Environmental exposure – annoyance relationships in black and gray urban areas

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It is quite seldom to find individuals who are only annoyed by a single type of urban environmental exposure, and extremely rare to find individuals that cherish or complain about only a single aspect of urban living quality. In black and gray urban areas exposed to high and intermediate noise levels, people are usually multi-exposed and react adversely to more than one type of environmental exposure. Nevertheless, different classes of exposures and aspects of urban life are often studied in isolation, and exposure-annoyance relationships estimated separately and with disregard of urban context. Measures to reduce and alleviate the various quality of life impacts are also often undertaken by authorities focusing on one type of exposure at a time. In this paper we summarize some results and insights from Norwegian socio-acoustic and socio-environmental research containing elements of a broader conceptual framework.

INTRODUCTION

In the 1996 EC green paper on noise exposure and the cost to society defined three noise exposure classes (EC 1996). Black areas that have an equivalent exposure level of L_{den} above 65 dBA, gray areas levels lie between 55 dBA and 65 dBA, whereas green areas have noise levels below 55 dBA. According to the EEA 60 % of the EC population exposed to more than 55 dB live in gray areas (EEA 1999). This is somewhat less than the ca. 70 % estimated in the Green Paper –See Figure 1.

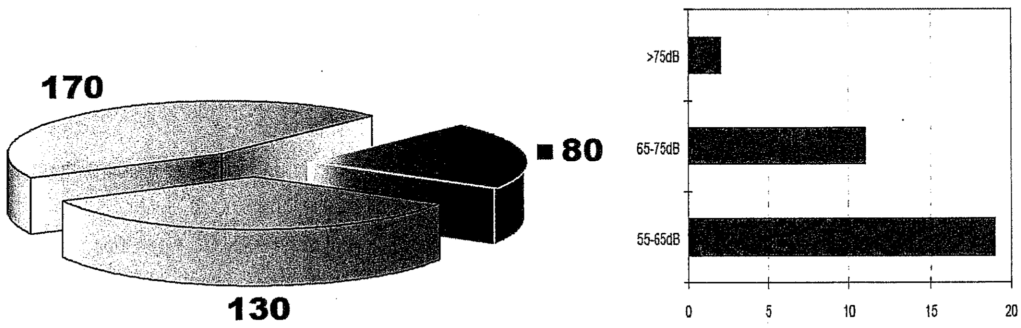

Figure 1: Share of citizens in different exposure intervals (L_{den}), EC 1996, EEA: http://www.eea.europa.eu/data-and-maps/figures/estimated-percentage-of-population-exposed-to-different-road-trafic-noise-levels

Both The Netherlands and Norway have information on the changes in population noise impacts over time (Berg 2011; Statistics Norway 2007). With the caveat that there are several methodological challenges in comparing noise exposure over time, both sets seem to confirm the finding in the EC 1996 green paper that "*the numbers of those acutely exposed are decreasing but the overall problem is getting worse*". Modern policies to reduce noise in urban areas thus need to address noise problems in gray areas. I argue here that this means taking more of the urban context into account and to cherish the benefits of reducing annoyance for all citizens -- not only those severely annoyed.

NOISE EXPOSURE AT THE FACADE NOT SUFFICIENT

Exposure-annoyance curves for road traffic noise employing the noise level on the most exposed facade of an apartment or dwelling show a consistent increase in annoyance with increasing exposure (Miedema & Oudshoorn 2001). However, the spread of annoyance responses for a given exposure interval e.g. 60-65 dBA is great - See Figure 2 Left panel. It is well known that individual noise sensitivity is uncorrelated with noise exposure and has an impact equal to that of 10 dB. However, when noise sensitivity is entered as a simple moderating factor in exposure--annoyance relationship models each sensitivity group exhibits the same (horizontally shifted) spread in responses. We must consequently look elsewhere if we want to explain more of the variability in annoyance responses at a given level of noise exposure. In this paper we focus on urban situations where people seldom are only exposed to one environmental exposure. The Norwegian Survey on Life Quality feature questions on a few additional exposures such as dust and grime and exhaust/odor in addition to noise from road traffic, rail traffic and aircrafts. Most respondents are at least a little annoyed from at least one other exposure. About a quarter of the population are highly annoyed by two or more exposures – see Figure 2: Right panel (Kolbenstvedt & Klæboe 2002).

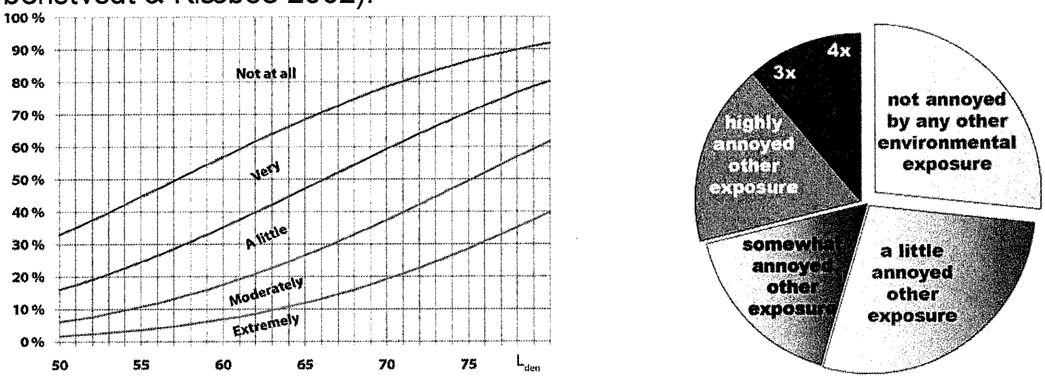

Figure 2: Left panel Exposure annoyance relationships (based on (Miedema & Oudshoorn 2001). **Right panel:** Number of annoyance combinations reported in social survey

In this paper we collate results from Norwegian papers, some published in air pollution journals, on contextual factors such as vehicular air pollution exposure and neighborhood noisescapes and their impact on noise annoyance For a recent review of international studies on the impact of combined agents – see Lercher (2011).

THE NORWEGIAN STUDIES

The Norwegian research program "Traffic and the Environment" started 25 years ago and lasted 20 years. The prime motivating factor for its unique design was to view noise, air pollution, insecurity, and barrier effects from road traffic as a whole. Studying air pollution annoyance met opposition. It broke with the traditional focus in the field of air pollution epidemiology of concentrating on more narrowly defined health effects (Evans et al. 1988), and the calculated values of the indicators of the exposures in question (NO_2, PM_{10}) were deemed insignificant/difficult/impossible to perceive.

The studies revealed that people become annoyed from air pollution, and respond to ambient air pollution by keeping doors and windows shut, and by refraining from using their balconies or outdoor areas. They visit parks and venture outdoors less often than they otherwise would. These are the same type of behavioral adaptations or coping activities exhibited by residents exposed to noise.

Exposure-annoyance relationships relating annoyance with indicators of NO_2, PM_{10}, and $PM_{2.5}$ were subsequently established for the first three surveys in the Oslo Area Klæboe (Klæboe et al. 2000) and thereafter expanded with two follow up studies in the city of Drammen (Amundsen et al. 2008).

All exposure-annoyance relationships for air pollution annoyance display narrow bands of error with respect to average population responses – see Figure 3. The exposure indicators in these studies were 3 month averages based on hourly calculations using actual meteorological data (e.g. that the wind direction is such that air pollution from a busy street during the rush hour affected a given dwelling location). The calculations were checked against measurement station time series (Clench-Aas et al. 2000). The indicators are here all used as indicators of the ambient pollution mix. It should be noted that though the average pollution indicators were highly correlated and also correlated well with the 98-percentile exposure indicators. The narrow error bands from the multi-year/multi-site study - see Figure 3 top and bottom left panels -- indicate that these air pollution component indicators must be well correlated with those air pollution components actually causing the annoyance.

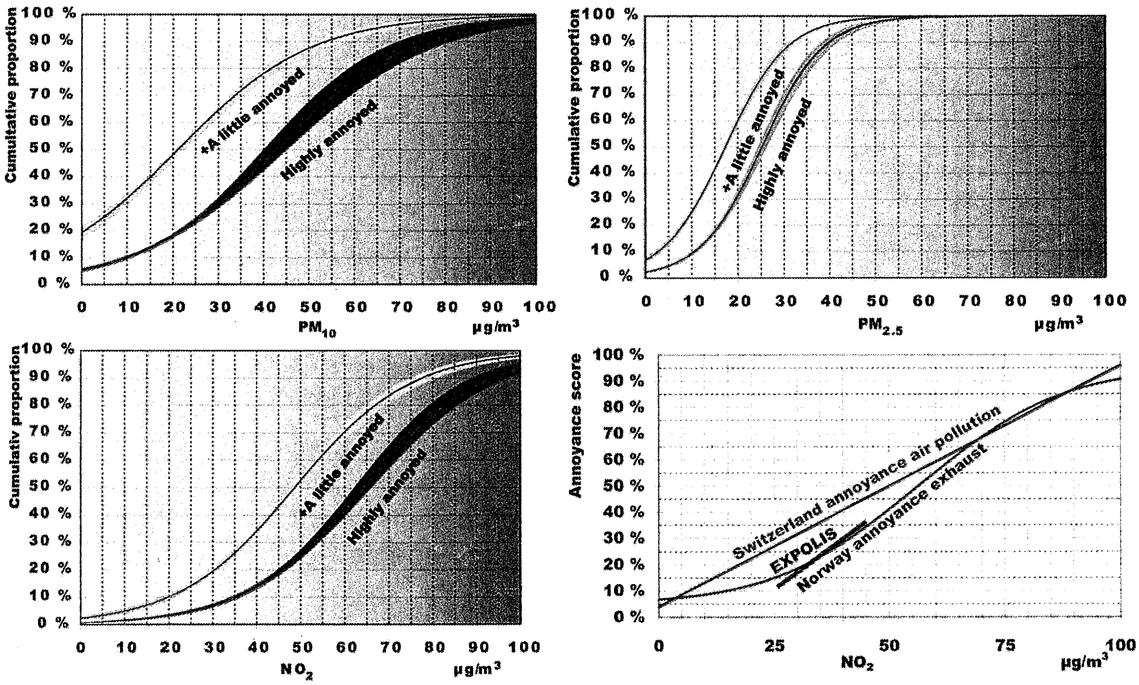

Figure 3: Exposure--annoyance relationships for NO2, PM2,5 and PM10 (Amundsen 2008). Comparison of European annoyance score results) - lower right panel (Klæboe 2008)

There are relatively few European studies that specifically look at residential annoyance with air pollution. However, the estimated exposure-annoyance relationships from these studies are roughly similar (Atari et al. 2009; Forsberg et al. 1997; Jacquemin et al. 2008; Klæboe et al. 2008; Modig & Forsberg 2007; Oglesby et al. 2000; Rotko et al. 2002).

Having established that people's annoyance with dust/grime and exhaust/odor are intimately linked to ambient air-pollution levels in urban areas, the next question is whether annoyance with air pollution could affect people's reactions to noise and vice versa. We need to examine the correlation between noise and air pollutant indicators, and, if possible, statistically analyze whether there are combined impacts.

Combined impacts of noise and air pollution

People near busy roads can be shielded from noise by having a dwelling that faces a courtyard or a silent side. These apartments will none the less be exposed to relatively high air pollution exposure levels. Vice versa -- dwellings located on the front side of a house very close to a road with moderate traffic, can have relatively high noise exposure due to the closeness to the traffic whereas the local contribution of vehicular emissions to overall ambient air pollution concentrations is negligible. In addition there are regional and climatic factors that affect air pollution and not noise. In the Oslo studies it was concluded that the correlation between noise exposure and air pollution was not very high (50 %). The low correlations are ideal for using multivariate regression models to separate the impacts of noise and air pollution and study their interaction.

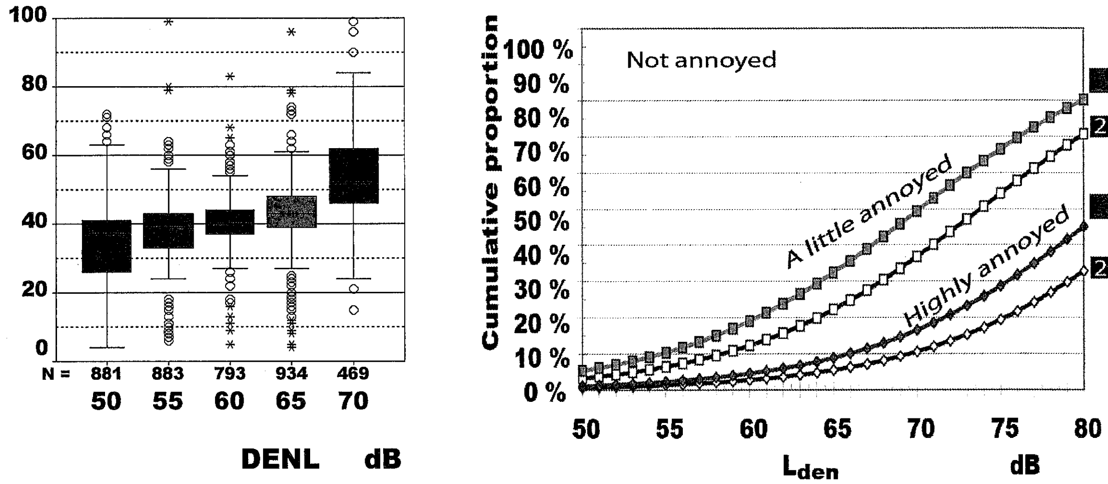

Figure 4: Variation in air pollution exposure for different noise exposure intervals.The estimated modifying effect of higher levels of air pollution (Clench-Aas et al. 2000; Klæboe et al. 2000).

From the Oslo studies the conclusion from such multivariate regression models was that *"... the higher the road traffic noise levels people are exposed to, the more likely they are to be highly annoyed by exhaust smell at a specified air pollution level. The higher air pollution levels people are exposed to the more likely they are to be annoyed by road traffic noise at a specified noise level." (Klæboe et al. 2000)*

The Neighborhood noisescape

In soundscape research the focus has been on public and private areas with relative quiet, and where sound quality, and not only the amount of noise, matters. We can perhaps better use the term dwelling "noisescape" to describe the spatial distribution of high levels of noise in the immediate vicinity of an apartment and apartment residents encounter when walking, cycling, playing, waiting for public transport, visiting neighbors, shopping locally etc.

The focus in the Norwegian studies was on arterial or ring roads that cut through residential areas with courtyard building structures. Here the noise levels in the neighborhood can vary a great deal over short distances. (Klæboe 2007; Klæboe et al. 2005, 2006).

Utilizing information from noise calculations on the emissions affecting sidewalks and outdoor areas, and spatial routines of geographical information systems it was possible to ascertain how much noisier or quieter the noisescape was in relation to the single point residential exposure indicator (Klæboe 2007; Klæboe et al. 2005).

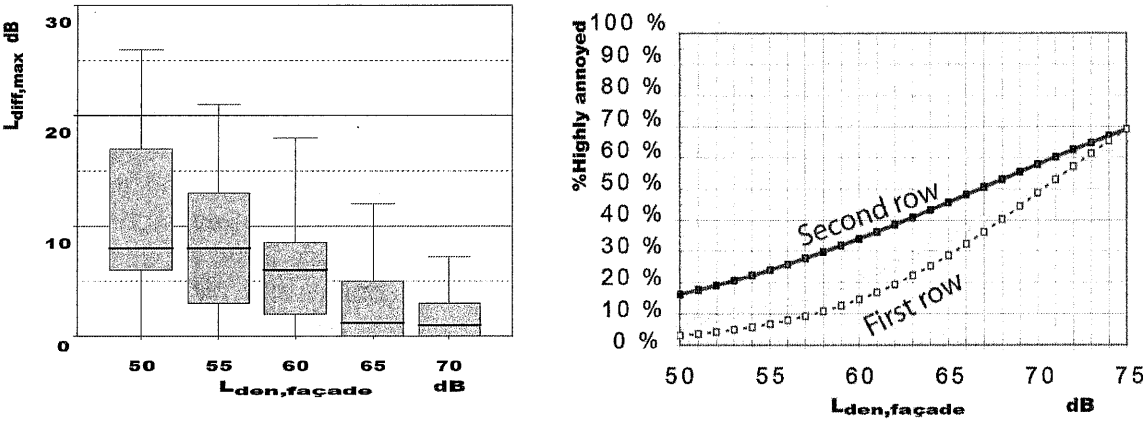

Figure 5: Box plots of how much noisier the neighborhood is relative to the noise level at the apartment (Klaeboe et al. 2005). Exposure effect relationships for front row and second row apartments

That the neighborhood soundscape can vary quite a lot for apartments having the same exposure on the facade is evident from Figure 5. Dwellings facing a side street or court yard that benefit from the shielding provided by the intervening buildings, are still left with a neighborhood noisescape that is worse than the matching front row situation with less traffic. In the former case the exposure indicator is a bad indicator of the relevant noisescape. In the latter case the noisescape conforms more to what could be expected from the facade exposure indicator.

Dwellings or apartments exposed to a high noise level on the facade usually have a noisier neighborhood than those exposed to lower levels. This average relationship is captured by exposure-annoyance relationships used in the EC (Miedema & Oudshoorn 2001). However, the impact of having a noisier or less noisy neighborhood than usual will not be captured. From the results of multivariate regression models it can be shown that annoyance for second row situations lies above that when the dwelling is in a front row situation -- see Figure 5 - right panel. The advantage of taking the noisescape into account when assessing noise annoyance, is estimated to be "worth" the equivalent of a 3 dB exposure adjustment to the facade exposure indicator for more than 30 % of the dwellings (Klæboe 2007; Klæboe et al. 2006) .

For noise mitigation policies in urban areas the difference in annoyance reactions depending on the contextual influence of the dwelling noisescape means that more (not less) of the urban noise problem is associated with busy roads cutting through residential areas, and consequently that traffic management, silent road surfaces, and noise screens have two separate beneficial effects:

A) They reduce the noise levels on the facades (taken into account today).

B) They improve the neighborhood soundscape of dwellings in the second and third row more than is captured by the change in facade exposure indicator.

It becomes more attractive to reduce noise along densely populated urban streets with courtyard buildings than areas where front row situations are more common.

Changes in noise annoyance reductions after traffic changes

When the amount of traffic changes, not only do noise emissions change, but air pollution levels, vibrations, and the dwelling noisescapes change as well. To the degree that these changes are of the same size as those usually associated with changes in the level of traffic they are already captured in average exposure effect relationships. A "noise" exposure indicator is representative of all factors correlated with traffic - not only noise on the facade. Why then do reactions to noise exposure change when traffic changes (Brown & van Kamp 2009).

The answer provided by the Oslo Studies is that the relative quality of the neighborhood and air quality improve more than what could be expected from the facade noise changes - see Figure 6 left panel for a visual illustration of the improvement in noisescape. Here the facade exposure is held constant, allowing us to examine the change in the relative quality of the noisescape. In addition to the noise reductions affecting the dwellings, the noisescape associated with a given exposure on the facade has been improved.

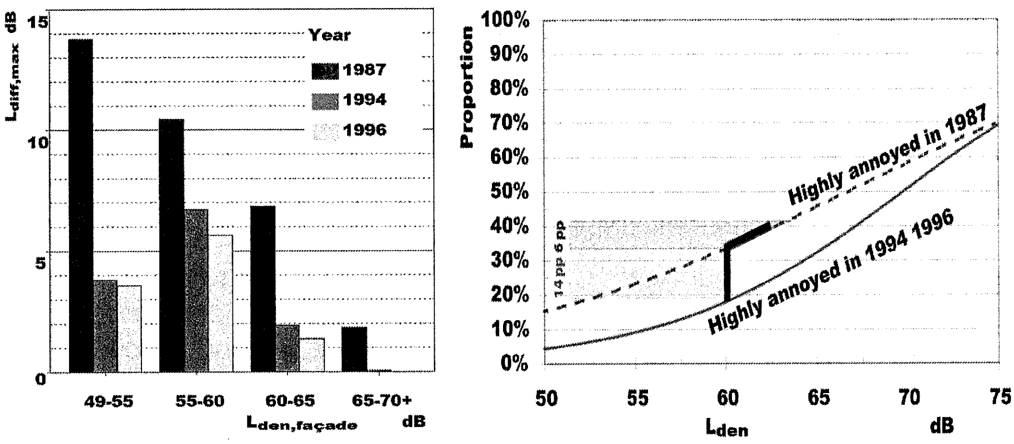

Figure 6: How much noisier the neighbourhood of dwellings in different 5 dB exposure intervals, are before and after traffic changes. **Right panel** changes in noise annoyance after traffic reductions Based on: (Klæboe et al. 2000, 2005) respectively.

From the Oslo studies it became also clear that the changes in the exposure to air pollution also changed more after traffic reductions than could be expected from the noise changes. The changes in traffic affected the whole surrounding area, not only the particular street responsible for the noise emissions. This had a larger effect on overall air pollution levels than noise. The size of annoyance reductions after traffic changes thus consists of two components:

1. The reduction that could be expected from the curve for the before situation, and
2. The downwards shift in exposure-annoyance relationship due to the air pollution and noisescape improvements in the area – see Figure 6 Right Panel.

Should we only count citizens that are seriously annoyed?

Due to the size of the gray areas, the metrics for counting population annoyance is important. The Norwegian noise annoyance index (NAI) counts population annoyance by applying exposure--annoyance relationships to national noise mapping data. Each citizen's degree of annoyance is given an annoyance score on a scale from 0 to 100 % and the total population annoyance obtained by aggregating. Two persons 50 % annoyed count as much as one 100 % annoyed. I have previously argued that this puts too much weight on lower degrees of annoyance (Klaeboe 2011).

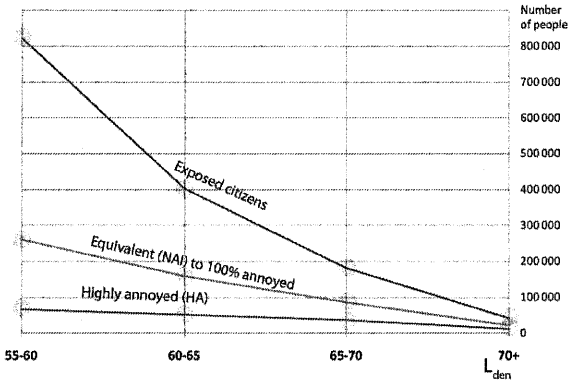

Figure 7: The number of exposed citizens, Norwegian noise index (NAI) and number highly annoyed by noise exposure. National noise mapping (Statistics Norway 2007)

However, it is possible to go too far in the opposite direction. Counting only people who are seriously/highly annoyed, neglects the substantial adverse effect road traffic noise has on people's daily life in terms of sleep, rest, and activity interferences (also present at noise exposure levels below 55 dBA). People who are moderately annoyed experience noise qualitatively in much the same way as those seriously annoyed. All exposure--effect relationships for annoyance and activity interference show the same gradual continuous slopes with increasing exposure.

A probabilistic understanding of how ill health in gray areas come about - as the result of the interaction between individual disposition, physiological variability, and multiple stressors across different life arenas, argues against using a severity index of zero for other than those seriously annoyed.

An unintended consequence of confining the WHO health definition to only include severe annoyance - for a discussion see Hollander (2011) - is that efforts to reduce noise exposure in gray areas will be viewed as less effective. Traffic management, efforts to deploy silent road surfaces, measures to reduce the propagation of noise by noise barriers, surface treatments or vegetation will seem to have fewer benefits than they have, and it will be become more difficult to motivate their deployment. Focusing only on those who are highly annoyed could thus be of disservice to the very group one seeks to protect the most.

CONCLUSIONS

Noise control policies in black areas have met with some success, and – due to the European Noise Directive and the Soundscape movement, there is a new vigor in the efforts to protect and improve sound quality in green areas. However, there is also a case to be made for modern noise control policies specifically addressing noise in conjunction with other environmental impacts in gray areas. To do so successfully, it has been argued here that it is necessary to view noise exposure and noise impacts in a broader urban context. It could be further argued that since gray areas are the typical situation facing urban planners, research to produce tools and methods for dealing successfully with multisource and multi-exposure situations must also be a priority.

Adopting a more holistic perspective on urban exposures improves the chances of undertaking successful interventions, and sharing the cost of these among all groups benefiting from measures. Traffic management and traffic reductions produce multiple benefits as do green walls, roofs, and vegetation. Counting all types of benefits – not only noise reduction at the façade, and valuing both larger and smaller benefits cannot other than improve the chances of more being done to improve life quality and health of European citizens.

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