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Improving the shielding of road traffic noise in courtyards: absorption treatments

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ABSTRACT

Access to closed courtyards in city centres can offer the people living there a place of health and well-being regarding the adverse effects of road traffic noise. Due to combined effects of the contribution of many distant sources and multiple façade reflections in the courtyards, the equivalent sound levels might exceed 45 dB(A), a level desired regarding health and well-being. In this numerical study, the effect of adding absorption material for two courtyards modelled from real situations has been investigated for an incoherent line source outside the courtyards, modelled as canyons. The position and absorption coefficient of the applied absorption material have been varied. It can be concluded that façade absorption material is most effective when applied in the upper part of the façades. Also, it is shown that absorption material distributed over both façades gives a larger reduction than when concentrated to one façade only. The reduction by adding absorption is largest for observer positions low in the canyon. By applying absorption treatments, low frequencies can be reduced more effectively than high frequencies.

1 INTRODUCTION

The current paper covers the most recent part of research work attributed to urban sound propagation within the Soundscape Support to Health research programme. The research programme aims at developing methods and models and providing tools for predicting and optimizing acoustic soundscapes with respect to effects on health and well-being. The tools are intended to be applied in connection with traffic and city planning. As a contribution to the solution of the urban noise problem a focus has been directed towards creating quiet urban areas[c] like courtyards. Traditional traffic noise control measures as noise barriers however fail when applied to courtyards [1]. Therefore, the urban sound propagation research work within the research programme has been addressed to developing models and performing measurements in order to gain knowledge within urban sound propagation, which helps in assessing proposals to reduce noise immission in urban environments, in particular at courtyards. The research approach has been split up into two types of calculation models.

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[c] In the project, a quiet side of a dwelling is defined as follows: a dwelling with access to a quiet side is a dwelling that has a window towards at least one side where the total sound level – $L_{Aeq,24h}$ – from road traffic and other disturbing noise sources is lower than 45 dB free field value, with the relation + 3 dB measured 2 m from the façade corresponding to 48 dB.

In order to study sound propagation for a city, or a large part of a city, macroscopic urban sound propagation models have been developed: the linear transport model [2] and the flat city model [3]. The linear transport model accounts for sound propagation through built up areas where houses are treated as scatterers of sound waves. The model includes a mean free path of sound waves and absorption by the multiple reflections. The transfer path over rooftops is taken care of by the flat city model. In this model, traffic noise sources are 'elevated' to rooftop level and a semi free field decay to 'elevated' observer positions is calculated [3]. The contribution of multiple roads can easily be handled in the models. Both models are meant to predict a background noise level, i.e. the direct path is not included. When parameters regarding the elevated sources and receivers in the flat city model can be estimated correctly, the flat city model has been shown to yield a good agreement with measurements [3]. Using the models, the potential of redistribution of traffic as well as increasing the absorption in the transfer path has been shown [4].

At a second kind of scale, the microscale, an Equivalent Sources Method (ESM) for detailed prediction of single street-to-courtyard situations has been developed [5]. With this wave-based model, the influence of physical aspects as multiple reflections, diffusion, façade absorption and diffraction on sound propagation between canyons have been studied. The model was initially developed for a coherent line source, and further developments enabled predictions for an incoherent line source and point source [6]. This provides a better model for road traffic than the previous limitation to a coherent line source. Alternatives to using the ESM are for instance to use a Boundary Element Method (see e.g. [7]) or a Finite-Difference Time-Domain method [8].

In a scale model study of two parallel canyons, the various effects of façade absorption and diffusion were studied for a point source as well, and a comparison with the ESM was made [9,10,11]. In future work, the ESM will be used to estimate the parameters in the flat city model. To improve the properties of a courtyard as a restorative environment, sound pressure level reductions by means of a noise abatement scheme is a natural issue. Such a study was executed before for a coherent line source [7,12]. In this paper, a numerical study has been made to reveal the reduction attained by increasing the amount of sound absorption, by either placing material on the courtyard façades or changing the ground impedance. The work aims at obtaining excess attenuations for realistic situations; existing courtyards have been modelled as reference cases and an incoherent line source has been used. The study is limited by the two-dimensional geometry of the courtyards. Similar work on the influence of several types of screens has been done in a parallel study [13].

2 CALCULATION SET-UP

2.1 Selected environments

From the city of Göteborg, two areas have been selected for investigating the effect of noise abatement schemes. Göteborg, as of 2005 populated by 487,000 inhabitants, has several parts characterized by building blocks containing a closed yard or a partially closed yard. A typical urban centre region is the area around the street Linnégatan. A courtyard in this street has been selected for this study. The building consists of 8 apartment floors with a total height of around 26 meters. The façades mainly consist of brickwork and windows. At the location of the building block of interest, the width of the courtyard and the width of the street are both around 25 meters, giving a height to width ratio (H/W) of the canyons of approximately 1. The presence of narrower courtyards leads to the choice of a second geometry with a courtyard width of 14 m (H/W ≈ 1.8).

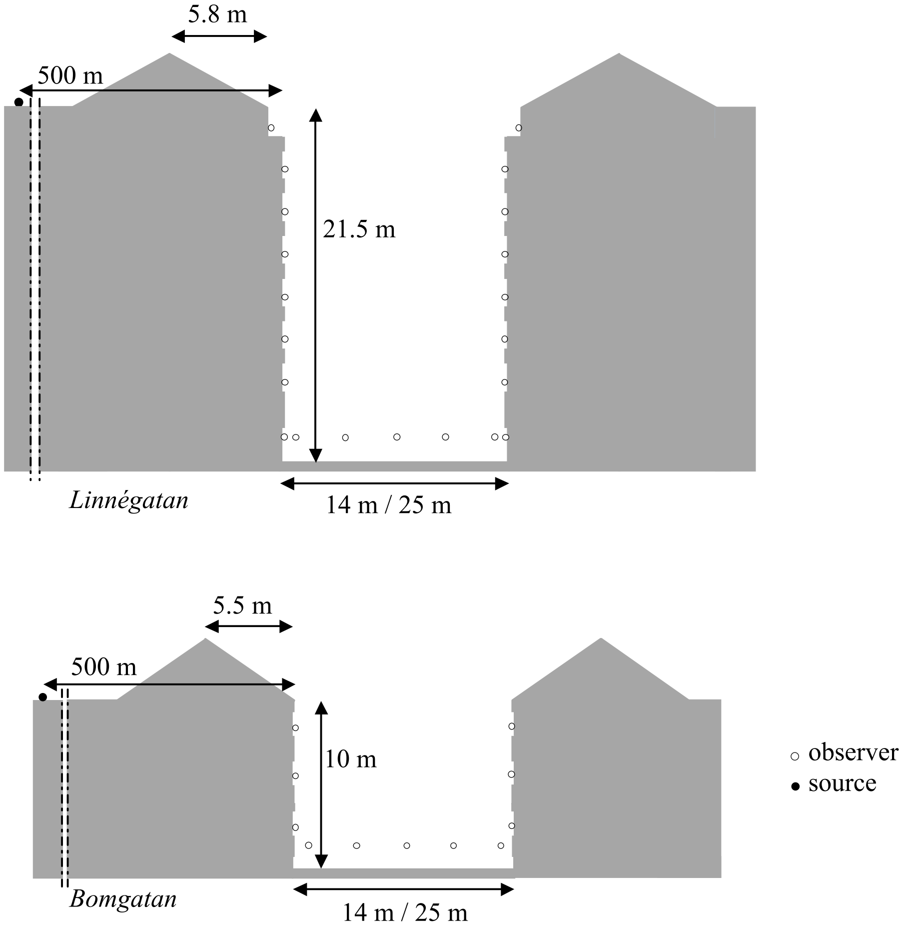


Figure 1: Cross section of the modelled courtyard in Linnégatan (upper) and Bomgatan (lower).

Other typical areas in Göteborg characterized by their closed courtyards are the areas with the so called Landshövdingehus. These buildings are characterized by a ground floor of plastered brickwork and two floors with a wooden façade. Bomgatan is a street with such houses and has been selected for the calculations. The height of the buildings is around 14 m. Because the width of the streets and courtyards are comparable to the ones at Linnégatan (25 m), the H/W-ratio is approximately 0.6. As in the Linnégatan environment, narrower streets and courtyards also exist. A width of 14 meters is therefore used as a second choice (H/W ≈ 1.0). The above-described situations comprise the four reference cases. Asphalt has been chosen as the ground surface in the reference cases.

Urban canyons, i.e. two-dimensional geometries, have been used in the modelling, and the closed courtyards are thus not modelled fully. The relation to enclosed yards can be made, at least approximately, with the aid of the results from scale model measurements [10]. It was shown for a point source that façade treatments for canyons are less efficient than for closed yards. The results of the current study can thus be seen as an underestimation of the real treatment effects. For the effect of measures in the shielded canyon, a sound source at a long distance from the shielded canyon is used. This source is situated at the canyon roof level, at a distance of 500 m (see Figure 1). For the source spectrum, a road traffic distribution of 90 % light and 10 % heavy vehicles with a speed of 50 km/h has been chosen. The traffic spectra have been taken from Danish measurement data [14]. The effect of measures in the shielded canyon has been evaluated at a number of observer points. The observer points are located at a height of 1.5 m over the canyon ground floor and at windows (see Figure 1).

2.2 Noise abatement schemes

For the selected environments, several noise abatement schemes have been calculated for. Note that the reference situations as of Figure 1 already have some façade absorption by their existing materials and diffusive effects due to window depths. From the possible noise abatement schemes, absorption treatments will here be addressed.

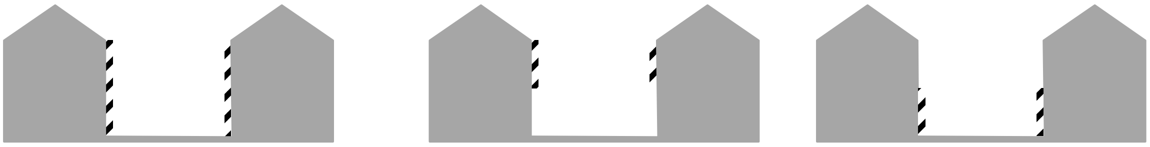
First, the absorption coefficient of the façades has been increased to the frequency independent values 0.4, 0.6 and 0.8 (for a normal incident sound wave). In the calculation, the impedance of all parts of the façades apart from the windows has then been changed. This comes down to a façade area percentage of 32 % in the Linnégatan cases and 48 % in the Bomgatan cases.

Second, the effect of the ground surface material has been investigated by changing it from asphalt to grass. A flow resistivity of $2 \cdot 10^7$ Pa s/m^2 is used to model asphalt and $5 \cdot 10^5$ Pa s/m^2 to model grass. The situation with a grass ground has again been modelled for the various absorption values of the façade material: the reference situation and façade material absorption coefficients of 0.4, 0.6 and 0.8.

Finally, the preferable position of the façade absorption material has been investigated. A constant absorption area has been used either to both facades, the upper part of the façades, the lower part of the façades, the right façade or the left façade. Figure 2 shows the various types of absorption distribution. The absorption area equals the case with a façade absorption coefficient of 0.4 for an even distribution. The absorption coefficient of the patches thus varies over the cases in order to obtain the same total absorption area in the canyon.

2.3 Numerical model

The effect of the noise abatement schemes has been calculated using the Equivalent Sources Method (ESM). This method has been applied to the urban canyon geometry by Ögren and Kropp for a coherent line source [5], and by Hornikx and Forssén for a point source and an incoherent line source [6,10]. The ESM has been validated by other calculations and a scale model study [7,10]. For the study of the abatement schemes, an incoherent line source has been used.



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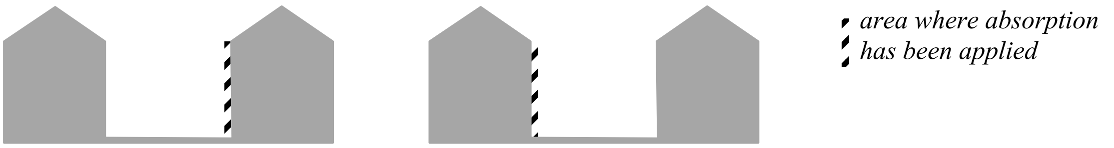

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Figure 2: Sketches of the various types of absorption distribution in the canyons.

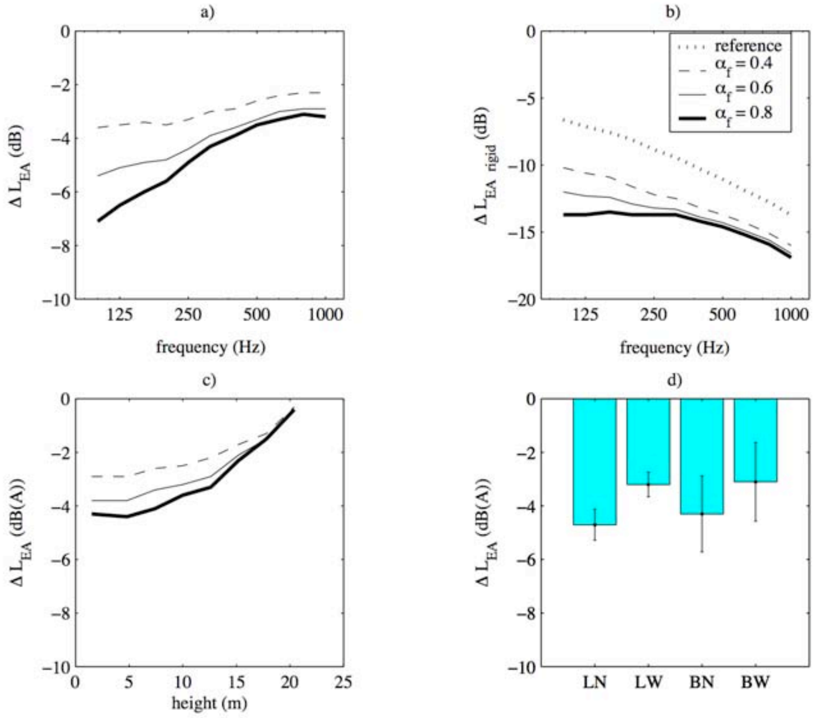

Figure 3: The excess attenuation due to façade absorption treatments. α_f is the absorption coefficient of the façades for a normal incident sound wave. The plot legend is shown in b). a) Averaged ΔL_{EA} in all canyons; b) Averaged $\Delta L_{EA,rigid}$ in all canyons; c) Averaged ΔL_{EA} over cases in Linnégatan geometries, plotted as function of height; d) Averaged ΔL_{EA} per geometrical situation for $\alpha_f = 0.8$. LN = Linnégatan, Narrow canyon, LW = Linnégatan, Wide canyon, BN = Bomgatan, Narrow canyon, BW = Bomgatan, Wide canyon.

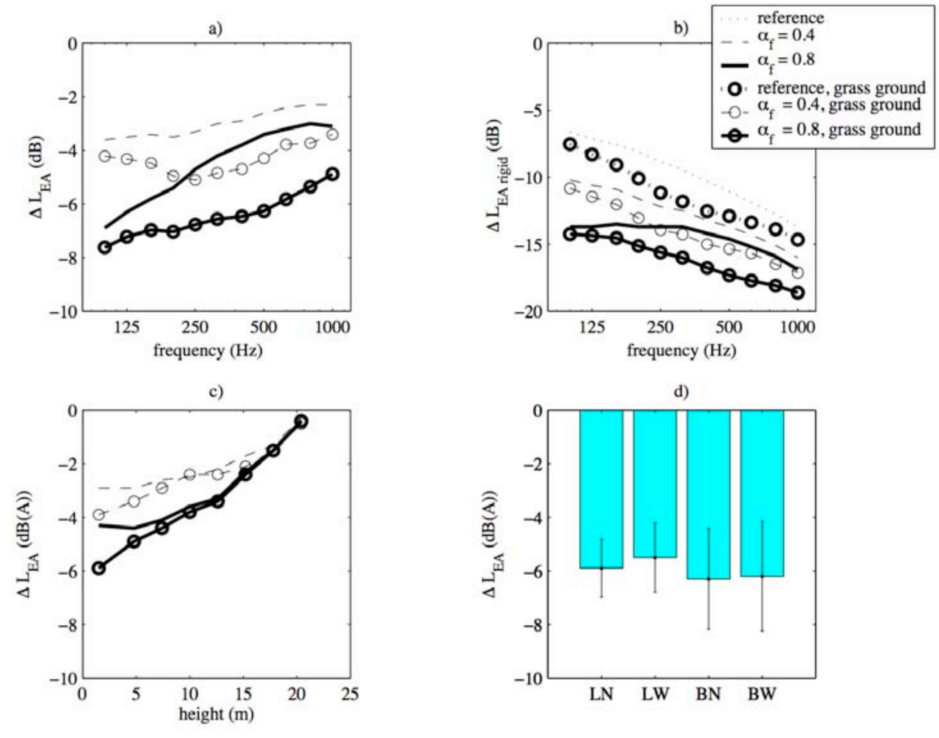

Figure 4: The excess attenuation due to a grass ground and façade absorption treatments. Sub-figures captions as in Figure 3. The plot legend is shown in b). Plot d) has been calculated for $\alpha_f = 0.8$.

The ESM solves the Helmholtz equation in the domain of urban canyons in a 2-D geometry. In the method, the domain is divided in sub-domains and equivalent sources are placed at the sub-domain interfaces. The strengths of the equivalent sources fulfil the Helmholtz equation in the sub-domains, the boundary conditions and the continuity conditions of pressure and normal velocity across the interfaces. The sub-domains are rectangular cavities, a (semi) free field, or a locally reacting impedance patch. Since the Green's functions in all sub-domains are known, the equivalent source strengths can be calculated, and the complex pressure in the domain can be solved for. The rooftops are modelled as wedges, and diffraction theory [15] is used for calculating the strength of the incoming, exciting sound field. The façade absorption has here been modelled by real valued impedances and an impedance model for porous materials has been used to calculate the frequency dependent ground surface impedance [16].

3 RESULTS

The calculation results are presented as 1/3-octave band values. Thirty logarithmically spaced frequencies per 1/3-octave band have been used. Results are expressed as the excess attenuation difference ΔL_{EA}. This is the excess attenuation (the sound pressure level minus the free field sound pressure level) of a situation with a treatment minus the excess attenuation of the reference situation. Also $\Delta L_{EA,rigid}$ has been used. Then, the excess attenuation of a treatment has been compared to the excess attenuation of the canyon with all boundaries acoustically hard and flat. Results have been averaged over their effect in dB(A), or dB when shown over frequency.

3.1 Façade absorption

Figure 3a shows ΔL_{EA} as a function of frequency for the three absorption treatments. The ΔL_{EA} are averaged values over observer positions in the lower half of the canyon, and over all four situations (i.e. the two canyons of Figure 1, each with two canyon widths). The effect of absorption increases with the absorption coefficient, and increases with decreasing frequency. This latter effect is put in an other viewpoint in Figure 3b. There, $\Delta L_{EA,rigid}$ is shown as a function of frequency for the three absorption treatments and the reference situation. The (unrealistic) case of acoustically hard and flat boundaries is here referred to. The plot reveals that the reference case, with its slight absorption and irregular façades, has an increasing reduction with frequency compared to the case with acoustically hard and flat boundaries. By further increasing the absorption leads to a total reduction compared to the rigid case that is more flat over frequency than the reduction of the reference case. When applied to the reference situations, absorption is thus more effective for the lower frequencies.

A height dependent insight is obtained by Figure 3c. This figure contains the values averaged over the observer positions of both façades for the two Linnégatan cases in dB(A). The reduction gradually decreases over the height.

The ΔL_{EA} in dB(A), averaged over observer positions in the lower half of the canyon for the case of a façade absorption coefficient of 0.8, is, together with the standard deviation, shown per case in Figure 3d. It indicates that the effect of façade absorption is more effective for the narrower canyons. The effects are similar for Linnégatan and Bomgatan. The standard deviation is largest for the Bomgatan cases.

3.2 Façade absorption and a grass ground surface

The effect of changing the ground surface from asphalt to grass in combination with façade absorption is displayed in Figures 4a-d. The plots have been calculated in an identical way as was done for Figure 3. For clarity of the plots, the case of façade absorption material with an absorption coefficient of 0.6 has been left out. The circled curves denote the

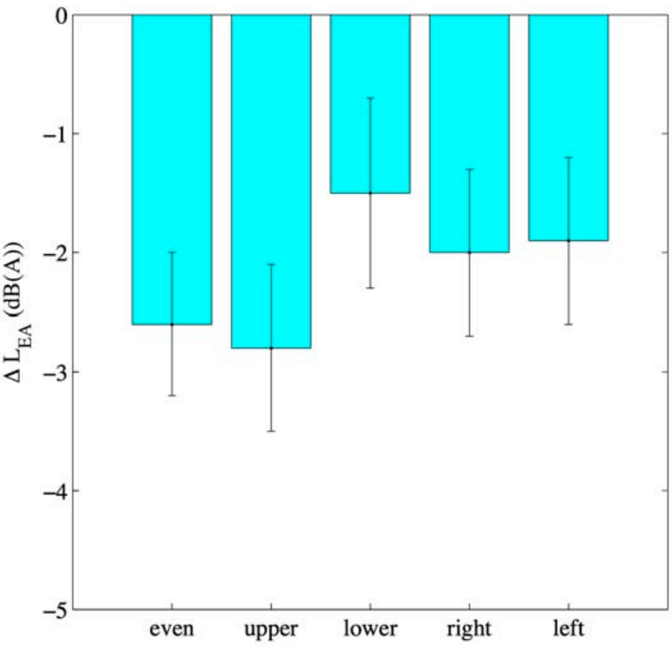

Figure 5: The excess attenuation due to façade absorption treatments with various placements, see Figure 2. Values are averaged over all geometrical situations.

combined cases of a grass ground surface and an absorption treatment, whereas the curves without markers are equal to the curves in Figure 3.

Figure 4a shows that changing the ground surface material from asphalt to grass additionally enlarges the reduction due to façade absorption material. The largest reduction is in the range 250 – 500 Hz. Around these frequencies, the observer positions at a height of 1.5 m meet a broad interference effect from direct and ground reflected waves.

Figure 4b also shows the effect of grass only (without increasing the absorption coefficient of the façades). The frequency dependent change is there visible as well. Note that the effect of the ground surface does not just add onto the effect of a façade material change.

From the height dependent figure, Figure 4c, it is clear that the effect of the ground surface mainly affects the lower observer positions. Observer positions in the upper half of the canyon are only slightly influenced.

In Figure 4d finally, it is shown that the average effect of a façade absorption coefficient of 0.8 and the ground treatment is around 6 dB(A). Compared to Figure 3d, the difference between the wider and narrower canyons has partly disappeared showing that the ground effect is larger for the wider canyons.

3.3 Placement of façade absorption

When applying façade absorption material, it is of interest to know the most effective position to place the material. Figure 5 shows the effect of five different types of absorption material placements, according to the sketches of Figure 2. The absorption area is left constant for all cases. The shown ΔL_{EA} and standard deviations averaged over observer positions in the lower half of the canyon for all four cases together. Although the total reduction in dB(A) is not large, the shown differences are significant. The cases with evenly distributed absorption material and absorption material in the upper part of the canyon lead to a larger reduction than the other cases.

4 DISCUSSION

Noise abatement schemes have been examined in order to investigate the effect of applied sound absorption in courtyard situations with road traffic outside the canyon. The Equivalent Sources Method has been used for the predictions where courtyards have been modelled as canyons. Real courtyards have been modelled as reference situations. Relative to the reference situations, absorption treatments are more effective for lower frequencies than for higher frequencies. Also, absorption treatments in the canyon effect the lower observer positions the most. When the ground surface has been changed from asphalt to grass, the extra reduction is visible over the whole frequency range and effects mostly the lower observer positions. Façade absorption has a larger effect for narrower canyons, whereas the ground effect is largest for the wider canyons. Changing the ground surface from asphalt to grass and the façade material to a material with an absorption coefficient of 0.8 leads to an averaged reduction of 6 dB(A) for observer positions in the lower half of the canyon. When the position of the façade absorption material is of interest, it can be concluded that, for a constant absorption area, a maximum coverage of absorption material or absorption material in the upper part of the façades lead to the largest reductions.

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