Higher sound classes possible also in areas with traffic noise, combining high façade sound insulation with fresh air supply and efficient thermal control

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ABSTRACT
Sweden has recently introduced a new governmental regulation that allows dwellings close to noisy roads, railways and industries. However, the buildings must then provide at least one so called "quiet side", which is defined as a façade with $L_{Aeq,24h,freefield} \leq 55$ dBA, corresponding to a $L_{DEN}$ of about 58 dBA road traffic noise. However, looking close to the results of some questionnaire surveys, it becomes apparent that their results may be interpreted in a new way. The role of the façade sound insulation seems to have been systematically underestimated, as well as the effects of poor indoor air quality and over-temperature. If dwellings would provide high sound insulation in the façades as well as clean air supply and comfortable temperature at all times, occupants would not be forced to sleep with their windows opened and therefore not need a quiet side to the same extent. Thus, such buildings could provide satisfying indoor noise conditions also in areas with heavy traffic in all directions, where no quiet side can be realized. However, there should still be outdoor areas designed for social activities and rest that are easily accessed, e.g. on top of the roof or in a nearby space. These conclusions will be suggested to the working group ISO TC 43/SC 2/WG 29, working on a new international standard on sound classification of dwellings (ISO/NP 19488).

Keywords: Traffic noise, façade insulation, indoor environment 51.3 51.6 52.3 52.9 63.2 66.2 69.5

1. INTRODUCTION
The Swedish Ordinance 2015:216 requires residential buildings in noisy locations to be designed such that at least half of the residential rooms face a less noisy side. Single-sided apartments are not permitted if they face a direction where the sound pressure level exceeds $L_{A_{eq,24h,freefield}} \leq 55$ dB (60 dBA is accepted for small apartments, e.g. student dormitories). The purpose of these regulations are to allow occupants to keep at least some windows slightly opened during warm days to ventilate the dwelling without being disturbed by excessive noise. This level is certainly higher than assumed as a quiet side or silenced side in recent research, where 45-50 dB would be considered merely a “less noisy side” rather than quiet. However, quiet sides are impractical to implement in many locations, e.g. where there is not enough space or where higher buildings must be used. In this paper, complementary requirements are suggested that would provide at least the same level of health protection. They would allow more efficient and less expensive designs of the buildings in noisy locations, also where the present regulation prohibit dwellings to be built.

2. PROPOSAL FOR AMENDED REGULATIONS
2.1 Basic principles
The following principles are considered for the proposal, based on reasons explained later in this paper:
• Dwellings and their service equipments shall be designed so that occupants can work, socialize, listen to the TV / radio / music, recover and sleep without being disturbed by noise in their homes.
• The noisier it is on the outside, the quieter it should be inside the dwellings, to facilitate rest or sleep.
• Occupants should have access to well-designed patios outdoors, for recreation and relaxation.
• The dwellings shall be ventilated with fresh air of good quality, normally through filters.
• The dwellings shall be protected against over-temperatures, so that occupants are not forced to open the windows except for technical purposes, e.g. cleaning and maintenance.

2.2 Specific acoustic, temperature and air quality requirements
• Dwellings exposed to traffic noise below 55 dBA on all sides shall fulfil the basic requirements of SS 25267 sound class C, i.e. maximum $L_{pAeq,24h}$ 30 dB and $L_{pAFmax}$ 45 dB in habitable rooms, free field.
• Dwellings exposed to traffic noise above 55 dBA, where there is access to a “quiet” side (less than 50 dBA) from at least 50% of the residential rooms, shall fulfil all requirements of SS 25267 sound class B (4 dB stricter than class C, maximum $L_{pAeq,24h}$ 26 dB and $L_{pAFmax}$ 41 dB traffic noise, free field).
• Dwellings exposed to traffic noise above 55 dBA, without any access to a quiet side, shall fulfil all requirements of SS 25267 sound class A (8 dB stricter than C, i.e. maximum $L_{pAeq,24h}$ 22 dB and $L_{pAFmax}$ 37 dB traffic noise, free field).
• These requirements are supplemented by specific requirements on sound insulation at low frequencies of façades facing sides where the traffic noise exceeds 55 dBA, ranging from 31 Hz to 200 Hz.
• At least one outdoor space for recreation and socializing with $L_{pAeq,24h,freefield} \leq 50$ dB and $L_{pAFmax,freefield} \leq 70$ dB must be easily accessed from all dwellings, e.g. balconies, common roof terraces or common playground gardens adjacent to the building.
• All bedrooms and living room facing a noisy side ($\geq 55$ dBA) must be ventilated with fresh air and protected against over-temperature ($T \leq 26$ °C at all times), with the windows closed.
• At least one window in each room shall be openable, e.g. for short-term ventilation, cleaning etcetera.
• The area in front of the building entrance shall be silenced, e.g. with screens or special road surfaces.
• The verification of the requirements of the building shall be rigorous and no deviation accepted in locations where the traffic noise exceeds 55 dB at one side or several sides. Building design and construction work should be checked regularly during the project period to ensure the requirements will be fulfilled.
• A mandatory follow-up shall be made after 2 years, using a standardized questionnaire distributed to all occupants and evaluated by an independent party. If the survey shows that more than 20% of the occupants are very disturbed by the noise, relevant measures must be undertaken to reduce the noise exposure.

3. Relations between indoor environment descriptors and health effects

Several researchers criticized the Ordinance 2015:216, saying it will put occupants health at risk. Broad epidemiological studies in several countries point to considerable health risks related to noise exposure. In spite of this knowledge, the new ordinance implies that new dwellings will be erected, exposing habitants to high noise levels as well as pollutions from heavy road traffic.

3.1 Noise

Studies on the relationships between noise, disturbance and ill-health have typically been based on extensive epidemiological studies and questionnaire surveys. More recently, more attention has been paid to the relation between different health descriptors and sound levels outdoors, which among other things has enabled calculations of statistically significant disturbances of sleep and elevated risks for cardiovascular diseases and others. Overviews, see the article by Babisch (1) and the report by Öhrström et al in the so called “TVANE” project (2).

In some recent studies, perceived annoyances/disturbances (self reported in questionnaires) have been statistically correlated to exposures in terms of A-weighted sound levels outdoors. These sound levels were determined by measurements or calculations at discrete locations under the assumption that they would represent all dwellings being included in the survey. Subdivisions of the results, e.g. for various façades or intervals of sound level have not been made since it has been considered too difficult to distinguish such groups of data without having a too large statistical uncertainty in the results.

Noise health effects are long term, where "incubation periods" may be 20-30 years. A reasonable question to the government is then “How do you know whether this change of rules can be justified without increasing the risks of health effects?” It is also of vital importance to ensure a satisfying
"soundscape" where the occupants stay, including their workplaces and routes of public transportation. A good outdoor environment can contribute to people’s physical and mental recovery process, which is assumed to provide several health benefits. A WHO report addresses the situation of major cities and points out that traffic noise causes a number of lost healthy life years (so called DALY:s), using the example of 66,000 DALY:s only in Paris, with similar figures for London.

However, a finding that came as a shock to the author of this paper is one underlying assumption in these studies: **The indoor levels have not been documented in those studies.** It seems to have been obvious to the researchers, that the façades would provide sufficient sound insulation, especially since energy conservation has promoted the use of multi-layered glass units. It is likely to be true that existing Swedish dwellings indeed are built with satisfactory sound insulation – for the traffic conditions at the time of construction. But all types of traffic has increased in intensity, especially during the nights. Measures to improve both the heat and sound insulations, e.g. replacement of windows or adding more glass panes, have increased the sound insulation merely at mid and high frequencies, but rarely at low frequencies where the heavy traffic emits the most energy. In many new building projects, heavy and thick windows have been used to reach 4 dB lower sound levels indoors than the minimum requirements. The assumption of satisfactory sound insulation in the existing residential building stock may therefore be questioned.

### 3.2 Temperature and air quality

The influence of combined exposures to noise and air pollutions has not been studied to the same extent as for noise alone. However, it is reasonable to assume that if the occupants are forced to sleep with their windows opened to cool down their bedrooms throughout the warmer part of the year in spite of noisy traffic outside, then this cannot be a sustainable solution with respect to long term health effects. The Swedish building regulations prescribes supply air to be taken from a side of the building without traffic, or the air shall be filtered before it is supplied to the dwellings. Airing in open windows can be a complement and provide a sense of freedom and contact with nature, but it should not be the only way to avoid having a stuffy and hot indoor climate. Also some new buildings with efficient thermal insulation have problems with overheating during long periods, which should lead to changes in the building regulations.

The National Board of Housing, Building and Planning (Boverket) made a major study in 2007 of the energy consumption and indoor climate in swedish detached houses as well as multi-family buildings (BETS1). The results of questionnaire surveys showed that about 70% of the occupants reporting annoyance from traffic noise also feel they have to keep their windows open because of over-temperatures and/or poor air quality. The air exchange rate is typically not satisfactory in older housing; they lack mechanical air handling (i.e. there are no exhaust fans). Noise could possibly be tolerated if it is necessary to cool down the dwelling during the hottest periods, but ventilating the room for fresh air might in many buildings be necessary at all times. Letting air to come from the noisy side may be a risk factor, since it may contain pollutions and particles from the vehicles. Thus, air intake should be placed at another side of the building and the air filtered if necessary. This means open windows should not be an acceptable means of ventilating habitable rooms in dwellings in noisy locations. So called noise attenuated ventilators, various types of glass screens in front of the façade etcetera do not solve the pollution problem and should not be used in such locations, unless complemented by mechanical ventilation and/or cooling systems.

Over-temperatures must be avoided in locations where the rooms cannot be cooled through open windows. The temperature in bedrooms should be low and never exceed 26 degrees Celsius. At such temperatures, the speed of supply air may exceed 0,15 m/s, which implies that forced airflows may be used to cool down the dwelling. Such systems might certainly consume more energy, which is unwanted, but various types of sun screens, heat exchangers, heat pumps, cooled ground water, heavy building materials etcetera may be used to respect the energy conservation aspects.

### 4. DISCUSSION OF SOME QUESTIONNAIRE STUDIES

#### 4.1 Annoyance related to noisy and quiet sides

The present minimum requirements on the sound insulation of façades state they should provide indoor sound levels lower than $L_{\text{P}_{\text{Aeq},24h}}$ 30 dB and $L_{\text{PA} \max}$ 45 dB during yearly average traffic conditions. As pointed out by some researchers and consultants, a common misunderstanding is that these requirements would provide silence in habitable rooms. This is not correct, traffic noise will
still be clearly audible and they may even disturb social activities, rest and sleep to some extent.

Having a bedroom facing the back yard rather than the busy street at front may provide a substantial difference in annoyance, as illustrated by Figure 1. This figure was published in a report on traffic noise and health effects by the Swedish national board of health and welfare (Socialstyrelsen).

![Figure 1](image-url)

**Figure 1** – Fraction of occupants (ranging from 0.0 to 0.7) being disturbed by road traffic noise in their homes at least once per week, at various noise levels described by \( L_{DEN} \) (day-evening-night equivalent A-weighted sound pressure levels on the outside, ranging from 40 dB to 75 dB). The descriptor \( L_{pAeq,24h} \) is typically 3 dB lower than \( L_{DEN} \). *Captions:* –Δ– denote rooms with windows facing a major road, –o– denote rooms with windows facing a quieter side without a major road. From ref (5).

The substantial difference between rooms having a window facing a noisy side or a quiet side implies that dwellings designed to allow rest and recovery should hardly allow any audible sound to penetrate the façade, or at least limit the traffic noise indoors to much lower levels than are currently permitted by the building regulations. Maximum acceptable levels should rather be in the order of \( L_{pAF,30-35 dB} \), i.e. at least 10 dB stricter.

### 4.2 The Partille intervention study, before and after reduction of noise exposures

A major refurbishment project in the Swedish municipality of Partille (near Gothenburg) has been studied with respect to the effect of noise reduction measures. Researchers at the University of Gothenburg have studied the occupant’s annoyance and published two questionnaire studies.

Before the buildings were reconstructed, they contained several small dwellings having all windows facing the busy E20 highway. Those dwellings were then merged into fewer and larger dwellings. They were also equipped with new and highly insulating windows facing the highway and new windows facing the quieter back yard. The gaps between the buildings were filled up with new dwellings, which were expected to improve the noise shielding and turn the back yard into an almost quiet side. Screens of about 4 m height were constructed on the front side between the E20 highway and the façades. Figure 2 illustrates the buildings and the road traffic noise screens.

Questionnaire studies before (2004) and after the reconstruction (2009) indicate the annoyance caused by traffic noise had then been reduced considerably, but the outdoor environment was still not as quiet as intended. The \( L_{pAeq,24h} \) were reduced from 71 dBA to 63 dBA in front of the windows of the second floor of buildings A to D, but less reduction was achieved at the third and fourth floors.
Behind the buildings, on the back yard, the resulting sound levels were approximately 48 dBA (free field, 1.5 m above ground level), which were 3 dB above the target level 45 dBA. This was however a major improvement compared to the noise levels before the refurbishment.

Figure 2 – The Partille Study. Refurbished buildings with new and highly insulating windows and a 4 m transparent noise screen in front of the busy highway E20. The light coloured façades belong to new dwellings, improving the screening effect of the buildings and reducing the noise on the backside. From ref (7).

Figure 3 illustrates the effect of the refurbished constructions on the perceived annoyance of road traffic. The charts show the change of sleep disturbances (difficulties to fall asleep, being awakened by noise or having less quality of sleep). The red lines illustrate questionnaire results in buildings A-D before the refurbishment (in 2004) and the blue lines show the results afterwards (in 2009). Results from the other buildings show less improvement, which seems logical because the refurbishment measures did not change the sound exposure to the same extent as for the buildings A-D.

The fraction of occupants being disturbed by traffic noise when they talk to each other, listen to radio/TV or concentrate to work is reduced considerably after the refurbishment. However, there were still some occupants feeling disturbed by the fact they could still not have their windows opened on the noisy side.

As the Figure 2 shows, the noise screen is not high enough to block the sight of line from all lanes of the highway, which may explain why sound levels are still high on the higher floors. There are still gaps between a few buildings, which allow noise to reach parts of the backside. It may be assumed that further improvements with a higher screen, closing of the remaining gaps and establishing a more attractive garden or a playground on the backside would improve the outdoor environment even more. This would be highly interesting to study in the future.

Another question that may be raised is whether all types of “disturbance” should be considered equally important with respect to their impact on health of the occupants. In Sweden, the cold climate makes people stay indoor except during nice summer days. Cold or rainy days, people stay outdoor mainly to travel to work, shop etcetera. During the warm periods, it is more important to have access to a quiet and attractive recreation area, preferably nearby the dwelling. Many cities offer parks or other recreational areas not too far away, but they should only be considered complementary to nearby outdoor areas for social activities and rest. Having the sleep disturbed during the night, either by noise or by over-temperature or poor air quality, should be considered a severe type of disturbance.
4.3 Some other studies

Amundsen et al have studied the influence of the sound insulation of the façades\(^8\), where refurbishments had been made and where indoor sound levels were reduced by 7 dB. The fraction of heavily annoyed occupants was reduced from 43% to 15%. The authors conclude: "...the effect of reducing indoor noise levels could be predicted from exposure-response curves based on previous studies". Their results indicate that reduction of noise indoors reduce the perceived disturbance to the same extent as a reduction of the outdoor sound would, at the same level of outdoor sound. If the façade insulation would not have been an important parameter, this would not have been the case.

The County Administrative Board of Stockholm has published several reports on questionnaire studies in residential buildings with various noise exposures\(^9\). The fourth report is a comprehensive summary of results and conclusions. The questionnaires were distributed to 3300 occupants in buildings constructed between 1999-2009, of which 72% responded. The fifth report is a detailed study on a few buildings exposed to very high levels (>75 dBA), to be published within shortly. The results indicate, that buildings fulfilling 4 dB stricter indoor requirements (sound class B) have a small fraction of annoyed occupants. The results also show that an unacceptable annoyance may be expected where only sound class C is fulfilled. The authors recommend stricter minimum requirements (class B) in buildings exposed to high levels. They also conclude that the level outdoors is not a major factor determining the annoyance if a quiet side is offered to the occupants,
preferably accompanied by other compensation factors. Thus, it should not be necessary to open a window to the noisy side in order to ventilate the dwelling, there should be windows facing the quiet side for this purpose. Also, noise shielded and attractive outdoor recreational areas seem to reduce the overall annoyance also in cases where the noise levels are high on the front side of the building. Older buildings without a quiet side, where noise has increased because of increased traffic load, have occupants being more disturbed by noise, in particular where the dwellings only have windows towards the noisy side. Hence, such buildings should be refurbished so that the noise exposure indoors is reduced.

5. CONCLUSIONS

The present Swedish ordinance prescribes that residential buildings close to noisy roads, railways or airports must offer a so-called quiet side, for the purpose of airing and cooling the dwellings during warm periods. It is suggested in this paper, that other solutions may be acceptable from a health perspective, where high sound insulation is combined with technical solutions to provide fresh air and avoid over-temperatures during warm periods, as well as outdoor areas nearby designed for recreation and recovery. Many studies have focused on the correlation between outdoor noise levels and general annoyance, but the studies discussed in this paper indicate that a high façade sound insulation does reduce the annoyance if cooling and air exchange is provided by other means than through windows opened towards the noisy side. Sound classification standards should provide rules for such designs, in particular for higher sound classes (above the minimum level).

ACKNOWLEDGEMENTS

The kind support of many colleagues is acknowledged, who have helped the author to understand published studies and to discuss new interpretations of those. The financial support of Skanska Sverige AB is also acknowledged.

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