Summary

Authors/contributors to Action 3:

Yvonne de Kluizenaar, Anita Gidlöf-Gunnarsson, Dick Botteldooren, Annelies Bockstael, Sabine Janssen, Frits van den Berg, Henk Vos, Jens Forssén, Mikael Ögren, Evy Öhrström, Timothy van Renterghem, Weigang Wei, Han Zhou, Erik Salomons

S.1 Background and aim

Road traffic noise is a predominant source of noise annoyance and sleep disturbance in urban areas. In a recent study in to the burden of disease from environmental noise, it was concluded that sleep disturbance and annoyance form the main burden of environmental noise (WHO, 2011). The Directive 2002/49/EC on the Assessment and Management of Environmental Noise (END) is geared towards defining a common approach to prevent or reduce the adverse effects of environmental noise exposure. Developing effective policy to reduce exposure and effects is however challenging and often not straightforward. A locally optimized approach may require a smart combination of measures. There is a need for more insight in effectiveness of various measures that may be applied.

One aspect that is expected to affect possible adverse effects of noise, is the exposure at the least exposed side of the dwelling. Creating ‘quiet façades’ to dwellings and ‘quiet areas’ may reduce these adverse effects of exposure by offering an ‘escape’ from the noise. Previous studies have indeed indicated that the availability of a ‘quiet side’ at the dwelling may reduce the adverse effects of noise (e.g. Öhrström et al., 2006). In The FP7 project QCITY it was hypothesized that least exposed façade exposure may affect the effects in two ways: People living in dwellings with relatively low exposure or high exposure at the least exposed side may be expected to be *better off* or *worse off* than average, respectively (Miedema and Borst, 2007).

QSIDE offered the possibility to investigate the hypothesized influence of least exposed façade exposure more closely. Within the framework of QSIDE the effect of road traffic noise exposure at the least exposed side on noise annoyance and noise induced sleep disturbance were further investigated. A number of dedicated studies were carried out

in different EU cities in three countries: Sweden, Belgium and the Netherlands, , including Gothenburg, Stockholm, Antwerp, Gent and Amsterdam. This offered the unique possibility to assess and compare results between studies, within different populations, and in different cities and countries, to further strengthen the evidence of least exposed side exposure, and to further quantify the hypothesized effects. In addition to the influence of quiet side exposure, the potential influence of quiet areas was further explored.

Several databases were further analyzed with 3 main objectives in mind:

First: Further strengthening of evidence: To investigate if there is an effect;
Second: Further quantification of the effect: To investigate the magnitude of the hypothesized effect;
Third: (If possible) to further quantify the (shape of) the hypothesized effect.

S.2 General approach

Studies that were (re)analyzed included 2 Swedish studies (with 1 large cross-sectional study focused on ‘quiet side’, and 1 intervention study), 2 studies in Belgium (with 1 cross-sectional population based study, and 1 cross-sectional study focused on quiet side) and 1 study in the Netherlands (a cross-sectional large population based study). Thus, this not only allowed comparison between studies in different EU cities and countries, but in addition between studies complementary in design. Study populations were located in 5 different European cities: Stockholm, Gothenburg, Antwerp, Gent and Amsterdam. In Table S.1 an overview of the different types and size of included studies by country and city is presented. In addition to road traffic noise annoyance, some studies offered the possibility to further investigate effects of least exposed side exposure on sleep disturbance. In addition, a study in Sweden, allowed investigation of the impact of the physical environmental quality of the least exposed façade and perceived accessibility of green areas.

Table S.1 *Overview of studies and analyses carried out within QSIDE*

Country	City	Type	N
Sweden	Stockholm, Gothenburg	Cross-sectional (Focused study)	956
Sweden	Gothenburg	Intervention	132 (55 before, 77 after)
Belgium	Antwerp	Cross-sectional	675
Belgium	Gent	Cross-sectional (Focused study)	100
Netherlands	Amsterdam	Cross-sectional (Population based)	1967

The influence of exposure at the least exposed façade was explored in different ways, including:

1. A cut-off value for exposure at the least exposed side (L_{denmin});
2. A cut-off value for a relatively small versus a relatively large difference between most and least exposed façade (DIF: L_{denmax} - L_{denmin});
3. The least exposed side exposure (L_{denmin} in dB, as a continuous variable).

The different analyses performed correspond to different potential models for the ‘quiet side effect’. Two of those, are inspired by the idea that the possibility to ‘escape’ from the noise (and thereby providing an ability to cope), reduces noise annoyance. The first, using an ‘absolute’ value as cut-off to define a quiet side, explores the hypothesis that this requires a side with a maximal disturbance by road traffic noise of exposure at the least exposed façade (explored in QSIDE: L_{denmin} < 50 dB versus L_{denmin} >= 50 dB), the second one, using a relatively large difference in exposure between most and least exposed façade as indicator of ‘relative quietness’, assumes that noticeable less disturbance will influence the effects (explored in QSIDE: DIF < 10 versus DIF >= 10 dB). The third evaluation is grounded in a somewhat different model assuming that both most and least exposed façade exposure contribute to noise annoyance.

It was investigated how the different indicators for least exposed side exposure, in addition to exposure at the most exposed façade, affected the mean annoyance score (linear regression models: main analyses). In addition, it was explored if the least exposed façade affects the probability of having an annoyance score above a certain cut-off value for at least annoyed (A) (in addition to the exposure at the most exposed façade) (logistic regression models: exploratory, note that the aim here was not to derive (local) exposure response curves). In one study, this was additionally done separately for LA, A and HA to test whether the effect of least exposed façade exposure, differed for these different outcome variables.

S.3 Main results

S 3.1.1 General description of main findings

Results of the different studies carried out within QSIDE provided further support for the influence of exposure at the least exposed façade. Significant effects were found for different indicators of road traffic noise exposure at the least exposed façade in most studies, with the exception of the Antwerp study. The effects of L_{denmin} seemed independent of L_{denmax}.

If expressed in terms of L_{denmax} the magnitude of the effect on predicted annoyance score ranged (between studies) from 3 to about 5 B for a 10 dB change in L_{denmin} (i.e. a 10 dB change in L_{denmin} corresponded to approximately a 3 to 5 dB change in L_{denmax}). A similar range in effect estimates was found for DIF > 10 dB versus DIF < 10 dB.

Regarding the shape of the effect, the results indicate that the differences in response between the subgroups are not significantly increasing with increasing noise levels at the most exposed side (i.e. no interaction effect). Possible interaction between L_{denmin} and L_{denmax} was investigated in the large cross sectional studies in Sweden (Gothenburg, Stockholm) and The Netherlands (Amsterdam), and no significant interaction effect was found.

Results from the cross sectional study carried out in Sweden indicate that for the predicted sleep disturbance score, having the bedroom window facing the least exposed side corresponds to a reduction of approximately 7 dB (with closed window) and 6 dB (with open window) at the most exposed façade. Furthermore, results from the Flemish focused study indicate that people sleeping at the most exposed side of their dwelling close their windows more often, although having a preference to sleep with open window. Also awakening at night by noise and difficulties to fall asleep could be linked to the presence of the bedroom at the quiet side of a dwelling.

Based on these results, it can be concluded that taking into account road traffic noise exposure at the least exposed façade (L_{denmin} or $L_{nightmin}$, respectively) could improve the predictability of reported noise annoyance and sleep disturbance by road traffic noise over using the road traffic noise exposure at the most exposed façade (L_{denmax} or $L_{nightmax}$, respectively) alone.

Additional analyses on the Swedish data, indicated the importance of the physical environmental quality at the least exposed side, which (if low) may counteract the beneficial effect of a quiet side. Furthermore, the influence of perceived accessibility to green areas on the inhabitant’s responses to road traffic noise was explored (adjusting for the influence of ‘quiet’ side), a significant association between the perceived accessibility to green areas and annoyance was found.

The population studies and focused studies complement each other, with population studies showing that the effects are not restricted to specific situations, and the focused studies suggesting that the effects may be larger in specific cases.

S.3.1.2. Scientific output and dissemination

QSIDE scientific work has resulted in several international journal and conference publications (De Kluizenaar et al., 2011; De Kluizenaar al., 2012; De Kluizenaar et al., 2013a; De Kluizenaar et al., 2013b; Gidlöf-Gunnarsson et al., 2012; Van Renterghem et al., 2012), and was internationally presented and discussed at a dedicated international workshop for policy makers in cities (Lyon, 24th of April 2013) and at international conferences.

S.4 Discussion of results

In this project significant associations were found between various indicators of the exposure at the least exposed façade and health effects (annoyance and sleep disturbance). However, the road traffic noise annoyance score for individual inhabitants, is expected to be affected by a broader range of factors, and the exposure at the least exposed façade may only explain a small part of the individual variance. Therefore, in population studies, the effect may easily be hidden by confounders such as e.g. differences in insulation, presence (or absence) of other noise sources, position of the bedroom (facing most or least exposed side) and type of dwelling. Indeed, the effect seems most clearly visible when looking at data of 'quiet side focused' studies with large contrasts in exposure (e.g. high L_{den} at both most and least exposed side versus high L_{den} at most exposed side with low L_{den} at the least exposed side). However, this does not imply that access to a quiet side is a factor of minor importance on the group level. To more clearly observe the influence of $L_{den,road}$ at the least exposed façade in broad surveys on reported noise annoyance, thus more specific information may be needed. Focused studies including sub-populations with and without access to a quiet side but no other differences in exposure or context such as the Swedish studies and the study in Ghent, easily reach statistically relevance, even with relatively small population samples. Furthermore, even in population studies, such as in Amsterdam, significant effects of the least exposed façade exposure were found, despite a variety of other factors that may have masked effects. As compared to exposure on the least exposed façade, exposure at the most exposed façade however, is still the dominant factor in the prediction of annoyance.

In the Antwerp study, no statistically significant effect was observed. The correlation between the L_{den} at the least exposed façade and additional indicators for the exposure at the most exposed façade may be too strong. Indeed, very different exposure situations leading to a similar L_{denmax} may exist in this study area. Dwellings along larger roads – a historical Flemish spatial planning – may have a quiet backyard but at the same time a most exposed facade level that is characterized by high noise peaks, strong diurnal pattern, high emergence of peaks during the night. Dwellings in detached buildings, often single family, are typically exposed to more constant noise levels surrounding the dwelling. Other factors such as non-traffic sound sources and visual attractiveness of the backyard may also contribute.

In the Amsterdam study a significant influence of road traffic noise L_{den} at the least exposed façade was observed. The strength of the effect depends partly on the model that is chosen: e.g. adding reported noise annoyance by neighbors and humming noise (e.g. fans), improves the strength of the observed associations. For the latter, it should be noted that adding a reported quantity to the model implicitly may include personal factors such as noise sensitivity and appraisal and valuation style, as well as total (indoor) exposure detail.

Conclusions of epidemiologic research are strengthened by the existence of a causal model that explains why an effect would be present. The model that is most commonly found in literature starts from the hypothesis that noise annoyance is caused by the noise level (characterized by L_{den}) at the most exposed façade. In this model, having access to a quiet side gives the inhabitant of a dwelling the ability to cope with the noise by orienting some of his or her activities (including sleep) towards this quiet side. In this model tranquility and even restorative potential of the quiet side are important characteristics. Tranquility implies that all unwanted sound should be banned – not only road traffic noise – from the quiet side, but also that the visual aesthetics and the presence of natural or wanted sounds has a potential benefit. A first prerequisite for the existence of a quiet side could then be that the contribution of road traffic noise remains below a set limit.

An alternative model assumes that the level at all facades contributes to the emergence of noise annoyance from the start. In this view noticing the unwanted noise is a prerequisite for annoyance. Both noise peaks and continuous noise contribute to this noticing. The presence of a façade where noise levels are clearly lower in combination with the orientation of the different rooms in the dwelling could then result is less noticing and thus lower noise annoyance. This model also indicates that the plain average of noise levels around the house is probably not the best indicator since noise intruding through the loudest façade will dominate noticing. Then a certain combination of the noise exposure levels over all facades may be the best overall indicator for noise exposure. In this model the spectro-temporal dynamics of the noise exposure at the different facades is important. Such aspects include the temporal fluctuation and the emergence of noise peaks (De Coensel et al., 2009; http://www.harmonica-project.eu). The most obvious reason for not including spectro-temporal details in the analysis of noise exposure is that these exposure indicators are hard to model.

Road traffic data is typically available for the urban roads with substantial traffic intensities (e.g. roads with a traffic intensity above about 2 500 vehicles per 24 hour). In future population studies, the exposure assessment may be further refined, not only by application of a refined noise model dedicated to model exposure at the noise shielded side (see Action 2), but also when traffic intensity data will become available also for the smallest roads in the network. Currently, however, this data is typically not available at that level of detail. It is expected that in future population studies, when such data becomes available, effects may become visible more clearly still.

S.5 Implication for urban noise policy

In this project, the beneficial effect of a quiet side on self-reported annoyance and sleep disturbance by road traffic noise has clearly been established, particularly for situations where the overall quality and usability of the quiet side can be guaranteed. Therefore we recommend that urban noise policy includes creation and preservation of a quiet side of highly exposed buildings. Actions conducted for this purpose should include all aspects of the environment at the quiet side and not merely rely on road traffic noise mapping alone.

Reducing the adverse effects of environmental noise in urban planning processes needs to be first of all addressed by aiming at low exposure at dwellings in general, starting with the most exposed façade, which still appears to have the highest impact on annoyance. In existing situations with high exposure levels, particular attention may need to be paid to dwellings with high exposure at multiple sides.

The perceived accessibility of a tranquil area in some studies also influenced the annoyance response at home – and not only the evaluation of the quality of the living environment. Thus urban noise policy should address tranquil public spaces as well. The available evidence does not allow quantifying the positive effect of access to a tranquil area.

S.6 Thoughts on an instrument for refinement of strategic noise mapping

Partly under the impulse of the European Environmental Noise Directive many regions and cities are now conducting strategic noise mapping. Although the 2002 version of the END mentions the potential benefit of a quiet side and suggests including it in local noise policy, the effect has not been quantitatively described. It is also observed that the interpretation of L_{den} (and L_{night}) exposure distributions is clarified by calculating the number of annoyed or highly annoyed persons based on average exposure effect relationships.

At the start of the QSIDE project and based on previous projects, some basis requirements such instrument should fulfill were formulated. First, it should enable refined calculation of expected annoyance using the standard exposure response relationship for annoyance, if possible, taking into account not only the most exposed side, but also the least exposed side. Second, it should incorporate the fact that by definition not only a part of the population may be expected to be better off (benefit) than average, but also part of the population may be worse off than average. This implies a two way correction is needed: A one way correction ('benefit' only), would introduce systematic error: i.e. systematic underestimation of annoyance.

Within QSIDE dedicated studies were carried out with 3 objectives in mind: (1) Further strengthening of evidence: To investigate if there is an effect; (2) Further quantification of the effect: To investigate the magnitude of the hypothesized effect; (3) (if possible) to further quantify the (shape of) the hypothesized effect.

With respect to (1), we conclude an effect of exposure at the least exposed side, in addition to exposure at the most exposed side, has clearly been observed. With respect to (2), we observed effect estimates ranging in magnitude (e.g. for road traffic noise annoyance, when translated to an equivalent change in L_{denmax}, ranging from approximately 3 to 5 dB for a 10 dB change in L_{denmin}. With respect to (3) it may be noted that results suggest that the effect of L_{denmin} is independent of L_{denmax} (in the populations investigated here, and for the investigated exposure range). The regression results for the prediction of annoyance score show no evidence for a significant interaction effect between L_{denmax} and various indicators of least exposed façade exposure. Thus, a potential refinement method for prediction of annoyance, taking into account the least exposed side exposure may be L_{denmin} based.

The results discussed in this report confirm that the average annoyance score as well as the probability of being at least moderately and highly annoyed are significantly lower in situations where the L_{denmin} is substantially lower than the L_{denmax} compared to situations where this is not the case. This effect was most clearly observed when either the locations were carefully selected (to avoid other sounds or unusable side of the house: Swedish studies and Gent focused study), or a correction is applied to eliminate the contribution of non-mapped sounds that may ‘spoil’ the quietness at the least exposed side (Amsterdam study). In the Antwerp study, straightforwardly using L_{den} from noise maps to identify quiet sides did not result in a better predictability of reported street traffic noise annoyance.

As such, the suggestion for quantitative estimate of the effect given below should be used only after it has been established that the quiet side is undisturbed by other sounds, is ‘attractive’ in terms of physical environmental quality, and is indeed a usable façade.

References

De Kluizenaar Y, Salomons EM, Janssen SA, van Lenthe FJ, Vos H, Zhou H, Miedema HME, Mackenbach JP. Urban road traffic noise and annoyance: The effect of a quiet façade. Journal of the Acoustical Society of America 2011; 130(4): 1936–1942.

De Kluizenaar Y, Salomons EM, Janssen SA, Van den Berg F. Traffic noise and annoyance: The effect of quiet facades and quiet areas. Euronoise 2012, Prague, 10 – 13 June, 2012.

De Kluizenaar Y, Janssen SA, Vos H, Salomons EM, Zhou H and Van den Berg F. Road traffic noise and annoyance: A quantification of the effect of quiet side exposure at dwellings. International Journal of Environmental Research and Public Health 2013a.

De Kluizenaar Y, Gidlöf-Gunnarsson A, Botteldooren D, Bockstael A, Janssen SA, Vos H, Van den Berg F, Salomons EM. Annoyance and disturbed sleep due to road traffic noise: The importance of the least exposed side –QSIDE. Submitted Internoise 2013b, Innsbruck, 15 – 18 September 2013.

European Commission, DG Environment. 2002a. Directive 2002/49/EC of the European Parliament and of the Council. Brussels: EU/DG Environment. http://ec.europa.eu/environment/noise/

Öhrström E, Skånberg A, Svensson H, Gidlöf Gunnarsson A. Effects of road traffic noise and the benefit of access to quietness. Journal of Sound and Vibration 2006; 295: 40–59.

Gidlöf-Gunnarsson A, Ögren M, Jerson T, Öhrström E. Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise and Health 2012; 14 (59): 190–201.

Gidlöf-Gunnarsson A, Öhrström E, Forssén J. The effect of creating a quiet side on annoyance and sleep disturbances due to road traffic noise. Internoise 2012, New York, 19 – 22 August 2012.

Van Renterghem T and Botteldooren D. Focused Study on the Quiet Side Effect in Dwellings Highly Exposed to Road Traffic Noise. International Journal of Environmental Research and Public Health 2012; 9(12): 4292-4310

WHO. World Health Organization Regional Office for Europe and JRC European Commission: Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. WHO, Copenhagen, Denmark (2011).