the results for limited frequencies. Consideration of the total spectrum of emitted noise with the A-weighting is needed for the annoyance assessment. Besides, the A-weighting, as a consequence, creates the advantageous position for propagation description, which is based on high frequency approximation.

To analyse possibilities of acoustical climate improvement in complex urban systems, simulation programs are the best tools. For the average sound level due to a multilane road flanked by arbitrary aligned buildings, they allow observation of variations caused by successive changes in the chosen input parameters, while the others are kept constant.

In the paper, the applied simulation program is based on the environmental noise model where propagation is described by the image method and a road is represented by point sources spread over lanes. The propagation space under interest is a half-space with obstacles of different shape whose dimensions and distance from a road are in the range of few tens meters. Thus, omission of weather conditions and the assumption of propagation in ideal gas at rest are allowed. The propagation description is based on the image method with high frequency approximation of the canonical solutions of wave interaction with obstacles [19]. The ray tracing method, which also is based on high frequency approximation, differs from the here-applied image method in diffraction concept. Contrary to the Keller diffraction theory applied in the ray tracing method, the applied Rubinowicz concept relates the diffraction wave to the wedge active point (defined by the shortest travelling path), which emits the wave of cylindrical character and specific directional characteristics [20]. The applied approach results in the unique propagation description. The sound pressure at the receiver is a sum over wave possible paths. The wave path is defined by an ordered chain of multiple interactions where diffraction and reflection can appear at arbitrary positions [21, 22]. The purely image method becomes more accurate the higher is interaction order, while in the ray tracing method due to approximate special resolution, the larger passed path the less accurate is the final result.

In the paper, to assess the effect of a shaped façade, the simulation program verified by field measurements for smooth and shaped facades is applied [23, 24, 25]. It begins with the brief description of the simulation procedure (section 2) followed by description of the applied urban system model (section 3). Then, the results of acoustical field analysis within the confines of the applied model are presented (section 4). The paper is summed up with conclusions of applicability of a recess in a building as noise abatement means (section 5).

2. Simulation procedure

The reliable prediction of noise abatement effect requires an assessment of accuracy of a used tool – simulation program. To the expected accuracy of the simulation program, the accuracy of its two parts: propagation model and a source model have to be adjusted. For a defined kind of an urban area, the propagation model is based on the physical processes most important for this propagation space. Since most of propagation models are of heuristic nature, their accuracy can only be observed indirectly in isolated experimental conditions and/or by mutual comparison between different models. Completing the simulation program, a road model as a noise source has to be described with accuracy adjusted to the propagation conditions.

Application of the simulation program requires acquisition of input data that are estimated with their own accuracies. They define an urban system by number of present obstacles, their positions, shapes and acoustical properties, and a set of point sources representing a road including. The assumed description of an urban system can be less or more detailed. By observation of the final result sensitivities, limits of the modelling accuracy can be introduced. The propagation model together with accompanying source model, appropriately defined for the space under consideration, allow avoidance of model complexity above required level and make the simulation efficient from the viewpoint of calculation time. Validation range, assessed in confrontation with field measurement, allows to define the applicability range where, for similar urban systems, the drawing conclusions obey.

The here-applied simulation program PROP5 is developed for a road proximity where interactions with arbitrary aligned obstacles dominate propagation process. The program is based on the environmental noise model assuming noise source composed of point sources and propagation model involving multiple interactions with obstacles in a form of an ordered chain of transmission, reflection and diffraction [21, 22, 26]. Considering a road proximity with expected obstacle dimensions and A-weighting, the high frequency approximation and propagation in a loss-free medium are assumed. For obstacles modelled by panels

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

Table I. Urban system models. d: Point P distance from façade.

model	façade	reflection coefficient ground	reflection coefficient walls	d [m]	Δx_E [m]
S(1)	shaped	0.9	0.9	1.0	5.0
S(2)	shaped	0.9	0.9	0.5	5.0
S(3)	shaped	0.5	0.9	1.0	5.0
S(4)	shaped	0.5	0.5	1.0	5.0
S(5)	smooth(a)	0.9	0.9		
S(6)	smooth(b)	0.9	0.9	1.0	5.0
S(7)	smooth(c)	0.9	0.9		

joined at appropriate angles, in the pressure-based interaction description, diffraction is considered with the first order approximation. For reflection and transmission the single real values coefficients are assumed.

Due to road proximity, its model requires consideration of lanes structures with appropriate flow rates over them. Noise emission is based on a vehicle passes-by. The approximate calculation of the sound exposure level introduces the limited integral boundaries and replaces integration by summation with the step Δx_E in defining vehicle position in a lane assumed parallel to the x-axis. The length of the significant lane segment is defined based on the assumption that a vehicle emission at the end positions is 10 dB lower than at the central position. For the spatial receiver position at successive floors, the segment length growth with height is considered. The assumed value of the Δx_E step has to fulfil the condition $\Delta x_E \ll 2\pi R_0$ where R_0 is the distance between a lane and a receiver [27]. For optimization of calculation time, the value of the Δx_E step has to be adjusted to the assumed accuracy of the analysed urban system modelling. The procedure of the sound exposure level calculation allows avoidance of arbitrary definition of the significant lane segment. Moreover, in place of an arbitrary lane division into sub-segment represented by point source, the equivalent source spread along a lane with the step Δx_E, physically, represents a vehicle movement.

Complex noise emission by a vehicle can be modelled by a set of equivalent point sources their directivity including. Again, under conditions defined by the assumed accuracy of the analysed urban system model, the calculation time economy is decisive for the choice of modelling accuracy of vehicle noise emission. In the MAK2 road model, applied in the simulation program PROP5, the vehicle fleet is divided into light (l) and heavy (h) vehicles with vehicle noise emission by a single, omnidirectional equivalent point source. The equivalent sources are defined by their $L_{WA}^{l(h)}(v_j^{l(h)})$ power levels with $q^{l(h)}(v_j^{l(h)}, f_w)$ reduced spectra [28], and $z_0^{l(h)}$ positions above ground [29].

For a J-lane road of lane positions y_{0j}, with vehicle flow rates $\mathcal{N}_j^{l(h)}$ and average speeds $v_j^{l(h)}$ in them, resulting in spacing

$$\Delta x_j^{l(h)}(v_j^{l(h)}) = v_j^{l(h)} / \mathcal{N}_j^{l(h)}), \tag{1}$$

the time-average sound level of an interval T is obtained as a result of summation over road lanes and two distinguished vehicle classes,

$$L_{Aeq}(T) = 10 \log \left\{ \sum_{j=1}^{J} 10^{0.1 L_{Aeq_j}^{l}} + 10^{0.1 L_{Aeq_j}^{h}} \right\} \tag{2}$$

The contribution to the time-average sound level at the point P due to light or heavy vehicles moving in the j-lane [30] is given by

$$\begin{aligned} L_{Aeq_j}^{l(h)} &= L_{Aeq_j}^{l(h)}(v_j^{l(h)}, \mathcal{N}_j^{l(h)}) \\ &= L_{WA}^{l(h)}(v_j^{l(h)}) + 10 \log \frac{\Delta x_E}{\Delta x_j^{l(h)}(v_j^{l(h)}, \mathcal{N}_j^{l(h)})} \\ &\quad + L_j^{l(h)}\left(q^{l(h)}(v_j^{l(h)}, f_w), \Delta x_E, z_0^{l(h)}, P\right). \end{aligned} \tag{3}$$

The last term represents the propagation in road surroundings

$$L_j^{l(h)}\left(v_j^{l(h)}, U_j(\Delta x_E), P\right) = \tag{4}$$
$$10 \log \left(\frac{1}{4\pi} \sum_w q_A^{l(h)}\left(v_j^{l(h)}, f_w\right), w^{l(h)}\left(f_w, U_j(\Delta x_E), P\right) \right).$$

It is a level at the point P due to the set of $U_j(\Delta x_E)$ point sources representing a $l(h)$-class vehicle movement along a j-lane (the sound exposure level calculated for discrete source positions distant by Δx_E). The acoustical energy averaged over hundred tones in the w-octave-band

$$\begin{aligned} &w^{l(h)}\left(f_w, U_j(\Delta x_E), P\right) = \\ &\quad w^{l(h)}\Big(N, \{\mathbf{R}(n)\}, \{R(n)\}, \{T(n)\}, \\ &\qquad \mathbf{R}(P), \{\mathbf{R}(S_{ju}^{l(h)})\}, K, \Delta x_E, f_w\Big) \end{aligned} \tag{5}$$

results from the urban system transfer function defined for transmission from vehicles' positions in lanes

$$\left\{ \mathbf{R}\left(S_{ju}^{l(h)}\left(x(u\Delta x_E), y_{0j}, z_0^{l(h)}\right)\right)\right\}$$

to the receiver at $\mathbf{R}(P(x_p, y_p, z_p))$. For the defined point source position, the sound pressure observed at the receiver is a sum over all possible paths, which number is limited by the assumed upper order of interactions K. The road surroundings as a propagation space is defined by its geometry (number of panels forming obstacles (N) and their position $\mathbf{R}(n)$), acoustical properties of panels forming obstacles (reflection $\{R(n)\}$ and transmission $\{T(n)\}$ coefficients).

3. Validation range

Comparing the simulation results with the field measurements carried out in the system presented in Figure 1, the basic model of the system (Table I, S(1)) and its validation range have been established [25]. For the applied simulation program PROP5, the simulation error resulting from

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

the error in speed estimation has been used as the criterion for the modelling accuracy. In this way, objects that appeared to be of the second importance have been omitted. The operational parameters' values Δx_E, K have to be also adjusted to the assumed accuracy in the urban system modelling. The summation step Δx_E determines the number of sources regarded over lanes, while the upper order of interactions K limits the number of the summed field components. Their choice is of special importance since they determine the calculation time and, in this way, decide about the simulation efficiency.

3.1. Propagation space

For the simulation error stemming from the accuracy in vehicle speed estimation a little less than ±1 dB(A) [25], the basic urban system model of a half-space with the building of specific shape and the simplified road model of four lanes have been assumed. The building on the opposite side and the fifth lane of the real road have been omitted as the elements of the second importance (Figure 1).

The tests performed to estimate the basic urban system model have included analysis of the influence of reflection order up to $K = 4$. The tests, with and without the building on the opposite side of the road and reflection coefficient for all surfaces present in the model, have confirmed that the upper reflection order $K = 3$ is sufficient for the analysed urban system modelling. The observed differences have been below 0.2 dB(A) [25].

3.2. Source model

To investigate the influence of corrections in propagation space, the constant noise emission is introduced by defining the standard traffic composition (Table II). It presents a simplified form of the real traffic composition. Only the light vehicle movement is considered, since it dominates. Moreover, higher flow rates and speeds are assumed for inner lanes. By loading the standard traffic composition of constant parameters, the influence of the factors determining propagation in the surroundings could be observed regardless of traffic composition and with only one kind of the equivalent source representing light vehicles. In this way, for the j-lane, the first two terms in equation (3) remain unchanged while the change in the surroundings is reflected by variations of the third term (equations 4,5).

The performed comparison has shown that the omission of heavy vehicles, smaller in number but noisier, and simplification of vehicle spacing over lanes only slightly rise the sound level over the building facade by about 0.2 dB(A) [25]. The same order of differences has been observed due to replacement of the summation step $\Delta x_E = 5$ m by the shorter one $\Delta x_E = 0.5$ m. The similar results have been obtained for other urban systems typical for city [26, 27, 30].

3.3. Applicability of accepted urban system model

For the road surroundings model, for which reduction of propagation space to a half-space with the investigated

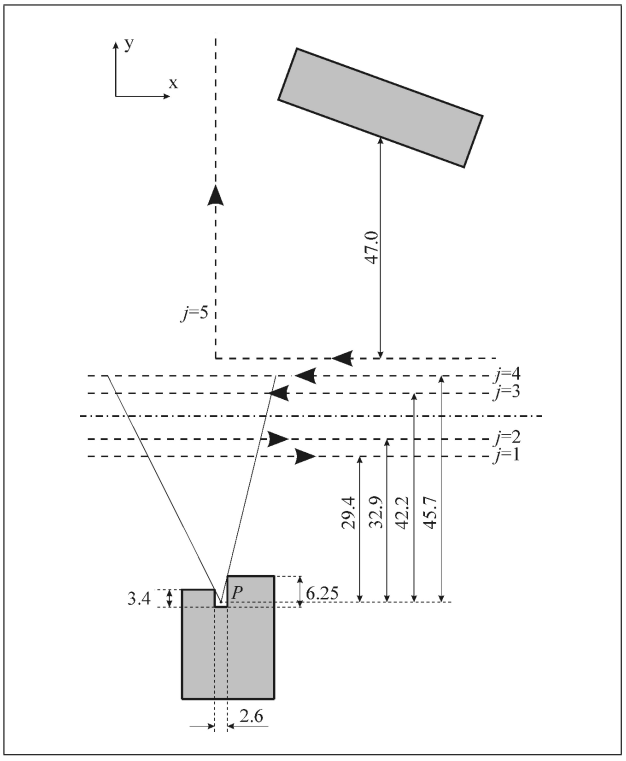

Figure 1. A sketch of an urban situation (dimensions in meters).

eleven-story building is allowed, the validation range extends above 4th floor and covers 2/3 of the building façade [25]. The range of agreement with the measurements is observed for the distance from the first lane exceeding 40 m. This is the distance greater than ten times the average length of light vehicles, prevailing in traffic. For the distances smaller than 40 m, at the lowest floors, the sound levels have been overestimated. For this range, the characteristic growth with height is observed in the measurements. As a consequence, the measurements and prediction have met above 4th floor. Up to now, the attempts to find the urban system model, which allows extending the validation range to the whole façade, have not been fully successful.

Looking for extension of validation range, the single omnidirectional equivalent point source used in the MAK2 road model has been replaced by the more detailed HARMONOISE model of a vehicle noise emission. In this model, four equivalent sources with appropriate directivity characteristics represent a vehicle [31]. The obtained simulation results have not shown the rise of the sound level with height on the lowest floors. Moreover, the sound levels over the whole façade are higher than those obtained for the MAK2 road model. The difference of 3 dB(A) in the region of the lowest floors grows with height up to 4.5 dB(A) at the highest floor [25].

Independently tested directivity of the vehicle noise emission, which privileges the lower angles above the ground, causes stronger decrease of the sound level with height and only enlarges the disagreement with the measurement [23, 32]. Therefore, the explanation of overestimation in the simulation of the sound level at the lowest

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

Table II. Standard traffic composition and vehicles' parameters. *[28], **[29]

lane	flow rate [veh(h]	mean speed [km/h]	source power level* [dB(A)]	position above ground** [m]
$j = 1$	$N_1^l = 600$	$v_1^l = 70(60)$	$L_{WA}^l(v_1^l) = 103.73(101.70)$	$z_0^l = 0.5$
$j = 2$	$N_2^l = 1200$	$v_2^l = 80(70)$	$L_{WA}^l(v_1^l) = 105.49(103.73)$	$z_0^l = 0.5$
$j = 3$	$N_3^l = 1200$	$v_3^l = 80(70)$	$L_{WA}^l(v_1^l) = 105.49(103.73)$	$z_0^l = 0.5$
$j = 4$	$N_4^l = 600$	$v_4^l = 70(60)$	$L_{WA}^l(v_1^l) = 103.73(101.70)$	$z_0^l = 0.5$

floors has to be related to the process, which blocks the noise emission in their direction. Consideration of such a process, resulting from mutual screening by vehicle bodies, has shown the sound level reduction in the range of the lowest floors but only by about 0.5 dB(A) [33].

The recent investigation in a road close proximity confirmed applicability of the MAK2 road model with the single omnidirectional source [34]. The range of agreement with the measurements is 1.5 dB(A). For the angular range adequate to the receiver positions over the shaped façade, different behaviour of the low and high frequency field components has been observed. The low-frequency components increase with height while the high-frequency components decrease. This different behaviour of ±1 dB magnitude, observed in the road proximity, can be enforced due to the interaction within a recess in a building façade. This effect will be an object of further investigation.

In the current study, analysis of the acoustical field for upper floors allows assessment of protecting properties of a recess in a building façade. For lowest floors, the collected information of field structure will be useful in searching for the urban system model of validation range covering the whole façade.

4. The acoustical field within a recess in a building facade

The field at a base of a vertical recess in a building façade is investigated. The façade is at the distance of 23.5 m from the first road lane. The recess is 2.6 m wide and has asymmetric arms of 6.25 m and 3.40 m (Figure 1, Figure 2).

4.1. The field components

According to the assumed basic urban system model, the field at the base of the recess is the result of emission of the point sources spread over four road lanes. For the assumed neutral atmospheric conditions and travelled distances of a few dozen meters, the wave propagation is assumed in the free-lost gas at rest. The observed field is a sum of the acoustical pressures of the waves reaching the receiver by different paths available for the assumed upper order of interactions $K = 3$. The total field results as a sum of the geometrical and diffraction parts of the field [35, 36]. Due to the investigated building distance from the road, the ground reflection takes place at the hard surface of the road or, for the lower floors, at the hard surface of the pavement. Thus, reflection from the hard ground

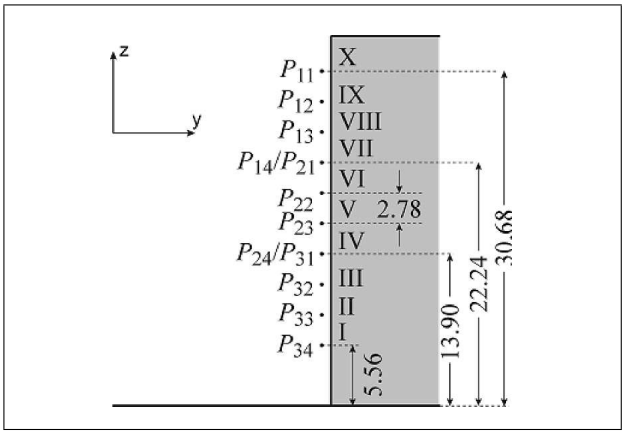

Figure 2. Receiver positions above ground.

and interactions with the hard building façade account for the field creation. For the recess base, where the receivers have been placed, the geometrical field is composed of the direct waves delivered by the sources just in front of the recess and successive reflections from the ground and the three recess walls. The terms due to all possible wave paths up to the third reflection have been summed. In creation of the diffraction part of the field participate all the sources: the 24 sources just in front of the recess with five in the first lane, and further ones spread over lanes with step $\Delta x_E = 5$ m. The diffraction part is a sum of the components which, apart from reflections, contain the single or double diffraction at the recess wedges. The diffraction part of the field is the sum of terms for which the upper interaction order is smaller or equal to three.

4.2. The field structure

To present the field features, the standard traffic composition (Table 2) has been assumed for the basic urban system model with the summation step $\Delta x_E = 5$ m, interaction order up to $K = 3$ and reflection coefficient $R = 0.9$ for all surfaces present in the model (Table I, S(1) model). The fields, at the recess base, at two distances from the façade (S(1) model, S(2) model) have been compared.

The details of the sound level spread, in a form of maps calculated on a 0.2 m × 0.2 m grid, at a distance of 1 m and 0.5 m from the recess base can be seen in Figure 3 and Figure 4. The field structure within the recess is presented for six octave bands (125 Hz–4 kHz) and the total sound level. The maps of the total sound level at the recess base present the relatively smooth field. Despite complex nature of the field in the range of the lowest floors, at the centre line the

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

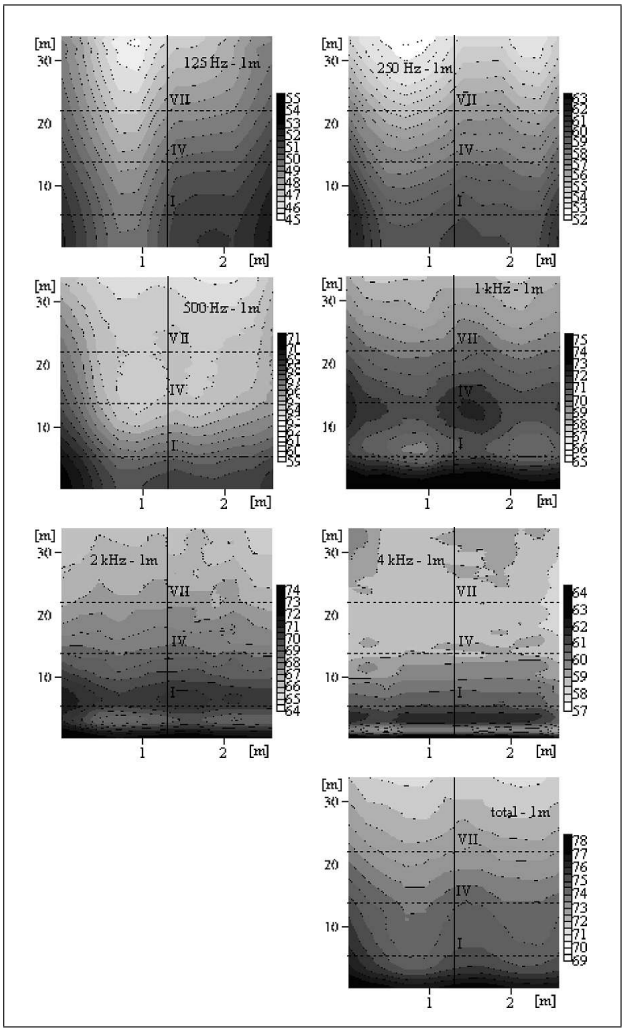

Figure 3. The maps of sound level at the base of the recess in the building façade (Figure 1) at a distance of 1 m from the wall.

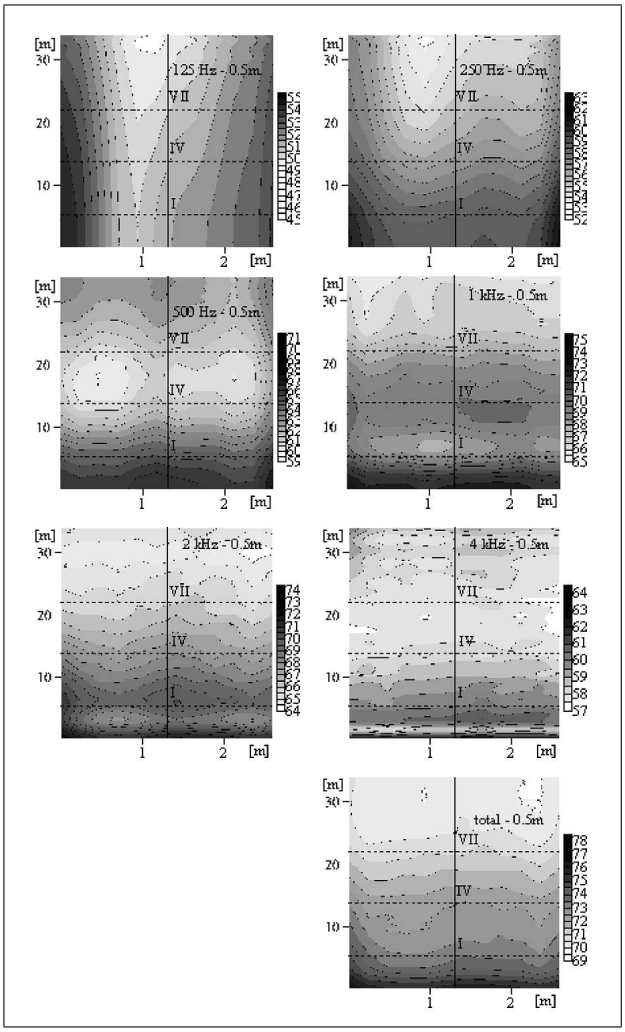

Figure 4. The maps of sound level at the base of the recess in the building façade (Figure 1) at a distance of 0.5 m from the base wall.

almost steady decrease of the total sound level with height appears. The visible field asymmetry is due to asymmetry in the length of the recess arms (Figure 1).

The varying field structure can be observed for the octave bands. At a distance of 1 m from the recess base, the specific behaviour of the 1 kHz component with a local maximum in the region of the lowest floors is observed (Figure 3). Thus, the source signal with dominating 1 kHz component could explain the sound level growth with height in the region. The collected information concerning the field structure will be useful in searching for the urban system model, which would validate for the range of the lowest floors.

The sound level dependence on the receiver distance from the recess base has been presented in Figure 5. There is shown the difference in the sound levels along the central line at distance of 0.5 m and 1 m from the base of the recess (Figures 3, 4). For the analysed case, it is characteristic that approaching the façade results in lower sound levels. Moreover, the difference between the sound levels at the two distances slightly decreases with the height, showing noticeable fluctuations for the highest floors.

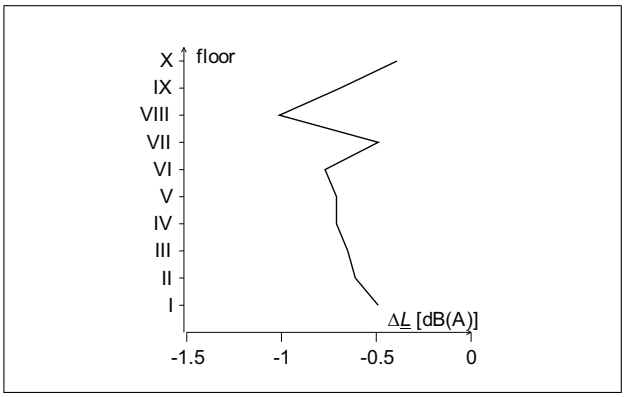

Figure 5. The effect of the receiver approaching, presented as the difference in the sound levels along the central line at distance of 0.5 m and 1 m from the base of the recess (Table 1, S(1), S(3)).

4.3. Absorbing material influence

To examine the role of reflections, the effect of absorbing properties of the ground and the recess walls is analysed (Table I). Taking as a reference the sound level for the S(1)

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

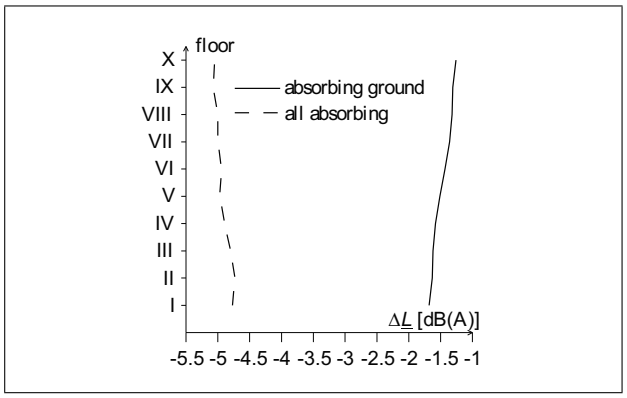

Figure 6. The effect of the absorbing ground presence (S(3) model) and all the absorbing surfaces (S(4) model) calculated in relation to all the reflecting surfaces (S(1) model) as difference in the sound levels along the central line at the base of the recess.

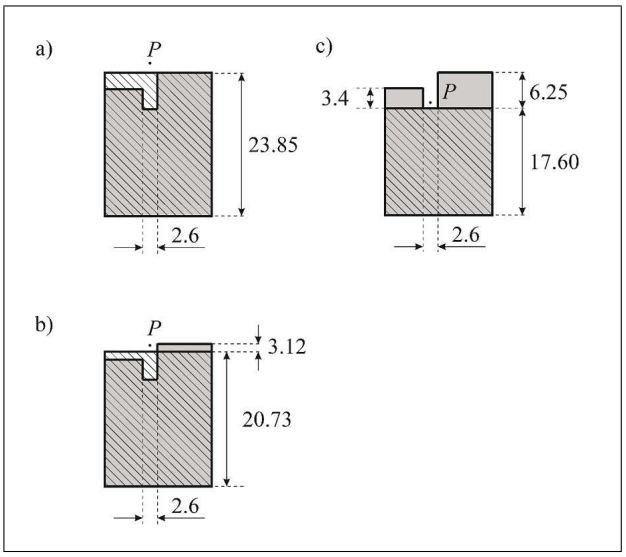

Figure 7. The virtual buildings of smooth facades (dashed area) to which the recess benefits are compared. They are obtained on the basis of the building with recess (Figure 1), when the shaped façade is replaced: (a) by the one completely filling the building contour, (b) by an averaged one, (c) by the one cutting out the recess.

basic urban system model of all the reflecting surfaces (Table I), the effect of the absorbing ground (S(3) model) and the effect of all the absorbing surfaces (S(4) model) are presented in Figure 6. The presence of the absorbing ground does not cause substantial differences in the sound level spread over façade. Near the ground, the sound levels are 1.5 dB(A) lower than in the case of the reflecting ground. The difference decreases with height to 1.3 dB(A). When the ground and all the walls (panels) forming the recess are absorbing ($R = 0.5$), the reflection field is substantially reduced. As it can be seen in Figure 6, the obtained sound level is about 5 dB(A) lower than in the case of the reflecting panels (R=0.9). The full acoustical adaptation, diminishing reflections, makes the effect of screening by the recess wedges dominating and useful in noise abatement solution designing.

5. Effectiveness of shaped façade as protector against road noise

The field measurements carried out over the building façade of specific shape with the recess [25] have encouraged investigation of this shape efficiency for noise protection. The simulation program PROP5 with MAK2 road model, for the assumed basic urban system model (Table I, S(1)), validates in the region of the higher floors. In this region, the simulation reliably reflects real processes of noise emission and propagation. For the lowest floors, the predicted sound levels are overestimated in comparison with the field measurements. Thus, the lowest floor, where real conditions are better than the predicted ones, is left out when the possibility of acoustical climate improvement by a recess application is analysed. The information gathered in course of investigation will be useful in further study on improvement of the urban system modelling to obtain the applicability range covering the whole façade.

The simulation results for the shaped façade, taken as a reference have been compared with the results for smooth facades. In the case of the smooth facades the validation range of the applied urban system model covers the whole façade [23, 24]. In place of the building with shaped façade, one of three virtual buildings of smooth facades (Figure 7) was introduced into the analysed urban system (Figure 1). The effect of shaped façade is presented in relation to the three different systems because in design practice, there could be some reasons for the use of one of these three options. Depending on the way of filling the recess to obtain a smooth façade, the positions of the receivers are at different distances from the road. For the virtual building with completely filled recess (a) and the one obtained by averaging the recess (b), the receiver positions are nearer the road than those over the shaped façade. For the virtual building with the cut out recess (c), the receivers are at the same positions as in the case of shaped façade. In this case, the distance from the road equals the natural one, occurring in the real urban system (Figure 1).

5.1. Smooth facades against a shaped one

In Figure 8, the sound levels at the base of the recess in the façade of the real building (Figure 1) and at the smooth facades of the virtual buildings (Figure 7) are shown. As it can be seen, for the smooth façades, the sound levels are almost constant in the range of about 0.5 dB(A). Contrary to this, for the shaped façade, the decrease of the sound level with height appears. For the smooth façades it is a result of the two compensating effects: the decrease with the growing distance from the sources and the increase due to the growing lengths of the significant road lane segments considered in the sound exposure calculation. For a shaped façade, due to the constant number of the sources delivering direct waves, the effect of the growing distance from the road is not compensated.

The differences between the sound levels over the smooth facades (Figure 7) and at the base of the recess in

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

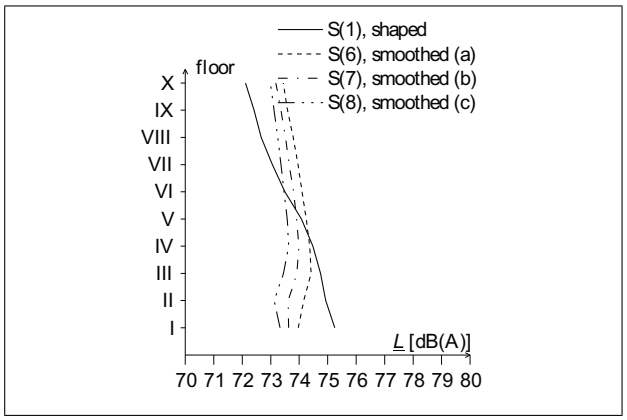

Figure 8. The sound level over the shaped façade and smooth façades for different smoothing (Figure 7): (a) completely filled, (b) replaced by averaged one, (c) cut out.

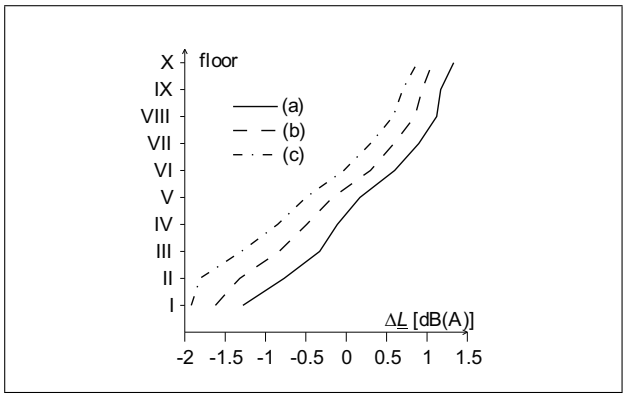

Figure 9. The effect of different smoothing (Figure 7): (a) completely filled, (b) replaced by averaged one, (c) cut out, calculated in relation to the shaped façade (Table 1, S(1) model) as difference in the sound levels along the central line at the base of the recess.

the façade of the real building (Figure 1) are presented in Figure 9. As it can be seen, the more favourable conditions due to the recess existence appear above the 4th floor. The recess existence causes the 2 dB(A) increase of the sound levels on the lowest floors and 1.5 dB(A) decrease on the highest floors.

The different distances from the road for three buildings of the smooth façade result in parallel shift of the curves in Figure 9. In the c-case, the comparison is made for the same distance from the road. Thus, the difference between situation when the receivers are in the front of smooth façade and when they are surrounded by the recess walls is shown. Within the confines of the basic urban system model, just for this case, the obtained results can be used to interpret the recess action. For the lowest four floors, the positive effect of screening by the recess wedges is overcome by the negative one, due to multiple reflections between the recess walls. Above the sixth floor the positive effect prevails. The acoustical adaptation of the ground and the recess walls can enlarge the positive effect of the recess by 5 dB(A) (Figure 6).

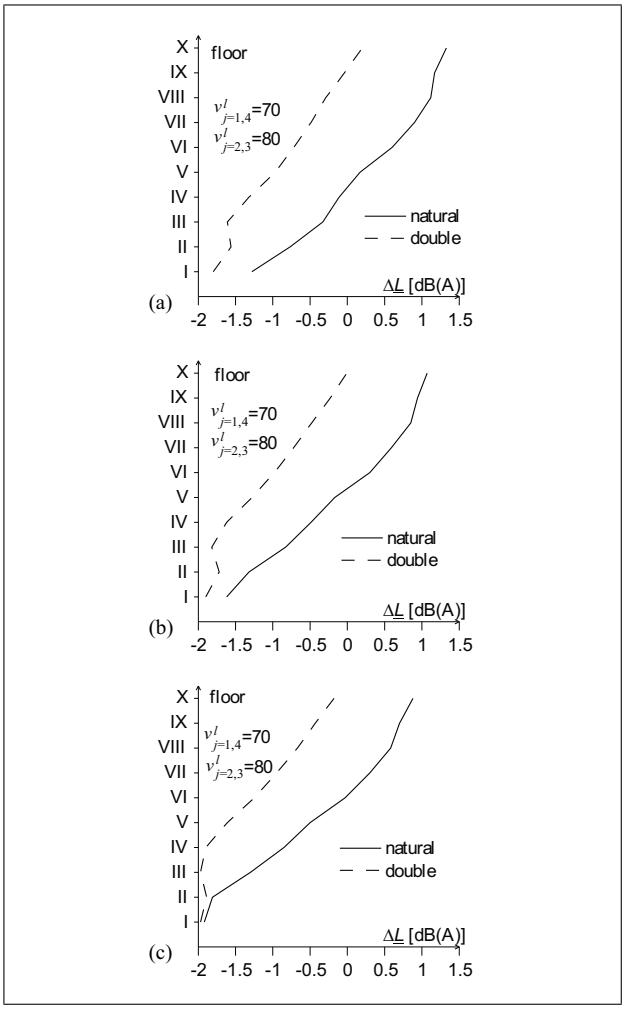

Figure 10. The effect of different smoothing (Figure 7): (a) completely filled, (b) replaced by averaged one, (c) cut out, calculated in relation the shaped façade (S(1) model) as difference in the sound levels along the central line at the base of the recess, for higher speeds (Table 2), natural and double distance from the road.

5.2. The shaped façade effect dependence on vehicle speed and distance from the road

The sound level over the smooth façades against the shaped one has been compared for the natural distance from the road in the real urban system (Figure 1) and the double one. In Figures 10 and 11, the variation caused by the double distance from the road can be observed for two sets of speeds: $v^l_{j=1,4} = 70$, $v^l_{j=2,3} = 80$ and $v^l_{j=1,4} = 60$, $v^l_{j=2,3} = 70$ (Table II). For all the three options of smoothing, the double distance from the road results in disappearance of the positive effect of the shaped façade. Interesting information is obtained for the lowest floors where the distance doubling is especially noticeable.

In the range of the lowest four floors, the curves presenting the effect of smooth facade against the shaped one run differently for the natural distance and the double one. For the set of lower speeds $v^l_{j=1,4} = 60$, $v^l_{j=2,3} = 70$, the negative effect of the shaped façade appears around the third floor (Figure 11). For higher speeds $v^l_{j=1,4} = 70$,

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

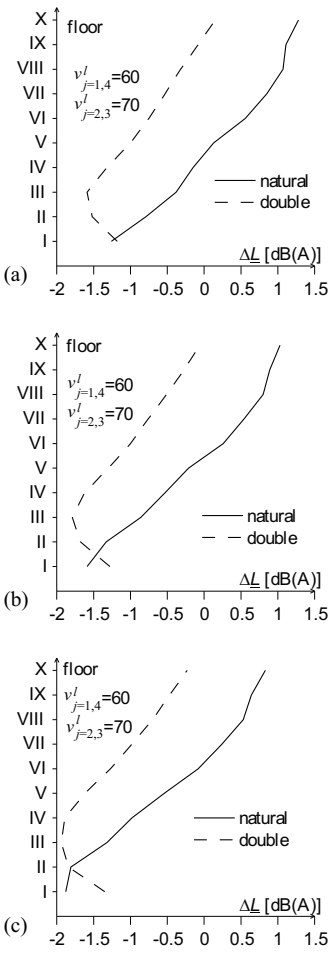

Figure 11. The effect of different smoothing (Figure 7): (a) completely filled, (b) replaced by averaged one, (c) cut out, calculated in relation the shaped façade (S(1) model) as difference in the sound levels along the central line at the base of the recess, for lower speeds (Table 2), natural and double distance from the road.

$v^l_{j=2,3} = 80$, the relation is more complex (Figure 10). On the second floor, the local minimum in the negative effect appears.

In the expression of the sound level (equation 3), the speed change affects the $L^{l(h)}_{WA}(v^{l(h)}_j)$ source power level, its relative spectrum $q^{l(h)}(v^{l(h)}_j, f_w)$ and vehicle spacing in lanes $\Delta x^{l(h)}_j(v^{l(h)}_j)$ (equation 1). The relative spectrum influence is the most complex because of the complex field dependence on frequency. The sound level spread over the building facade depends on frequency due to two different phenomena. The first one is related to the fact that the sound pressures of field components are summed, including the phase differences due to the travelled paths. For the smooth façade, there are only reflections from the ground and the façade due to the receiver position 1 m from it. In the case of shaped façade, in the region of the lowest floors, the reflections from the ground and the recess walls are important, contrary to the region of higher floors where only the reflections from the recess walls are important. The second phenomenon of frequency dependence is diffraction, which appears at the recess wedges in the case of the shaped facade. The field components resulting from diffraction are strongly dependent on the source position in relation to the diffraction wedge and the spectral composition of the signal reaching the wedge active point. The field dependence on frequency can be observed in the sound level map for 1 kHz octave (Figure 3). There, in the region of the lowest floors, a local maximum appears. This kind of maximum could account for the sound level growth with height in the region, when the 1 kHz component would appear more dominant in the whole spectrum than it is now.

6. Conclusions

In the paper, abilities of a shaped building façade to provide a locally improved acoustical climate are present. In addition to frequently applied balconies shaping façade in vertical direction, here, a horizontal shaping is considered. A recess in a façade perpendicular to the ground is taken as an example. The obtained recess in a high-rise building creates protected zone at its base. To predict the recess efficiency against traffic noise, the simulation program PROP5 has been used. The applied software differs from other commercially available software in the assumed purpose. The commercial software is mostly worked out for a quick evaluation of noise hazard while the simulation program PROP5 allows the designing of individual noise abatement solutions. For different urban systems, all specific possibilities of the local sound level reduction could be considered.

The accuracy of the urban system modelling limits the range where the program can be applied as an effective tool in prediction of the acoustical climate in built-up area. The simulation program PROP5 with assumed urban system model has passed the field verification for buildings of smooth facades and for a building with shaped façade for the limited region of the higher floors. Thus, for this region it can be used as a design tool and can offer reliable information about the recess application as the noise protection means. For lower floors, the program as a research tool provides insight into the acoustical field structure within the recess in the building façade. The collected information allows definition of further investigation directions aimed to obtain the urban system model of the validation range covering the whole façade.

The protection features of the façade shape for the higher floors have been quantitatively evaluated for the urban system of defined parameters. In the analysed case, the investigated façade is about 30 m from the first road lane. The receiver s have been placed at the base of the vertical recess which is about 3 m wide and 6 m deep. For the assumed parameters, the noise abatement of 1.5 dB(A) obtained for all the reflecting surfaces could be enlarged by about 5 dB(A) due to the acoustical adaptation of the ground and recess walls. For similar urban systems the

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only

same range of acoustical climate improvement can be expected. To obtain an exact value of improvement, the appropriate simulation has to be performed because, as it was shown, for the double distance from the road the positive effect of the façade shape disappears.

References

[1] T. van Renterghem, D. Botteldooren: Prediction-step staggered-in-time FDTD: An efficient numerical scheme to solve the linearised equations of fluid dynamics in out door sound propagation. Applied Acoustics **68** (2007) 2001–216.

[2] R. Blumrich, D. Heiman: A linearized Eulerian sound propagation model for studies of complex meteorological effects. Journal of Acoustical Society of America **112** (2002) 446–455.

[3] R. Blumrich, D. Heiman: Numerical estimation of atmospheric approximation effects in outdoor sound propagation modeling. Acustica united with Acta Acustica **90** (2004) 24–37.

[4] T. van Renterghem, D. Botteldooren: Numerical simulation of the effect of trees on downwind noise barrier performance. Acustica united with Acta Acustica **89** (2003) 764–778.

[5] T. van Renterghem, E. M. Salomons, D. Botteldooren: Efficient FDTD-PE model for sound propagation in situations with complex obstacles and wind profiles. Acustica united with Acta Acustica **91** (2005) 671–679.

[6] T. van Renterghem, E. M. Salomons, D. Botteldooren: Parameter study of sound propagation between city canyon with coupled FDTD-PE model. Applied Acoustics **67** (2006) 487–510.

[7] D. Heimann: Three-dimensional linearised Euler model simulations of sound propagation in idealized urban situations with winds effect. Applied Acoustics **68** (2007) 217–237.

[8] J. Defrance, E. Salomons, I. I. Noordhoek, D. Heimann, B. Plovsing, G. Watts, H. Jonasson, X. Zhang, E. Premat, I. Schmich, F. Aballea, M. Baulac, F. de Roo: Outdoor sound propagation reference model developed in the European Harmonoise project. Acta Acustica united with Acustica **93** (2007) 213–227.

[9] D. Maercke, J. Defrance: Development of an analytical model for outdoor sound propagation within the Harmonoise project. Acta Acustica united with Acustica **93** (2007) 201–212.

[10] E. A. Mohsen, D. J. Oldham: Traffic noise reduction due to screening effect of balconies on a building façade. Applied Acoustics **10** (1977) 243–257.

[11] D. J. Oldham, E. A. Mohsen: The acoustical performance of self-protecting building. Journal of Sound and Vibration **65** (1979) 571–591.

[12] H. H. El-Dien, P. Wołoszyn: Prediction of the sound field into high-rise building facades due to its balcony ceiling form. Applied Acoustics **65** (2004) 431–440.

[13] H. H. El-Dien, P. Wołoszyn: The acoustical influence of balcony depth and parapet form: experiments and simulations. Applied Acoustics **66** (2005) 533–551.

[14] K. M. Li, W. K. Lui, K. K. Lau, K. S. Chan: A simple formula for evaluating the acoustic effect of balconies in protecting dwellings against road traffic noise. Applied Acoustics **64** (2004) 633–653.

[15] D. C. Hothersall, K. V. Horshenkov, S. E. Mercy: Numerical modelling of the sound field near a tall with balconies near a road. Journal of Sound and Vibration **198** (1996) 507–515.

[16] K. Fujiwara, T. Nanba: Application of a noise barrier to high rise apartment house. Proceedings of Internoise 2001, The Hague, 2001, paper number 180.

[17] W. Kropp, J. Bérillon: A theoretical model to consider the influence of absorbing surfaces inside the cavity of balcony. Acustica united with Acta Acustica **86** (2000) 485–494.

[18] E. Walerian, R. Janczur, M. Czechowicz: Efficiency of screen application in built-up area. Applied Acoustics **72** (2011) 511–521.

[19] J. J. Bowman, T. B. A. Senior, P. L. E. U. (ed): Electromagnetic and acoustical scattering by simple shapes. North-Holland Company, 1970.

[20] W. Rubinowicz: Die Beugungswelle in der Kirchhoffschen Theorie der Beugung. PWN Publishing House, Warsaw, 1957.

[21] E. Walerian, R. Janczur, M. Czechowicz: Applications of the road traffic noise model to urban systems. Archives of Acoustics **24** (1999) 145–160.

[22] E. Walerian, R. Janczur, M. Czechowicz: Practical description of diffraction at wedges. Acustica united with Acta Acustica **88** (2002) 65–76.

[23] E. Walerian, R. Janczur, M. Meissner, M. Czechowicz: Influence of vehicle noise emission directivity on sound level distribution in a canyon street. Part II: Experimental verification. Applied Acoustics **67** (2006) 659–679.

[24] E. Walerian, R. Janczur, M. Czechowicz, J. Smirnowa: Possible improvement of acoustical climate. Part I: Measurements and theoretical description. Archives of Acoustics **35** (2010) 307–332.

[25] R. Janczur, E. Walerian, M. Meissner, M. Czechowicz: Application of simulation program to specific urban situation. Applied Acoustics **70** (2009) 973–985.

[26] E. Walerian, R. Janczur: Noise shielding efficiency in an urban system. Journal of Sound and Vibration **212** (1998) 187–214.

[27] E. Walerian, R. Janczur, M. Czechowicz: Sound levels forecasting for city-centers. Part II: Effect of source model parameters on sound level in built-up area. Applied Acoustics **62** (2001) 461.

[28] R. Makarewicz: Representative spectrum of road traffic noise. Journal of the Acoustical Society of Japan (E) **17** (1996) 249.

[29] S. A. Glegg, J. R. Yoon: Determination of noise source heights. Part II: Measurement of the equivalent source height of highway vehicles. Journal of Sound and Vibration **143** (1990) 39.

[30] E. Walerian, R. Janczur, M. Czechowicz: Sound levels forecasting for city-centers. Part I: Sound level due to a road within urban canyon. Applied Acoustics **62** (2001) 359.

[31] H. G. Jonasson et al.: Source model for road vehicles. Harmonoise Report HAR11TR-041210-SP10, December 2004.

[32] E. Walerian, R. Janczur, M. Czechowicz: Influence of vehicle noise emission directivity on sound level distribution in a canyon street. Part I: Simulation program test. Applied Acoustics **67** (2006) 643–658.

[33] E. Walerian, R. Janczur, M. Czechowicz: Road model as a noise source. Acta Acustica united with Acustica **95** (2009) 156–167.

[34] E. Walerian, R. Janczur, M. Czechowicz, J. Smirnowa: Validation of a complex urban noise model close to a road. Applied Acoustics **72** (2011) 790–802.

[35] R. Janczur, E. Walerian, J. Ogłaza: Acoustical field in space with obstacles. Part I: Description of geometrical field. Acustica **78** (1993) 154–162.

[36] E. Walerian, R. Janczur: Acoustical field in space with obstacles. Part II: Propagation between buildings. Acustica **78** (1993) 210–219.

Document downloaded by @DAEL, 2026-10-31 06:30:13 - personal use only