QSIDE

REPORT

Title	**QSIDE Action 4: demonstrations and scenarios**
Status	**Final**
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Date report	**22 August 2013**

PROJECT

Acronym	QSIDE		
Project title	The positive effects of quiet facades and quiet urban areas on traffic noise annoyance and sleep disturbance		
Project start date	1 September 2010		
Duration of the project	36 months		
Coordinating partner	TNO Delft	TNO	NL
Other partners	Universiteit Gent	UGENT	BE
	Chalmers Teknsika Högskola AB	CUT	SE
	University of Gothenburg	UGOT	SE
	VTI, Statens väg- och transportforskningsinstitut	VTI	SE
	Gemeente Amsterdam	AMS	NL
	City of Gothenburg	GOT	SE

FUNDING

Funding	Project funded by the European Commission
Funding program	LIFE+ program Environment and Eco-innovation
Project number	LIFE09 ENV/NL/000423

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1 Introduction

QSIDE is a European project with Dutch, Belgian and Swedish partners focusing on the positive effects of quiet façades and quiet urban areas. The project runs from 1 Sep 2010 until 31 August 2013. The project is partially funded by the European Life+ program.

An objective of QSIDE is to demonstrate how European cities can effectively reduce harmful effects of traffic noise – in particular annoyance and sleep disturbance - by protecting and creating quiet façades and quiet urban areas. The protection of quiet façades and quiet urban areas is supported by the European Noise Directive 2002/49/EC (END)[1].

In QSIDE, two new scientific models have been developed:

1) A noise model for improved prediction of noise levels at shielded locations in cities, in particular quiet façades and quiet areas.
2) A new human-response model for the effect of the quiet façade on annoyance.

The noise model is an extension of conventional noise-mapping models. This means that a two-stage approach should be followed:

- first a conventional noise-mapping model is used for calculating 'basic' noise levels representing only direct and reflected sound waves,
- next the new QSIDE model is used for calculating noise level contributions representing complex effects from multiple canyon reflections, intermediate canyons, rooftop shape, and turbulent scattering (see figure 1.1).

For more information, see www.qside.eu, the QSIDE Action 2 report, and scientific papers about the model.

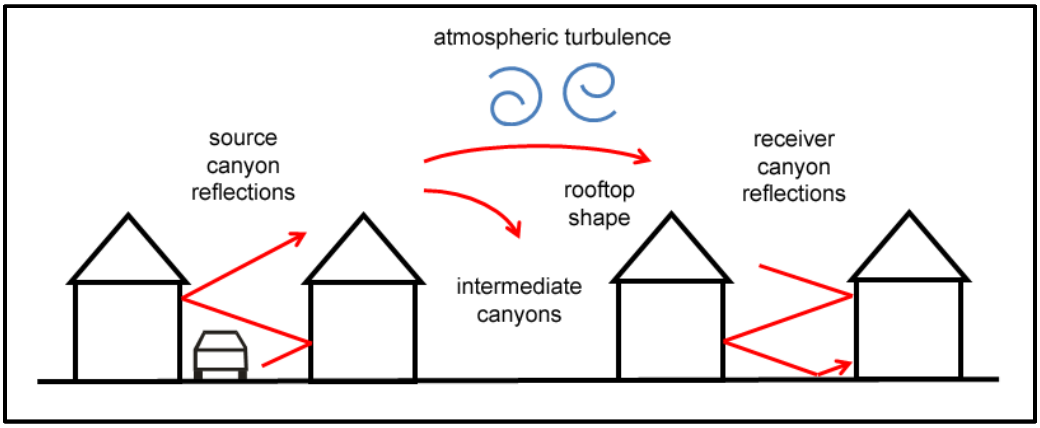

Figure 1.1. Illustration of the elements of the QSIDE noise model for shielded urban locations.

[1] European Directive on Environmental Noise, 2002/49/EC, available at the website of the European Commission: http://ec.europa.eu/environment/noise/home.htm.

The QSIDE human-response model is a calculation scheme for the effect of a quiet side on annoyance by traffic noise at home. The scheme is a refinement of conventional prediction methods for traffic noise annoyance. The conventional methods yield annoyance as a function of a noise level at the most-exposed façade of the dwelling. The QSIDE calculation scheme yields a refinement of the annoyance prediction based on a noise level at the least-exposed façade. A detailed description of the QSIDE calculation scheme for the quiet-side effect can be found elsewhere in the QSIDE documentation.

The developments of the QSIDE models are based on:

- sound-propagation studies performed by the QSIDE partners,
- noise level calculations and annoyance surveys performed in Swedish, Belgian, and Dutch cities.

Some illustrative elements from these studies are collected in this report, serving as demonstration material of quiet façades and quiet urban areas (chapter 2).

Chapter 3 of this report summarizes recommendations for noise levels at quiet façades and in quiet areas, as formulated by the QSIDE consortium (see www.qside.eu).
The noise indicators of interest are the equivalent levels Lden and Lnight. In addition, maximum levels of night-time traffic noise are considered.

In chapter 4 of this report, optimizing cities with respect to traffic noise and quiet areas is considered in the broader perspective of sustainable urban development. In general, sustainable urban development aims at an optimization of the quality of life of the inhabitants of a city, both present and future inhabitants. The description presented here focuses on traffic noise in relation to long-term future scenarios of cities, including traffic scenarios. The effects of shapes of building blocks on noise levels at quiet façades are also considered. The description may be helpful to cities for making their own urban development plans taking into account traffic noise control in general, and the positive effects of quiet façades and quiet urban areas in particular.

2 Research on quiet façades and in quiet urban areas

In this chapter some elements of the research performed in QSIDE on quiet façades and quiet urban areas are presented. Noise levels are considered in Section 2.1. Effects on people are considered in Section 2.2.

2.1 Noise levels

2.1.1 Ghent

An illustrative example of the improved prediction of traffic noise levels at shielded urban locations was presented in the Action 2 report of QSIDE[2]. The example includes both measurements and calculations of traffic noise levels, and is briefly described in this section.

Measurements of traffic noise levels in Ghent have been performed using a network of microphones located at various locations in the city, both shielded locations and locations that are directly exposed to traffic noise. Nine of the measurement locations are indicated on the map of Ghent shown in Fig. 2.1.

Figure 2.2 presents a comparison between the measured noise levels and calculated noise levels, for the nine locations shown in Fig. 2.1. The noise level is the level Lday in this case. At some locations the level Lday is as high as 70 dB, while at other locations the level is about 55 dB. The latter locations are shielded locations.

Two types of calculated levels are included in Fig. 2.2:

- standard calculated levels reported in the framework of the END
- levels calculated with the noise model developed in QSIDE.

At the directly exposed locations, the END levels agree within a few decibels with the measured levels. At the shielded locations 8 and 9, the END levels are considerably lower than the measured levels. The model developed in QSIDE considerably improves the agreement between measured and calculated levels at the shielded locations.

As described in Chapter 1, the QSIDE model follows a two-stage approach: first the ‘basic’ noise levels are calculated, and next a correction is applied for the effects of multiple canyon reflections and turbulent scattering. The basic noise levels in this example were calculated in accordance with the END levels. The effects of the multiple reflections and turbulent scattering is an increase of the END levels by about 5 to 15 dB. For more information, see the QSIDE Action 2 report.

[2] QSIDE Action 2 report: “Estimation of parameters in the global propagation”, August 2013.

Figure 2.1. Measurement locations in Ghent, Belgium.

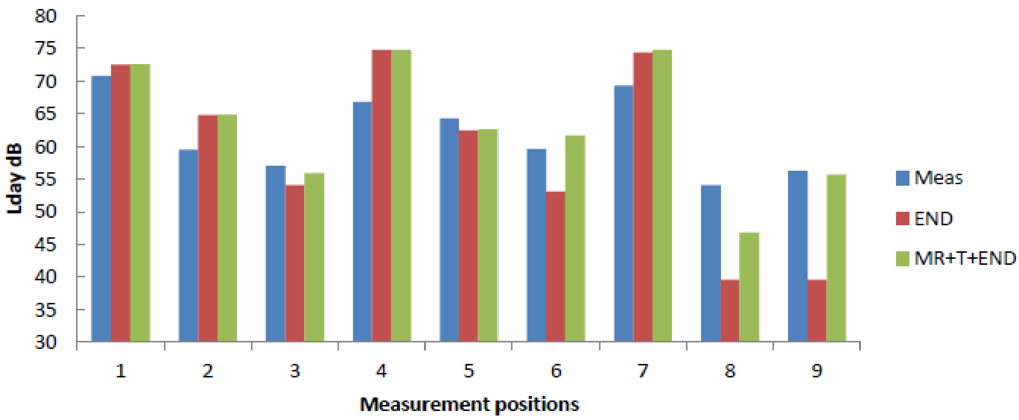

Figure 2.2. Comparison of predicted and measured levels Lday. Blue: measurement. Red: standard calculation performed in the framework of the Environment Noise Directive of Europe (END). Green: prediction of the noise model developed in QSIDE, calculated by summing the ‘basic’ END level and the background level accounting for multiple reflections (MR) and turbulence scattering (T).

2.1.2 Gothenburg

The final noise model developed in QSIDE has not yet been applied in Gothenburg. However, some calculations have been performed to demonstrate the effects of multiple canyon reflections and turbulent scattering – along the lines of the QSIDE model.

Figure 2.3 shows such a demonstration calculation. The figure shows two noise maps, one calculated with a standard model (left) and one calculated with an improved model, similar to the QSIDE model (right). The main difference between the two noise maps is that the levels in the shielded locations are considerably higher on the improved noise map than on the standard noise map.

It is interesting to mention here that about ten years ago Swedish researchers have developed a simple empirical noise model for improved predictions in shielded urban areas[3,4]. The model is called 'flat city model', and contains empirical parameters derived from extensive measurements at shielded locations in Sweden.

In contrast, the model developed in QSIDE is based on extensive numerical calculations with advanced sound propagation models. It would be interesting to perform comparisons of results of the QSIDE model with results of the flat city model.

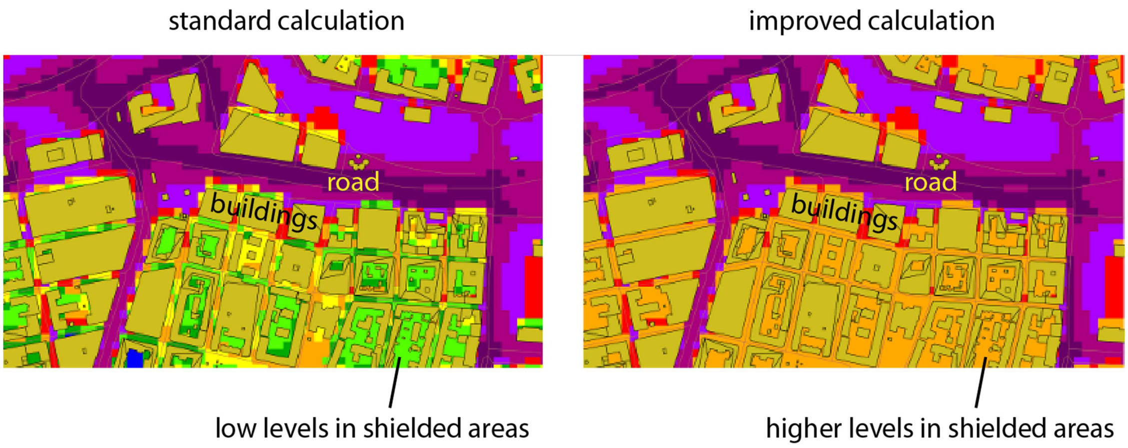

Figure 2.3. Illustration of the effect of an improved calculation model for shielded urban locations. The noise map on the left was calculated with a standard calculation model and the noise map on the right was calculated with an improved model similar to the final QSIDE model. On the roads and in nearby areas, the noise levels are high (purple).
In areas that are shielded by buildings (yellow), the standard noise map shows low levels (green) while the improved noise map shows higher levels (orange).

[3] P. Thorsson, M. Ögren, and W. Kropp, "Noise levels on the shielded side in cities using a flat city model," Appl. Acoust. **65**, 313–323, 2004.
[4] M. Ögren, "Prediction of traffic noise shielding by city canyons," Ph.D. thesis, Chalmers University, Göteborg, Sweden, 2004.

2.1.3 Amsterdam

In this section some illustrations are presented of quiet façades and quiet areas in Amsterdam. The noise levels in this section have been calculated with the standard Dutch traffic noise model, so the improved QSIDE model has not yet been applied here.

Figure 2.4 shows the road traffic noise map of Amsterdam, calculated with the Dutch standard model according to the Environmental Noise Directive. Busy roads are visible as narrow red bands. Near the city center, an urban park – the Vondelpark – is visible as a blue area, corresponding to traffic noise levels of 45 dB or lower. Figure 2.5 shows a picture of the park.

The only traffic noise in the Vondelpark originates from roads in the neighborhood of the park. In the park itself, automobiles are not allowed. Also mopeds are not allowed, which makes the park an attractive location for pedestrians and runners.

It should be noted here that mopeds are usually not taken into account in traffic noise calculations. However, mopeds are often mentioned by people as important sources of annoyance. Therefore, it is recommended that cities try to keep mopeds away from quiet areas such as parks.

Figure 2.6 shows an illustration of a quiet façade in Amsterdam. The noise map in this figure is a small section of the complete noise map shown in figure 2.4. The urban area shown here is a lively area (called Jordaan). The upper photograph in the figure shows a view from a quiet façade on a quiet courtyard. So the quiet façade and the quiet area partly overlap here. The noise level in the courtyard is lower than 45 dB according to the standard calculation. With an improved noise model the level is expected to be higher.

It is interesting to mention here that a few years ago a simple engineering model has been developed for improved predictions in shielded urban areas[5]. The model was called ‘street canyon model’, and yields higher noise levels at shielded locations than standard models do. The street canyon model was developed on the basis of some numerical sound propagation calculations and the idea that practical noise calculations schemes should be kept as simple as possible. It would be interesting to perform comparisons of results of the QSIDE model with results of the street canyon model.

The street canyon model was included in recent model calculations of exposure distributions of about 450.000 addresses in Amsterdam. The distributions are shown in figure 2.7. Distribution (a) was calculated with the standard Dutch noise model taking into account major roads, as usual for standard noise modeling. Distribution (b) was calculated with the same model, but now also minor roads were included with a default traffic intensity of 20 cars per hour was assumed. The importance of using accurate

[5] E.M. Salomons, H. Polinder, W.J.A. Lohman, H. Zhou, H.C. Borst, and H.M.E. Miedema, “Engineering modeling of traffic noise in shielded areas in cities,” J. Acoust Soc. Am. **126**, 2340-2349, 2009.

traffic input data is illustrated by the difference between distributions (a) and (b). Distribution (c) was calculated with the street canyon model taking into account all roads.

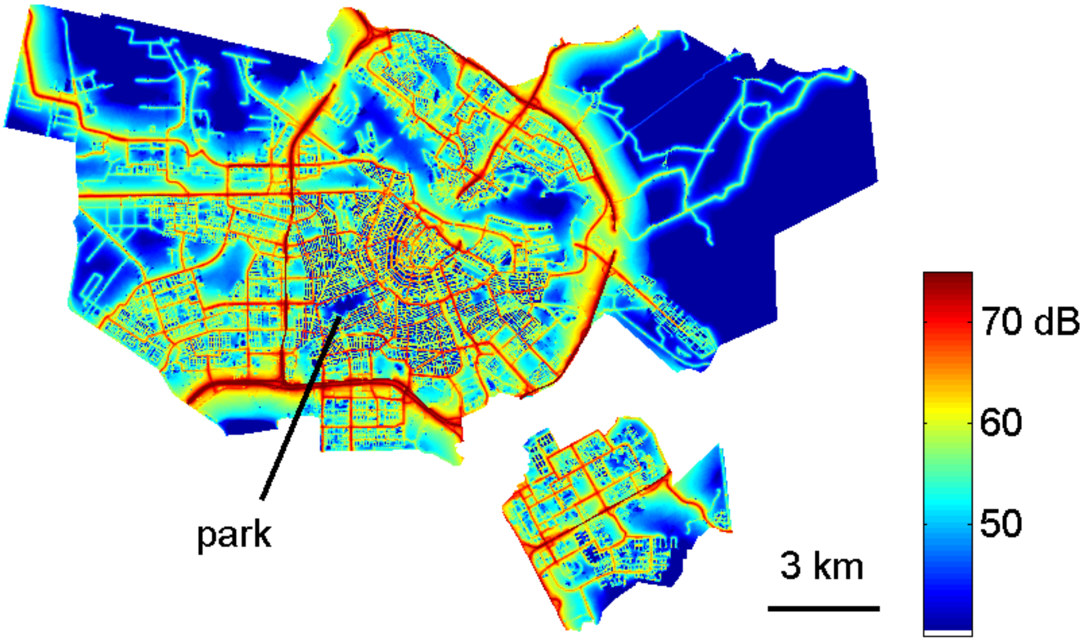

Figure 2.4. Traffic noise map of Amsterdam. The park of figure 2.5 is indicated. The color represents the traffic noise level (Lden). Noise levels in the park are lower than in the area around the park. Note: traffic in quiet streets is often ignored for noise mapping, but here a minimum of 20 cars per hour was assumed.

Figure 2.5. Park in Amsterdam (Vondelpark), indicated in figure 2.4.

Figure 2.6. Part of the traffic noise map of Amsterdam from figure 2.4. There are busy streets (orange), less busy streets (yellow), quiet courtyards (blue) enclosed by houses (grey). The less busy streets, illustrated by the lower photograph, are typical of this lively urban area (Jordaan area). The upper photograph shows a view from a quiet façade on a quiet courtyard.

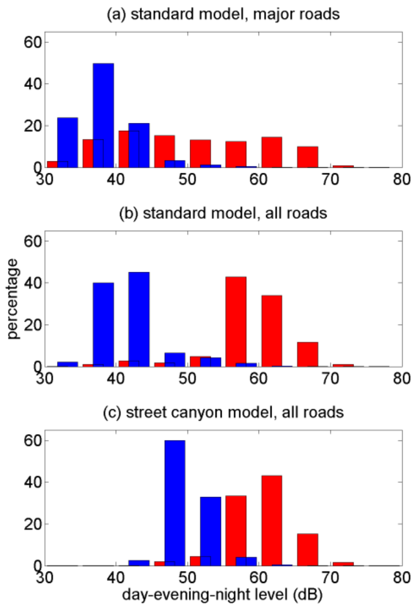

Figure 2.7. Exposure distributions of L_{den} traffic noise levels at the most exposed façade (red) and the least exposed façade (blue) of about 450.000 addresses in Amsterdam, calculated with the standard Dutch model using major roads (a), the standard Dutch model using all roads (b), and the improved street-canyon model using all roads (c).

2.2 Effects

2.2.1 Gothenburg and Stockholm

The Swedish human-response research in QSIDE comprised two studies:

- a cross-sectional study in Stockholm and Gothenburg, with 956 participants
- an intervention study in Gothenburg, with 111 participants.

In both studies the effects of a quiet façade have been investigated. Further, the studies focused on sleep disturbance and the influence of the location of the bedroom window, and also the influence of perceived availability to nearby green areas. Noise exposure in the two studies was determined by a combination of measurements and calculations. Quantitative results can be found elsewhere in the QSIDE documentation.

Figure 2.8 shows pictures of a situation in Gothenburg that was investigated in the intervention study in Gothenburg. The picture on the left was taken in 2006, showing the open courtyard facing the busy road. The picture on the right (2009) shows that a new building was constructed that fills the previous gap. The effect of the intervention was that noise levels decreased in the courtyard, and access to a quiet façade increased. This resulted in a decrease of annoyance and sleep disturbance by road traffic noise.

Figure 2.8. Pictures of the situations before and after the intervention in Gothenburg (Bomgatan). The picture on the left shows the area in 2006 with the open courtyard facing a busy road. The picture on the right (2009) shows the new building that fills the previous gap.

2.2.2 Antwerp and Ghent

The Belgian human-response research in QSIDE comprised two studies:

- a Flemish survey, restricted to Antwerp, with 675 participants
- a focused study in Ghent, with 100 participants.

The Flemish survey was focused on the quality of the living environment. Some of the questions were related to environmental noise. For the noise exposure use was made of the official noise map of Antwerp, while also use was made of improved prediction of noise levels at the least exposed façade using the QSIDE model.

The studies focused on the influence of the noise level at the least exposed façade, sleep disturbance and the location of the bedroom window, and the role of environmental noise in quiet areas such as city parks. Quantitative results can be found elsewhere in the QSIDE documentation.

2.2.3 Amsterdam

The Dutch human-response research in QSIDE comprised one study:

- a study in Amsterdam, with about 2000 participants

Survey data were collected by the Public Health Service of the city of Amsterdam. The main purpose of the survey was to gauge the health status of the Amsterdam adult population. The survey included questions on annoyance caused by a number of noise sources.

Noise exposure was calculated with the Dutch standard model for road traffic noise. Noise levels were determined at the most and least exposed façades of the dwellings. Also noise levels in areas around the dwelling were determined. The analysis focused on the influence of the noise level at the least exposed façade. Also the influence of noise in the area surrounding the dwelling of a respondent was investigated. Quantitative results can be found elsewhere in the QSIDE documentation.

3 Protection of quiet facades and quiet areas

An objective of QSIDE was to help cities with the creation and protection of quiet façades and quiet areas. The focus in the project is on road traffic noise, which is the most important outdoor source of noise. For example, a city may protect a quiet area by restricting traffic near the area.

On the QSIDE website www.qside.eu, recommendations are given for traffic noise levels at quiet façades and in quiet areas, intended for noise policies of cities. The recommendations are summarized in section 3.1 below. For night-time traffic noise at a quiet façade an additional recommendation is given on the QSIDE website, namely to restrict maximum noise levels. This is described in section 3.2. Some calculations that support the recommendation are also described.

3.1 Recommended noise levels at quiet façades and in quiet areas

As described on the QSIDE website www.qside.eu it is recommended that the L_{den} level at the least exposed façade of a dwelling is preferably limited to values below 45 dB and should not be higher than 50 dB. The corresponding values of L_{night} are about 36 and 41 dB, respectively. In addition, the outdoor space at the quiet façade must have sufficient quality. For example, a garden or a park is better than a parking lot.

For quiet areas it is recommended that the L_{day} level (of traffic noise) in a quiet area is preferably limited to values below 45 dB and should not be higher than 55 dB. In addition, the area must have sufficient quality with respect to use, view, cleanliness and safety.

3.2 Additional recommendation for night-time traffic noise

One of the potential benefits of a quiet façade is the possibility to have a bedroom on the quiet side of the house. As described in the previous section it is recommended that the L_{night} level on the least exposed façade is limited to values below 40 dB (preferably below 36 dB). However, in addition to this recommendation for the equivalent noise level L_{night}, it may also be important to consider a maximum noise level as an additional noise indicator; this is also suggested in a WHO document[6]. In this section a few simulations of night-time traffic noise exposure are presented, which show that this indeed the case. As a consequence it is recommended that *direct* traffic-noise exposure at the quiet façades of dwellings at night should be avoided. This recommendation is relevant for future scenarios of cities that include the creation or protection of quiet façades.

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[6] World Health Organization, “Burden of disease from environmental noise: Quantification of healthy life years lost in Europe”, WHO Regional Office for Europe, Copenhagen, Denmark, (2011). Available at http://www.euro.who.int.

3.2.1 Calculations of maximum noise levels

We consider the quiet side of a house at night. We distinguish equivalent levels (L_{eq}) and maximum levels (L_{max}), both inside and outside. The equivalent level outside is L_{night} (although usually L_{night} refers to the most-exposed façade).

> *Question*: if L_{night} at the quiet side is limited to levels of 40 dB (outside), are the corresponding maximum indoor levels sufficiently low to avoid sleep disturbance?

The WHO document 'Night Noise Guidelines for Europe' (NNG)[7] indicates *threshold levels* for various effects of sleep disturbance. Thresholds of 32-42 dB are given for the maximum indoor level. Thresholds for L_{night} are higher. It should be noted that L_{night} in the NNG is considered without distinction between most-exposed façade and least-exposed façade.

A façade insulation of 21 dB is assumed in the NNG, for a situation with windows that are opened (slightly). We will use this value of 21 dB here, so we have the relation $L_{max,inside} = L_{max,outside} – 21$ dB.

We consider two extreme cases.

1) The traffic noise at the quiet façade is dominated by *direct* (unscreened) traffic noise in a street at the quiet façade.
2) The traffic noise at the quiet façade is determined by the more or less constant background traffic noise in the city.

These cases are illustrated in figure 3.1. In case 1 the sound level shows high peaks as a function of time during the night. In case 2 the sound level is nearly constant.

Case 1: direct exposure at quiet side | *Case 2: urban background noise at quiet side*

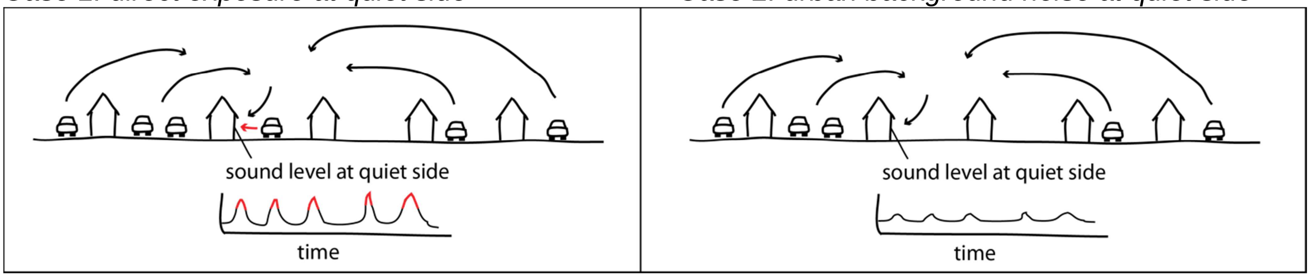

Figure 3.1. Illustration of two cases of night-time traffic noise exposure at the quiet side.

A few simulations for case 1 are shown in Figure 3.2. The simulations are for direct exposure of a façade by cars driving at 50 km/h. In the context of QSIDE, the façade is interpreted as the quiet façade. The Dutch standard traffic noise model has been used for the calculations. Complex sound attenuation effects have been neglected in the simulations. Equivalent and maximum levels (outside) are indicated in the graphs.

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[7] World Health Organization, "Night noise guidelines for Europe", WHO Regional Office for Europe, Copenhagen, Denmark (2009). Available at http://www.euro.who.int.

The first graph is for cars passing the quiet façade at a distance of 5 m: $L_{max,outside}$ = 74 dB and $L_{max,inside}$ = 53 dB. If the distance is increased to 50 m, we get 54 and 33 dB, respectively. The *equivalent* façade level, i.e. the level L_{night}, depends on the number of cars passing per hour. For 100 cars per hour and a distance of 5 m, $L_{night,outside}$ is 59 dB. For 1 car per hour and a distance of 5 m, $L_{night,outside}$ is 39 dB. The graphs show that very low vehicle intensities on the quiet side are required to reach L_{night} levels below 40 dB, and even then there may still be high noise peaks causing sleep disturbance. Note that we assumed here that there are only cars (automobiles). In situations with occasional trucks at night, the difference between L_{max} and L_{eq} is larger.

3.2.2 Conclusion

The calculations presented in the previous section show that limiting L_{night} to values below 40 dB, does not eliminate the chance of sleep disturbance. This leads us to the following conclusion.

In order to minimize chances of sleep disturbance by night-time traffic noise, it is recommended that cases of *direct* traffic-noise exposure at the quiet façade are avoided.

A good example of a quiet façade without direct exposure is a quiet façade that is located at a closed courtyard. Low-intensity streets on the quiet side are 'dangerous', since a few noisy vehicles per hour may cause high peak levels and thus sleep disturbance.

In cases of *indirect* traffic noise exposure at the quiet façade (case 2), the difference between $L_{max,outside}$ and $L_{eq,outside}$ (=$L_{night,outside}$) is much smaller than in case 1. In these cases, we can assume that limiting L_{night} to 40 dB is a better approach, since then the maximum indoor level will very often be below 35 dB (although we can of course not exclude an isolated very noisy vehicle, such as a heavy truck or a moped).

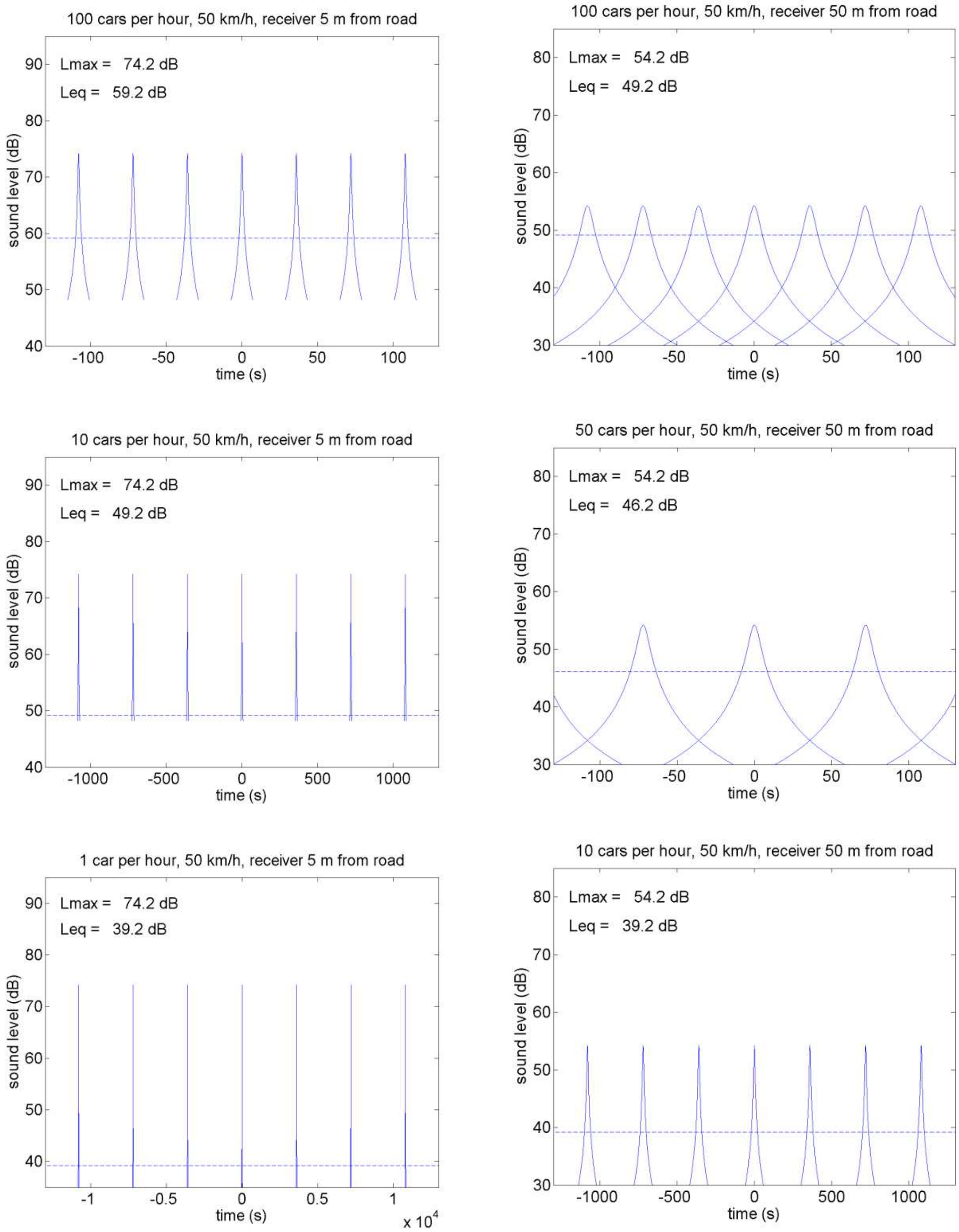

Figure 3.2. Results of a six simulations of direct traffic-noise exposure, with different traffic intensities and source-receiver distances (indicated above the graphs).

4 Traffic noise control and sustainable urban planning

In this chapter some elements are described of the relation between traffic noise control and sustainable urban planning. The description focuses on long-term future scenarios of cities, including traffic scenarios. The effects of shapes of building blocks on noise levels at quiet façades are also considered. The description is included on the QSIDE website www.qside.eu, since it is of interest for cities aiming at traffic noise control and the protection of quiet façades and quiet areas.

Outline
Sustainable urban planning aims for an optimization of the quality of life of the inhabitants of a city, both present and future inhabitants. The quality of life depends on a broad range of factors, including economic, social, and environmental factors. Traffic noise is one of the environmental factors. Traffic noise control should be considered as an important element of sustainable urban planning.
In this note, we consider a few elements of the relation between sustainable urban planning and traffic noise control. The implications of urban densification strategies, leading to higher population densities and traffic volumes, are addressed. Illustrations for specific cities are presented, in particular for Amsterdam, which is representative of many European cities with a historic center and suburbs developed in the 20th century.

4.1 Traffic noise in cities

Road traffic noise levels in cities show large spatial variations. The noise levels are high near busy roads and low in shielded areas or areas far from busy roads. Thus, the traffic noise levels are related to the local traffic volumes. The traffic volumes are in turn closely related to the infrastructure of the city, in particular to the road network and the buildings (dwellings, offices, shops, …). Thus, we have a two-stage relation from infrastructure to traffic noise, as illustrated schematically in Figure 1:

1) Buildings and road network influence traffic volumes.
2) Traffic volumes determine traffic noise levels, in particular traffic noise levels at the houses of the inhabitants.

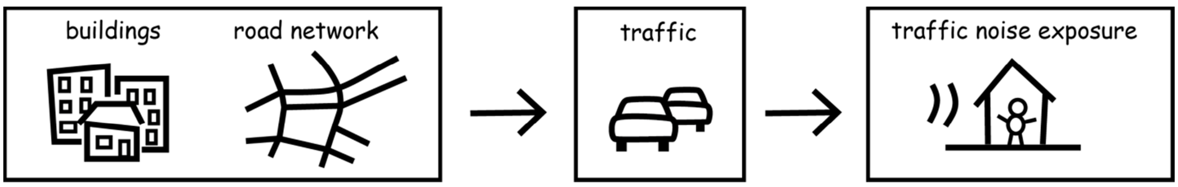

Figure 1. Schematic illustration of the causal chain of traffic noise exposure of inhabitants of a city (at home). Traffic volumes in the city depend on the locations of buildings and on the road network.

The first relation, from infrastructure to traffic volumes, is complex. Traffic volumes in the city depend on the locations of buildings and on the layout of the road network, but there are also other factors of influence. The buildings are usually starting points and/or end points of trips by car on the road network, except for trips of cars that only use the road network for passing through the city. The spatial and temporal distributions of trips on the road network depend on the complex system of travel behavior of people, with many interrelated factors of influence, such as labor market demand, travel times, quality of public transport, bicycle paths, and footpaths.

The second relation, from traffic volumes to traffic noise exposure, is also rather complex. Noise levels at the façade of a dwelling depend on the distances to the roads and on the traffic volumes. Intermediate buildings also play a role: a building may screen or reflect sound waves generated by traffic. Further, the design of building blocks is of interest. In general, closed building blocks lead to lower noise levels at façades that are not exposed directly to traffic noise (quiet façades).

The above considerations imply that there is also a close relation between traffic noise *control* and the *planning* of the city, in particular the planning of new developments of buildings and roads. In other words, traffic noise control is closely related to urban planning.

A further implication is that cities should consider noise reduction plans as a part of broader urban development plans. A city is concerned not only with traffic noise control, but with a wide range of aspects of urban life and sustainability. Sustainable urban planning needs to address more than one issue; win-win situations where many interests are addressed by the same overall plan must be the goal.

4.2 Sustainable urban development

Sustainable development may be defined as development that optimizes the quality of life of people, including future generations, considering both economic and environmental aspects. This definition is in line with the definition given in 1987 by the Brundtland commission [1].

Sustainable *urban* development can be seen as sustainable development applied to a city [1]. Elements of a sustainable city are:

- sustainable economy
- good housing of the inhabitants
- clean environment, low noise and air pollution
- good health of the inhabitants
- sustainable transport system, less automobile use, more non-motorized transport
- community participation
- efficient land use (compact city).

Most elements are related to each other. For example, public health is affected by noise and air pollution caused by road traffic. Sustainable urban development requires a careful balance between the elements. For example, there may be an optimum situation with a moderate amount of motorized traffic in a city, considering both positive (economic) effects and negative (environmental) effects of motorized traffic.

An important question is: which spatial urban planning strategies are best for urban sustainability? There is an ongoing debate on the answer to this question [1]. Presently, many urban planners believe that urban *densification* strategies are preferable, and they consider a *compact* city as a sustainable city. However, there is no consensus about this. To understand the evolution of ideas about sustainable urban planning, it is useful to take a brief look at urban development in Europe in the past century.

4.3 Development of European cities in the 20th century

The structure of many European cities has been influenced by the ideas of Le Corbusier and coworkers, formulated in the first half of the 20th century. In view of problems in industrial cities at the beginning of the 20th century, Le Corbusier wanted to create better living conditions and a better society. A central idea was that one should separate the four basic functions of a city: housing, work, transport, and leisure. For example, houses should be concentrated in residential quarters and (major) roads should preferably be located far from houses. Le Corbusier was influenced by the book “Garden cities of tomorrow”, published by Ebenezer Howard around 1900. The designs of Le Corbusier have been called ‘vertical garden cities’.

An example of the influence of Le Corbusier’s functionalism is the Amsterdam urban plan of 1935 (“Algemeen Uitbreidingsplan van Amsterdam”), with its characteristic garden cities (suburbs) on the west side of the city (see Figure 2). The plan was executed after the Second World War and has resulted in open urban areas in the outer parts of Amsterdam, which differ from the more compact areas in the central part of the city developed in the 15th to 19th century.
In the sixties the new quarter Bijlmermeer was developed, with high-rise apartment buildings separated by green areas (see Figure 3). The green areas were intended for leisure, but unfortunately it turned out that they were considered as unsafe areas by the inhabitants.
To counteract a population decrease in the seventies, and to increase the liveliness of the city and the quality of life of the inhabitants, urban development ideas in Amsterdam shifted to the concept of the compact city, i.e. a densely populated city that mixes housing, work, and leisure.

The tendency towards the compact city still exists today. It can be seen as a response to urban sprawl and the creation of suburbs far from the city center. Cities have grown in size considerably over the last century. This has its positive effects (more living space per inhabitant) but it may also have negative effects. People living in suburbs are likely to use motorized transport more often than people in the center do. A compact city may have better environmental qualities than a sprawling city (see section 4.5), and furthermore may improve economic and social aspects of urban life.

The above considerations focus on the density of a city - for example, building density or population density. The road network is another important element of the structure of a city. This can be seen in Paris, with its long boulevards developed by Haussman in the 19th century. At that time one could not foresee that road traffic would grow as much as it has done over the past decades. The wide boulevards and streets in Paris are still able to contain current large traffic volumes (see Figure 4), but smaller streets in Paris, and many other cities, are less suitable for today’s traffic.

Figure 2. The Amsterdam urban plan of 1935, with its characteristic garden cities (suburbs) shown in orange on the left.
Source: http://commons.wikimedia.org/wiki/File:Algemeen_uitbreidingsplan_amsterdam1935.jpg

Figure 3. View of the Amsterdam quarter Bijlmermeer built in the 1970s (picture 2008).
Source: http://commons.wikimedia.org/wiki/File:Gooiord,_Bijlmer.jpg

Figure 4. A crossing of wide streets in Paris (rue de Rennes and rue du Four).

4.4 Urban plans for the next decades

Important questions for cities for the next decades are the following questions.

1. Should traffic be reorganized?
    - Should motorized traffic in the city center be restricted?
    - How?
    - How do we achieve a modal shift to sustainable transport modes?
2. What type of spatial urban planning is preferred?
    - Sprawl or infill?
    - Separation of functions?
    - Compact city?

For example, the cities of Amsterdam and Rotterdam address these questions in plans for the next decades [2-6]. Both cities foresee a significant population increase.

The answers to the above questions depend on the local situation. There are no universal answers. In the following sections we present a few general considerations, which may help in the process of finding local answers to the questions, and thereby developing local sustainable urban plans. We first consider spatial urban planning (Section 4.5) and next traffic planning (Section 4.6).

4.5 Spatial urban planning: sprawl or infill?

As described in a previous section, the ideas of urban functionalism were abandoned in the 1970s or 1980s. The reason is that 'the human side' of the city had been forgotten by the functionalist movement. This is described by Halbertsma and Ulzen in their book about the cultural history of the European city [7]. After the Second World War, cities became less lively: people worked in the daytime, while at night the cities became 'ghost cities'. This caused problems in cities that previously flourished, such as Liverpool, Manchester, cities in the Ruhr area, and Bilbao.

In the 1980s there was an increase of creative activities in cities, such as IT, advertising, marketing, and art. 'Bad' urban areas were revitalized by the inflow of creative inhabitants. This process is called *gentrification*. An example is the city of Glasgow, which even became cultural capital of Europe in 1990. Another example is the urban quarter Jordaan in Amsterdam (see figure 5).

Gentrification is a process that is difficult to control or stimulate by urban planners. It occurs often 'spontaneously'. Nevertheless, ideas of the compact city and urban densification are in line with gentrification. An increase of population density ('infill') may increase liveliness and social interaction, and thereby improve the quality of life of the inhabitants. In other words, sustainable urban planning may be associated with infill scenarios.

Figure 5. The Amsterdam quarter Jordaan is an example of an urban area that was revitalized by gentrification in the 1980s.

What are the implications of urban sprawl or infill for traffic noise and traffic-related air pollution? Two counteracting effects play a role here:

1) effect of automobile use
2) effect of the distance between automobiles and people.

In a sprawling city, with suburbs located far from the city center, automobile use is higher than in a compact city (see Figure 6). Automobile use depends on many factors, and travel distance is clearly an important one. This is addressed in more detail in the next section.

In a sprawling city, or in a city developed along the ideas of functionalism, with major roads located far from houses, average distances between cars and inhabitants (or dwellings) are generally larger than in a compact city. On the other hand, screening of traffic noise by buildings is less effective in a sprawling city than in a compact city.

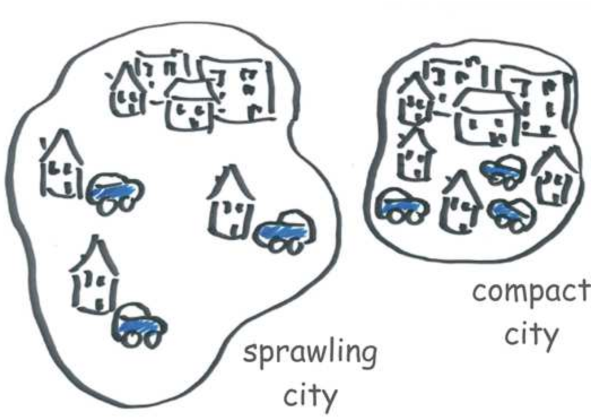

Figure 6. Comparison of a sprawling city and a compact city. Inhabitants of suburbs in a sprawling city use automobiles more often than inhabitants of a compact city do.

Consequently, an increase of urban density may lead to an increase or a decrease of average noise levels and air pollution concentrations. Details of the urban layout, i.e. buildings and road network, play a role. One way to get a better grip on the details is the use of a three-dimensional urban density (Spacematrix), as introduced by Berghauser Pont and Haupt [8]. The three elements of the Spacematrix are

- ground space index (GSI)
- floor space index (FSI)
- road network density (N)

which are defined by the illustrations in Figure 7. In general, a compact city or a compact urban area corresponds to a high value of the floor space index FSI.

In Ref. [9], the relation between the three-dimensional urban density and urban traffic noise is analyzed for the cities of Amsterdam and Rotterdam. It is found that average traffic noise levels (at the most exposed façades of dwellings) decrease slightly with increasing floor space index. This trend is derived by comparing different areas in the cities. The same trend was also found for artificial urban fabrics, taking into account the fact that automobile use per person decreases with increasing floor space index (see Section 4.6).

The trends for air pollution are in general not identical to the trends for traffic noise. For air pollution the above mentioned counteracting effects also play a role, but dispersion of air pollution and noise propagation are two different physical phenomena. For more information, see for example Ref. [10].

Urban density can also be related to traffic noise levels at the backsides of houses. In general, a compact city is characterized by a high concentration of high buildings (high values of FSI). Figure 8, reproduced from Ref. [9], shows two examples of urban fabrics with FSI of the order of 0.75. Example (a) has closed building blocks, with low traffic noise levels at the inner courtyards shielded from the streets. Example (b) has 'tower-like' buildings without inner courtyards.

These observations can be related to the structure of Amsterdam. The central part of the city has many closed building blocks, while the suburbs developed in the 20th century have a more open structure. Consequently, in the city center low traffic noise levels occur in closed courtyards, while high levels occur along busy streets. In the suburbs there are less busy streets close to the houses, so levels on the most-exposed façades are lower here than in the city center. On the other hand, there are less closed courtyards with quiet façades in the suburbs.

This illustrates that urban infill scenarios have the danger of high noise (and air) pollution, in particular if the scenarios do not include a reduction of automobile use per person. Traffic reduction measures (see next section) will help to reduce the high noise levels in a compact city. Furthermore, screening by buildings in a compact city may be exploited to create quiet backsides and quiet areas.

As indicated before, traffic noise control should be considered in the context of sustainable urban development, taking into account a broad range of urban factors. This applies also to the question whether urban planners should go for dense cities with shielded areas and closed courtyards or rather for a city with a more open structure. Traffic noise is only one aspect of shielded areas and closed courtyards. Other aspects are for example public security and social interaction of inhabitants, which may be higher in cities without closed courtyards. The detailed balance of all relevant factors depends on the local situation in a city.

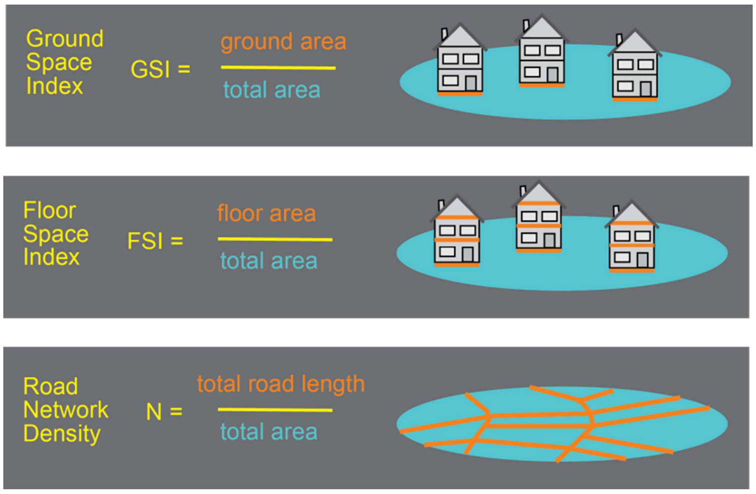

Figure 7. Illustrations of the definitions of GSI, FSI, and N, which are the elements of the three-dimensional urban density called Spacematrix.

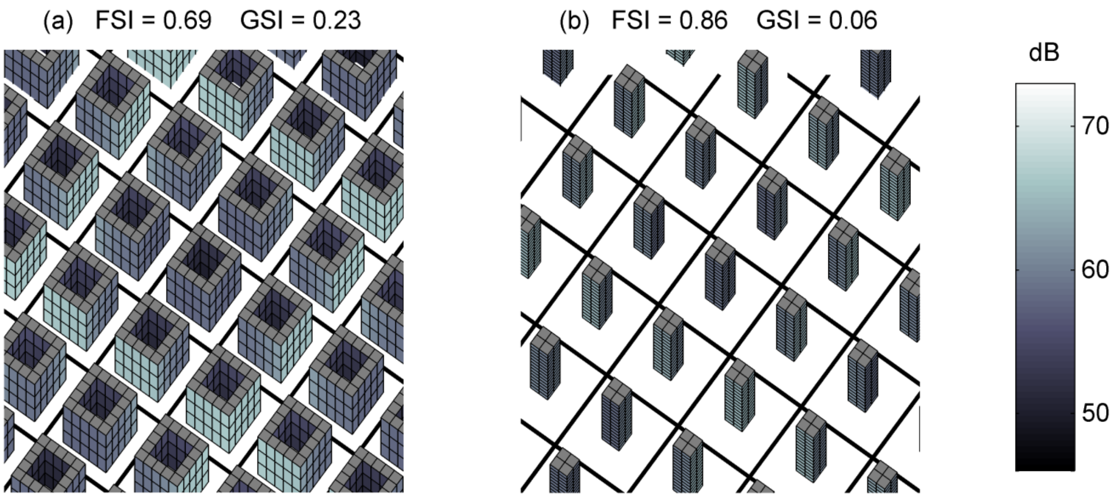

Figure 8. Two examples of urban fabrics with a rectangular grid of streets between building blocks, and traffic noise façade levels represented by a gray scale. Example (a) has blocks with sides of 5 building units and 3 floors. Example (b) has blocks with sides of 2 building units and 15 floors.

4.6 Traffic planning: think global, act local

4.6.1 Global analyses

Traffic noise in a city is directly related to the traffic volumes on the road network. The traffic volumes depend on various characteristics of the city, such as

- road network and buildings (dwellings, offices, shops,…), as described in Section 4.1,
- public transport,
- infrastructure for cyclists and pedestrians.

Travel behavior of the inhabitants (and visitors) also plays a role, which is related to personal parameters such as lifestyle, wealth, or car ownership [11]. Other parameters are also important such as labor market demand and accessibility to city functions such as schools, hospitals, grocery stores and so on.

On a different ‘level’, traffic volumes are related to urban density or population density. For example, automobile use may be low in a compact city or a city center, and higher in a sprawling city or low-density suburbs. Kenworthy and coworkers [12,13] have presented extensive studies of automobile use in a large number of international cities. They concluded that automobile use is more strongly related to urban density than to wealth (represented by gross regional product). Automobile use decreases with increasing urban density, and public transport increases with urban density.

Figure 9 shows results of Newman and Kenworthy [13], illustrating that automobile use decreases with increasing urban density. Automobile use is high in North-American sprawling cities and low in more compact Asian cities like Hong Kong. It should be noted that there have been critical comments on the statistical methods underlying the graph in Figure 9.

More recently, Marshall [14] performed a similar study of automobile use in US cities. This study yielded a graph comparable to the graph of Newman and Kenworthy, showing that automobile use decreases with increasing urban density.

Rather than comparing car use in different cities, one may also compare traffic volumes in different areas within a city, and relate this to local traffic noise levels. This approach was followed in Ref. [9]. The results are relevant for intra-urban analyses of traffic noise distributions within a city. Efficient traffic noise control in a city requires that traffic - or more precisely traffic noise emission - is restricted in the areas where urban density is highest.

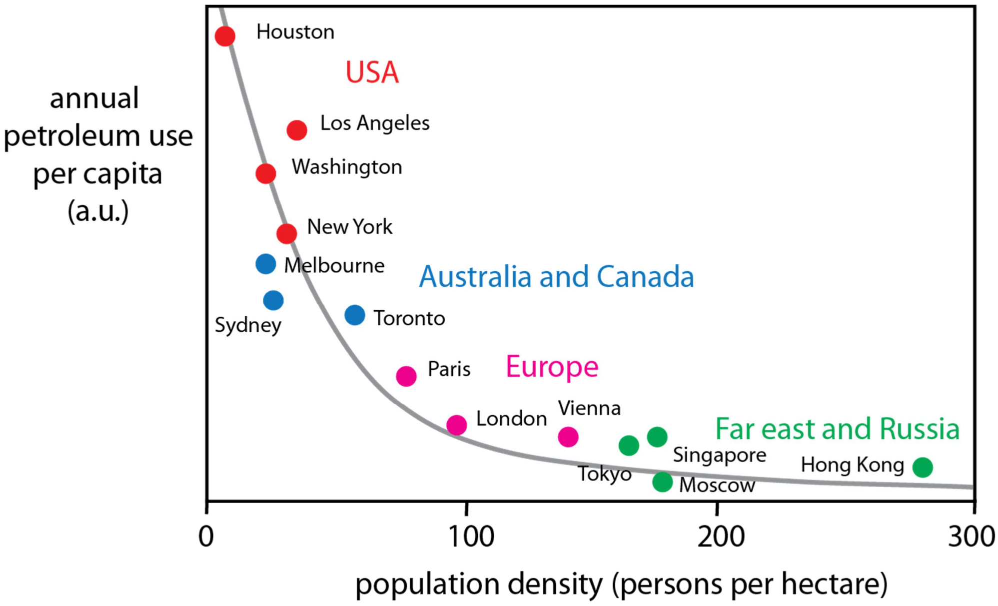

Figure 9. Graph showing the relationship between urban density and automobile use (expressed as petroleum use), after Newman and Kenworthy [13].
Source: http://en.wikipedia.org/wiki/File:Petrol_use_urban_density.svg

4.6.2 Local action

The above mentioned studies focus on comparisons between different cities, or different areas within a city. The observation that car use is lower in compact cities in Asia than in sprawling cities in the US, for example, does not imply that car use is reduced ‘automatically’ if a European city enhances urban density by an infill scenario. Local action is required to achieve a modal shift from cars to other transport modes.

One way to stimulate people to use bicycles in cities is *road sharing* on urban roads. This means that the roads are designed in such a way that they can be shared by motorized vehicles, cyclists, and pedestrians. Road sharing requires that the speeds of motorized vehicles be low, say 30 km/h. In other words, road sharing requires *traffic calming*. This can be achieved by a proper design of the roads, for example, with obstacles on the road.
Actually, the idea of road sharing was introduced in the Netherlands already in the 1970s. The shared roads in the Netherlands still exist, and are called ‘woonerf’ – a word that is also used sometimes in English. Figure 10 shows the traffic sign used to indicate a ‘woonerf’.

Danish architect Jan Gehl is an internationally known promoter of road sharing and protection of pedestrians and cyclists in cities. Videos of his observations on the streets of cities can be found on the internet [15,16]. Many cities in the world have consulted Jan Gehl for advice on urban development plans.

Figure 11 shows an artist impression of a transformation of a busy and noisy street into a street that is more attractive for cyclists and pedestrians. This example was taken from material presented at a meeting on road sharing in Amsterdam in November 2011 [3]. Figure 12 shows an actual example of road sharing, in the third arrondissement in Paris.

Figure 10. Traffic sign used to indicate a ‘woonerf’ in the Netherlands.

Figure 11. Artist impression of a transformation of a busy and noisy street (top) into a street that is more attractive for cyclists and pedestrians (bottom). Used with permission of the artists [3].

Figure 12. Example of road sharing, in the third arrondissement in Paris. Picture taken by the author, June 2013.

4.7 Case study: an infill scenario for the center of Rotterdam in 2030

In Reference [6] an analysis is presented of an infill scenario for the center of Rotterdam in the year 2030, corresponding to a population increase from about 30,000 to 60,000 inhabitants. Here we summarize the results of the analysis, since it nicely illustrates the message of this note that traffic noise control should be considered as an important element of urban sustainability plans. The analysis focuses on traffic, environmental pollution, and public health.

Starting point of the analysis was the Rotterdam infill scenario for the year 2030, as described in Refs. [4,5], with 20,000 new dwellings and 30,000 new inhabitants in the central urban quarter 'Stadscentrum' of Rotterdam. The buildings with the new dwellings have been designed by urban architects, and are indicated as yellow blocks in the three-dimensional view shown in Figure 13.

Figure 13. Three-dimensional view of the central area of Rotterdam, with yellow blocks representing new buildings for the infill scenario for the year 2030.

The city of Rotterdam has also developed plans for traffic in the year 2030 [5]. A general objective is that the city center should become (more) *attractive and accessible*, both for the inhabitants and for visitors. Therefore the following traffic measures have been formulated.

1) Modification of major roads – narrower roads, lower speeds.

2) Improved infrastructure for bicycles and pedestrians.
3) Modifications of parking fees.
4) Improved Park and Ride facilities.

The aim of the measures is to achieve a *modal shift*, i.e. a reduction of automobile use in the city center and an increase of non-motorized transport modes.

In principle, the traffic plans should have been taken into account in the analysis of the infill scenario for Rotterdam in 2030. However, the approach to follow here is not straightforward, since at least three competing effects play a role: i) effects of modal-shift measures, ii) autonomous growth of traffic, and iii) effects of the population increase by 30,000 inhabitants. As a crude approximation, it has been assumed that each new inhabitant generates one additional car trip per day.

The results of the analysis are represented schematically in Figure 14. For details about the results we refer to Ref. [6]. The figure shows that, as a result of the population increase:

- Traffic volumes on the roads increase,
- Urban density increases - in fact this was an objective of the infill scenario, since the ambition of Rotterdam is to achieve a more compact city center,
- Traffic noise and air pollution increase.

The increase of traffic noise levels is relatively small. As a consequence, the increase of the estimated *percentage* of inhabitants that is highly annoyed by traffic noise (at home) is also relatively small: 7.0% in 2012 and 7.5% in 2030. However, since the number of inhabitants doubles, the increase of the *absolute number* of highly-annoyed inhabitants is large: about 2300 inhabitants in 2012 and 4600 inhabitants in 2030. The latter number of 4600 highly-annoyed inhabitants has been converted into a health effect expressed in (healthy) life years lost, using a calculation scheme recommended by the World Health Organization. The scheme gives 0.02 life years lost per highly annoyed person (per year), so we find that 4600 highly-annoyed inhabitants correspond to about 100 healthy life years lost (per year).

This negative health effect may be used as an argument for (further) reducing motorized traffic in the city center. In fact the traffic reduction measures described before are in line with this argument. A modal shift from car to non-motorized transport modes will have positive effects on congestion, traffic safety, traffic noise, and air pollution.

A modal shift from car to bicycle will have another positive effect on public health: enhanced physical activity improves the health of the inhabitants. Cyclists are physically more active than car drivers. Using a mathematical technique called Life Table analysis, based on age-specific mortality rates of a population, it was estimated that the modal shift from car to bicycle in Rotterdam in 2030 corresponds to a health gain of 200 life years gained (per year). Here it has been assumed that 10% of the 60,000 inhabitants of the Rotterdam city center in 2030 make the shift from car to bicycle, for short trips (15 km at most) on a daily basis, for example for commuting or shopping.

Finally we mention another positive effect on public health. The Rotterdam infill scenario not only includes measures for promoting cycling in the city center, but also measures aiming for a city center that is more attractive for pedestrians. Improved public space in the city center will have positive health effects through enhanced physical activity of pedestrians. However, these effects have not been quantified in this analysis.

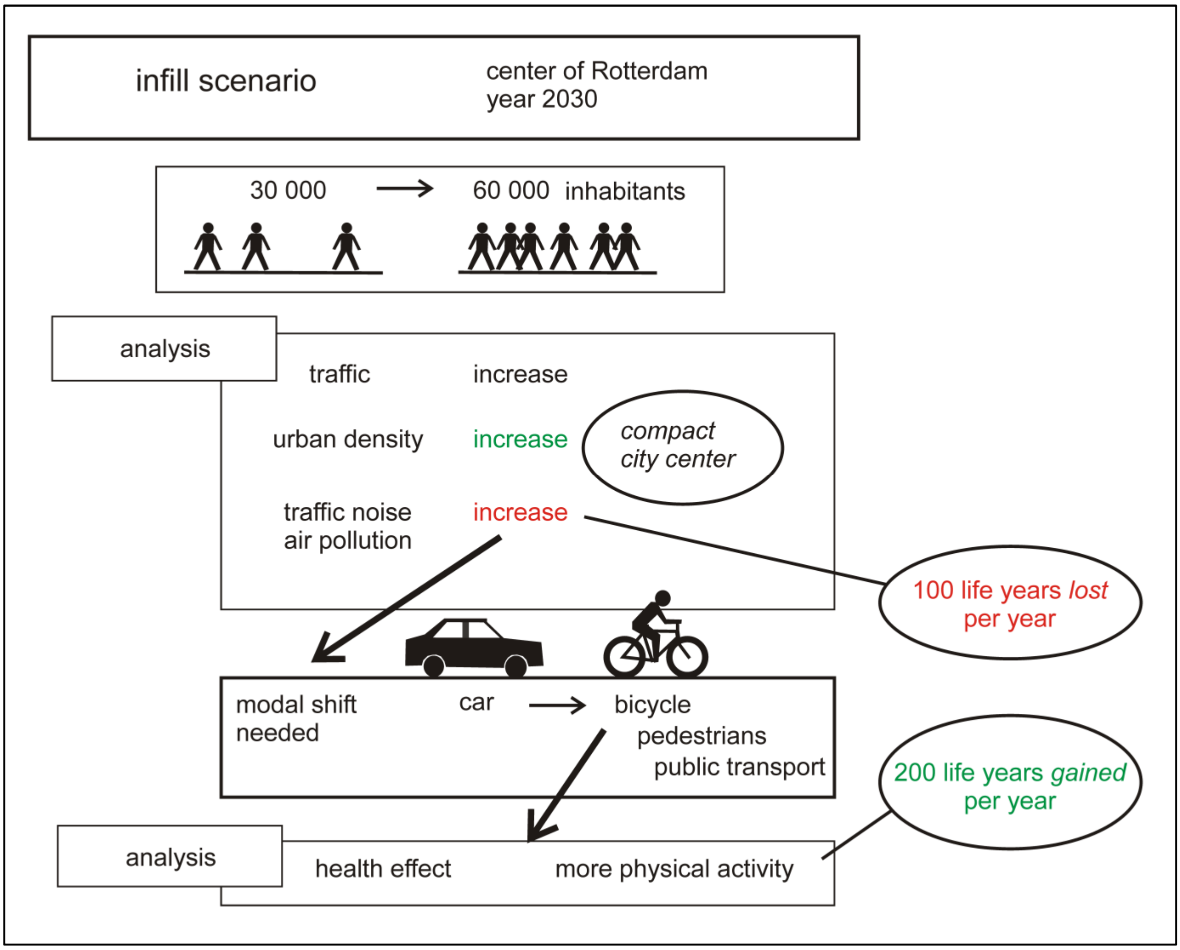

Figure 14. Schematic illustration of the results of an analysis of various elements of an infill scenario for the city center of Rotterdam in 2030, based on an urban sustainability plan aiming at an attractive and accessible city center [4,5]. Increased traffic noise annoyance in 2030 is expressed as a health effect of 100 life years lost per year. This effect can be reduced by modal-shift traffic measures, which in addition has a positive health effect of 200 life years gained per year due to enhanced physical activity of cyclists compared to car drivers.

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