The effectiveness of quiet asphalt and earth berm in reducing annoyances due to road traffic noise in a residential area

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INTRODUCTION

Current noise abatement measures largely focuses on caring the indoor sound environment with closed windows (today, façade reduction > 40 dB is possible). The outdoor sound environment has been much more difficult to protect. For example, roadside noise barriers may reduce traffic sound levels from 7 up to 10 dB. An alternative technique is "quiet" asphalt or "silent roads", which commonly reduces the level slightly less than a barrier does, but has less impact on the visual landscape. There is, however, very little research on how effective these types of abatement measures are in improving the perceived sound environment and reducing adverse noise health effects. Studies on noise barriers (e.g., Lambert 1978; Kastka et al. 1995; Öhrström 1995; Nilsson & Berglund 2006) indicate both greater and smaller effects on annoyance than would be expected from the amount of reduction of the noise level. Suggested factors of importance for explaining these findings are, for example, the physical and visual effects of barriers and expectations about the effectiveness of barriers to reduce traffic noise (Öhrström 1995), the use of a different response pattern to noise or coping patterns in the before and after situations (e.g., Kastka et al. 1995), if noise sources are visually hidden or not (e.g., Watts et al. 1999), not separated measures of indoor and outdoor annoyances (Nilsson & Berglund 2006), a psychological treatment effect (Adair 1984), and attitudes towards the noise source (Job 1988).

The application of quiet asphalt has during recent years steadily increased and been suggested as an effective abatement measure to reduce noise levels from road traffic. However, it is hard to find studies that evaluates how the quiet asphalt affect subjective experiences e.g., perceptions of the sound environment and effects on health and well-being. Bendtsen and colleagues (Bendtsen et al. 2002) conducted an intervention study with the application of various types of two-layer pavements on an urban road (speed limit 50 km/h). The reduction of noise levels were ~7.6 dB and annoyance indoors with closed window decreased from ~38 to ~12 % in the after study. The residents also experienced less annoyance from air pollution, dust/dirt and vibrations due to the traffic.

The objectives first stated in the present before-after study was to investigate the effects on resident's noise responses of two types of roadside noise barriers; a conventional noise barrier of wood and an earth berm. However, after the before study was conducted in 2005, responsible authorities decided to replace the wooden barrier with quiet asphalt. This consequently changed the circumstances for the after study. The objectives then shifted to study how an intervention with quiet asphalt only and an intervention with quiet asphalt and an earth berm as a combined noise abatement measure affected the resident's responses to noise.

METHOD

Design, study area and population, and response rate

A longitudinal questionnaire field study including two waves was conducted in the same residential areas: Wave 1 in September 2005 and Wave 2 in September 2007 after implementation of noise abatement measures during 2006. The investigated area, which consists of 3-4 storey apartment buildings built during 1950 and 1960, is located close to a traffic-intensive road ("Högsboleden") in Gothenburg, Sweden (see the aerial photograph in Figure 1). In Quarter A, three buildings and a small play-ground are exposed to high levels of traffic noise, up to $L_{Aeq,24h}$ 71 dB (free field value) at the most exposed dwellings. In Quarter B, one building is located diagonally towards the main road. A green area with trees separates the building and "Högsboleden". An open parking deck is also situated there, but it has a minor screening effect on the traffic noise. Sound levels at most exposed dwellings are about $L_{Aeq,24h}$ 66 dB. The buildings in Quarter C are mainly located along a local road ("Guldmyntsgatan") with sound levels between $L_{Aeq,24h}$ 58-61 dB.

The study population were all 262 adult residents (18-75 years of age) living in the apartment buildings. In the before study, the participation rate was 68 % (n=177). In the after study, 93 out of 152 residents (61 %) responded (some had moved, were sick or had died). Out of the original study population, 53 % participated both before and after the intervention of noise abatement measures.

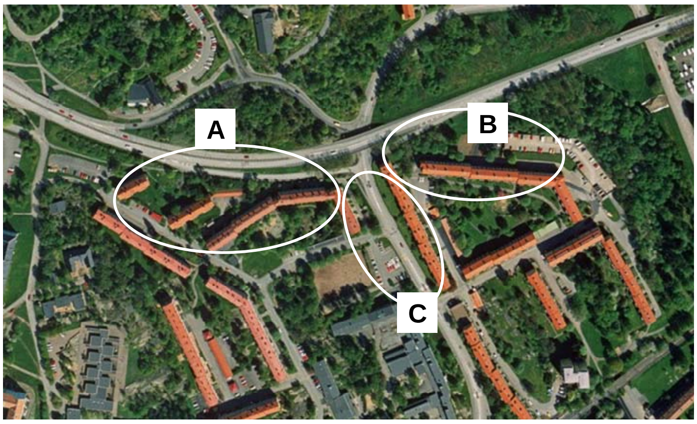

Figure 1: Aerial photograph shows residential areas before noise abatement measures were implemented: Quarter A = quiet asphalt; Quarter B = quiet asphalt+earth berm; and Quarter C = no direct abatement measure were applied here.

Noise abatement measures

The first suggestion of noise abatement measures to implement referred to a 376 m long and between 2.4 to 2.7 m high conventional noise barrier of wood in Quarter A and a 115 m long and 3.4 m high earth berm in Quarter B (Figure 2). However, due to insufficient financial resources it was decided that 2-Layered Porous Asphalt (max chipping size of first and second layers are 11 and 16 mm, respectively) should replace the noise barrier of wood in Quarter A, but also be laid further down the main road passing Quarter B (approximately length after implementation = 700 m of quiet asphalt). The length and height of the earth berm decreased somewhat to 105 m and 2.4 m, respectively, when implemented.

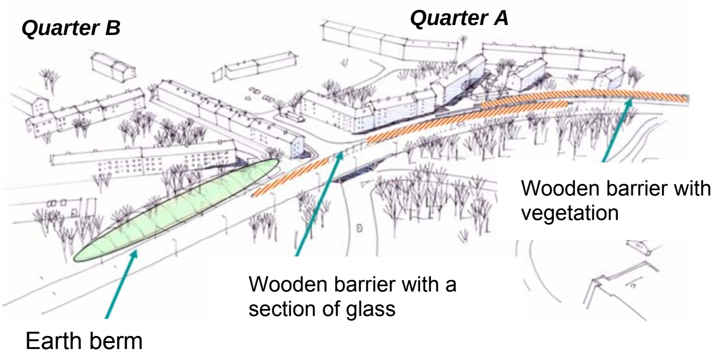

Figure 2: Schematic picture of planned noise abatement measures (the study area is shown in an opposite angle compared to Figures 1 and 3).

Assessment of traffic sound levels

In 2001, the number of counted vehicles on the main road "Högsboleden" was between 19,700 to 24,100 vehicles/24h (7 % were heavy vehicles). The speed limit is set to 70 km/h. Calculations of equivalent sound levels ($L_{Aeq,24h}$) in the before study were made based on the Nordic Calculation Model (Swedish EPA, 1996) at noise-exposed and quieter facades, 5 m above ground, which corresponds to the second floor of the houses (see the circles in Figure 3). A set of short-term measurements (~30 min) were made in October 2005 and 2006 by the Environmental and Health Authority in Gothenburg (Brandberg 2006), before and after the implementation of noise abatement measures.

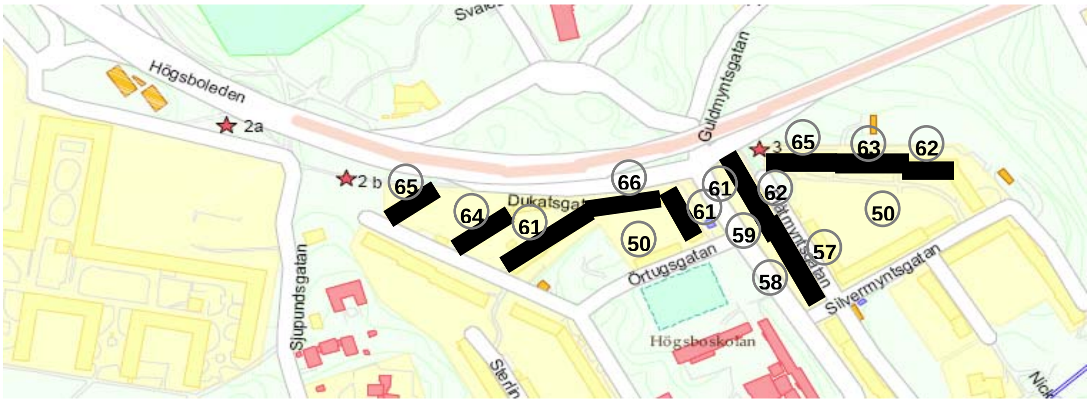

Figure 3: Calculated $L_{Aeq,24h}$ in the studied residential area (circles) before implementation of noise abatement measures and locations of short-term measurements (red stars) in 2005 and 2006.

Short-term measurements of A-weighted sound pressure level with time weighting FAST (L_{AFmax}) and $L_{Aeq,30min}$ before and after implementation of noise abatement measures (see location in Figure 3, red stars) show that the application of quiet aphalt in Quarter A decreases both L_{AFmax} and L_{Aeq} with ~5.5 dBA (median sound levels of 2 X $L_{Aeq,30min}$).

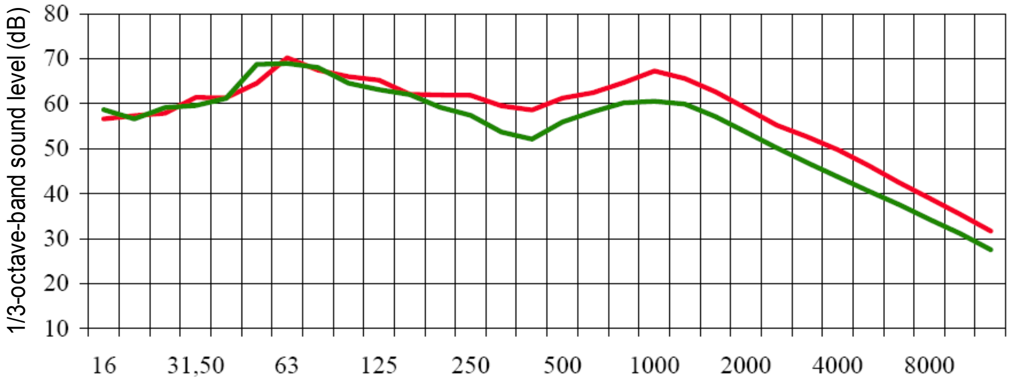

Figure 4: Spectra for two 30 min measurements conducted in Quarter A before (red line) and after (green line) application of quiet asphalt.

Figure 4 shows average 1/3-octave band spectra of two 30 min measurements, before (red line) and after (green line) the application of quiet asphalt in Quarter A. The result indicates that the quiet asphalt did not reduce the sound levels in the low-frequency bands, i.e., below ~200 Hz band. Correspondingly, the implementation of quiet asphalt+earth berm in Quarter B reduced the sound levels somewhat more, ~6.5 dB, but up to 10 dB in the low-frequency band between 100-250 Hz (Figure 5), which mainly depends on the shielding effect of the earth berm. The reduction of sound levels in Quarter C was estimated to be ~4 dB. (Brandberg 2006).

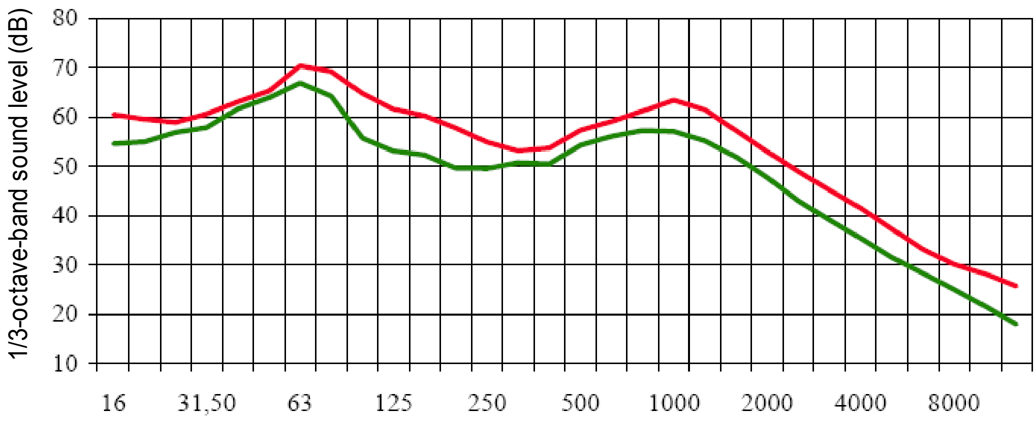

Figure 5: Spectra for two 30 min measurements conducted in Quarter B before (red line) and after (green line) application of quiet asphalt+earth berm.

Questionnaire

The self-administered questionnaire was based on previously developed questionnaires evaluating adverse health effects and well-being due to road traffic noise (Öhrström et al. 2006), but adapted to the present intervention study. Overall, the same questionnaire was used in both study waves. The questionnaire contained sections about subject's living environment and various sources of nuisance, noise annoyance and interferences with various activities, percieved sleep quality, socio-demographic and person factors etc. The current paper is mainly focused on presenting the effect of noise abatement measures on road traffic noise annoyances, perceptions of the outdoor sound environment, appraisal of sound quality outdoors, as well as resident's expectations of how noise abatement measures will change the sound environment.

RESULTS

Traffic noise annoyances as a function of type of noise abatement measures

Noise annoyance at home was assessed with an ISO standardized 5-point category scale ranging from "not at all annoyed" to "extremely annoyed" (ISO 2003). Left panel in Figure 6 shows percentage of annoyed residents (moderately and very and extremely) as a function of intervention of noise abatement measure. Only the implementation of quiet asphalt+earth berm in Quarter B significantly decreased the proportion of annoyed residents from 41 to 19 % (p<0.05, McNemar-test). For noise annoyance indoors with open window (10-point numeric scale with verbal end points; 0=not at all annoyed and 10=extremely annoyed), the average annoyance significantly decreased with quiet asphalt+earth berm (p<0.01, paired samples T-test). There were no significant effects of quiet asphalt on annoyances in Quarter A.

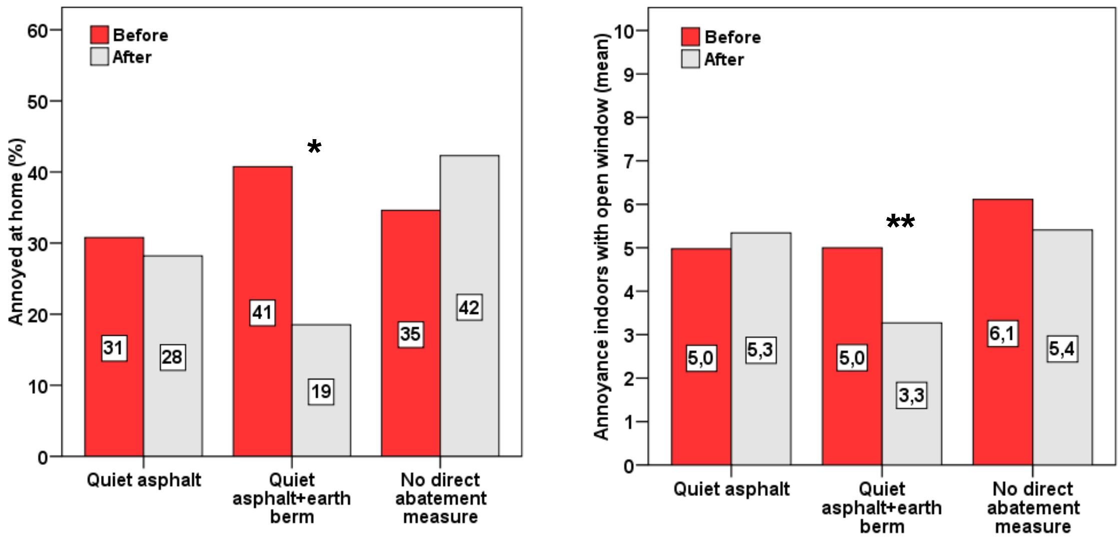

Figure 6: Percentage annoyed residents (left panel) and mean annoyance with open window (right panel) before and after noise abatement measures in Quarter A = quiet asphalt, n=39; Quarter B = quiet asphalt+earth berm, n=27; and Quarter C = no direct abatement measure implemented, n=27. *p<0.05; **p<0.01

Perceptions of the outdoor sound environment appraisal of sound quality

Perceptions of the outdoor sound environment were assessed with two statements referring to experiencing the sound environment as relaxing and as dominated by road traffic noise. Four-point scales were used ranging from "totally disagree" to "totally agree". Figure 7 shows percentage of the residents "totally agree" in the statements in relation to type of noise abatement measures. The results indicate that the perceived outdoor sound environment differ a lot between the quarters. Before the intervention, a greater proportion of resident's in Quarter A experienced the outdoor sound environment in a positive way than resident's in Quarter B and C did. However, the implementation of quiet asphalt and earth berm did not significantly change the perceptions of the outdoor sound environment in any of the three Quarters.

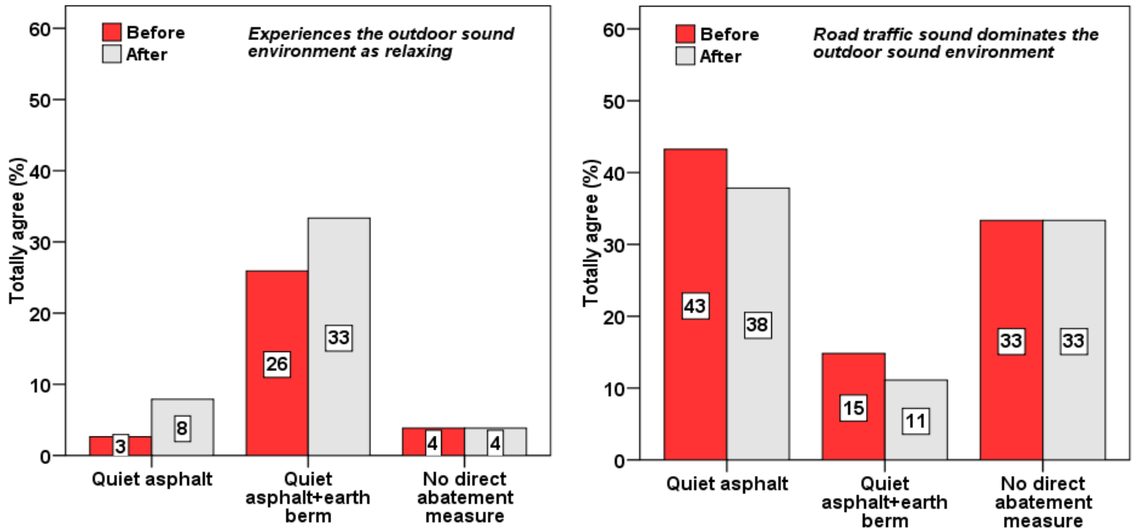

Figure 7: Percentage of residents who totally agree in statements about the outdoor sound environment before and after noise abatement measures in Quarter A = quiet asphalt, n=39; Quarter B = quiet asphalt+earth berm, n=27; and Quarter C = no direct abatement measure implemented, n=27.

Appraisal of sounds when being outdoors close to the dwelling were assessed with 14 sound quality descriptors on 5-point category scales ranging from “not present” to “dominates”. A principal component analysis with varimax rotation of the before-study data extracted three factors with an eigen value above 1. In total 63 % of the variance was explained by these three factors. Factor 1 represent distinct sounds (e.g., sharp, rattles), Factor 2 represent high frequency sounds like swishing and buzzing, and Factor 3 represent low frequency sounds such as muffled and dull. Figure 8 shows the sound quality descriptor with the highest loading in each of the three factors extracted as percentage of the resident’s hearing the sounds very clearly or dominating when being outdoors close to the dwelling. In the before-study, sounds of sharpness appeared most clearly in Quarters A and C, and correspondingly for Quarter B, it was the swishing sounds. After application of the quiet asphalt and the earth berm, the sharp and muffled sounds were found to have decreased significantly for residents in Quarter B and the sharp sounds in Quarter C (p<0.05, McNemar-test).

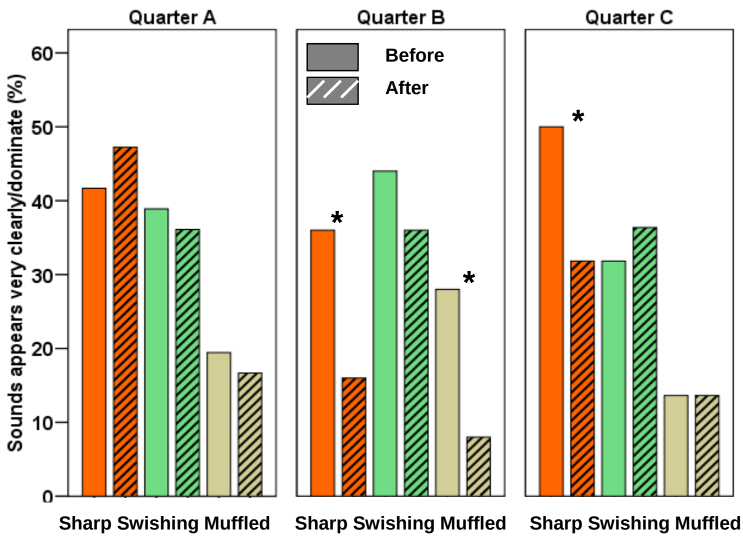

Figure 8: Percentage of residents reporting sounds appearing very clearly/dominating in the outdoor environment close to the dwelling before and after noise abatement measures in Quarter A = quiet asphalt, n=39; Quarter B = quiet asphalt+earth berm, n=27; and Quarter C = no direct abatement measure implemented, n=27. *p<0.05

Expectations of a better sound environment and association with annoyance

Since a noise barrier of wood and an earth berm were the planned noise interventions in 2005, statements about the effectiveness of a noise barrier (not quiet asphalt) in improving the outdoor sound environment were asked in the before study (four response categories ranging from “no or low expectations” to “very high expectations”). As can be seen in Table 1, about the same amount of residents in Quarters A and B had high expectations about the noise barrier’s effectiveness of improving the outdoor sound environment (fewer residents in Quarter C). However, high expectations about possibilities to be outdoors without being disturbed by traffic and be able to have a relaxed communication in the before study were only significantly correlated (r) with high noise annoyance outdoors in the after study for Quarter A.

Table 1: Expectations in the before study about effects of the erection of noise barriers (%) for Quarter A = quiet asphalt; Quarter B = quiet asphalt+earth berm; and Quarter C = no direct abatement measure implemented and associations with noise annoyance outdoors (r).

	Quarter A		Quarter B		Quarter C	
Expectations about effects of noise abatement measures on various residential situations	%[a]	r[b]	%[a]	r[b]	%[a]	r[b]
To be able to be outdoors closed to the dwelling without being disturbed by traffic	36	0.41*	35	0.26	23	0.14
To be able to communicate outdoors in a relaxed way without being disturbed by traffic	36	0.45**	38	0.17	19	-0.12
To be able to hear sounds from nature (e.g., birdsong, whistling wind) when being outdoors	51	0.28	50	0.10	31	0.03

[a] Percentage with high and very high expectations

[b] Pearsons’ product moment correlation coefficient between expectations and noise annoyance outdoors (0-10 response scale)

*$p < 0.05$; **$p < 0.01$

COMMENTS AND CONCLUSIONS

The overall results indicate that only the implementation of both quiet asphalt and an earth berm in Quarter B significantly reduced resident’s general noise annoyance and annoyance indoors with open window. Unexpectedly, the application of quiet asphalt in Quarter A had a negligible effect on annoyance. In Quarter C with no direct noise abatement measure implemented, the annoyance result was mixed. According to short-term measurements, sound levels in quarter A, B, and C decreased in year 2007 by ≈5.5, 6.5, and 4 dB, respectively, which are in agreement with estimated reduction of the sound levels for the three situations before the intervention. However, the differences in annoyance reduction indicate that there is not a simple causal relation with noise level reductions. Although the general noise annoyance in the before study was somewhat higher in Quarter B than in Quarter A and C, the mean noise levels estimated for each resident did not differ much between Quarter A and B (mean=64.3, SD=1.60 and mean=63.6, SD=1.37, respectively). In Quarter C, sound levels were lower (mean=59.1, SD=1.31).

For perceptions of the outdoor sound environment nearby the dwelling, we found a small or no effect of the implementation of the quiet asphalt and the earth berm. However, there were differences between the three Quarters in responses. Before the implementation of the noise abatement measures, only very few in Quarter A and C perceived the outdoor sound environment as relaxing, whereas one fourth perceived this in Quarter B. In both Quarter A and C many residents instead experienced the outdoor sound environment as dominated by road traffic sounds. A probable reason for this is that more residents in Quarter A had access to a quiet outdoor place (59 %), as self-reported in the questionnaire, in comparison with Quarter A (13 %) and C (30 %). Previous studies show that access to a quiet side of one's dwelling is important for reducing adverse health effects due to road traffic noise (Öhrström et al. 2006). Thus, a quieter shielded outdoor place, such as a common courtyard, will give opportunities to escape from the noisy outdoor side of the building and to perceive a more positive sound environment.

The appraisal of sounds heard when being outdoors close to the dwelling and the decrease of some sounds in the after study indicates an association with locations of the buildings and type of noise abatement measure implemented. In both Quarter A and C, the sharpness sound appeared very clearly among a somewhat higher proportion of the residents than in Quarter B. This may be due to the fact that the apartment buildings in both Quarter A and C are located closer to the trafficked roads than the apartment building in Quarter B, which is diagonally situated towards the main road. The significant reduction of the muffled sounds in Quarter B indicate an effect of the earth berm. This is supported by the reduction of the low-frequency noise mearsured in the before and after studies and shown in Figure 5.

A potential important factor in explaining the insignificant effect of the quiet asphalt in the present study is the unexpectedly change of planned noise abatement measure from a noise barrier to the application of quiet asphalt for the residents in Quarter A. This change together with high expectations of a significant improvement of the sound environment after the intervention may have created feelings of disappoinment that could have influenced the results.

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