Technical Note

NOISE ABATEMENT MEASURES IN DENMARK

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INTRODUCTION

When constructing new buildings or roads in Denmark special consideration is given to traffic noise. A national noise mapping indicates that around 30% of Danish homes are exposed to noise levels that exceed the guideline value of 58 dB(A) (L_{DEN}) and that noise problems are concentrated in cities. Road traffic noise may impact people in different ways such as impacting communication, and interrupting sleep. Studies have shown that noise can contribute to an increased risk of cardio-vascular diseases [1]. The effects of noise are also of an economic nature because noise influences house prices. Furthermore, health related issues caused by noise also incur costs. The socio-economic costs related to road traffic noise have been calculated to amount to between 1.1 and 1.6 billion AUD annually in Denmark [2].

The first part of this article introduces noise guidelines, prediction of noise and socio-economic evaluation of noise. This is followed by a typical planning situation where noise can be considered in relation to planning a new highway.

TECHNICAL CONSIDERATIONS

Noise Guidelines

For many years, the noise indicator $L_{Aeq,24h}$ has been used in Denmark when assessing noise from road traffic. $L_{Aeq,24h}$ is an expression of the average noise level over the 24 hours of the day. The guideline for noise exposure outside at the façade of residential buildings has been 55 dB(A) (not including the noise reflected from the façade). On the background of a European Union Directive on environmental noise [3] the new indicator L_{DEN} was introduced by the Environmental Protection Agency in 2007 in a new guideline on road traffic noise [4]. With L_{DEN} the noise is predicted for the day, evening and night period. 5 dB is added to the evening time level and 10 dB is added to the night level in order to reflect the difference in sensitivity to noise during day and night time. The three time periods are defined as:

- Day: 07:00 – 19:00
- Evening: 19:00 – 22:00
- Night: 22:00 – 07:00

L_{DEN} is then calculated as the weighted sum of the adjusted noise levels for the three periods of the day using the formula

$$L_{DEN} = 10\log_{10}(12*10^{L_{day}/10} + 3*10^{(L_{evening}+5)/10} + 9*10^{(L_{night}+10)/10}) \quad (1)$$

According to [4] for a “normal” distribution of the traffic over the 24 hours of the day, L_{DEN} can be predicted by adding 3 dB to $L_{Aeq,24h}$

$$L_{DEN} = L_{Aeq,24h} + 3 \text{ dB} \quad (2)$$

Therefore the existing noise guidelines were adjusted by 3 dB when L_{DEN} was introduced in order to maintain the same level of noise protection as when $L_{Aeq,24h}$ was used. In other European countries other relations between L_{DEN} and $L_{Aeq,24h}$ are used [5]. The new Danish noise guidelines for road traffic noise, expressed as L_{DEN}, is as follows:

- Recreational areas on the countryside, summer houses, campsites, etc.: 53 dB(A)
- Residential areas, kindergartens, schools and education facilities, hospitals, outside recreational areas and parks: 58 dB(A)
- Hotels and offices: 63 dB(A)

It must be emphasised that these are guidelines and not mandatory noise levels that should not be exceeded anywhere along the highway and road network. These guidelines are generally used when planning and constructing new residential areas as well as planning new roads and highways.

The Noise Exposure Factor (NEF)

The Noise Exposure Factor (NEF) is the basis for all cost-benefit analyses of noise from road traffic in Denmark [6]. It is an expression of the accumulated noise load on all the dwellings in an area. It is calculated as the sum of the weighted noise loads on the individual dwellings in the area, so that dwellings with high noise levels weight more than dwellings with less noise.

The calculation of the NEF is based on noise levels outside the façade of the dwelling. It is calculated as free-field values on the facade and can be interpreted as the noise level to which the inhabitants are exposed, when the windows are open. The NEF is based on a dose-response relation called the annoyance factor and given by:

$$\text{Annoyance factor} = 0.01*4.22^{0.1(L_{Aeq}-K)} \quad (3)$$

where K=41 and L_{Aeq} starts at 55 dB for noise outside dwellings. The relation between the annoyance factor and the noise levels is shown in Figure 1.

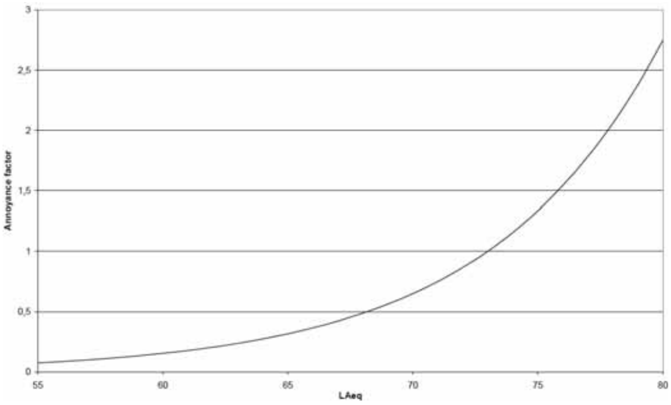

Figure 1: Relation between the annoyance factor and the noise outside dwellings.

The number of dwellings exposed to noise is calculated in 5 dB intervals using the NORD2000 noise prediction method [7, 8] and multiplied by the corresponding annoyance factor, see Table 1. The resulting values are summed to give the NEF for the investigated situation. An example for calculating the NEF is given in the next section.

Table 1: Annoyance factor in 5dB intervals for the ordinary dwellings (indoor).

Noise level dB(A)	Annoyance factor
55-60	0.11
60.1-65	0.22
65.1-70	0.45
70.1-75	0.93
75.1-80	1.92

The price of noise

A survey conducted by the Danish Ministry of Transport set the value of noise to AUD $6,519, based on the reduced value of the house price. Added to the costs to society due to health effects the total value of noise is thus AUD $10,704/year per NEF (2003 price level) [9-11]. A new evaluation of the price of noise is currently being conducted by the Danish Economic Council. The NEF makes it possible to compare the benefits of different noise reducing strategies such as noise barriers, noise reducing pavements and sound insulation.

APPLYING THE NEF TO THE PLANNING OF A NEW HIGHWAY

An important part of planning new highway sections in Denmark is to perform an Environmental Impact Assessment (EIA) study. Noise is normally one of the environmental components included in the EIA. A report by the Danish Road Directorate shows how noise was handled in the EIA conducted as part of the planning of a new highway in Denmark [12]. The first step is to predict the noise map of the existing road network as it would be in 2015, this takes into consideration an increase in traffic. In these examples the old L_{Aeq} noise levels are used. The existing road network includes the existing highway carrying the main traffic as well as other minor roads that might see a reduction of traffic of 15% or more if a new highway is constructed. This predicted situation is called the reference situation. Three different alternatives to this reference situation are proposed. They offer different traces and therefore different noise mapping. They are referred to as the main solution, alternative 1 and alternative 2. Noise mapping is conducted for these four situations. The number of dwellings exposed to different noise levels is counted based on the noise mapping and the NEF is then calculated. The results are found in Table 2. In the reference situation, 660 dwellings along the existing road network are exposed to more than 55 dB(A). This represents a NEF value of 153.8. For the main solution this is reduced to 562 dwellings with a reduction of the NEF by 31.5. Alternatives 1 and 2 represent slightly higher reductions of NEF, respectively 37.6 and 34.6. This shows that alternative 1 is the one offering the least noise exposure for the dwellings in the vicinity of that road.

Table 2: Number of dwellings exposed to noise, the NEF and the change of NEF in relation to the reference situation.

Scenario	Total of noise exposed dwellings					NEF	Change in NEF
	55-60 dB	60-65 dB	65-70 dB	>70 dB	Total		
Reference	272	153	197	38	660	153.8	
Main solution	189	159	214	0	562	122.3	31.5
Alternative 1	201	132	222	0	555	116.2	37.6
Alternative 2	222	133	221	0	576	119.2	34.6

This type of pre-study helps detecting which solution is best in terms of noise protection. This can be combined with the actual price of a road project [13]. The example below is from the M3 highway and it shows how the NEF can be used to choose between different types of noise barrier, as shown in Table 3. As expected the highest noise barrier (5m) brings more noise reduction to the dwellings and hence has the lowest NEF. The price of such a barrier needs to be taken into account to see which solution is best. A 5 m high barrier requires stronger foundation compared to smaller barriers. The overall cost of the three types of barrier and their respective NEF reduction is shown in Table 4. From this study it can be concluded that a 4-m high barrier provides the best “value for money” in terms of noise reduction. A similar study can be made with pavement offering different degree of noise reduction, different earth mound heights, etc. The completed M3 highway is presented in Fig. 2 and an example of noise level measurement using the statistical pass-by (SPB) method is shown in Fig. 3.

Table 3: Number of dwellings exposed to noise, NEF for different noise barrier heights and change of NEF in relation to the reference situation.

Scenario	Total of noise exposed dwellings					NEF	Change in NEF
	55-60 dB	60-65 dB	65-70 dB	>70 dB	Total		
Existing	6503	3244	482	76	10305	1717	
3m barrier	5472	2985	526	78	9061	1568	149
4m barrier	4766	1890	253	36	6945	1087	630
5m barrier	4027	1663	238	35	5963	948	769

Table 4: Evaluation of the price and cost effectiveness of the different barrier solutions [20].

Scenario	Total price [mil. AUD]	ΔNEF	ΔNEF per 1mil. AUD
3m barrier	25	149	5.9
4m barrier	31	630	20.3
5m barrier	39	769	19.7

Figure 2. The M3 highway once completed, with porous asphalt and tilted 3m and 4m noise barriers.

Figure 3: The Danish Road Institute measures the noise level at a test location for noise reducing pavement using the SPB method.

CONCLUSIONS

This article has presented the tools used in Denmark to mitigate road traffic noise. This includes noise guidelines, prediction of noise and socio-economic evaluation of noise. Different examples have been presented where the NEF was applied. It showed that the NEF can be a very helpful parameter to consider prior to major road projects.

A European noise group from the Conference of European Directors of Roads (CEDR) has published a list of fourteen recommendations to National Road Administrations for good governance regarding noise management and abatement [14]. The interested reader is referred to the free English publications of the Danish Road Institute available from www.roadinstitute.dk

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