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Experiences with sound insulating open windows in traffic noise exposed housing

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Sound insulating windows are widely used in traffic noise exposed residential areas to reduce indoor noise levels to acceptable levels. However, such windows are typically only designed to provide sound insulation in closed position, and many people prefer open windows parts of time for ventilation purposes, including during night, or simply because it's a good feeling to have windows open to be in contact with the surroundings. High noise exposure can lead to adverse effects on comfort and health, and thus, there is a need for sound insulating open windows to reduce noise exposure in homes, when windows are open, not least to reduce sleep disturbance. Unfortunately, such window solutions are complicated and expensive and practical experience limited. Nevertheless, they have been included in some Danish projects. To support further development and use, experience from seven field cases with different solutions has been collected, and additional field experiments have been carried out in a case with transparent external shutters with sound absorbing slits for ventilation along window sides.

It is concluded that occupants in general are satisfied with the solutions and further development for more general use is recommendable, but investigation of ventilation performance should be integrated in future research.

1 INTRODUCTION

Health effects of noise have been described in several publications published by WHO, e.g. explaining the adverse impacts on health of noise during night time in [1], and defining noise exposure in the home as one of the essential inequality indicators in society, see [2], which also refers to noise as an inequity indicator. Due to the impact of noise on health, the European Environmental Agency has analyzed the traffic noise situation and published a report “Noise in Europe 2014” [3], concluding that road traffic is the most dominant source of environmental noise with an estimated 125 million people in Europe affected by noise levels exceeding 55 dB L_{den} as defined in the EU Environmental Noise Directive (END) [4] and considered a limit value for a healthy environment. Of those, it is estimated that more 37 million people are exposed to

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noise levels above 65 dB L_{den} . The report also provides estimates for numbers of people being annoyed and for suffering from sleep disturbance, for premature deaths, for cases of hypertension and hospital admissions, all caused by road traffic noise.

Thus, there are good reasons to reduce traffic noise exposure, both in outdoor and indoor environments. For new housing, planning can prevent excessive noise exposure, but for existing housing, other tools are needed. Sound insulating windows are commonly used and are effective for reducing indoor noise, if windows are closed. However, to get rooms ventilated and due to the good feeling of open windows, there is a need for sound insulating open windows, i.e. windows that are considerably better than normal, open windows, although of course the sound insulation could never compete with the sound insulation of closed windows.

In a Danish project [5], field experiences with such solutions have been collected aiming at communication of results and providing recommendations for further development and wider use of the solutions. This paper describes experiences from two field cases, both from areas with a high traffic noise exposure. As the number of dwellings exposed to other external noise sources than road traffic is relatively small [6], the focus in the project and this paper is housing exposed to road traffic noise, although the results can be applied also for other noise sources.

2 ROAD TRAFFIC NOISE AND LEGISLATION IN DENMARK FOR HOUSING

Traffic noise limits are defined in the Danish building regulations (indoor limits), and planning values for outdoor areas in the environmental legislation, in both cases for new housing. The building regulations, BR2010 [7] specifies $L_{den} \leq 33$ dB, indoor traffic noise level. The MST Guideline 4/2007 [8] specifies road traffic exposure $L_{den} \leq 58$ dB at outdoor areas. However, in certain situations, e.g. when having a gap in continuous housing blocks in traffic noise exposed areas ($L_{den} > 58$ dB), it is considered better for the housing area to fill the gap with a new housing block, as this will reduce significantly the noise exposure in the areas behind the blocks. In such cases the conditions are (implying a tightening of rules enforced before 2007):

1. Outdoor level $L_{den} \leq 58$ dB at all outdoor areas for stay (not just primary areas as before).
2. Indoor traffic noise level $L_{den} \leq 46$ dB with windows open, each 0.35 m^2 .
3. Dwellings should never be built in areas with $L_{den} > 68$ dB.

The max level 46 dB has been determined as the indoor level for a typical window opened 0.35 m^2 and outdoor level fulfilling the limit $L_{den} = 58$ dB. Special solutions are needed to fulfil the criterion.

Noise mapping is carried out in EU countries every 5th year according to the END, [4], starting in 2007. An example from the national traffic noise mapping in Denmark in 2012 is shown in Figure 1. The example is related to the Folehaven case described in Section 3.

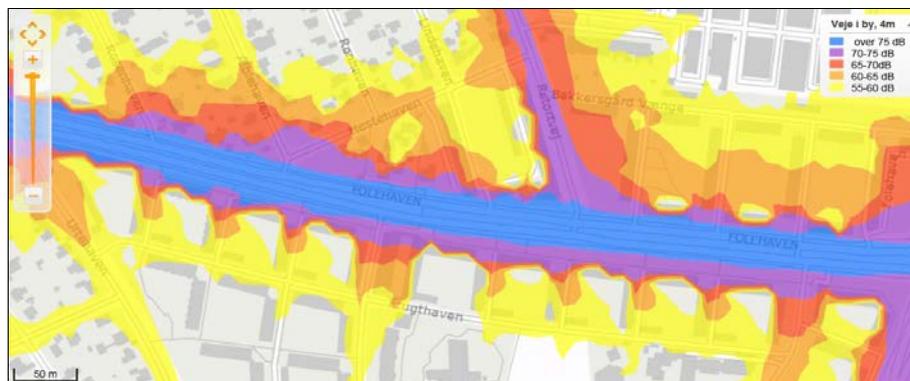


Fig. 1 – Example of traffic noise mapping 2012. The map shows noise levels along a regional road, Folehaven, in the Copenhagen area. Source: <http://noise.mst.dk> Example

The noise mapping of Denmark for 2012 [9] showed the following number of road traffic noise exposed dwellings:

- 723 000 dwellings are exposed to road traffic noise $L_{den} > 58$ dB, which corresponds to > 25 % of all Danish dwellings.
- 141 000 dwellings are strongly exposed with road traffic noise $L_{den} > 68$ dB, which corresponds to > 5 % of all Danish dwellings. Among these are 15 000 dwellings exposed to $L_{den} > 73$ dB.

The obligations of the EU member countries are according to END [4]:

- Informing and consulting the public
- Strategic noise mapping (2007, 2012, 2017 ff.)
- Action plans (2008, 2013, 2018 ff.)

Based on mapping results, action plans are prepared, aiming at reducing noise exposure. The ranked technical principles are: (1) to avoid and reduce noise at its source; (2) to reduce noise in its propagation; (3) to reduce noise at the receiver.

With 141 000 strongly exposed dwellings, $L_{den} > 68$ dB, and 15 000 dwellings of these exposed to $L_{den} > 73$ dB, facade sound insulation is needed, even after implementing traffic regulations, speed limits, noise reducing asphalt etc. In many of those situations, sound insulating open windows could be a useful tool to reduce traffic noise exposure indoor significantly, both when they are open and closed.

3 CASES AND FIELD MEASUREMENTS

This section describes two field cases, one with sound shutters mounted in front of existing windows, Folehaven, and the other one with a special ventilation window applied for student housing, Jægersborg Water Tower. The principles for the window types are illustrated in Figure 2.

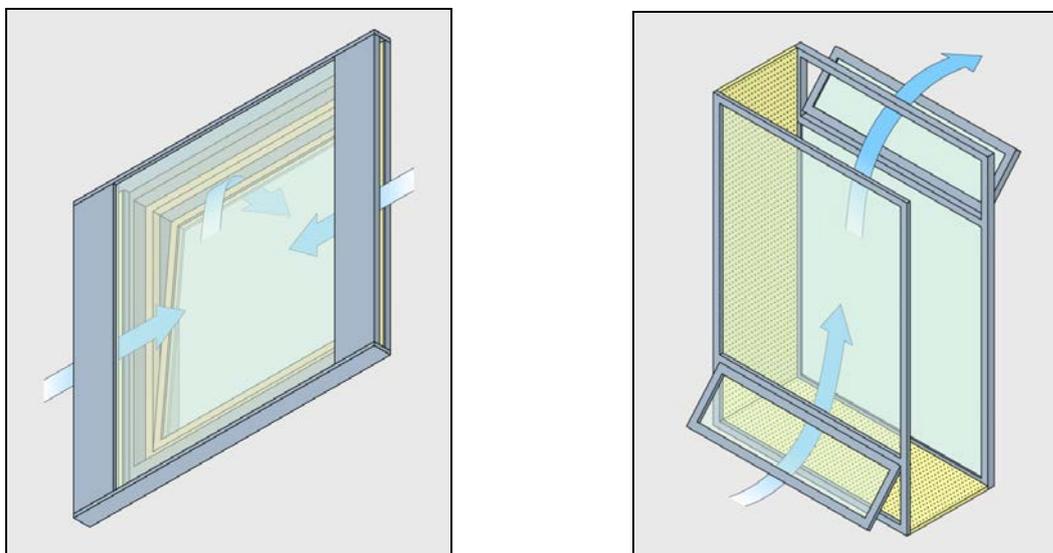


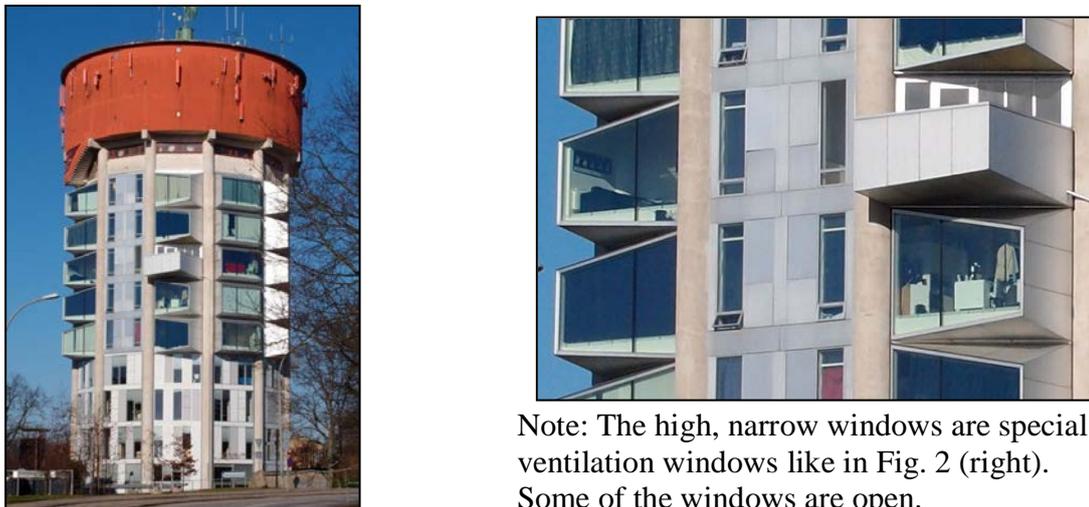
Fig. 2 – Principles of two different designs of special ventilation windows. The air flow is illustrated with arrows. Left window: Transparent external shutter with sound absorbing slits for ventilation along window sides. Right window: Ventilation window with an inner and outer glazing and sound absorbing materials mounted along all sides of the cavity. The window has a lower sash opening outwards and an upper sash opening inwards.

The sound shutters in Folehaven in closed and open position are shown in Figure 3. The ventilation area of the shutter slits is 0.14 m^2 , i.e. about 1/3 the area prescribed in [8]. The sound insulation R'_w+C_{tr} is 20 dB and 10 dB for the two situations, see Figure 5 (M02 and M05).



Fig. 3 – Housing in Folehaven. Left photo shows the sound shutter closed, and the photo to the right the open sound shutter. At both photos, the window is open (tilted inwards). An air photo is seen [here](#) (press top arrow to see the facade with the sound shutters).

In Figure 4 are found photos of the Jægersborg Water Tower with student housing. During the conversion in 2005, measurements of indoor noise levels were made, and the estimated results for L_{den} indoor were approx. 37 dB with closed window and 40 dB with open window, implying only 3 dB increase of indoor level with open window. However, opening area was 0.11 m^2 , i.e. about 1/3 of the required area for new housing according to the guideline [8] implemented in 2007. In another case reported in [10], the ventilation area was approx. 0.3 m^2 and the difference in indoor level for open and closed position more than 10 dB.



Note: The high, narrow windows are special ventilation windows like in Fig. 2 (right). Some of the windows are open.

Fig. 4 – Jægersborg Water Tower. The unused floors below the water reservoir have been converted to student housing. A noise map is seen [here](#). The water tower is approximately in the middle between two highways (blue) and a railway line (orange/red) crossing from southeast to northwest.

Included in the project [5], where other field cases also have been described, was an option for making field measurements. As the Folehaven sound shutter (ventilation area 0.1 m^2) seemed to be least documented and with potential for further development, field measurements were carried out with the window and shutter in different positions, see [5] or [11]. Some of the results are shown in Figure 5. Positions and opening of shutter and window are indicated at the diagram.

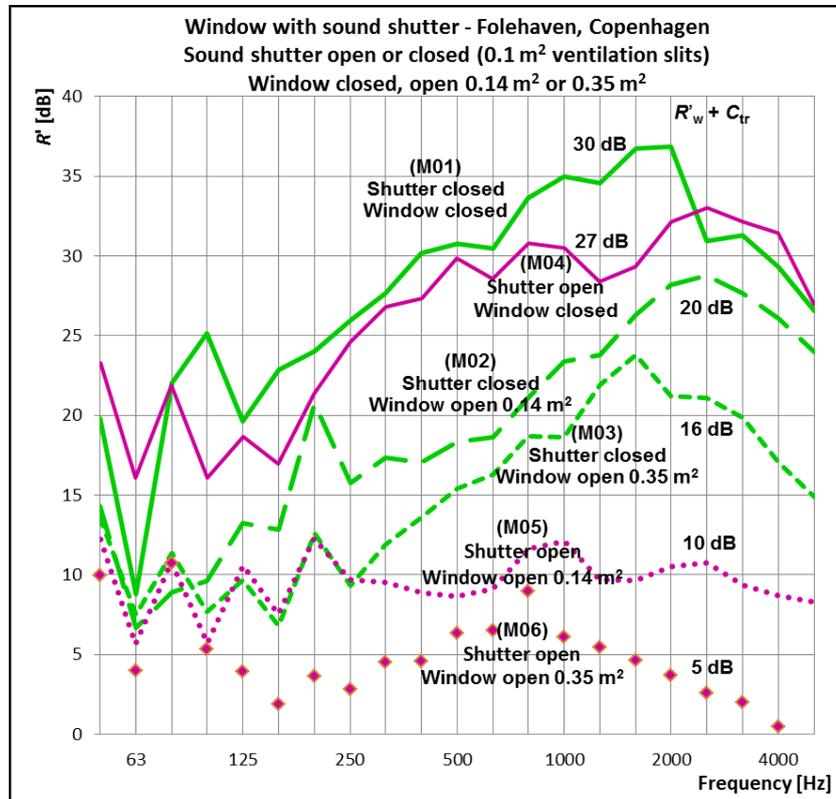


Fig. 5 – Sound insulation as a function of frequency for a window with sound shutter, both in different positions. Measurements carried out according to ISO 140-5 [12] with traffic as noise source and outdoor microphone mounted at the window, see [5].

The weighted values $R'_w + C_{tr}$ are determined according to ISO 717-1 [13]. As an example of comparison of results, it could be noted that with closed window, an improvement of sound insulation $R'_w + C_{tr}$ due to the shutter is only 3 dB (comparison of M01 and M02). However, with window open 0.14 m^2 (tilted), the shutter improves the sound insulation by 10 dB as mentioned in Section 3.

Additional experiments were made with the shutter installed temporarily (without possibility to move) in a position with ventilation area of slits being extended to 0.35 m^2 , thus fulfilling [8]. The sound insulation $R'_w + C_{tr}$ for the window closed and shutter was 29 dB. As expected, the sound insulation is reduced compared to M01 in figure 5 with smaller ventilation area of slits (0.1 m^2), but only 1 dB. However, as soon as the window is opened, the areas of the shutter ventilation slits become much more important. For example, with closed shutter and shutter ventilation area 0.35 m^2 , the sound insulation values for window opened 0.14 m^2 (tilted) and 0.35 m^2 (side-hung) become 16 dB and 12 dB, respectively, instead of 20 dB and 16 dB for shutter ventilation area 0.1 m^2 as in the original Folehaven shutter, see measurements M02 and M03 in the above diagram. - There is unfortunately no information available about ventilation capacity. If continuing development of sound shutters, such investigations should be included.

In Folehaven a questionnaire survey among occupants shows that people are very satisfied with the sound shutters, and some emphasize the significant improvement in quality of sleep.

4 COMPARISON INDOOR TRAFFIC NOISE LEVELS FOR VARIOUS OPEN WINDOWS

Both when designing new housing and improvement of existing housing with special sound insulating ventilation windows, the indoor noise level must be estimated. It is relevant to compare different window types and to calculate the indoor level with the actual number of windows. A simplified calculation of the indoor level L_{den} (indoor) = $L_{2A,nT}$ (standardized indoor level) for a window with area S and a room volume V can be made using the below equation from Reference Laboratory for Noise Measurements [14], eq. (2):

$$L_{2A,nT} = (L_{1A,freefield} + 3) - (R_w + K) + 10 \log ((S \times T_0) / (0.16 \times V)) \text{ [dB]}$$

$L_{1A,freefield}$ is determined according to [4] for the window position and $R_w + C_{tr}$ according to [13]. $T_0 = 0,5 \text{ s}$; $K = C_{tr}$, see [14], where the method and the symbols have been explained.

In Table 1, the values of the indoor level L_{den} have been compared for an ordinary, top-hung window and three different ventilation windows, all with opening area $0,35 \text{ m}^2$ fulfilling the requested area in Guideline 4/2007 [8]. To illustrate various situations from practice, the results are shown with four different outdoor levels and for two different room volumes. The situations fulfilling the limit 46 dB are marked in green.

Table 1 – Examples of indoor level L_{den} calculated for different open windows and room volumes. Condition: Sound transmission through ventilation window only

Indoor level L_{den} (dB) calculated for different window types - all with opening 0.35 m^2 XX = Outdoor level L_{den} (free field, [4]). Level difference outdoor-indoor are indicated in () Indoor levels: XX L_{den} max 46 dB fulfilled; XX L_{den} max 46 dB exceeded					
Room volume	Outdoor level L_{den} in dB	Ordinary top-hung window $S = 1,9 \text{ m}^2$ (1,25x1,50 m) $R_w + C_{tr} = 8 \text{ dB}$ Lab. test ⁽³⁾	Folehaven sound shutter moved out ⁽¹⁾ $S = 2,0 \text{ m}^2$ (1,32x1,5 m) $R'_w + C_{tr} = 12 \text{ dB}$ Field test ⁽³⁾	Special ventilation window ⁽²⁾ with sound absorber. $S = 1,9 \text{ m}^2$ (1,25x1,50 m) $R'_w + C_{tr} = 15 \text{ dB}$ Design-guide ⁽³⁾	Special ventilation window ⁽²⁾ with sound absorber. $S = 3,0 \text{ m}^2$ (1,25x2,40 m) $R_w + C_{tr} = 19 \text{ dB}$ Lab. test ⁽³⁾
Room 1 33 m^3	58	46 (12)	42 (16)	39 (19)	37 (21)
	63	51 (12)	47 (16)	44 (19)	42 (21)
	68	56 (12)	52 (16)	49 (19)	47 (21)
	73	61 (12)	57 (16)	54 (19)	52 (21)
Room 2 66 m^3	58	43 (15)	39 (19)	36 (20)	34 (24)
	63	48 (15)	44 (19)	41 (20)	39 (24)
	68	53 (15)	49 (19)	46 (20)	44 (24)
	73	58 (15)	54 (19)	51 (20)	49 (24)

Notes

(1) Sound absorber as in the original shutter, but shutter moved outwards to increase the opening of the ventilation slits to 0.35 m^2 (total for the two slits).

(2) Opening area of the special ventilation window locally reduced to approx. 0.20 m^2 at the glazing bar.

(3) Data from laboratory measurements according to ISO 10140, parts 1 & 2 [15] from Søndergaard & Olesen [16]; data from field measurement according to ISO 140-5 [12] from Olesen & Backalarz [11]; data from design-guide, Søndergaard & Olesen [17], 1 dB is subtracted due to uncertainty.

Grey shading of cells indicates that the upper limit 68 dB for outdoor level is exceeded for applying MST Guideline 4/2007 [8] for dwellings (new build, gap filling). However, $L_{den} > 68 \text{ dB}$ is relevant for 141 000 existing dwellings in Denmark, among these $L_{den} > 73 \text{ dB}$ for 15 000 dwellings, cf. Section 2.

When studying the table (or the equation), it becomes clear that both sound insulation, window area and room volume are important for the result. For example, it can be seen that double room volume means 3 dB lower indoor level. The last column defines a higher window with a 4 dB higher sound insulation than the window in the previous column (due to a longer distance between openings, see Figure 2, right), but the window area has increased by 60 %, and in the end the sound insulation is improved by 2 dB. Indirectly, the example also illustrates that sound insulation data must be available for the actual dimensions of the window, as wrong data may lead to big errors in the results.

Thus, it is important for a specific situation to consider several variants and to use the correct values of sound insulation (sound reduction index), window area and room volume for estimation of indoor level.

5 CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

Experience from use of special sound insulating ventilation windows has been collected in Denmark, but even if 141 000 dwellings are exposed to road traffic noise more than 10 dB above the Danish planning limit, i.e. $L_{den} > 68$ dB, use of such windows is very limited, probably because they are quite expensive.

However, sound insulating open windows could improve quality of life for many people living in areas with a strong traffic noise exposure, especially for those having difficulties falling asleep or waking up repeatedly during night due to traffic noise.

In general, people having sound insulating ventilation windows, seem satisfied, but insufficient ventilation capacity seems to be a problem in some cases, implying potential overheating during hot summer days. Information about ventilation capacity has not been available in any of the field cases found.

Further development for more general use is recommendable, but investigation of ventilation performance should be integrated in future research.

6 ACKNOWLEDGEMENTS

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