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Sound Insulation projects in Denmark

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ABSTRACT

This paper describes the Danish method for sound insulation projects including projects financed by the Danish Road Administration. The projects are evaluated according to the number of insulated houses and by measurement of the noise reduction achieved.

The Danish method includes a selection procedure for noise-affected houses along the road in question, a catalogue with technical solutions for noise insulation and a 20-month time schedule for the whole noise insulation process including communication with the house owners, inspection of their houses and description of the necessary measures. A selection of houses along roads or railways with a noise level of more than 63 dB (L_{den}) for roads and 64 dB (L_{den}) for railways are invited to sign up for the insulation project. Approximately 30-40 % of the invited houses are insulated. The house owners receive financial subsidies to implement the necessary insulation measures.

The sound insulation measures reduce indoor noise levels by 5-10 dB, and compared to other measures they are very efficient especially for city dwellings and apartment houses.

A large percentage of the participating house owners are satisfied with the noise insulation measures and are surprised by the level of noise reduction.

Keywords: Sound, Insulation, Transmission

1. INTRODUCTION

Noise from roads, railways and aircrafts can be reduced in many ways, e.g. by noise reducing pavements, noise restrictions at night, noise screens and noise reduced trains. However, for many dwellings, especially in city centers, noise insulation of the house facade is the only realistic measure to reduce noise.

Noise insulation can reduce indoor noise levels when windows are closed. The measure is effective in city centers with many apartments close to the road or railway line and limited outdoor areas. In suburban areas with many detached houses, the use of sound insulation is less effective because it only reduces indoor noise. Research has proven that noise at night has health effects and because people are mostly indoor at night, sound insulation could have a positive effect.

The first noise insulation project in Denmark took place in 1980-1986. When a new airport was planned in Copenhagen, it was decided to keep the existing location and develop the existing airport. To compensate the residential areas around the airport, the Danish Government gave approximately Euro 50 million (2016 prices) in grants to the house owners who installed noise insulation. In the period from 1986 to 2012, Banedanmark (The Danish Railway Company) carried out noise insulation projects along all main railway lines in Denmark. The reason behind was a legal document stating that Banedanmark should use 1% of the construction budget for noise screens and noise insulation. The Danish Road Directorate has carried out noise insulation projects since 2003 in relation to new road projects and along existing roads. The projects use different noise limits for road, railway and aircraft noise and different contribution limit but apart from that, the noise insulation procedure is the same in all projects.

This paper describes noise insulation projects in Denmark, developed during the last 35 years. It explains the procedure for a noise insulation project, the typical technical solutions and noise

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measurements of the effect. The paper is based on reports from the Danish Road Directorate (1,2).

2. NOISE INSULATION SCHEME

The Danish concept of a noise insulation scheme has been under development since 1980 where the Danish Environmental Protection Agency provided noise insulation grants to houses around Copenhagen Airport. The concept includes requirements and procedures for identification of houses eligible for insulation, a process with the house owners and requirements for the effect of the insulation.

2.1 Identification of Houses Eligible for the Noise Insulation Scheme

The identification of houses is based on noise calculations. The noise level is determined at each house based on either a noise map or a calculation of the façade noise level. Houses with a noise level higher than a predefined action limit are chosen for the scheme. An example of a noise calculation can be seen in figure 1.

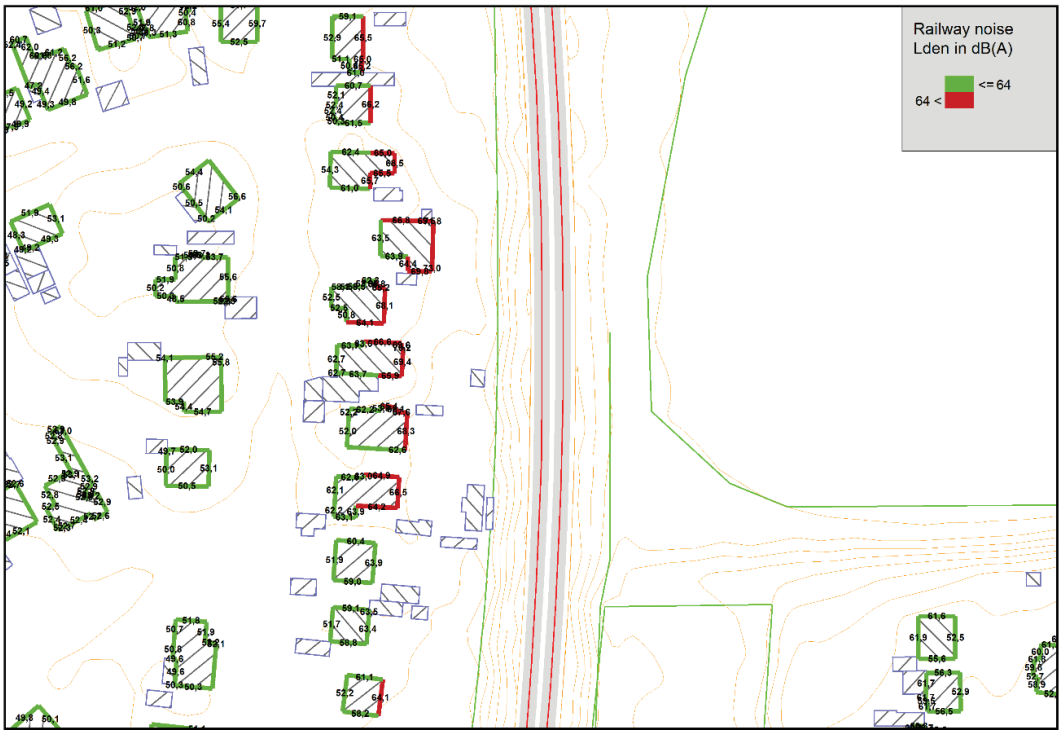

Figure 1. Results from a noise calculation of railway noise. Houses with façade noise levels greater than 64 dB (Lden) are eligible for noise insulation.

The action limit depends on the type of noise and the agency responsible for the noise insulation project. The Danish Road Directorate uses an action limit of 63 dB (Lden), which is 5 dB higher than the recommended noise limit for road noise in Denmark. The Danish Railway Company uses an action limit of 64 dB (Lden), which is equal to the recommended noise limit for railway noise in Denmark. In 1980, the Danish Environmental Protection Agency used an action limit of 65 dB (Lden) for the insulation project at Copenhagen Airport, which is 10 dB higher than the recommended noise limit for aircraft noise in Denmark.

The identified houses are divided into three groups based on the noise level at the houses, see table 1. Grants are allocated to the three groups according to the following model: Houses in Group 1, where the noise level is higher than the action limit (AL) + 10 dB, are granted 90% of the insulation costs. Houses in Group 2, where the noise level is between action level + 5 dB and + 10 dB, are granted 75%, and houses in Group 3, where the noise level is over the action limit and lower than the action limit + 5 dB, are granted 50 % of the insulation costs.

Table 1. Insulation groups.

Insulation groups	Noise interval	Grants share
Group 1 – Highest noise impact	$AL \leq L_{den} < AL + 5$ dB	90% of insulation costs
Group 2 – Medium noise impact	$AL + 5$ dB $\leq L_{den} < AL + 10$ dB	75% of insulation costs
Group 3 – Lowest noise impact	$L_{den} \geq AL + 10$ dB	50% of insulation costs

The grants are calculated from the actual insulation costs up to a maximum limit.

2.2 The Process with the House Owners

The authority who allocates the grants controls the selection of houses for the noise insulation project. The identified houses are invited by letter to participate in the project and from this date, a 20-month project period begins until the owner forwards documentation for the noise insulation work and payment. The house owner contacts the related noise consultant to sign up for the scheme and together they make an appointment for inspection of the house. The necessary noise insulation measures to achieve compliance with the requirements are described in a noise insulation report. The house owner receives the report and request quotations for execution of the insulation work. The house owner sends the quotations to the noise consultant for evaluation and if the quotation fulfils the requirements, the noise consultant forwards the proposal and a recommendation to the relevant authority. At this time, the house owner can start the insulation work. When completed, the house owner pays for the work and sends the receipt to the authority who pays out the grant. An example og timetable for the noise insulation scheme is given in Figure 2.

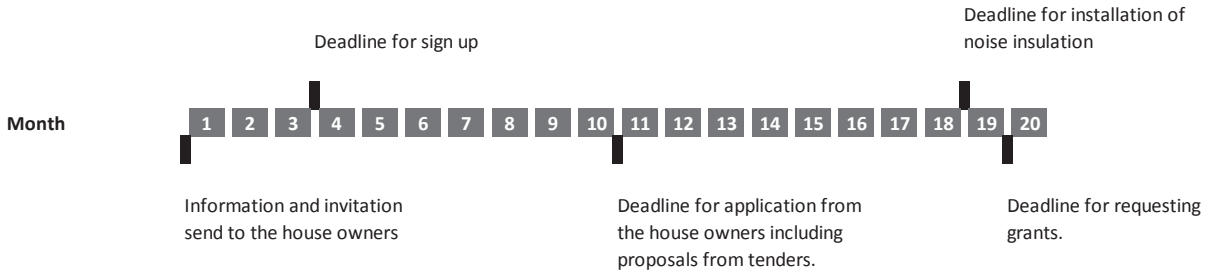

Figure 2. Example of timetable for the noise insulation scheme (1).

2.3 Insulation Requirements

The purpose of the noise insulation projects and grants to house owners is to reduce indoor noise levels. The purpose is not to maintain the house even though it can be a positive side effect.

The general requirement is to reduce the indoor noise impact by minimum 5 dB, which ensures a noticeable improvement. This requirement is achievable in most cases by means of standard solutions at a reasonable price but not in all rooms in a house. In some situations, it is difficult to completely meet the requirements and it can become necessary to include more complicated solutions, e.g. noise insulation of the roof, which is more expensive. In other rooms, e.g. rooms with windows towards the backside of the house, the noise level is already lower than the recommended indoor noise limit of 33 dB (L_{den}). The noise consultant will decide which rooms can be included and what is necessary based on the inspection of the house, calculation of the indoor noise level and his/her experience. The house owner can decide to insulate all rooms included in the noise insulation report or only part of the rooms but he must implement all the necessary measures to receive grants for a specific room.

3. Noise Insulation Measures

3.1 Evaluation of Noise Insulation Measures for Houses

Before the noise insulation takes place, it is very important to investigate the house and decide which measures are relevant to carry out. In most cases, the sound insulation includes the windows, which are the most dominant structures, with approximately 80% of the transmitted noise effect before insulation. Light walls and poorly insulated roofs can also be included but the effect of improving

heavy brick walls will be very low. An example of the distribution of the total transmitted sound energy on the different building structures is shown in figure 3.

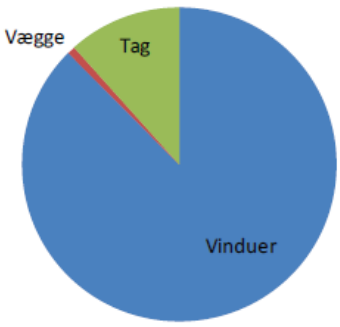

Figure 3. Distribution of the transmitted sound energy on windows, roof and walls (1).

A noise consultant visits the house and measures and categorizes the different building structures according to a database with insulation values for a large number of different structures. Based on the these data, the noise consultant calculates the indoor noise level for each room in the house and investigates the possible effect of replacing some of the building structures with components with a better insulation value.

3.2 Calculation of the Indoor Noise Level

The indoor noise level is calculated using a simplified method based on the outdoor façade noise level and transmission levels for each building structure. The 1/1 octave spectrum of the outdoor noise level is estimated based on generalized spectres for different types of noise. This is important to obtain the correct indoor noise level. Examples of generalized spectres from Nordtest (3) are given in table 2.

Table 2. Generalized 1/1 octave spectrum for road and railway noise.

Spectrum	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	dB(A)
City traffic, 50 km/h, 10% heavy	-18	-14	-10	-7	-4	-6	-11	0
Motorway, 90 km/h, 10% heavy	-27	-21	-13	-7	-3	-7	-14	0
Railway	-30	-15	-9	-4	-6	-9	-13	0
Aircraft noise	-40	-15	-9	-5	-4	-10	-17	0

The transmission level for each building structure is calculated by (1). The reverberation time in the room, T, is assumed to be 0,5 sec.

$$L_{dt}(i,j) = L_{out}(i) - R(i,j) + 10\log\big(S(j)\big) - 10\log(V) - 5\,dB \quad (1)$$

$L_{dt}(i,j)$: The transmission level for building structure j in frequency band i.
$L_{out}(i)$: Outdoor noise level in frequency band i.
$R(I,j)$: Sound reduction index for building structure j in frequency band i.
$S(j)$: Area of building structure j.
V : Room volume

The indoor noise level is calculated by (2) and (3).

$$L_{dt}(j) = 10 \log \sum 10^{0,1 L_{dt}(i)} \tag{2}$$

$$L_{in} = 10 \log \sum 10^{0,1 L_{dt}(j)} \tag{3}$$

$L_{dt}\ (j)$ The transmission level for building structure *j*. $L_{dt}\ (j)$ can be defined as the noise level in the room, if noise was only transmitted through building structure *j*.
L_{in} Total indoor noise level.

There is a substantial uncertainty in the calculations with the simplified method mentioned above mainly because the method uses estimated values of the noise reduction indexes for typical building structures. The noise insulation scheme operates with windows, doors, walls, roofs and ventilation, and estimated values of the noise reduction indexes for these structures are recorded in a database. The database contains different types of each structure and it takes into account the quality of the structure to a certain degree, e.g. leaky windows.

3.3 Windows

There are many different types of windows in Danish buildings with varying sound properties. Windows with two-layer glass are the most usual type and a typical cross section of that window type is shown in figure 4.

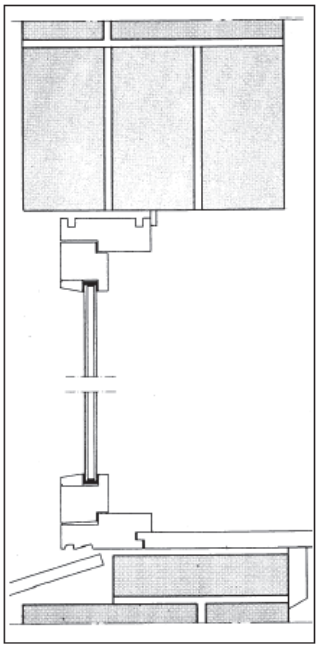

Figure 4. Cross section of a window with two-layer glass (1)

The typical windows often consist of poor quality wood and two-layer glass with equal thickness. In most cases, these windows will be changed to another type with a better sound reduction index especially if the window is old and leaky. The sound reduction indexes of different glass types are listed in table 3. The values are based on laboratory measurements where glass is fitted into openable windows.

Table 3. Sound reduction index for different types of glass (4)

Glass type	Rw	Rw + Ctr
Two-layer glass, 4-12-4	33	29
Triple-layer glass	33	28
Soundproof two-layer glass, 8-12-4	37	34
Laminated two-layer glass	40	35
Two-layer glass with attached single glass	44	40

According to the sound reduction data in table 3, changing a normal two-layer glass window to a soundproof two-layer glass of the same size will improve the sound reduction index by 5-6 dB. In many situations, the improvement will be even greater due to leaky sealing in the existing window and therefore a reduced apparent sound reduction index.

A house becomes more closed when it is sound insulated and it can be necessary to install a sound insulated ventilation duct. The duct must be fitted into the wall because a duct in the window frame cannot be sound insulated.

3.4 Roofs

It is necessary to take into account the noise transmission through the roofs of detached houses. In Denmark, most of these houses are thermally insulated with 100-200 mm mineral wool and it is not necessary to improve the sound insulation of the roof to meet the insulation requirement of minimum 5 dB. Detached houses with poor thermal insulation can benefit from extra sound insulation, e.g. plasterboards and extra mineral wool fitted on the inside of the ceiling.

3.5 Ventilation

Noise insulated houses are tighter and need more ventilation. The ventilation must be installed in the wall as a noise insulated duct. Ventilation valves in the window frame cannot be noise insulated. An example of a noise insulated ventilation duct can be seen in figure 5.

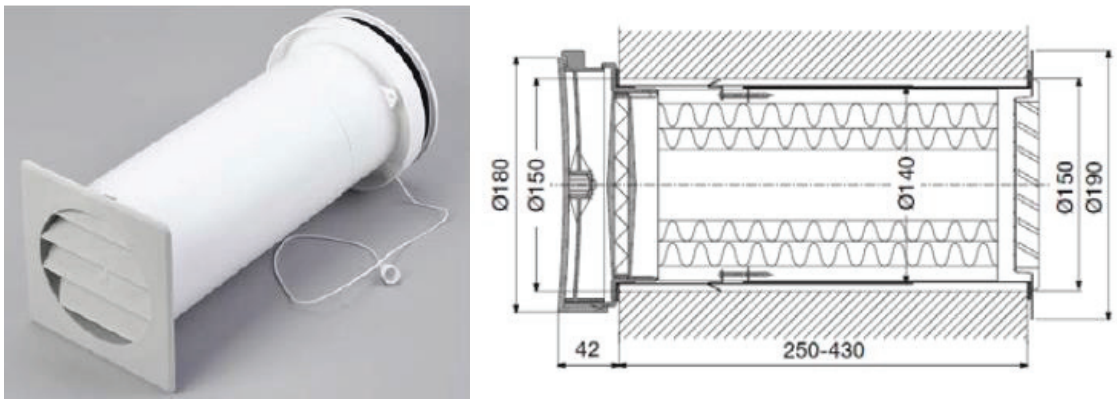

Figure 5. Example of noise insulated ventilation duct (Lindab ULA).

4. Participants in the Noise Insulation Projects

The success of a noise insulation project depends on the number of houses and apartments participating in the project. Table 4 and 5 show the total number of invited and insulated houses in the projects of the Danish Road Directorate (2010-2013) and the Danish Railway Company (1987-2012).

Table 4. Number of invited and insulated houses in the sound insulation projects of The Danish Road Directorate in the period 2010-2013.

	Group 1		Group 2		Group 3		Total
	Detached houses	Apart-ments	Detached houses	Apart-ments	Detached houses	Apart-ments	
Invited	93	214	161	325	136	377	1307
Insulated	44	115	54	131	21	140	505
Insulated in %	47	54	34	40	15	37	39

Table 5. Number of invited and insulated houses in the sound insulation projects of The Danish Railway Company in the period 1987-2012.

	Group 1		Group 2		Group 3		Total
	Detached houses	Apart-ments	Detached houses	Apart-ments	Detached houses	Apart-ments	
Invited	479	175	1944	1273	6121	6787	16779
Insulated	313	88	898	638	1141	1734	4812
Insulated in %	65	50	46	50	19	26	29

The Danish Road Directorate invited 1307 detached houses and apartments to participate in noise insulation projects in the period from 2010 to 2013 and 505 (39 %) of the invited houses were insulated. Houses and apartments in group 1 with the highest noise impacts are more often insulated than house and apartments in the other groups. The Danish Railway Company invited 16779 houses and apartments to participate in noise insulation projects and 4812 (29%) of these were insulated.

5. Noise Measurements before and after Noise Insulation

The Danish Road Directorate has performed noise measurements of noise insulation against traffic noise before and after noise insulation of a building. The measurements were carried out against the standard DS/EN ISO 140-5. Four properties were included in the measurements. The measurements were performed to validate the calculated noise insulation. The measurement results are given in table 6 together with the calculated noise insulation.

Table 6. Results of calculations and measurements of indoor noise levels before and after noise insulation.

Property	Calculation		Measurements	
	Before	After	Before	After
Bedroom on 1st floor in detached house. Normal two-layer windows changed to soundproof windows.	44	39	47	42
Bedroom in apartment. Soundproof windows changed to laminated soundproof windows.	39	35	38	33
Living room on 1st floor in detached house. Normal two-layer windows changed to soundproof windows and extra plasterboards on ceilings.	43	36	42	36

Kitchen in detached house. Two-layer window (two frames) changed to soundproof two-frame window.	45	34	44	34

6. CONCLUSIONS

A concept for noise insulation projects in Denmark has been developed since 1980. The concept has been used for noise insulation of houses affected by road, railway or aircraft noise. The Danish Road Directorate and Banedanmark (The Danish railway company) has invited 18,086 houses to participate in noise insulation projects and 5,317 of these houses (29 %) were insulated. Primarily windows and doors were noise insulated, but sometimes the roofs also have to be insulated to achieve a sufficient indoor noise reduction of minimum 5 dB. In most cases, the windows were changed to new windows with a greater noise reduction index.

There is consistency between the preliminary calculations of noise reduction and the measurements of noise reduction before and after noise insulation.

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