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The effect of creating a quiet side on annoyance and sleep disturbances due to road traffic noise

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There is growing evidence that having access to a quiet side of a dwelling reduces the harmful effects of road traffic noise on health and wellbeing. One measure to create a quiet side in existing noise-exposed residential areas is to erect shielding buildings that fill existing gaps through which road traffic noise penetrates. Within the EU-financed project QSIDE, we investigated the effect of this type of measure on the acoustical conditions and resident's noise responses in a socio-acoustic intervention study. Results on sound levels, road traffic noise induced annoyance and sleep disturbances, as well as the perceived sound environment before and after the creation of a quiet side are presented in relation to results from previous similar studies. The implication for guidelines and sustainable goals related to public health, urban noise policy and urban development plans are discussed.

1 INTRODUCTION

Many citizens are exposed to high levels of traffic noise in and around their homes that far exceed what characterizes a healthy and sustainable environment. Adverse health effects are e.g. annoyance, sleep disturbances, speech interference, and stress-related symptoms[1]. Growing evidence

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shows that traffic noise also has effects on the cardiovascular system[2-3]. At present, there is a negative trend of escalating noise pollution from traffic and a growing number of both traffic noise exposed and of adversely affected people. This increase is unsustainable and strategic actions are required to reduce the adverse effects of such environmental noise.

The Swedish government has formulated 16 national environmental quality goals[4] for describing what condition and quality of the country's environment that is sustainable in the long term. Within the generation goal, it is declared (among other things) that human health is exposed to minimal negative environmental impacts while the positive aspects of the environment on human health are promoted. Furthermore, noise and sound is included as clarifications of the goal for a "good built environment", such that people are not exposed to harmful air pollutants, chemicals, noise levels and radon or other unacceptable health or safety hazards. This defines the policy direction in the area and is intended to guide environmental efforts at every society level.

An increasing number of studies, although still few, show that access to a quiet side of the dwelling in noise polluted residential areas can reduce the adverse impact of noise on health and wellbeing[5-7]. The "Soundscape Support to Health" program has thoroughly investigated the effects of a quiet side[5-6,8-11]. Results show a beneficial influence of having a quiet side, with fewer inhabitants reporting noise annoyance, sleep disturbances, noise disturbed daytime activities, and stress-related symptoms than inhabitants with the same road traffic noise exposure, but without a quiet side[5]. Based on these and other findings and for ensuring a health-supporting sound environment (e.g. non-disturbed sleep with windows slightly open), the quiet side was defined as follows: $L_{\mathrm{Aeq,24h}} \leq 45$ dB, free field value with the relation +3 dB 2 m from the facade as a total level from traffic, ventilation and the like and, where appropriate, industry. The "quiet" side should also be visually, acoustically (with good soundscape quality), and functionally attractive to visit. Furthermore, as higher sound levels at the most exposed side were found to be related with more adverse noise effects, the researchers within the program considered it also important to keep these levels down and, therefore, recommended that they should not be higher than about $L_{\mathrm{Aeq,24h}}=60$ dB, even if there is access to a quiet side. This statement was made in order to protect most people (80 %) from being affected.

An active way to increase the access to quietness in existing noise polluted areas is to erect new residential buildings that fill existing gaps through which traffic noise penetrates. However, it is important to evaluate the actual outcomes both in acoustic and health terms and also the implications of applying the "quiet-side" concept. As part of the EU-financed project QSIDE, the present study aims at doing this.

The QSIDE project has a consortium formed between research organizations, universities and cities with the goal of providing strategies and tools for reducing the harmful effects of traffic noise on health and wellbeing by focusing on the positive effects of quiet sides and quiet areas[12]. A new method for accurate calculation of sound levels at quiet sides and quiet urban areas will be developed together with a human-response model for estimating the reduction of the expected numbers of annoyed and sleep-disturbed people. QSIDE aims also to describe consequences for environmental noise policies and to provide guidelines for city planners and other authorities based on the project outcomes[9].

The main objective of this study was to investigate the acoustical conditions before and after the creation of a quiet side by measured and model estimated noise levels and to explore the intervention effects on human response to traffic noise by a longitudinal socio-acoustic questionnaire study in relation to the obtained noise levels.

2 METHOD

2.1 Study Area and Intervention

The investigated area is located in one of the center districts of Gothenburg, Sweden. In 2006, the area consisted of three older residential buildings linked to each other and forming a partly open, U-shaped courtyard with the opening facing a traffic intensive road (Mölndalsvägen), which also has tram traffic (Fig. 1). The buildings were constructed in the 30's and have 3-4 floors. Noise levels ranged between $L_{\mathrm{Aeq,24h}}$ 53-63 dB (free field) at the most exposed side of the buildings. Throughout the paper, sound levels, $L_{\mathrm{Aeq,24h}}$, are presented as free field levels in order to relate to the guideline value set for residential buildings in Sweden, which is $L_{\mathrm{Aeq,24h}}$ 55 dB free field, i.e. a facade correction where 6 dB is subtracted from the measurement results for the positions on the facade.

To create a quiet courtyard/quiet side, a 4-6 floor building was erected in 2007 toward the very busy road. The new building is aimed for students and the flat stock is mainly made up of 2-3 room apartments; most of them being two-sided with windows facing both the courtyard and the road. There are a few single-sided apartments facing a less noise exposed road. The apartments were constructed with high sound insulation for not exceeding 30 dB and L_{AFmax} 45 dB during the night. In addition, a slightly less noisy road surface was laid on the road Mölndalsvägen.

2.2 Noise Exposure

The current noise situation in the area is complex with roads at all sides of the block, different types of traffic, height differences, and traffic signals creating an increased variation in the speed and acceleration of the road traffic. The main traffic goes on Mölndalsvägen with ca 12 330 vehicles/24h (6 % heavy vehicles) and with ca 400 trams/24h. Framnäsgatan north of the case area has ca 3 100 vehicles/24h (3 % heavy vehicles). Speed limit on both roads is 50 km/h. The highway E6/E20 is located ca 300 m east of the area.

During an evening in May 2006, traffic noise was measured at 1.5 m height for 10 min at four locations: two in the courtyard, one on the facade and one at a position that was anticipated to be on the facade of the new building in the after-study. Traffic counts of light and heavy vehicles were made on the major roads during the measuring period. In order to estimate a 24-hour equivalent level at each position ($L_{\mathrm{Aeq,24h}}$), the measured levels were corrected using the Nordic prediction model[13]. The calculations were only used for positions outside the courtyard, since the model is not applicable for propagation to inner yards where there is significant influence of multiple facade reflections. The noise in the courtyard was mainly coming from a ventilation source, but during shorter periods the road traffic noise was dominating. Because of the high background level in the courtyard, an alternative approach was used for estimating the equivalent level of the traffic noise. It is based on identifying peaks in the A-weighted sound level in the courtyard and analyzing these time segments with respect to the difference in level compared to the level near to the road. This difference is then used to estimate the levels in the courtyard from the equivalent levels measured at Mölndalsvägen[14].

After the erection of the new building, noise measurements were done in October 2010 at the same positions and in the same way as in 2006 and corrected using the Nordic prediction model[13] to estimate $L_{\mathrm{Aeq,24h}}$ at each position. The background noise in the courtyard was dominated by the ventilation noise (about 52 dB). With the ventilation source turned off, the noise level fell by about 10 dB. For the two measured positions in the courtyard, the resulting $L_{Aeq,24h}$ levels were 41 and 43 dB.

In order to connect the sound levels to the respondent's apartments in the study, we made a simple estimation of the noise levels at an increased number of positions. Figure 2 shows the estimated and corrected sound levels ($L_{Aeq,24h,}$ free field levels) for the 2nd floor at about 5 m in height at the noise-exposed sides and in the courtyard before and after the construction of the new building[15]. As can be seen in the Figure, the measured outdoor $L_{Aeq,24h}$ levels from road traffic noise in the courtyard decreased by 8-14 dB after the construction of the new building.

2.3 Study Population and Questionnaire

A questionnaire before-study was conducted in April 2006 involving all residents between 18 and 75 years of age living in the area. Fifty-five out of 101 individuals (54 %) participated. In the after study in May 2011, these numbers were 77 out of 199 (39 %). Forty-nine percent in the older buildings participated in the after-study, but only 9 % of these took part in both study occasions.

The postal questionnaire was distributed to the selected residents together with an introductory letter that presented the survey as an investigation on health and wellbeing in living environments. The design of the questionnaire was based on previous research on the adverse health effects of noise[5] and included about 50 questions in total. Overall, the same questionnaire was used in both study waves. The current paper is mainly focused on presenting the effect of the intervention on road traffic noise annoyances, disturbed sleep quality and perceptions of the outdoor sound environment.

In both study occasions, slightly more women (ca 54 %) than men participated, a majority was married or cohabitating (ca 65 %), 51 % had a university education, and about 30 % were sensitive to sound/noise. The average age in the after-study was somewhat lower than in the before-study (36, SD=14.3 and 39, SD=13.9, respectively). This was also reflected in a higher number of respondents studying (22 vs. 11 %, respectively) and fewer were employed (65 vs. 69 %, respectively).

3 RESULTS

3.1 Distribution of Respondents in Noise Exposure Categories

Three noise exposure categories were created based on sound levels at the most exposed side of the dwellings: 51-55 dB, 56-60 dB, and 61-64 dB. In the before-study, none of the respondents had access to a quiet side. The noise exposure data in the after-study was divided into two categories depending on whether the respondents lived in apartments with access to a quiet side (75 %) or not (25 %). Since the latter group consisted of rather few participants that with a further breakdown into noise categories will be even less, we decided to exclude this group in the analyses of the present paper. Table 1 shows the distribution of participants in the three noise exposure categories in the before- and the after-study.

3.2 Annoyances and Disturbed Sleep Before and After Creating a Quiet Side

Annoyance caused by road traffic noise was evaluated with a five-point verbal category scale according to the ISO standardization of annoyance scales[16]. The questions were phrased as follows:

“Thinking about the last 12 months or so, when you are here at home, how much does noise from road traffic noise bother, disturb or annoy you?” The response alternatives were: “not at all”, “slightly”, “moderately”, “very”, and “extremely”. In the presentation of the results, the “annoyed” category consists of those who were moderately, very, or extremely annoyed. Disturbed sleep quality due to road traffic noise was evaluated with two questions: in terms of “How often” (0=“never”, 1=sometimes, 2=“often” and in terms of “How much” (2=“slightly”, 3=“moderately”, 4=“much”). A disturbance score ranging from 0 to 6 was constructed, in which the value for frequency was added to the value for degree of disturbance. When analyzing the data, a score above three is used for assessing the percentage of disturbed respondents. This includes individuals who report that they are alternatively sometimes and moderately disturbed (score 4), often and moderately disturbed (score 5), or often and very disturbed (score 6).

Figure 3 shows the percent annoyed by road traffic noise in relation to $L_{\mathrm{Aeq,24h}}$ in the before-situation (black bars) and in the after-situation (green bars). At both study occasions annoyance increases with increasing noise levels. The creation of a quiet side with the new building resulted in a substantial reduction in noise annoyance: about three times less of the respondents are annoyed in the after-situation compared to the before-situation. The highest noise category (61-64 dB) consists only of respondents who live in the new house and 40 % are annoyed.

Figure 4 shows the percent of the participants who reported disturbed sleep quality due to road traffic noise with windows closed (left) and open (right) in relation to $L_{\mathrm{Aeq,24h}}$ in the before-situation (black bars) and in the after-situation (green bars). In the before-situation, over a third of the respondents (36-37 %) in the two lowest noise categories has disturbed sleep quality with windows closed. These numbers were significantly reduced in the after-situation to 13 % and of those with the highest noise levels in the new building, 27 % reported disturbed sleep quality. With windows open, the disturbance was much higher in both study occasions, but decreased after the creation of the quiet side. However, in the highest noise category road traffic noise affected sleep among a large proportion of the respondents (60 %, if they had windows open).

A battery of questions about nuisances commonly present in the neighborhood (e.g. industrial noise, exhaust fumes from road traffic, vibrations from tram, ventilation noise) were evaluated with a 6-point category scale ranging from “don´t notice” to “extremely annoyed”. Aside from annoyance due to road traffic noise, the dominant sources of annoyance (expressed as percentage moderately, very and extremely annoyed) in the before-study were exhaust fumes (43 %) and vibrations (36 %) from road traffic. Few were annoyed by noise and vibration from tram traffic (13 and 4 %, respectively), as well as from ventilation noise (9 %). Of these nuisances, only exhaust fumes from road traffic was considerably lower in the after-study (16 %) among those inhabitants living in the older buildings. Annoyance due to the other nusiances were generally unchanged. Among the inhabitants who moved into the new building, 37 % were annoyed by noise and 27 % were annoyed by vibrations from tram traffic, 27 % reported annoyance due to exhaust fumes and vibrations from road traffic, and 17 % were annoyed by ventilation noise.

3.3 Perceptions of the Sound Environment Indoors and Outdoors

The questionnaire contained six statements about how the sound environment was perceived indoors and outdoors (see Table 2 for exact wording) and the respondents were requested to indicate on a 4-point category scale how they agreed with the statements (“totally agree”, “partly agree”, “partly disagree” and “totally disagree”). Table 2 lists the percentages of the respondents in the different noise exposure categories that partly or totally agree with the statements before and after the erection of the new building. In the before-situation, the amount of respondents reporting that they most often “hear traffic noise indoors” was high and increased with higher sound levels: 75 and 92 %, in the 51-55 and the 56-60 dB categories, respectively (upper part of Table 2). Higher road traffic noise was also related with fewer respondents experiencing silence indoors (42 % with 56-60 dB and 64 % with 51-55 dB). About 40 % perceived the indoor sound environment as relaxing/soothing. After the erection of the new building, the indoor situation was improved for those living in the older existing buildings, particularly among those with lower noise levels.

The lower part of Table 2 shows that a vast majority of the respondents in the before-situation perceived the outdoor sound environment as dominated by noise from road traffic (75 and 96 % in the 51-55 dB and 56-60 dB-categories, respectively) and not many found the sound environment as relaxing (15 to 18 %). Fewer in the 56-60 dB category (37 %) heard sounds from the nature when being outdoors than those exposed to lower noise levels (54 %). Overall, the intervention resulted in a better perceived outdoor sound environment. However, given that a majority (>70 %) in the two highest noise categories area felt that the sound environment outdoors was dominated by road traffic noise and only about one third of those living in the new building perceived the sound environment as relaxing outdoors, the noise still prevails as a problem in 2011.

4 DISCUSSION AND CONCLUSIONS

The present study investigated the effects of creating a quiet side on the acoustical conditions before and after the erection of the new “noise blocking” building and also explored the inhabitants’ noise responses, both among those who already lived in the existing noise-exposed residential area as well as among those who moved into the new building. This type of intervention study typically involves rather few inhabitants, which is the case also with our study, so the results should be interpreted with some caution.

The new building resulted in an improvement of the acoustic environment in the courtyard. Sound levels from *road traffic* decreased significantly by 8 to14 dB, to about $L_{\mathrm{Aeq,24h}}$ 41-43 dB (free field levels). However, noise from a ventilation source on the roof of one of the older buildings contributed significantly to the background noise in the courtyard after the erection of the new building (ca. 10 dB stronger than traffic noise). Noise from ventilation sources are not uncommon in residential areas and can spoil an otherwise good sound environment. Nevertheless, this seems to be a minor problem since only a smaller proportion of the respondents (14 %) are annoyed by ventilation noise in the after-study (the ventilation noise is at present a case for the Environmental Protection Agency in Gothenburg). Sound levels at the most exposed side for the older buildings are in general unchanged between the two study occasions. For the new building, the sound levels from traffic at the most exposed side varies between $L_{\mathrm{Aeq,24h}}$ 60-64 dB, which exceeds the Swedish guideline value of $L_{\mathrm{Aeq,24h}}$ 55 dB.

The extent of general long-term annoyance due to road traffic noise in the *before-situation* is higher than findings from previous similar studies[5-7] and also higher than in the exposure-response curve for road traffic noise derived by Miedema and Vos[17]. The higher extent of annoyance does not seem to be caused by noise or vibrations from the near passing tram traffic since only a few of the respondents are annoyed by this. However, a considerable proportion is annoyed by exhaust fumes and vibrations from the road traffic. Due to the location and arrangement of the buildings and the prevailing south-west wind direction, it is possible that exhaust fumes from the traffic is trapped and remained in the U-shaped yard that potentially resulted in odor and dust/soot. Previous research has shown that noise combined with other exposures from e.g. air pollution and vibrations give an increased environmental load and higher annoyances of the nuisances than in a situation with, for example, noise alone[18-19]. After the erection of the new building and creation of a quiet side, noise annoyance among the respondents in the older buildings is substantially reduced – about three times lower than in the before-situation. These subjects are also much less annoyed by exhaust fumes from the road traffic, which indicates that the new building acts as a blocker of both noise and vehicle emissions. It is evident that the construction of the new building has had a beneficial impact for the inhabitants of the older houses by providing a refuge where they can escape from the noise and other nuisances at the most exposed side. However, the inhabitants in the new building are exposed to high noise levels at the most exposed side of their apartments ($L_{\mathrm{Aeq,24h}}$ 61-64 dB) and this is shown by the fact that many are annoyed due to road traffic noise (40 %), but also tram traffic noise (37 %). However, the overall extent of noise annoyance in relation to sound levels at the most exposed side in the after-situation agrees rather well with findings from previous studies in which the respondents also had access to a quiet side with sound levels around $L_{\mathrm{Aeq,24h}}$ 45-47 dB. It is here important to note that in these three studies, we can see a clear relationship between increasing annoyance and higher sound levels at the most exposed side, even though the respondents have access to a quiet side.

Disturbed sleep is a critical effect of exposure to road traffic[1]. A quiet side with low sound levels could provide the quietness needed to allow for undisturbed sleep. In the latest night noise guideline (NNG), which is based on the most recent evidence in the area, WHO has set a new target and recommends that night noise levels should not be greater than 40 dB of L_{night} outside the bedroom to protect the public (incl. most of the vulnerable groups such as children, the chronically ill and the elderly) from the adverse health effects of night noise[20]. After creation of the quiet side, disturbed sleep quality was largely reduced with about 24 %-units with closed window and between 16-25 % units with open window. Approximately 70 % of these respondents have the bedroom facing the quiet side. In the new building where all respondents have the bedroom towards the quiet side, an unexpected high number reported disturbed sleep quality with window open (60 %). However, as the bedroom windows in the new building also are facing exterior corridors where people pass to and from the apartments it is possible that many of the respondents are reluctant to open this window and instead open the window towards the major road with incoming traffic noise as a result.

The availability of a quiet side and a quiet courtyard resulted in better perceived sound environment indoors for many of the respondents in the older buildings, particularly among those with the lowest sound levels at the most exposed side (51-55 dB). However, a majority (about 63 %) of the respondents in the two highest noise exposure categories, which also include those who live in the new building, still report that they most often hear traffic noise when being indoors. This is a somewhat higher number than findings from a similar intervention project for creating a quiet side in a residential area close to a highway. In that study, sound levels at the most and least exposed side of the new noise-blocking building was $L_{\mathrm{Aeq,24h}}$ 61-71 dB and ca. 47 dB, respectively, and 48 % heard traffic noise indoors[6]. It is possible that the type of sound insulation and its efficiency differ between these buildings, but we have at present no valid information available to explore this more thoroughly. The perception of the outdoor sound environment improved as well in the after-study. However, the results indicate that noise levels on the most exposed side largely affect how the respondents experience their nearby sound environment outdoors, despite the availability of a quiet courtyard. At high noise levels (61-64 dB) more perceive it as dominated by road traffic noise and fewer perceive it as relaxing. This is also in accordance with findings from previous research[6].

It is necessary to clarify what is meant by the term “quiet side”, since it has come to be misunderstood. In the Soundscape Support to Health program, the definition was carefully chosen from the aspects of providing a health-supporting good sound and living environment ($L_{\mathrm{Aeq,24h}}$ $\leq$45 dB, free field value, total level from traffic, ventilation and the like). It does not refer to any absolute silence, but something that is essential for a healthy environment in a vibrant city. A quiet side refers to an environment where the contribution from traffic noise, fan noise and the like is low enough that sound from conversation, from wind in the leaves, bird song, etc. are heard and dominate the sound environment. A quiet side of the house gives the acoustic conditions for undisturbed sleep[5,8]. A quiet side is also visually and functionally attractive to visit[10-11]. However, it is important that we evaluate how the “quiet-side” concept is applied and the outcomes[6]. Unfortunately, we have seen a tendency that it is misused in the planning and development of residential settings, often in conjunction with planning and building of new large housing estates in urban central areas located close to busy routes and highways with noise levels that in many cases far exceed existing guideline values for the most exposed side. Although a “quiet” side is applied in this type of building projects, deviations from the sound levels that defines the quiet side is commonly applied. For example, the “quiet side” may have levels of about $L_{\mathrm{Aeq,24h}}$ 54 dB (or about L_{den} 58 dB) from road traffic noise. This cannot be considered quiet, because the traffic sounds will dominate and it complies not with the new health-based NNG recommendations from WHO ($L_{\mathrm{night,outside}}$ 40 dB)[20].

It is essential that solutions that lead to new noise problems and more noise-exposed people are counteracted. Therefore, we need to define more explicitly how a good built and sustainable environment that promote human health and life quality for everybody can incorporate a healthy sound environment. It is central that guidelines for urban noise policies and urban development plans are based on the evidence of the impact of noise on human health and wellbeing[1,20] and that a long-term public health perspective is adopted, which also to take into account the vulnerable groups. Within the QSIDE project, there is a discussion about the definition of the quiet side as well as of the quiet area and information from different sources of these issues is collected and evaluated, such as outcomes from the European Noise Directive, policies and definitions in European cities, and research findings[21]. The present study contributes to the latter by showing that: (i) a “quiet side” with low sound levels from traffic ($L_{\mathrm{Aeq,24h}}$ $\leq$45 dB) could be created in an existing noise-polluted residential area; (ii) a beneficial effect of getting a quiet side with a reduced number of noise annoyed and sleep disturbed respondents; (iii) a better perceived sound environment indoors and outdoors; (iv) overall, exposure-effect relationships between sound levels on the most exposed side and the outcomes; and (v) access to a quiet side can reduce but not remove the adverse effects of having high levels of traffic noise on the other side of the dwelling.

Based on previous research evidence, the “quiet-side” term should be reserved for the low sound levels (preferably about $L_{\mathrm{Aeq,24h}}$ $\leq$45 dB) since this can provide a health-supporting good sound environment[1, 5-7, 20]. Furthermore, to protect most people (80%) from experiencing annoyance and other adverse effects the sound levels from road traffic should preferably not exceed $L_{\mathrm{Aeq,24h}}$ 60 dB at the most exposed side, even if there is access to a quiet side[5-6]. The use of the “quiet-side” concept in noise action plans, such as the present intervention project, and in planning and development of residential settings, should always start from an approach that promote human health and life quality.

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Table 1 –Study sample: Number of respondents in different noise exposure categories.

Study occasion	Number of respondents per noise exposure category ($L_{Aeq,24h}$)			
	51-55 dB	56-60 dB	61-64 dB	Total
Before-study 2006	28	27	0	55
After-study 2011	25*	16*	15*, **	56

* Respondents having access to a quiet side with $L_{Aeq,24h}$=40-43 dB (ventilation turned off); ** Consists only of respondents living in the new building.

Table 2 –Percentages of the respondents in the different noise exposure categories that partly or totally agree with statements of the perceived sound environment indoors and outdoors before and after the creation of a quiet side.

		Noise exposure categories ($L_{Aeq,24h}$)		
Variables: Statements	Study	51-55 dB	56-60 dB	61-64 dB
When I am indoors;		*Perceived sound environment when indoors*		
I hear most often traffic noise (e.g. road,	Before	75	92	–
railway)	After	33	67	60
I perceive the sound environment as	Before	39	46	–
relaxing/soothing	After	93	71	72
there is opportunity to experience	Before	64	42	–
silence	After	89	71	80
When I am outdoors nearby the dwelling;		*Perceived sound environment when outdoors*		
the sound of traffic dominates the	Before	75	96	–
outdoor sound environment	After	39	76	72
I perceive the sound environment as	Before	18	15	–
relaxing	After	68	57	36
I often hear sounds from the nature such	Before	54	37	–
as birds, insects, and the wind	After	57	52	32

Table 3 – Comparison of the percent annoyed by road traffic noise in different "quiet-side" studies.

Study (published results)	$L_{Aeq,24h}$ most exposed side (dB)		
	53-57	58-62	63-68
Existing residential areas with a quiet side (JSV 2006[2])	11	21	38
Intervention project to create a quiet side (Inter-Noise 2010[7])	-	18	32
Intervention project to create a quiet side (present study 2011)*	12	19	40

* Somewhat different categorization of the sound levels, see Table 1.

Fig. 1 – The photo on the left shows the studied area (Bomgatan) in 2006 with the open courtyard facing the busy road. The photo on the right (2009) shows the new building that fills the previous gap.

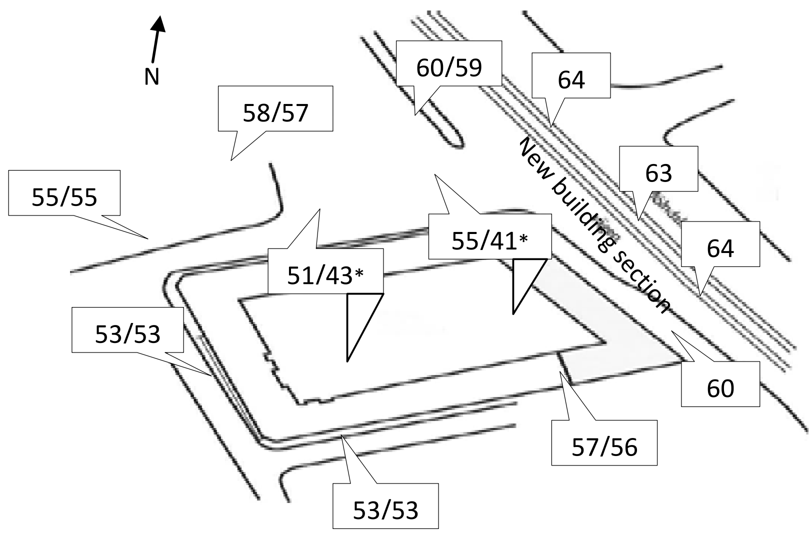

*Fig. 2 – Schematic drawing of the studied area with noise levels $L_{Aeq,24h}$ (free field value) in the before- and after situation (2006/2010). Noise levels concerns 2^{nd} floor at about 5 m in height. The light grey area marks the new building section. *Estimated levels with ventilation turned off.*

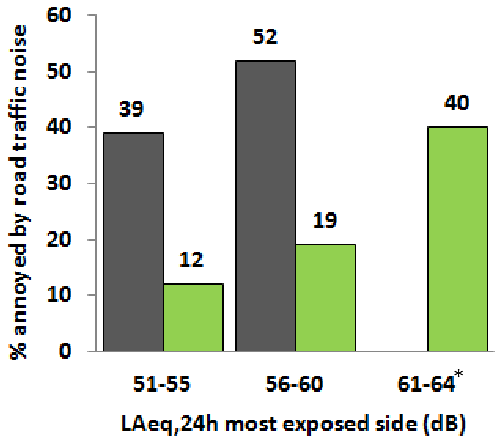

Fig. 3 – *Annoyance (% annoyed) by road traffic noise in relation to $L_{Aeq,24h}$ (free field value) in the before-situation (black bars) and in the after-situation (green bars, all respondents have access to a quiet side). *Consists only of respondents living in the new building.*

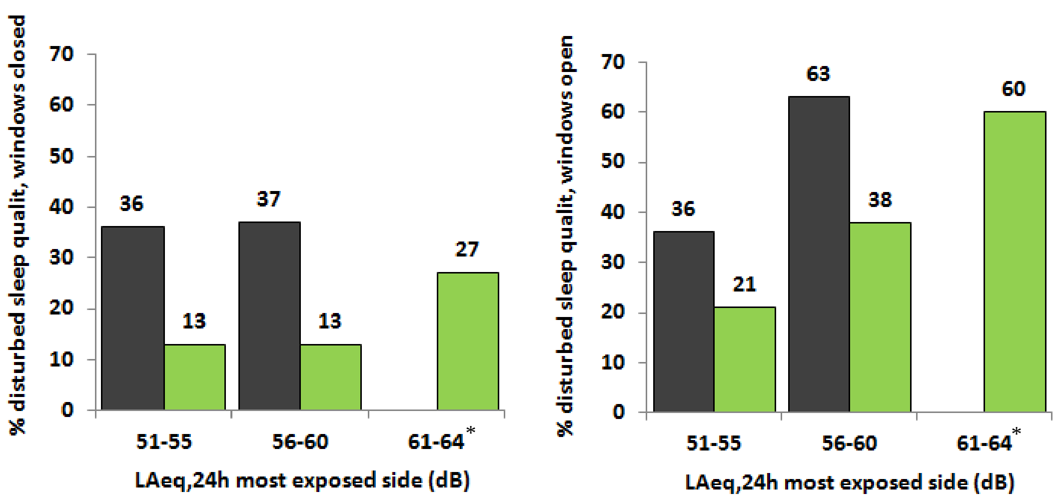

Fig. 4 – *Disturbed sleep quality (% >3) by road traffic noise with windows closed (left) and open (right) in relation to $L_{Aeq,24h}$ in the before-situation (black bars) and in the after-situation (green bars, all respondents have access to a quiet side). *Consists only of respondents living in the new building.*