**Full title**

# View on outdoor vegetation reduces noise annoyance for dwellers near busy roads

**Authors**

Timothy VAN RENTERGHEM, Dick BOTTELDOOREN

**Affiliation**

T. Van Renterghem: Ghent University, Department of Information Technology, Sint Pietersnieuwstraat 41, B- 9000 Gent, Belgium. (timothy.van.renterghem@intec.ugent.be)

D. Botteldooren: Ghent University, Department of Information Technology, Sint Pietersnieuwstraat 41, B- 9000 Gent, Belgium. (dick.botteldooren@intec.ugent.be)

**Corresponding Author**

T. Van Renterghem: Ghent University, Department of Information Technology, Sint Pietersnieuwstraat 41, B- 9000 Gent, Belgium. (timothy.van.renterghem@intec.ugent.be)

TEL: +32 9 264 36 34 FAX: +32 9 264 99 69

# 1 Introduction

Along major arterial roads and city ring roads, the noise levels to which dwellers are exposed can be very high, leading to serious health risks (Fritschi, Brown, Kim, Schwela, & Kephalopoulos, 2011). As the basic function of such roads is providing sufficient traffic throughput, this leads to inevitably high noise levels. In case of optimal urban environmental planning, dwellers should not appear there. However, in many countries, mainly due to city expansion, such zones become inhabited to an increasing extent.

The traditional measures to deal with road traffic noise problems, more precisely source level reduction (quieter engines, tire optimization, low-noise pavements, ...) (Sandberg & Ejsmont, 2002), achieving noise reduction during propagation between source and receiver (Kotzen & English, 2009; Van Renterghem, Forssen, Attenborough, Jean, Defrance, Hornikx, & Kang, 2015) (noise walls, earth mounds, exploiting ground-related effects, ...), and providing sufficient acoustical façade insulation, all have their merits. But clearly, there are many issues with these for the specific application along city ring roads: there is often a lack of available space for propagation related measures or these might be visually intrusive, and the technological improvement with relation to the noise emission of individual vehicles and road coverings is a steady but slow process. In addition, low-noise pavements typically need maintenance, regular replacement and only reduce rolling noise, making this often a less attractive solution. Even façade insulation is only part of the solution: people open windows resulting in an almost complete loss of insulation (Jean, 2009). This means that additional approaches are needed to complement these traditional measures to improve the noise climate at such highly exposed dwellings.

An approach that has been successfully applied is providing dwellers with a quiet side, either by building and street design (e.g. ensuring connected building rows (Gidlöf-Gunnarsson, Öhrström, & Forssén, 2012) and by traffic management (Salomons, Polinder, Lohman, Zhou, Borst, & Miedema, 2009)). Essential in this respect is a pronounced front-back façade level difference (END, 2002), compensating for the exposure at the loud side (Öhrstrom, Skanberg, Svensson, & Gidlöf-Gunnarsson, 2006). Clearly, some limits have to be set regarding the maximum level at the shielded façade as discussed by Öhrstrom et al. (2006). The presence of such a non-directly exposed façade was shown to significantly reduce the self-reported noise annoyance and self-reported sleep disturbance based on surveys in different European countries (Bodin, Björk, Ardö, & Albin, 2015; de Kluizenaar, Salomons, & Janssen, 2011; Gidlöf-Gunnarsson et al., 2012; Gidlöf-Gunnarsson & Öhrström, 2010; Öhrstrom et al., 2006; Van Renterghem & Botteldooren, 2012).

In general, the human perception of noise is strongly influenced by the visual scenery (see e.g. Fastl, 2004). Also for the specific case when vegetation is involved, positive effects have been reported. Viollon, Lavandier, & Drake (2002) showed that artificial sounds like road traffic noise are perceived less stressful and less unpleasant when the visual setting was less urban or greener. Attractiveness of courtyards, e.g. linked to the presence of vegetation, was found to be an important modifier when studying the aforementioned quiet side effect (Bodin et al., 2015;

Gidlöf-Gunnarsson & Öhrström, 2007;). Li, Chau, & Tang (2010) held surveys indicating that visible greenery is able to reduce noise annoyance for residents of high-rise buildings overlooking urban parks and wetlands. Visible natural features were shown to be relevant predictors of tranquility (Pheasant, Horoshenkov, Watts, & Barrett, 2008; Watts, Pheasant, & Horoshenkov, 2011). In another study, it was reported that landscape plants provide excess noise attenuation through the subjects' emotional processing based on analysis of electroencephalograms (Yang, Bao, Zhu, Yang, 2011). Aylor & Marks (1976) and Aylor (1977) concluded that as long as the source of sound can be seen, reduction in the visibility of the source, amongst others by vegetation, is accompanied by a reduction in apparent loudness. However, when vegetation fully visually screens the source there is a reversed effect namely an increase in noisiness, the latter consistent with findings by Watts, Chinn, & Godfrey (1999). Zhang, Shi, & Di (2003) reported that hedges that make passing vehicles invisible resulted in significantly less noise annoyance, and that such improvements are even more pronounced at higher noise levels. Vegetation on noise walls not only improved the overall environmental quality, but also enhanced the perceived noise attenuation performance (Hong & Jeon, 2014).

In addition to the potential of improving the perceived noise environment, there is an extended evidence base that a natural and green urban scenery is beneficial for general human health (De Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Kaplan & Kaplan, 1989; Thompson, 2011; Thompson, Roe, Aspinall, Mitchell, Clow, & Miller, 2012; Tzoulas, Korpela, Venn, Yli-Pelkonen, Kaźmierczak, Niemela, & James, 2007; Ulrich, 1984; Velarde, Fry, & Tveit, 2007).

The main aim of this study is to see how the self-reported amount of visible vegetation through the living room window influences the dweller's self-reported noise annoyance. Many studies aiming at elucidating the audio-visual interactions are typically well controlled but rather artificial in their setup by using projections on screens in laboratory conditions and/or by offering (very) short acoustic stimuli (e.g. Hong & Jeon, 2013; Hong & Jeon, 2014; Joynt & Kang, 2010; Preis, Kociński, Hafke-Dys, & Wrzosek, 2015; Viollon et al., 2002; Watts et al., 1999; Yang et al., 2011). In such experiments, soundscape characteristics like noisiness, pleasantness, stressfulness, comfort, harmony and others are then assessed. The focus in the current study is on the residents' experiences in their ordinary living environments, ensuring ecological validity and allowing to assess (long-term) self-reported noise annoyance. Noise annoyance is an important noise policy indicator, and one of the health-endpoints of environmental noise as identified by Fritschi et al. (2011). Furthermore, the focus is here on the effect of the mere presence of vegetation in a zone highly exposed to road traffic noise and not necessarily vegetation as a means of hiding the noise source or in relation to traditional noise walls (Aylor, 1977; Aylor & Marks, 1976; Hong & Jeon, 2014; Joynt & Kang, 2010; Watts et al., 1999; Zhang et al., 2003).

# 2 Methodology

## 2.1. Participant selection

Participants were selected along different sections of a highly noise-exposed inner city ring road in Ghent, Belgium, characterized by either an abundance of vegetation (street trees, parks bordering the road, vegetation on the central reservation, etc.) or a lack of vegetation. Such sufficiently contrasting parts of the ring road were selected in advance based on aerial photographs.

Dwellings directly bordered the ring road and were part of closed-row building blocks with enclosed backyards and should therefore have a similar and pronounced front-back level difference. Corner houses were not selected. Given the high road traffic noise levels at the front façade, it can reasonably be assumed that the ring road dominates the soundscape at the shielded façade as well.

Participants were directly contacted, without prior announcement, by knocking on doors. The survey was announced as general research on the living environment. The minimum age for respondents was 18 years. Before starting the survey, the number of years living at the dwelling was asked for and it was checked that the participants were living at least 1 year at their current location. It was ensured by the interviewer that the dwelling had a living room window facing the ring road. A single interviewer performed all 105 face-to-face questionnaires. The surveys were taken during summer in a two week's period. Multiple participants were allowed per dwelling, but interviewed separately. No informed consent was asked from the respondents.

## 2.2. Noise exposure assessment

### 2.2.1. Most exposed façade level $L_{den}$

The noise exposure at the most exposed façade was extracted from the road traffic noise map approved by the Flemish regional government for the agglomeration of Ghent, which has been reported to the European Commission in the framework of the Environmental Noise Directive (END, 2002). Such strategic noise maps predict long-term yearly-averaged noise indicators. For the current study, $L_{day}$ (i.e. the equivalent sound pressure level during daytime, from 7.00 h until 19.00 h) and $L_{den}$ (i.e. the equivalent sound pressure level over a 24-hour period, including penalties for the evening and night period) were considered. The front-door position of the dwelling was taken as a reference point, and the average of the noise levels within 7.5 m was calculated since sound pressure levels could vary along longer façades.

Although often concerns are raised related to the accuracy of such strategic noise maps, levels near busy roads, as those considered in the current study, are reasonably accurate since noise levels are strongly source driven there. Only large deviations from the actual traffic intensity or composition would lead to significant errors in the predictions. For less trafficked roads or at shielded urban locations, predictions are typically much less accurate (Wei, Botteldooren, Van Renterghem, Hornikx, Forssén, Salomons, & Ögren, 2014).

### 2.2.2. Living room window insulation

Façade/window insulation was measured at each dwelling after the survey was taken by simultaneous short-term measurements at the front door (microphone membrane facing the road) and in the living room (microphone membrane facing the window overlooking the street). Two identical type-1 accredited sound level measurement chains were used, consisting of an ½" electret free-field microphone (type MK250B, Microtech Gefell), a pre-amplifier (SV12, Svantek) and a logging unit (SV959, Svantek). The microphone capsule used has a flat frequency response over the full audible frequency range, with deviations less than 1 dB up to 15 kHz for normal incident sound. Both measurement chains were placed on a tripod with the microphone membrane at a height of about 1.5 m above the floor/ground. The sound level meters were calibrated at the start of each day with a 94-dB type-1 acoustic calibrator (SV30A, Svantek), producing a pure tone at a sound frequency of 1 kHz. A 90-mm diameter windscreen (UA0237, Bruel & Kjaer) was used to limit wind-induced microphone noise. The loggers were manually time-synchronized, and before further processing, the 1/3-octave band sound pressure levels were aggregated to 5-s periods.

Based on the measurements near the front-door, car passages were selected and the difference between the indoor and outdoor sound pressure levels at the corresponding moments were calculated as an indicator for the façade/window insulation. As there is some inherent variation in the insulation calculated in this way during various car passages at a single survey point, the medians were used for further analysis. True façade insulation measurements (see e.g. ISO 10140-2, 2010) are too time-consuming to conduct at 105 dwellings. The proposed methodology has nevertheless some advantages: the real road traffic noise sources and driving conditions at the specific location are considered, the typical range of angles of incidence on the window are included (that might alter the acoustic response), and such relative measurements allow estimating the spectral insulation properties. The influence of the acoustic response of the living room has not been assessed. The current level difference approach is therefore equivalent to the standardized airborne sound insulation indicator $D_nT$, as described in ISO 140-4, with a reverberation time $T_0$ (in the receiver room) of 0.5s.

### 2.3. Survey description

The survey started with a number of general questions concerning the quality of the living environment, and possible annoyances caused by environmental stressors. The first question looked at the general satisfaction regarding the quality of living in the neighborhood of the dweller, with indication of some examples of parameters to be taken into account (“e.g. safety, child-friendly, environment, ...”). A 5-point categorical scale was offered as detailed in Table 1.

Next, it was asked if the respondent would advise friends or relatives to come live in his or her neighborhood when considering the quality of the living environment. Then, the ISO-standardized question (ISO/TS 15666, 2003) was asked regarding annoyance by noise, odor, light and street littering (see Table 1). Finally, it was asked to rate neighborhood safety.

In a second part, more detailed information about possible sources of noise annoyance was looked for (see Table 1) and the same scale was used as for the general noise annoyance question. In addition, noise sensitivity was assessed using a Dutch adaptation of the widely used Weinstein's noise-sensitivity scale (Weinstein, 1978), used previously in large-scale Flemish quality-of-life studies. This part contained 10 questions, and some questions were reversed to keep the respondents attentive.

In a third part, it was asked to rate the view from the living room window towards the street on a 5-point categorical scale ranging from ”extremely green” to “no green at all”, followed by a similar question concerning the presence of plants in the living room. A next question asked for neighborhood greenery. A last question regarding vegetation assessed how important neighborhood or street green is for the respondent.

Next it was announced that the façade insulation would be measured, and it was asked how often the living room window, facing the road, was opened in general and during hot weather. In addition, it was asked how many hours the dweller typically spends in his living room during weekdays and weekends.

To finish, some personal questions were asked about gender, age, education and professional activities. A picture was taken from the front-door position facing the street.

[TABLE 1]

### 2.4. Statistical analysis

Given the rather limited number of respondents in the dataset (N=105), classification to dichotomous variables has been performed in order to have sufficient occurrences in the different cells when using frequency tables. The Chi-square test has been applied to check dependency between variables. Odds Ratios (OR) have been calculated, and logistic regression is used to predict confidence intervals on these. Logistic regression with a dichotomous outcome (true or false) has been used, based on continuous, dichotomous, or categorical independent variables. In order to be statistically sound, 95% confidence intervals on the ORs should not contain 1. Effect modifiers have been studied by multiple logistic regression. Statistical significance of model deviance reduction when including an additional variable has been checked by likelihood ratio testing (based on the Chi-square distribution).

## 3. Results

[TABLE 2]

### 3.1. Respondents' characteristics

An overview of the dwelling's and respondents' characteristics is shown in Table 2. In the current dataset, 57 respondents (54 %) were female, 48 respondents (46 %) were male. 55 persons (52 %) were under the age of 50, 50 participants (48 %) were older. 62% of the dwellers reported to have received higher education (after secondary school). The aforementioned noise sensitivity test indicated mainly noise-insensitive persons; only 23 persons (22 %) gave, on average, an answer larger than or equal to 3 on the 1-to-5 scale used to assess noise sensitivity. Dwellers living between 1 and 5 years at their current location were most frequently met (40 %); those living between 5 and 15 years, and more than 15 years, are of equal importance (30 %).

Most respondents were full time working (35 %) or retired (31 %), the percentage students (13%) and those in the rest group (20 %) show that a good social mix is present in the dataset. The 105 persons interviewed originated from 75 unique dwellings.

## 3.2. Noise exposure characteristics

### 3.2.1. Front level $L_{den}$

In Fig. 1, the distribution of the front façade $L_{den}$ noise indicator at the survey points is shown. 92% and 40 % of respondents are exposed to $L_{den}$ levels larger than or equal to 65 dBA and 75 dBA, respectively. $L_{day}$ values taken from the noise map at the same points (and similar processing as described in Section 2.2.1) gave a rather constant offset relative to the $L_{den}$ values of 1.6 dBA (with a standard deviation of 0.3 dBA); $L_{den}$ yields the higher levels.

[FIGURE 1]

### 3.2.2. Façade insulation

[FIGURE 2]

In Fig. 2, the insulation spectra at all survey locations are depicted. Insulation properties of windows may have a strong variety, depending whether single glazing, double glazing or triple glazing is present. In addition, the thicknesses of the individual glazing panels and voids between them play an important role (Quirt, 1982). Examples of a (standard) measurement of a single and double glazing (Quirt, 1982) are added on top of the measured façade insulations. The measured in-situ data gives somewhat lower insulations. In contrast to the standardized laboratory measurements, the in-situ measurements are an energetic summation over all angles of incidence during passing cars. The angle resulting in the lowest insulation will therefore dominate the overall result. The frequency spectrum from the in-situ measurements follows the course of the depicted laboratory data. However, at low and high sound frequencies there is an insufficient signal-to-noise ratio and data in these frequency ranges has been disregarded; the spectra depicted in Fig. 2 are therefore limited to the 1/3-octave bands with central frequencies between 50 Hz and 4000 Hz. For total A-weighted levels, there are no signal-to-noise ratio issues given the strong contribution of road traffic sound energy in the aforementioned frequency interval. The distribution of the total road traffic noise façade insulation is presented in Fig. 3.

[FIGURE 3]

## 3.3. Noise annoyance

### 3.3.1. Quality of the living environment and noise annoyance

Noise annoyance is strongly associated with self-reported satisfaction with the general living quality of the neighborhood. People at least moderately annoyed (grouping the "moderately", "highly" and "extremely" annoyed respondents) by noise are less satisfied (less than "moderately satisfied") with the quality of the neighborhood (OR = 6.1, 95% CI = 2.1–17.7). Independence of these variables can be strongly rejected ($\chi^2$ (=1) = 12.6, p = 4E-4). Dwellers annoyed by noise would not advice friends or relatives to come live in their neighborhood or are in doubt; very similar statistics as for the link noise annoyance-quality of the living environment are found. Street littering has a slightly smaller impact on the self-reported neighborhood satisfaction ($\chi^2$ (1) = 8.4, p = 4E-3; OR =4.0, 95% CI=1.5-10.8). However, street litter is a less strong argument for the respondents to dissuade their relatives or friends to come live in their neighborhood, although still marginally statistically significant ($\chi^2$ (1) = 3.6, p=0.06). Odor annoyance has the strongest negative impact on neighborhood satisfaction ($\chi^2$ (1) = 11.5, p=7E-4), characterized by an odds-ratio of 9.9 (95% CI = 2.1-46.1). Light pollution has no impact on neighborhood satisfaction and independency of these factors cannot be rejected ($\chi^2$ (1) = 0.5, p=0.49).

The self-reported neighborhood safety ("fully agree" or "agree" to live in a safe neighborhood versus being "neutral", "disagree" or "totally disagree") is a strong predictor of the general neighborhood appreciation ($\chi^2$ (1) = 13.5, p=2E-4) and has a strong dissuading effect towards friends and relatives to come live there (OR=7.5, 95 % CI=2.0-28.1). There is a tendency towards more noise annoyance when respondents feel unsafe, but the latter is not statistically significant. The links between odor annoyance and safety, and street littering and safety, are statistically significant at the 5 % level. However, some care is needed when analyzing links with neighborhood safety as only 10% of the respondents declares to be neutral or disagree with living in a safe neighborhood; some combinations have less than 5 occurrences in the corresponding frequency tables.

**3.3.2. Noise annoyance sources**

[TABLE 3]

There is a strong link between (general) environmental noise annoyance, and noise annoyance by road traffic noise. Both are strongly linked ($\chi^2$ (1) = 23.1, p=2E-6). The general noise annoyance question reveals that 53 % of the respondents are not annoyed, 47 % are at least slightly annoyed, 19 % are at least moderately annoyed, and 8% are at least highly annoyed (see Table 3). The specific question on road traffic noise yields 47 % not-annoyed respondents, 53 % at least slightly annoyed, 30 % at least moderately annoyed, and 8 % at least highly annoyed answers. A linear (Pearson's) correlation coefficient R=0.66 between general and road traffic noise annoyance is obtained (p<1E-6). Clearly, this is not unexpected as survey locations with a high road traffic façade load were deliberately looked for.

Other types of traffic noise annoyance sources (aircrafts, railway traffic and ships) were fully absent (100% of the respondents were not annoyed by these). All other potential noise annoyance sources like neighborhood noise and recreational noise ended up for 95% in the "not annoyed" or "slightly annoyed" class. There is only one exception namely construction noise (see Table 3); 11% of the respondents call themselves at least moderately annoyed by this type of sound. However, construction noise annoyance could not be convincingly linked to general noise annoyance ($\chi^2$ (1) = 1.8, p=0.18) in the studied area. Consequently, the linear (Pearson's) correlation coefficient is limited (R=0.26, p=0.01).

### 3.3.3. Noise annoyance and front façade $L_{den}$

Logistic regression between continuous $L_{day}$ or $L_{den}$ and the binary-coded self-reported noise annoyance (at least moderately annoyed versus "slightly" and "not" annoyed) gives p-values of 0.24 and 0.25, respectively. This indicates that the most exposed façade road traffic noise level indicators have no predicting power for annoyance in this study. The most probable reason is that almost all levels at the survey points can be considered as high; 63 % of the $L_{day}$ levels and 71% of the $L_{den}$ levels exceed 70 dBA. Therefore, the range of levels in this study is too narrow to derive standard dose-response relationships between façade level and noise annoyance. Note, however, that the survey points were deliberately selected for high noise levels in a range as narrow as possible to rule out this effect; the main interest in this study is analyzing self-reported view on vegetation on the self-reported noise annoyance with a limited number of interviewed respondents.

Using either $L_{den}$ or $L_{day}$ as noise indicator yields very similar results given the aforementioned rather constant offset. One could expect that $L_{den}$ would be a more appropriate choice when analyzing general noise annoyance, while $L_{day}$ would be the suitable parameter for looking at the visual aspect of perception since less relevant at night. $L_{den}$ has been used in the remainder of this article and this choice does not influence the findings and hardly changes the reported odds-ratios and p-values.

In the $L_{den}$-level range below 65 dBA, more respondents report a high degree of vegetation as seen from the living room window (see Table 2). However, only 8 respondents fall in this level category. Between 65 and 75 dBA, the number of respondents in the “green” and “no green” class is nearly the same. At the highest level class, above 75 dBA, more persons indicate to be looking at vegetation. A linear regression between (continuous) $L_{den}$ and vegetation view (using the original 5-point scale) shows that with increasing level the self-reported view moves to more vegetation, but the Pearson’s correlation coefficient is rather limited ($R=0.14$) and the model is not statistically significant at the 5% significance level ($p=0.26$). A positive association between a vegetation view and low levels, that could bias conclusions drawn from this survey, is clearly not present.

**3.3.4. Noise annoyance and living room window insulation**

Façade insulation was shown be an irrelevant predictor for noise annoyance in this study. Logistic regression between insulation (continuous variable, total A-weighted insulation for road traffic present near the dwelling) and the dichotomous noise annoyance indicator (at least moderately annoyed versus "slightly" and "not" annoyed) yields a p-value of 0.37. Using a sub-selection of persons that at maximum sometimes open their living room window (N=55), this p-value further increases to 0.80, indicating that a possible association between insulation and annoyance would by (nearly) purely random. Only considering the low-frequency insulation performance at the dwellings, here (arbitrary) defined from 50 Hz to 200 Hz, yields a similar p-value of 0.78. It was further confirmed that the obtained insulation parameter does not depend on the front-level $L_{den}$; correlation between these two is nearly absent (R=-0.01, p=0.94). This gives confidence in the measurement technique and signal processing.

The experimentally obtained insulation parameter and the dichotomous self-reported view on vegetation are negatively associated (logistic regression p-value of 0.02); there is a slightly higher insulation appearing in dwellings without view on vegetation (OR= 1.1, 95% CI= 1.0-1.3). A positive association between vegetation view and high façade insulation, which could bias conclusions drawn from this survey, is clearly not present.

**3.3.5. Noise annoyance and personal characteristics**

Diploma (dichotomously coded in "higher education" versus "at maximum secondary school finished"), noise sensitivity (dichotomously coded, linearly averaged noise sensitivity responses smaller than or equal to 3 versus larger than 3) and gender show no statistically significant dependence with the dichotomous self-reported noise annoyance. Although typically some associations between personal characteristics and noise annoyance are found in large scale surveys (see e.g. Van Gerven, Vos, Van Boxtel, Janssen, & Miedema, 2009), the limited number of respondents in the current study is not suited for such analysis. In addition, the current survey was not designed to reveal such personal links with noise annoyance. For a discussion of the effect of age and years living at the dwelling, the reader is referred to section 3.3.6.

### 3.3.6. Noise annoyance and view on vegetation

The chance of being at least moderately annoyed by noise in presence of an at least moderate view on vegetation through the living room window in the current dataset is only 8%, while this chance increases to 34% when there is at maximum some vegetation visible through the window. Although the front façade exposure, following the noise map that was used, is high at all survey locations, view on vegetation could strongly reduce self-reported annoyance to an acceptable level. It has to be stressed that all dwellings were selected to have a pronounced quiet side, a factor of importance as found in other studies (see Introduction), and also in the same region (Van Renterghem & Botteldooren, 2012). But even under these conditions, the view on vegetation could further reduce environmental noise annoyance significantly. The spatial distribution of noise annoyance (dichotomously coded) and view on vegetation (5-point categorical scale) is illustrated with the maps in Figs. 4 and 5.

[FIGURE 4]

[FIGURE 5]

Logistic regression shows that view on vegetation from the living room window is an important predictor of the self-reported noise annoyance in this highly exposed noise environment. The crude OR equals 5.8 (95% CI=1.9-17.5), meaning that dwellers that have at least a moderately green view are more than 5 times less (at least moderately) annoyed by noise than those that report to see at maximum some vegetation through their living room window. Their dependency is strong ($\chi^2$ (1) = 11.1, p=9E-4). Logistic regression statistics are summarized in Table 4.

In the current dataset, older persons (age above 50) have a higher chance of a pronounced view on vegetation. More precisely, 38 older persons see a lot of vegetation versus 12 older persons seeing none. As a result, age and vegetation view are strongly linked. Directly related to this, the number of years living at the dwelling is logically influenced by the age of the participant ($\chi^2$ (1) = 37.7, p=8E-10), and therefore also to having a vegetation view. Although the effects of age and years of living at the current location, and vegetation view, cannot be disentangled based on the current dataset, the strong effect described in the previous paragraph cannot be assigned to the age effect and years living at the location. In a similar study (also consisting of face-to-face interviews in the city of Ghent, see Van Renterghem & Botteldooren, 2012), the dependency of the respondent's age or years living at the dwelling, and self-reported noise annoyance, was rejected ($\chi^2$ (1) = 4.24, p=0.38 and $\chi^2$ (1) = 2.88, p=0.58, respectively). Vegetation as seen through the window was not asked for in that study. In general, based on larger scale surveys, there is some tendency for somewhat less annoyance with increasing age (van Gerven et al., 2009) and the longer a person lives at a specific location, but the strong effect observed here cannot be brought down to age effect alone.

Splitting up in younger (below 50) and older (above 50) respondents does not allow to draw statistically sound conclusions due to categories with too few occurrences, enhancing uncertainty. In the older class, the major portion of the respondents (76%) appears in the "vegetation view-no noise annoyance" class, while the "vegetation view-noise annoyance" category becomes empty. Therefore, it is not possible to draw statistics or calculate odds-ratios, although the latter could suggest a very strong positive effect of view on vegetation. In the younger category (55 respondents in total), all classes have sufficient occurrences, leading to an odds-ratio of 1.9 (=(11/5)/(21/18)). However, the 95% confidence interval extends below 1 ([0.6-6.5]) so this finding is not statistically significant at the 5 % significance level. When splitting up the dataset in persons living during a long time (more than 7.5 years) and shorter time (less than 7.5 years) at the current dwelling, very similar findings and conclusions can be drawn. This cut-off duration of 7.5 years corresponds more or less to ages below or above 50 years.

Previous research suggested that indoor plants could help to reduce noise annoyance in an office environment (Mediastika & Binarti, 2013). In the current study, the self-reported amount of indoor plants has a tendency to be positive for noise annoyance reduction, although not statistically significant ($\chi^2$ (1) = 1.3, p=0.26; OR=2.0, 95 % CI =0.6-6.4). The latter is neither a confounder when looking at the link between outside vegetation and noise annoyance.

Logically, living in a green neighborhood and vision on outside vegetation from the living room is strongly dependent ($\chi^2$ (1) = 25.1, p=5E-7). However, merely living in a green neighborhood shows only a slight tendency to reduce noise annoyance, far from being statistically significant ($\chi^2$ (1) = 0.3, p=0.6). Vision on outside vegetation from the dwelling seems essential to benefit from this effect.

Independent confounders on the link between self-reported view on vegetation and noise annoyance could not be found among the questioned parameters. Including the time a dweller usually spends in the living room does not lead to a statistically significant reduction in model deviation either.

In Fig. 6, the data and model results are presented employing the original 5-point categorical self-reported degree of vegetation as seen from the window as independent variable, and the dichotomous noise annoyance as dependent variable. Note that for category 3 (“moderately green”), no occurrences of at least moderate noise annoyance were found in the current dataset.

More than 90% of the respondents “totally agree” or “agree” with the statement that “street vegetation is important”. Further statistical analysis relating to fulfilling or not fulfilling the preference for street green, and the impact on noise annoyance, could not be made due to the near absence of persons disagreeing with or being neutral to previous statement. Self-reported neighborhood safety and vegetation view from the window are not at all linked ($\chi^2$ (1) = 0.06, p=0.8).

[FIGURE 6]

[TABLE 4]

**3.3.6. Objective versus subjective view on vegetation**

In this section, the self-reported view on vegetation through the living room window is opposed to the percentage greenish pixels in digital photographs taken at each dwelling from the front-door position towards the street. For fear of burglary, taking pictures of windows facing the street was not allowed by almost all respondents. As a proxy, the front-door position was therefore considered.

Photographs were taken with a Panasonic dmc-fz18 with the camera held horizontally at eye height (about 1.7 m above street level). Each digital picture consisted of 3264 x 2448 pixels and was saved in .jpeg format. The “RGB greenness” parameter $G_{RGB}$ (Ahmad, Muhamin Naeem, Islam, & Nawaz, 2007; Crimmins & Crimmins, 2008; Richardson, Jenkins, Braswell, Hollinger, Ollinger, & Smith, 2007) is used and calculated as $G_{RGB}=(G-R)+(G-B)$, where G, R and B are the relative intensities of the green, red and blue channels in the RGB picture, respectively. In a next step, an appropriate threshold was set. The .jpeg picture format was found to be well suited for such an image processing analysis (Lebourgeois, Bégué, Labbé, Mallavan, Prévot, & Roux, 2008). A more robust assessment of green vegetation is the (broadband) normalized difference vegetation index (NDVI), however, requiring a measurement of near infrared light. RGB greenness was shown to perform quite similar to NDVI in capturing the amount of vegetation as concluded by Richardson et al. (2007).

Note that all green is included when calculating $G_{RGB}$; so not only leafs from trees and bushes but also grass zones. Non-green vegetation is missed in this assessment. However, in the zone under study, during high summer, vegetation is predominantly green colored. Accidental non-vegetation green-colored objects were manually removed, typically accounting for only small zones in the photographs taken. Such a manual action was needed in less than 15 % of the pictures. In Fig. 7, examples are shown for a low, a moderate and a high vegetation percentage.

[FIGURE 7]

[FIGURE 8]

The linear regression in Fig. 8 proves to be a statistically sound model to link the percentage greenish pixels in photographs and subjective view on vegetation; the categorical 5-point scale is used as a continuous variable here (in approximation). A correlation coefficient of 0.79 was obtained, with a p-value of less than 0.001. The dwellers are capable of correctly evaluating vegetation view from their living room window. In the zone under study, there is a high variation in the degree of vegetation at road segments within short distance that could help respondents in getting such a classification reasonably accurate.

However, the rating of vegetation view stays a subjective measure, as shown by the relative broad range of objective assessments corresponding to a single subjective class. To some extent, there could also be differences between the living room window view and the front-door position, especially in case of living rooms at higher storeys.

## 4. Discussion

The current survey was held in an area highly-exposed to road traffic noise, and a strong self-reported noise annoyance reduction by the self-reported presence of visible outdoor vegetation has been observed. This finding confirms previous work showing that view on gardens and parks moderate noise annoyance ratings by individuals at their homes (Li et al., 2010). In that study, predicted levels were mostly in the 65 dBA noise level class. Current results are also consistent with those reported by Zhang et al. (2003), where vegetation was shown to have a pronounced positive perception effect mainly at high (70 dBA) and not at low road traffic noise levels (55 dBA). Somewhat related, Hong & Jeon (2014) concluded that at 65 dBA aesthetic preference of noise barriers is more important than at 55 dBA. In their study, the aesthetics of a barrier could be linked to the presence of vegetation.

Somewhat contrasting, Hong, & Jeon (2013) indicate that the overall environmental quality could benefit from an improved visual environment mainly at lower levels around 55 dBA, while at 70 dBA the acoustic environment would be dominant. Following Viollon (2003), high road traffic noise levels could be incongruent with view on vegetation, potentially degrading the soundscape quality. Such mechanisms did not seem to apply to the current study.

Combining the effect of view on vegetation in combination with a wide range of front façade noise levels could be interesting. This would allow to calculate the equivalent level reductions associated with view on vegetation (shift of dose-effect curves) to be applied more easily in e.g. noise action plan maps. However, the question remains what would be the effect at the low end of the noise level range.

In the current study, all dwellings were deliberately selected based on similar building geometry to approach a constant front-back noise level difference to rule out this effect given the limited number of interviews taken. No specific measurements or assessments were made regarding front-back noise levels differences or quiet-side soundscapes. Previous research suggests a link between a noise-shielded side and its visual attractiveness, and in extension, its vegetation content; a nice visual setting at the shielded façade was shown before to strengthen the quiet side perception effect (Gidlöf-Gunnarsson & Öhrström, 2010; Bodin et al., 2015). A relevant question, therefore, is how the quiet side effect and the green visual effect at the loud side would interact.

Visibility of the source was shown before to be important for perceived loudness (Aylor & Marks, 1976); vegetation has the potential to visually screen road traffic. At the selected dwellings, at least the nearby traffic lanes were in all cases visible. Traffic lanes carrying vehicles driving in opposite direction might have been visually screened by vegetation on e.g. the central reservation of the ring road.

In addition, the presence of vegetation might add natural sounds to the urban soundscape like e.g. rustling of leafs or animal sounds, potentially leading to masking of traffic noise. Especially bird sounds, coming along with the presence of and view on vegetation (Hao, Kang, & Krijnders, 2015), could have a positive effect (Hong & Jeon, 2013; Oldoni, De Coensel, Boes, Rademaker, De Baets, Van Renterghem, & Botteldooren, 2013; Ratcliffe, Gatersleben, & Sowden, 2013). This type of sound is ranked at the top of desired natural sounds by citizens (Yang & Kang, 2005) and sound frequency adaption by birds has been observed (Cardoso & Atwell, 2011; Halfwerk & Slabbekoorn, 2009) increasing its impact in a noisy environment. Specific data on these topics was not gathered in the current study.

Another point of interest would be assessing the link between the dweller's preference regarding living in a green neighborhood and their actual situation. Almost all respondents wish to live in a green neighborhood while 42% indicate to see at maximum some vegetation. It could be expected that less interest in a green neighborhood could reduce the large effect seen in the current study. In this respect, preconceptions regarding the noise reducing effect of vegetation could be relevant. It was reported in Yang et al. (2011) that 90% of their subjects believed that landscape plants contribute to noise reduction and that 55% overrated the plants' actual ability to attenuate noise. In relation to noise walls (in combination with vegetation), preconceptions can be rather strong (Joynt and Kang, 2010) and vegetation was found to enhance the expected noise reduction (Hong & Jeon, 2014).

The current statistical analysis is based on the self-reported degree of outdoor visual vegetation through the living room window. The latter could be successfully linked to the RGB greenness parameter as calculated from front-door photographs towards the street. It could be of use for urban planners to further refine such an objective measure e.g. by using the actual surface (in $m^2$) or the fraction (in percentage) of visible vegetation in the face of the window.

## 5. Conclusions

Face-to-face interviews were taken at 105 respondents, all highly exposed to dominant road traffic noise. All dwellings were deliberately selected to have a pronounced front-back level difference. The (self-reported) degree of vegetation as seen through the living room window was shown to be a strong and statistically significant predictor of the self-reported noise annoyance. The complete absence of view on vegetation resulted in a 34 % chance of being at least moderately annoyed by noise, while this chance reduced to 8 % for respondents answering to have an extremely green visual, notwithstanding median $L_{den}$ levels of 73 dBA at the street-facing side of the dwelling. Real vision on outdoor vegetation was shown to be essential - living room (indoor) plants and the mere presence of vegetation in the neighborhood was shown to be insufficient. The self-reported degree of vegetation as seen through the living room window could be linked to the objective fraction of green pixels in photographs using the RGB greenness parameter.

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**TABLE CAPTIONS**

**Table 1.** Overview of the categorical answering scales used for the questions in the survey.

**Table 2.** Overview of the dwelling and respondent characteristics/answers grouped by self-reported vegetation view; "green view" means an at least moderate degree of vegetation as seen from the living room window towards the street, while "no green visual" groups the "some green" and "no green at all" answers. The number of respondents is given in each category (N=105).

**Table 3**. Noise annoyance sources for which at least 5 % of the respondents report to be at least moderately annoyed.

**Table 4.** Overview of logistic regression model statistics to predict at least moderately annoyed persons (dichotomous outcome; 1=annoyed, 0=not annoyed) based on the self-reported view on vegetation from the living room window. The logistic regression coefficients (beta), the standard errors (SE) on these variables, and the probabilities that model coefficients are equal to zero (*p*) are given together with their t-distribution values (*t*-value), odds-ratios (OR) and their 95% confidence intervals (95% CI on OR).

**Table 1.** Overview of the categorical answering scales used for the questions in the survey.

| Question | Subcategory | Categorical answering scale |
|---|---|---|
| "To what extent are you satisfied or not satisfied with the quality of living (e.g. safety, child-friendly, environment, ...) in your neighborhood?" | | "very satisfied", "satisfied", "moderately satisfied", "not satisfied", or "not at all satisfied" |
| "Would you advise friends or relatives to come live in your neighborhood when considering the quality of the living environment?" | | "yes", "undecided", or "no" |
| "If you consider the past 12 months, to what degree were you annoyed or not annoyed by ... ?" | • noise<br>• odor<br>• light<br>• street littering | "not at all annoyed", "slightly annoyed", "moderately annoyed", "strongly annoyed", or "extremely annoyed" |
| "To what extent do you agree or disagree with the following statement:" | "I am living in a safe neighborhood" | "totally agree", "agree", "neutral", "disagree" or "totally disagree" |
| "If you consider the past 12 months, to what degree were you annoyed or not annoyed by the following sounds ... ?" | • Traffic: "road", "railway", "air", "water"<br>• Industry and small/medium enterprises: "delivery of goods by trucks", "construction noise", "industrial plants", "trade and services"<br>• Leisure activities and tourism: "music from pubs, bars, and restaurants", "music in cars", "outdoor concerts", "sports activities"<br>• Neighbors:"children playing", "animals", "do-it-yourself home improvement", "loud music/television", "gardening", "heating, ventilation and air conditioning units" | "not at all annoyed", "slightly annoyed", "moderately annoyed", "strongly annoyed", or "extremely annoyed" |
| *Noise sensitivity questions*: "To what extent do you agree or disagree with the following statements:" | e.g. "I find it difficult to relax in a noisy place." | "totally agree", "agree", "neutral", "disagree" or "totally disagree" |
| "How would you describe the view from your living room window towards the street ?" | | "extremely green", "very green", "moderately green", "some green" or "no green at all" |
| "How would you rate the amount of vegetation in your living room?" | | "extremely green", "very green", "moderately green", "some green" or "no green at all" |
| "To what extent do you agree or disagree with the following statements:" | • "I am living in a green neighborhood."<br>• "Vegetation (trees, bushes, stretches of grass, ...) in my street/neighborhood is important." | "totally agree", "agree", "neutral", "disagree" or "totally disagree" |
| "How often do you open your living room window facing the street ... ?" | • in general<br>• during hot weather | "never", "rarely", "sometimes", "most of the time" or "always" |

**Table 2.** Overview of the dwelling and respondent characteristics/answers grouped by self-reported vegetation view; “green view” means an at least moderate degree of vegetation as seen from the living room window towards the street, while “no green visual” groups the “some green“ and “no green at all” answers. The number of respondents is given in each category (N=105).

| | | green visual | no green visual |
|---|---|---|---|
| **Exposure** | | | |
| front façade level $L_{den}$ | $L_{den}$ < 65 dBA | 7 | 1 |
| | 65 dBA ≤ $L_{den}$ < 75 dBA | 27 | 28 |
| | $L_{den}$ ≥75 dBA | 27 | 15 |
| road traffic noise façade insulation ΔLp | ΔLp <20 | 4 | 2 |
| | 20≤ΔLp <30 | 37 | 22 |
| | ΔLp ≥30 | 20 | 20 |
| **Neighborhood** | | | |
| general neighborhood satisfaction | at least moderately satisfied | 51 | 32 |
| | “not” and “not at all” satisfied | 10 | 12 |
| recommend neighborhood to friends/relatives | “yes” | 56 | 30 |
| | “no” or “undecided” | 5 | 14 |
| importance of neighborhood/street green | “very important” and “important” | 61 | 36 |
| | “neutral” or less | 0 | 8 |
| safe neighborhood | “totally agree” or “agree” | 55 | 39 |
| | “neutral” or less | 6 | 5 |
| **Annoyance** | | | |
| general noise annoyance | “not at all” and “slightly” annoyed | 56 | 29 |
| | at least moderately annoyed | 5 | 15 |
| road traffic noise annoyance | “not at all” and “slightly” annoyed | 49 | 24 |
| | at least moderately annoyed | 12 | 20 |
| odor annoyance | “not at all” and “slightly” annoyed | 57 | 40 |
| | at least moderately annoyed | 4 | 4 |
| light pollution | “not at all” and “slightly” annoyed | 61 | 41 |
| | at least moderately annoyed | 0 | 3 |
| street litter | “not at all” and “slightly” annoyed | 48 | 26 |
| | at least moderately annoyed | 13 | 18 |
| **Living room** | | | |
| time spent in living room facing the road | Less than or equal to 20% of the day (=4.8 hours) on average (over both weekdays and weekends) | 16 | 22 |
| | more than 20% | 45 | 22 |
| living room indoor green | at least moderately green | 24 | 8 |
| | “no green” or “some green | 37 | 36 |
| **Personal characteristics** | | | |
| gender | male | 29 | 19 |
| | female | 32 | 25 |
| respondent’s age | below 50 | 23 | 32 |
| | above 50 | 38 | 12 |
| higher education (after secondary school) | no | 24 | 16 |
| | yes | 37 | 28 |
| noise sensitivity | not sensitive (<3.0) | 49 | 33 |
| | sensitive (≥3.0) | 12 | 11 |
| employment | full-time | 17 | 20 |
| | student | 6 | 8 |
| | retired | 27 | 6 |
| | part-time, unemployed and housewife/man | 11 | 10 |
| years living at location | less than 5 years | 20 | 22 |
| | between 5 and 15 years | 16 | 15 |
| | more than 15 years | 25 | 7 |

**Table 3**. Noise annoyance sources for which at least 5 % of the respondents report to be at least moderately annoyed.

| | not annoyed | slightly annoyed | moderately annoyed | highly annoyed | extremely annoyed |
|---|---|---|---|---|---|
| Environmental noise in general | 56 | 29 | 12 | 7 | 1 |
| Road traffic noise | 49 | 24 | 24 | 8 | 0 |
| Construction noise | 73 | 20 | 5 | 7 | 0 |

**Table 4.** Overview of logistic regression model statistics to predict the at least moderately annoyed persons (dichotomous outcome; 1=annoyed, 0=not annoyed) based on the self-reported view on vegetation from the living room window. The logistic regression coefficients (beta), the standard errors (SE) on these variables, and the probabilities that model coefficients are equal to zero (*p*) are given together with their t-distribution values (*t*-value), odds-ratios (OR) and their 95% confidence intervals (95% CI on OR).

| | **beta** | **SE** | ***t*-value** | ***p*** | **OR** | **95% CI on OR** |
|---|---|---|---|---|---|---|
| cst | -0.6592 | 0.3180 | -2.0728 | 0.04 | | |
| self-reported view on vegetation from the living room window (1=at least moderately green, 0=at maximum some green) | -1.7567 | 0.5648 | -3.1102 | 0.002 | 1/5.79 | [1/17.53, 1/1.91] |

**FIGURE CAPTIONS**

Figure 1. Histogram of the $L_{den}$ level as taken from the city noise map near the respondents' dwellings.

Figure 2. Overview of the measured insulation spectra of the façades/windows at all survey locations (thin lines), including an example of a standard insulation measurement of (single) 3-mm glazing and a double 3-mm glazing (without void space) (Quirt, 1982).

Figure 3. Histogram over all survey locations of the difference between the A-weighted front-door sound pressure level (outdoors) and the indoor level (near the closed window facing the street) as a measure for the acoustical façade insulation.

Figure 4. $L_{den}$ noise map (in dBA) near the survey points, showing the buildings within 250 m of each survey point. The circles, representing the positions where the surveys were taken, are filled with red (indicating an "at least moderately annoyed" inhabitant) or green ("not at all annoyed" or "slightly annoyed").

Figure 5. $L_{den}$ noise map (in dBA) near the survey points, showing the buildings within 250 m of each survey point. The color scale of the circles, representing the positions where the surveys were taken, range from white ("no self-reported view on vegetation from the living room window") to green ("extremely vegetation view") in 5 steps.

Figure 6. The chance of being at least moderately annoyed (self-reported) by environmental noise versus the self-reported view on vegetation from the living room window (on a 5-point categorical scale with 1="extremely green", 2="very green", 3="moderately green", 4="some green", 5="no green at all"). The open circles are the data from the survey, the squares connected with full lines are the predicted results (logistic regression); the dashed lines indicate the 95% confidence intervals on the predictions.

Figure 7. Example photographs, taken from the front door of the respondent's dwelling, facing the street. Road segments having a low, a moderate and a high green percentage are shown. On the left, the original photographs are depicted. On the right, the corresponding photographs are shown, with only the pixels that were identified as green retained.

Figure 8. Scatter plots and best fitted line between the percentage greenish pixels in the front-door photograph and the self-reported view on vegetation by the dwellers as seen through the living room window (on a 5-point categorical scale with 1="extremely green", 2="very green", 3="moderately green", 4="some green", 5="no green at all"). The dots indicate the data points, the full line is the regression line and the dashed lines indicate the upper and lower 95 % confidence intervals on the regression line.