# POSITION PAPER ON
# DOSE-EFFECT RELATIONSHIPS FOR NIGHT TIME NOISE

Working Group on Health and Socio-Economic Aspects

11 November 2004

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**Acknowledgement**

**NOTES**

This document reflects the opinions of the majority of the members of the Working Group.

It should not be considered as an official statement of the position of the European Commission.

*Front page: Statue in Meyendel, photograph by M van den Berg*

# 1 Introduction

Article 6.3 of the Environmental Noise Directive (END) states that *Harmful effects may be assessed by means of the dose-effect relations referred to in Annex III*. The purpose of this article is to induce the Member States to evaluate noise situations in terms of affected populations. The dose-effect relations provided by the Commission serve in this respect not as a compulsory set (..."may be assessed"...) but as a general set which gives the effect of a general population exposed to a well-defined range of noise levels.
Annex 3 of the END is entitled: "*Assessment methods for harmful effects*" and as indicated in Article 6.3 serves to assess the effects of noise exposure.
The first set of dose-effect relations for noise emitted from traffic and transportation was provided to the Commission in 2002[4] by Working Group II, and can be considered as a base set for assessing annoyance using the $L_{den}$ metric.
The terms of reference for the Working Group on Health and Socio-Economic Aspects call for the provision of a Position Paper on the second important base set, the dose-effect relations for $L_{night}$. The relations between $L_{night}$ and the effects of this exposure will be provided to the Commission like was the case with the relations between $L_{den}$ and annoyance . It is then up to the Commission, pursuant to article 13 of the END, to adjust Annex III accordingly.
The basis for this document is the study "*Elements for a position paper on night-time transportation noise and sleep disturbance*". The study was financed by the Commission, the contractor was TNO (Delft, Netherlands), and the study was published in February 2003[16]. An extension to this paper "*Self-reported sleep disturbance caused by aircraft noise*" was published on April 1, 2004 (financed by the Dutch government). Unless stated otherwise, results are taken from these reports.
In addition to this study other documents and knowledge from the experts in the group were used in order to prepare a comprehensive overview of useable dose-effect relations.

It should be stressed here that establishing a dose-effect relation for noise is no easy task. It requires substantial resources and technical know-how, so it is fitting that a set of general use relations is provided at EU-level. This leaves room for other parties to make use of their localised version if sufficient evidence is available.

The Terms of Reference demand specifically and exclusively dose-effect relations for (long-term) $L_{night}$. The Working Group is well aware of the discussion about additional (short- term) indicators such as SEL and Lamax,and has therefore allowed for evidence on these indicators as well. However, where possible, the relations are expressed in $L_{night}$, by using a "worst case" approach based on the effects of the short term indicators.

*reading instructions:*
References are in [1] bold italics, superscript. Footnotes and powers are in normal superscript, like in $a^2$.
Formula numbers are between square brackets [2]

## 2 Exposure in the EU

Complaints about night-time exposure to noise are wide spread and not exactly new: Roman writers used to complain about racket in the streets at night.
More precise information about the levels of exposure of the EU-population to noise will have to wait until the implementation of the END has delivered the $L_{night}$ noise maps. Nevertheless, information available from a few member states can help to give an impression of the anticipated levels of exposure.

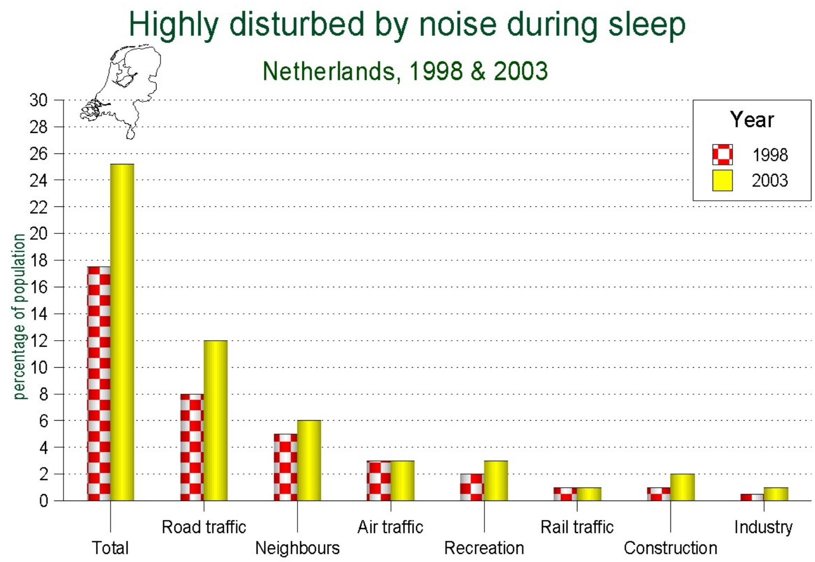



*Figure 1. Percent of population stating to be highly disturbed by noise during night time (RIVM survey 2003[9]).*

Figure 1 shows the relative contributions to overall sleep disturbance caused by noise from different sources in the Netherlands. These data were derived from surveys in 1998 and 2003 in which 4000 and 2000 people, respectively, all of whom were randomly selected, were asked: "To what extent is your sleep disturbed by noise from (*source mentioned*)...." on a scale from 1 to 10. People recording the 3 highest points in the scale were considered "highly disturbed", according to an international convention . The totals are calculated from the number of people reporting serious sleep disturbance from 1 or more sources.
Unfortunately, the WG was unable to find comparable research data from other countries or regions, and there is reason to believe that there may be considerable differences in the figures. The EU Member States are encouraged to consider comparable studies, as this may provide insight into the scale of the problem and which sources make the highest contribution to that problem.
Since this study is based on a survey conducted in the Netherlands, it is not representative for other Member States in the EU. General (not specific for night time) annoyance data from Germany and the UK give an indication that the same order of magnitude in terms of number of people is affected.
The WG is aware that noise from neighbours and military sources is not covered by the END. However the fact that other nuisances may contribute significantly to overall sleep disturbance by noise should not be overlooked. Further research on this topic is needed in

order to gain an insight into the contribution of various noise sources to sleep disturbance caused by noise.

## 3 Considerations with regard to night-time noise indicators

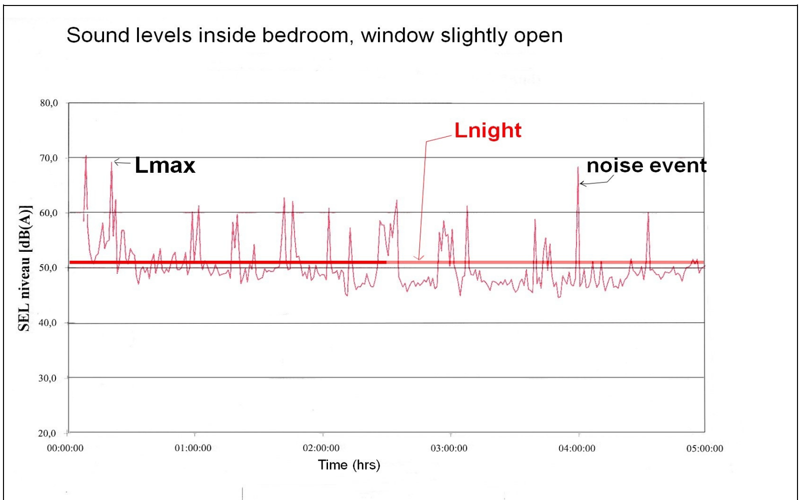
The $L_{night}$ was introduced in the END following the Position Paper from the Working Group on Indicators[7]. In Figure 2, the relation between the indicators $L_{Amax}$, SEL and $L_{night}$ is explained.
Briefly, the fundamental choices of the $L_{night}$ indicator with respect to
- assessment point
- length of night
- use of single event descriptors
- long-term average
are commented on to assist the reader in understanding the relations presented in later chapters .

### 3.1 Assessment point

The $L_{night}$ is defined as a descriptor of the incident noise measured or determined by computation on the facade. For mapping purposes, it is to be assessed at a height of 4 meters, for more detailed evaluations on the position of the bedroom. It was not defined as an inside level because insulation quality and window-behaviour differs considerably between individuals and between countries, and in Europe a large proportion of the population likes to sleep with their windows open to some extent. Another problem that may arise is that in most cases the sound levels are determined by computation at the most exposed side of the house. As people will try to avoid high noise levels by choosing a bedroom on the least exposed side, research results may get biased if only the most exposed value is taken. Thi is looked at in greater detail in section 5.

### 3.2 Length of night

Although it seems fairly obvious that sleep is an important "activity" that requires special attention and therefore the time people sleep should be the basis of any night-time noise descriptor, the issue is not always that simple. Time use studies show that the average time people are in bed is around 7.5 hours, so the real average sleeping time is somewhat shorter. Due to personal factors like age and genetic factors there is considerable variation in sleeping time and in begin and end times. For these reasons, 8 hours is a minimal choice for night-time




*Relation between $L_{night}$, $L_{Amax}$ and SEL*
*This is a sound recording in a bedroom for one night. The top of the peaks are the $L_{Amax}$-levels, the total energy is the $L_{night}$ (thick horizontal line). The sound energy in one event is the SEL (not represented, it is a calculated value over 1 second). In reality the $L_{night}$ is the average of all nights over one year.*

*Figure 2 showing the relation between $L_{Amax}$, SEL and LAeq* protection, as provided for in the END. It should also be borne in mind that (young) children have much longer sleeping times.

### 3.3 Event or long-term descriptor

Much attention has been paid to the use of single event descriptors like $L_{Amax}$[1] and SEL. As the Position Paper on Indicators[7] points out, this is an important laboratory tool to describe instantaneous reactions to noise. But when it comes to long-term protection, the number of events is equally important. The possibility of predicting after-effects like sleepiness, reaction time, sleeping pill use and health complaints in particular require a combination of number of events and their level instead of just the average $L_{Amax}$ or average SEL. For events with a similar time pattern there is a relatively simple relation between $L_{Amax}$ and SEL, and therefore between $L_{Amax}$ and $L_{night}$. Appendix I describes this in detail. For now let it suffice to say that a choice for an $L_{night}$ level ties the $L_{Amax}$ related effects to a maximum and therefore allows for a protective/conservative approach.
This reasoning applies also to the issue of long-term average. A value for an arbitrary single night will, except in extreme cases, bear no relationship to an individual's health, whereas a sustained high level over a long period clearly will.

### 3.4 Conversion between indicators

introduction
The definition of $L_{night}$ is the long-term LAeq over 8 hours outside at the most exposed facade. As $L_{night}$ is a relatively new definition and because the studies rarely cover such a long period, the research data are expressed in anything but $L_{night.}$ The most frequently used noise descriptor in sleep research is the $L_{Amax}$ or SEL near the sleeper. This means that a considerable amount of conversion work needs to be done if relations are to be expressed in Lnight.
There are 4 issues:
- conversion between SEL and $L_{Amax}$
- conversion from instantaneous to long-term
- conversion from inside to outside
- conversion from (outside) bedroom level to most exposed facade

Further background information on these issues is provided in section 6. This section details the conversions that are actually carried out.

#### 3.4.1 SEL to $L_{Amax}$

This is only used for aircraft noise in this report and, according to reference [21] from ground-based measurements, this is:

$$SEL=23.9+0.81*L_{Amax} . \qquad [1]$$

A more general approach can be used to estimate SEL for transportation noise.
If the shape of the time pattern of the sound level can be approximated by a block form, then SEL ≈ $L_{max}$ + 10lg(t), where t (in seconds) is the duration of the noise event. This rule can be used *inter alia* for a long freight train that passes at a short distance. When t is in the range

[1] Although widely used, $L_{Amax}$ is not well defined or standardized.

from 3 to 30 s, then SEL is 5 to 15 dB(A) higher than $L_{max}$. For most passages of aircraft, road vehicles or trains, the shape of the time pattern of the sound level can be better approximated with a triangle. If the sound level increase with rate a (in dB(A)/s), thereafter is at its maximum for a short duration before it decreases with rate -a, then SEL $\approx$ Lmax - 10lg(a + 9.4). Depending on the distance to the source, for most dwellings near transportation sources the rate of increase is in the order of a few dB(A)/s up to 5 dB(A)/s. When a is in the range from 9 to 1 dB(A)/s, then SEL is 0 to 9 dB(A) higher than Lmax.

3.4.2 Events to long term

When the SEL values are known (if necessary after converting from $L_{Amax}$) they can be converted to $L_{night}$. In general terms, the relation between $L_{night}$ and SEL is:

$L_{night} = 10lg \sum_i 10^{SELi/10} - 10 \log T$.

If all (N) events have approximately the same SEL-level, this may be reduced to:

$L_{night} = SEL + 10 \log N – 70.2$ [2]

in which
N = the number of events occurring in period T
T = time during which the events occur in seconds. For a (night) year 10lg(T) is 70.2

The annotation adheres to the END. Any reference to an inside level is noted as such, eg. $L_{night,inside}$.

3.4.3 Inside to outside

As the $L_{night}$ is a year value, the insulation value is also to be expressed as such. This means that if the insulation value is 30 dB with windows closed and 15 dB with windows open, the resulting value is 18 dB if the window is open 50% of the time. If these windows are closed only 10% of the time, the result is little more than 15 dB. The issue is complicated by the fact that closing behaviour is, to a certain extent, dependent on noise level.
When data about effects are expressed with indoor (i.e. inside bedrooms) as the parameter, they need to be converted to $L_{night}$., in accordance with the END definition. The most important assumption is the correction for inside levels to outside levels. An average level difference of 21 has been chosen, as this takes into account that even in well-insulated houses windows may be open a better part of the year. Therefore:

$L_{night} = L_{night,inside} + Y$ dB [3]

Y is the year average insulation value of the (bedroom) facade. In this report a default value of 21 is used (see also section 6.1). It should be stressed that this conversion is thought to be highly dependent on local building habits, climate and window behaviour.

3.4.4 Most exposed facade

If an inside level is converted to an outside level with [3], it is assumed that this is equivalent to an $L_{night}$ value on the most exposed facade. No information is available on bedroom

position and use, so no explicit conversion factor can be given in this report.
This means that the effect determined by computation corresponds to an upper limit, because part of the bedrooms will be on a less exposed facade. If an estimate of the exposed population is based on a relation derived with [3], the actual prevalence will be less. From a practical point of view the most exposed facade safeguards protection in cases where there is a possibility that rooms can be swapped .
It should be pointed out that the above does not apply if a relation is based on $L_{night}$ values which are directly measured or determinded by computation . These relations will show a large variation because of a misclassification effect, but they give a “correct” estimate of the prevalence of effects in the population.

# 4 Choice of effects

Sleep is a more complex state then it may appear when looking at a sleeping person (or indeed any sleeping organism; even fruitflies apparently have a sleep like state). Accordingly, the influences of noise are just as complex. It is useful to make distinctions between instantaneous, short-term and long-term effects. This is summarised in table 4.1:

Table 4.1 **overview of effects of noise during sleep** [16];
*underlined* are effects with dose-effect relationships ; ■ indicates for which sources relations are available, ♦available thresholds.

| | Effects for which sufficient evidence exists. | Noise sources for which sufficient quantitative data are available | | |
|---|---|---|---|---|
| | | Road | Rail | Aircraft |
| **Instantaneous** | release of stress hormones | | | |
| | change in blood pressure | | | |
| | change in heart rate | | | |
| | vasoconstriction | | | |
| | *instantaneous (onset) of motility* | | | ■[16] |
| | change in sleep stage | | | |
| | *awakening* | | ■[17] | ■[17] |
| **Short term** | **Night** | | | |
| | sleep latency | | | |
| | average motility | | | ■[16] |
| | duration REM/SWS | | | |
| | sleep structure fragmentation | | | |
| | cortisol after wake-up | | | |
| | **Overnight** | | | |
| | (nor)adrenaline/dopamine | | | |
| | mood/performance next day | | | |
| | complaints | | | |
| **Long term** | **Chronic changes** | | | |
| | *self-reported (chronic) sleep disturbance* | ■[16] | ■[16] | ■[17] |
| | *chronic increase of motility* | ■[16] | | |
| | use of sleeping pills | | | |
| | *increased risk of hypertension* | ♦[15] | | |
| | increased risk of myocardial infarction | | | |

For the underlined effects sufficient evidence exists to provide dose-effect relations or a threshold value.
It is not sufficiently known how these different effects in different time frames are interrelated and how they affect human health and well-being. For an adequate assessment of night time exposure, one key effect per time frame (instantaneous, short term, long term) may have to be considered. It is difficult to say which effect will be the more important given the circumstances in which the assessment takes place.

# 5 Dose-effect relations

## 5.1 Instantaneous reactions to single events

### 5.1.1 Introduction

In this section reactions to **single events** are presented. For the usual environmental noise sources covered by the END, the number of events varies considerably. Large airports and railway lines have smaller number of events (10-50) per night and higher levels per event, while large roads have higher numbers and somewhat lower levels at the usual distances.

To achieve 25 $L_{Aeq}$ with events each of which reach 45 SEL, 300 events per night are needed (11.000 per year). Or another example: with events of SEL=95 (about $L_{Amax}$=88 for aircraft), only 1000 per year (3 per night) suffice to give a $L_{night}$ of 55.

### 5.1.2 Awakening

In [18] a review is published of 9 studies on awakening by noise. It was found that these studies had different definitions of what constituted an “awakening”. In this review, however, all awakening data were collected on *behavioural awakening*: these are awakenings that were followed by an action (like pressing a button) from the sleeper. The number of awakenings defined in this manner is much smaller than the number of sleep stage changes which lead to EEG-patterns similar to wakefulness.
Data were available for rail traffic noise, ambient (probably road) noise, civil aviation noise and military aviation noise.
The rail traffic noise study is very small (only 20 subject nights), but showed no awakenings. The study states that “*there is some evidence, be it very limited, that railway noise events, in the range of SEL_i considered (up to 80 dB(A)), do not increase (the) probability of awakening”*.
Ambient noise also showed no effect on the probability of awakening, but as it is uncertain exactly what noise is meant, no firm conclusions could be drawn.
Military aircraft noise showed a very strong effect, but this study is of limited applicability since the few subjects (military) lived near the end of the runway.
For civil aviation noise there were sufficient data to derive a dose-effect relation:

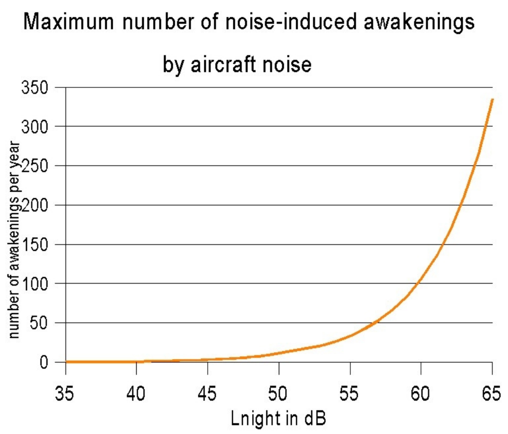



*Figure 3 Worst case prediction of noise induced behavioural awakenings.$L_{night}$, converted from inside relation with [3]*

percentage of noise-induced awakenings= $-0.564 + 1.909*10^{-4}*(SEL_{inside})^2$ [4]

where $SEL_{inside}$ is the Sound Exposure Level of an aircraft noise event in the bedroom.

With this relation, it is possible to calculate for an individual $L_{night}$ the expected number of noise-induced behavioural awakenings. This requires all single contributions over the year to this $L_{night}$ to be known. Alternatively (if, for instance a future situation has to be estimated for which no exact data are available) a worst case scenario can be calculated. Figure 3 represents the results of this worst case approach (converted to Lnight, see section 3.4), and so gives the maximum number of awakenings $n_{max}$ that may be expected.

$$n_{max} = 0.3504 * 10^{(Lnight-38.48)/10} \quad [5]$$

It can be demonstrated that the number of awakenings reaches a maximum when the $SEL_{,inside}$ value is 58.8 dB(A).
It should be noted that, on average, 600 spontaneous awakenings are reported per year. This also explains why so many more awakenings are reported than can be attributed directly to aircraft noise. At 55 $L_{night}$, nearly 100 overflights per night with $SEL_{,inside}$=58.8, or 1 per 5 minutes are possible. It is therefore very likely that an overflight coincides with a spontaneous awakening. It is interesting to note that by using the conversion of SEL→$L_{Amax}$ (see 3.4), $L_{Amax,inside}$=44 dB(A), just below the value of 45 dB(A) recommended by the WHO[2] .

### 5.1.3 Body movements during sleep: motility

Body movements during sleep are normal. Under normal circumstances, people show movements for approximately 3% of the time. Measuring this is relatively easy (and cheap) nowadays with the aid of portable devices which are usually worn around the wrist.
Motility (as this phenomenon is called by sleep researchers) has been found to be a sensitive measure for sleep disturbance. It has been shown to be a predictor for a range of effects like awakening, sleep quality, general health feelings and other effects.
In Passchier-Vermeer et al[18]. (2002) motility is registered in 15-second intervals. A distinction is made between 2 variables:

- the *presence of motility* in the interval (indicated by *m*) and
- the *onset of motility*,
  meaning the presence of motility when there was no motility in the preceding interval (indicated by *k*).

Relations between a noise-induced increase in motility (*m*) or a noise-induced increase in the onset of motility (*k*) in the 15-s interval with the maximum sound level of an overflight, and $L_{Amax,inside}$ or *SEL,inside* have been approximated by quadratic functions with the following format:

$$m = b( L_{Amax,inside} - a) + c( L_{Amax,inside} - a)^2 \quad [6]$$

The coefficients a, b and c are given in Table 5.2. The value of a is the value below which *m* or *k* is zero. Figure 4 shows the relationship between *m* and $L_{Amax,inside}$ together with the 95% confidence interval. Relations apply to $L_{Amax,inside}$ and *SEL,inside* values of at most 70 and 80 dB(A), respectively.

**Table 5.2:** Coefficients of the quadratic equation (formula [6]) of *m* and *k* as a function of $L_{Amax,inside}$ or $SEL,_{inside}$ for the 15-s interval in which an indoor maximum sound level of an aircraft noise event occurs. The equations are applicable in the $L_{Amax,inside}$ range from 'a' up to 70 dB(A), or $SEL_{,inside}$ range from 'a' up to 80 dB(A). Below 'a', *m* and *k* are zero.

| | (Aircraft) noise-induced increase of probability of motility (m) | (Aircraft) noise-induced increase of probability of onset of motility (k) |
|---|---|---|
| range | $32 < L_{Amax,inside} < 70$ dB(A) *(see figure 3)* | $32 < L_{Amax,inside} < 70$ dB(A) |
| a | 32 | 32 |
| b | 0.000633 | 0.000415 |
| c | $3.14x10^{-5}$ | $8.84x10^{-6}$ |
| range | $38 < SEL_{,inside} < 80$ dB(A) | $40 < SEL_{inside} < 80$ dB(A) |
| a | 38 | 40 |
| b | 0.000532 | 0.000273 |
| c | $2.68x10^{-5}$ | $3.57x10^{-6}$ |

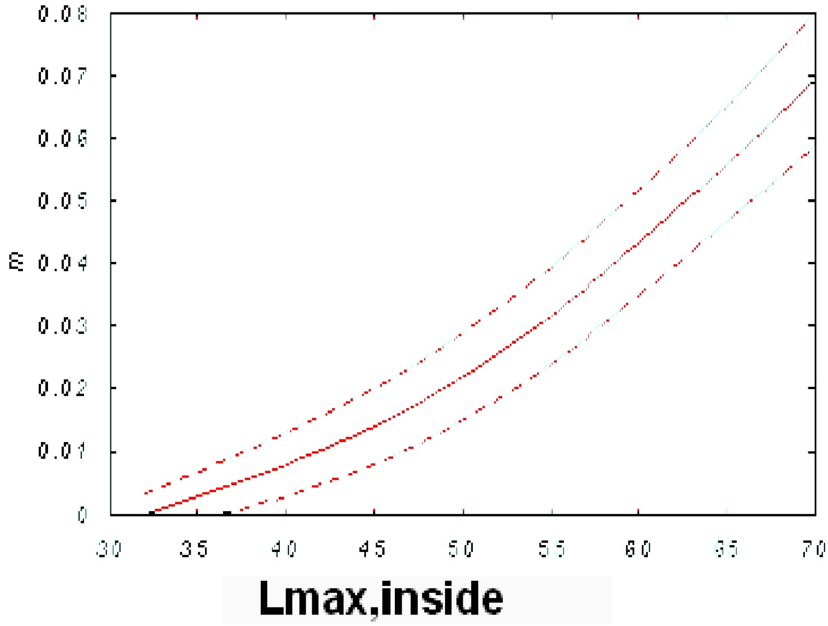



*Figure 4. Probability of (aircraft) noise-induced motility (m) at the 15-s interval in which the indoor maximum sound level occurs (solid line) and the 95% confidence interval, as a function of $L_{Amax}$, inside bedroom (Passchier-Vermeer et al[18]., 2002).*

The study report also gives the upper boundaries for motility, based on the relationship between $L_{Amax}$, SEL and $L_{night}$(figure 5). This figure is mathematically derived from relation [6] as described in Annex I.

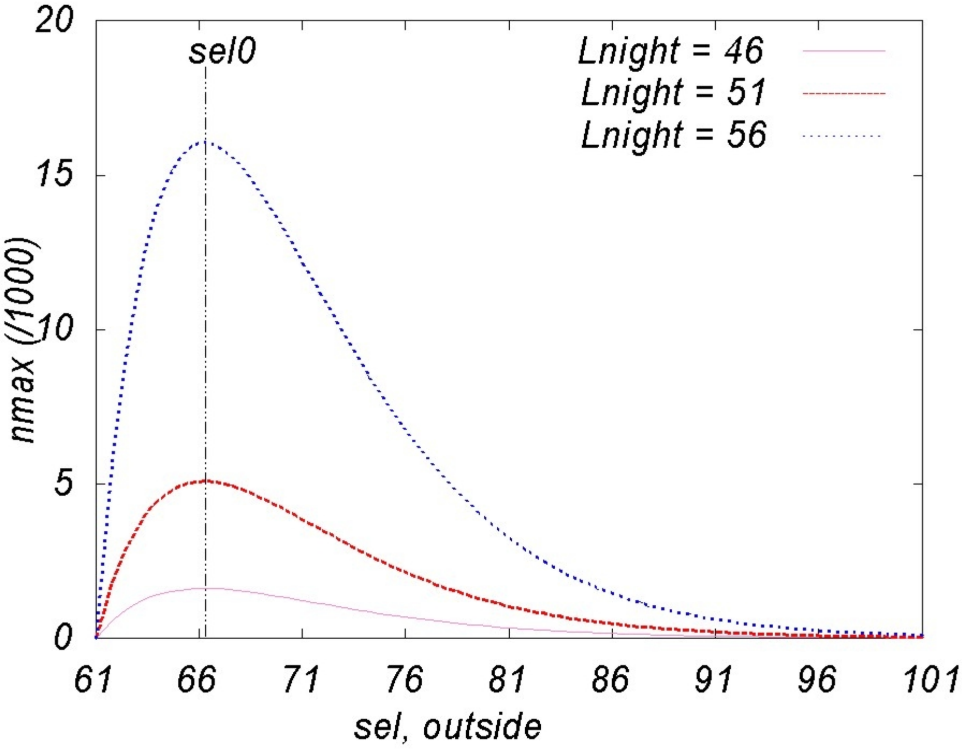



*Figure 5. Maximum number of noise induced motility for 3 values of $L_{night}$. Converted from inside relation with [3]*

This area of study is still under development. Although the results of the German Nocturnal Aircraft Noise study[29] could not be analysed for this paper, the published results so far do not seem to lead to different conclusions. In the study report[16] a detailed account is given of the relation of the study[18] used for the data presented here and earlier studies like the much quoted CAA-study[19] by Ollerhead et al. and earlier work done in the US.

## 5.2 Chronic effects

### 5.2.1 Chronic increase of motility

Mean motility - all body movements counted together - during sleep is strongly related to age and is also a function of noise exposure during the sleep period. The relationships between mean motility and $L_{night,\ inside}$ are shown in figure 6. Mean motility during sleep is lowest at the age of 45 years, and greater higher and lower ages. The relation between mean motility, and $L_{night,\text{inside}}$ and age is:

$$\textit{Mean motility} \;=\; 0.0587 + 0.000192 L_{night,inside} - 0.00133 age + 0.0000148 age^2 \qquad [7]$$

The relation between the increase in mean noise-induced motility, $m_{night}$, and $L_{night,inside}$ is:

$$m_{night} = \quad 0.000192 \mathrm{L}_{\text{night,inside}}, \qquad [8]$$

assuming, as described in section 3.4, that $L_{night,inside} = L_{night} - 21$:

$$m_{night} = 0.000192\ L_{night} - 0.004032 \quad [8a]$$

The increase in $m_{night}$ is 22% if indoor $L_{night}$ increases from 0 (absence of aircraft noise) to 35 dB(A) (living close to a runway). This increase is independent of age, although the absolute level varies.

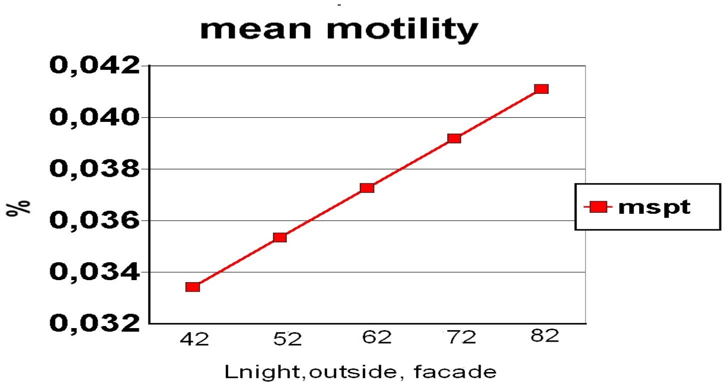



*Figure 6 Increase in mean motility (body movements during sleep). Converted from inside relation with [3]*

### 5.2.2 Self-reported (chronic) sleep disturbances

Self-reported sleep disturbance is investigated by means of a questionnaire containing questions regarding sleep disturbance. Often sleep disturbance is not the main focus of the questionnaires used in studies of self-reported noise effects. This means that considerable effort is needed to harmonise the different response categories. The relationships for self-reported sleep disturbance are based on analyses of the 15 data sets with more than 12000 individual observations of exposure-response combinations, from 12 field studies.
The curves are based on data in the $L_{night}$(outside, maximally exposed facade) range 45-65 dB(A). The polynomial functions are close approximations of the curves in this range and their extrapolations to lower exposure (40-45 dB(A)) and higher exposure (65-70 dB(A)). The formulae of these polynomial approximations for **road traffic** are as follows:

$$\%HSD = 20.8 - 1.05L_{night} + 0.01486(L_{night})^2 \quad [9]$$

$$\%SD = 13.8 - 0.85L_{night} + 0.01670\ (L_{night})^2 \quad [10]$$

$$\%LSD = -8.4 + 0.16L_{night} + 0.01081(L_{night})^2 \quad [11]$$

in which SD=Sleep Disturbed; H=Highly; L=Lowly

for **aircraft**:

$$\%HSD = 18.147 - 0.956L_{night} + 0.01482(L_{night})^2 \quad [12]$$

$$\%SD = 13.714 - 0.807L_{night} + 0.01555\ (L_{night})^2 \quad [13]$$

$$\%LSD = 4.465 - 0.411L_{night} + 0.01395(L_{night})^2 \quad [14]$$

and for **railways**:

$$\%HSD = 11.3 - 0.55L_{night} + 0.00759\,(L_{night})^2 \quad [15]$$

$$\%SD = 12.5 - 0.66L_{night} + 0.01121\,(L_{night})^2 \quad [16]$$

$$\%LSD = 4.7 - 0.31L_{night} + 0.01125\,(L_{night})^2 \quad [17]$$

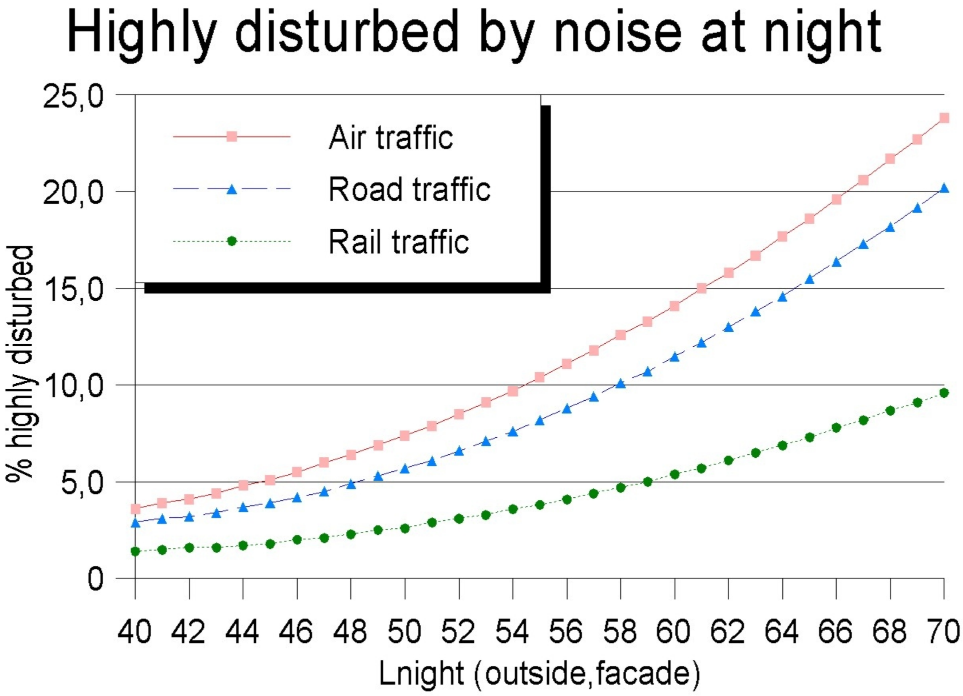



*Figure 7. Percentages of highly disturbed when exposed to rail and road traffic noise*

in which again SD=Sleep Disturbed; H=Highly; L=Lowly

The above relations represent the current best estimates of the influences of $L_{night}$ on self-reported sleep disturbance for road traffic noise and for railway noise, when no other factors are taken into account. Figure 7 illustrates the relations [9] [12] and [15] for persons highly disturbed by road, aircraft and rail noise.
With regard to the relations for aircraft noise it should be noted that the variance in the responses is large compared to the variance found for rail and road traffic. This means that the uncertainty regarding the responses for night-time aircraft noise is large, and such responses can be considered as indicative only. In the report[17] the following causes are suggested:
- The time pattern of noise exposures around different airports are varies considerably due to specific night-time regulations;
- the sleep disturbance questions for aircraft noise show a large variation;
- the most recent studies show the highest self-reported sleep disturbance at the same $L_{night}$. level. This suggests a time trend.

For industrial noise there is an almost complete lack of information, although there are some indications[27] that impulse noise may cause considerable disturbance at night.

### 5.2.3 Medicine use

Several studies[11,2,19] indicate an increase in use the of medicines as noise levels increase. One study shows that the effect tends to be higher with increasing age. However, due to the differences in medicine use and prescription behaviour in Europe, no generally valid dose-effect relations can be derived at the present time.

5.3 Long-term health effects

Several studies and meta-analysis point to a relationship between noise exposure, hypertension and cardio-vascular diseases. It is not clear, however, to what extent air pollution influences this finding. Recent results by Babisch[1] and Maschke[15] seem to indicate that noise exposure during the night may be more important for predicting the effect than noise exposure during the day. The results by Maschke are presented here as an indication that above 50 dB(A) $L_{night}$ the precautionary principle should play a role in decisions about night-time exposure and not - yet- as a dose-effect relation in the sense of the END.

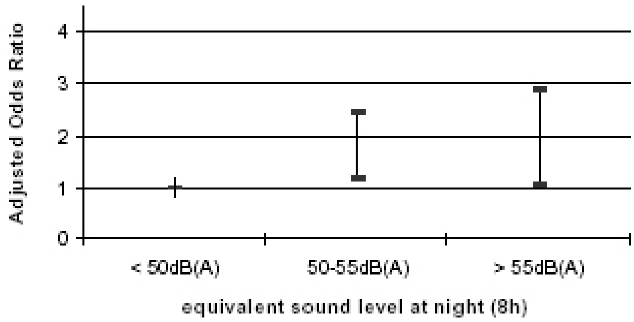



Fig. 5: Statistical connection between nightly road traffic noise and hypertension in the lifetime (N = 1335; adjusted for "age" "alcohol intake" "tobacco intake" "motion in the profession", "sporting activity", "body mass index ", "socio economic index ", "partner loss in the marriage", "hearing ability", and "noise sensitivity").

*Figure 8: relation hypertension treatment and night time noise. Figure 5 From ICBEN-publication[15].*

# 6 Practical observations

## 6.1 Inside / outside differences

Night-time environmental noise affects residents mainly inside their homes. In order to protect residents inside their homes against noise from the outside sources, attention should be focused on windows since they are generally the weakest points in the sound propagation line. Roofs must also be considered with regard to aircraft noise.

There are many types of window in the EU, varying from single thin panes within frames without additional insulation, to four-pane windows within insulated frames. The simplest types of facade have a sound reduction (from outside to inside) of usually less than 24 dB, and the most elaborated facades (built to cope with cold climates, for example), have sound reductions of more than 45 dB. In central Europe, most windows are of the double-pane (thermopane) type, mounted in a rigid and well-insulated frame. Their range of sound reduction is between 30 and 35 dB when closed.

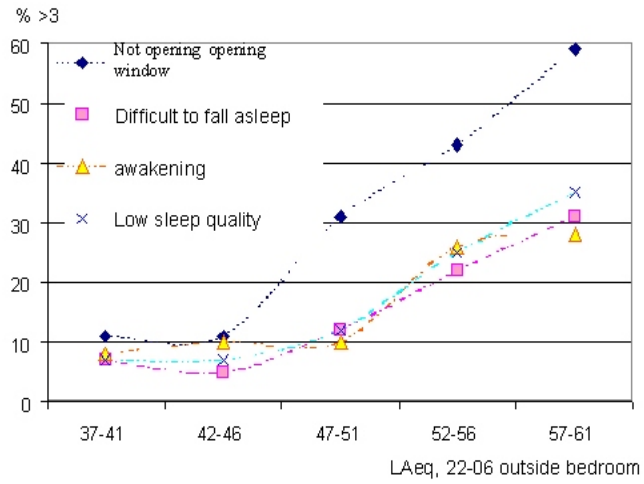



*Figure 9. Results from Swedish Soundscape research program[20].*

When night-time environmental noise reaches high levels, residents tend to close their bedroom windows (cf.[4, 14, 23, 24]). The two latter studies found that more than 50% of bedroom windows are closed when outside road traffic noise levels exceed 55 dB ($L_{Aeq}$). Nevertheless, while residents with closed windows reported a reduction of sleep disturbances due to noise, they also reported an increase in sleep disturbances due to poor ventilation. Schreckenberg et al[23]. (1999) report a much steeper increase in the incidence of closed windows when road traffic noise reaches high levels of than is the case with increased levels of railway noise. Even when night-time noise levels reach 55 dB, only 35 % of the residents exposed to railway noise reported that they close their windows at night. It is remarkable that this finding is replicated in Sweden, according to recent results from the Swedish soundscape research programme on road traffic noise (figure 9).

When windows are slightly open, outside sound levels are usually reduced by 10 – 15 dB. It should be acknowledged that most European residents want to keep their bedroom windows slightly open at night in order to provide for proper ventilation[12,13,23], and the WHO paper on community noise[2] also recommends that people should be able to sleep with their bedroom windows open.

In Passchier-Vermeer[18] detailed noise measurements were carried out inside and outside the bedroom and at the same time window position was measured with sensors. The results showed that windows are fully closed in only in 25% of the nights.

| Table 6.1 Window positions during research period (April-November)[19] | |
|---|---|
| Window position | % Nights |
| Closed | 25 |
| Slightly open | 43 |
| Hand width | 23 |
| Half open | 5 |
| Fully Opened | 4 |

This results in average inside-outside differences of around 21 dB, with there being only a slight difference between single and double-glazed windows. The survey did not include dwellings which ad been specifically insulated against noise. Nevertheless, there was a large variation in insulation values.

| Table 6.2 Average inside-outside differences in dB(A) | | |
|---|---|---|
| | single-glazed window | double-glazed window |
| average difference at night | 21.3 | 22.2 |

It should be stressed that this figure only applies to facades that have not been fitted with special appliances to reduce noise impact. To give an extreme example of where this general finding does not apply, rooms may be equipped with air-conditioning so that windows can stay closed, or could even be sealed. Less drastic provisions are sound-attenuated ventilation openings. Little is known however about the experiences (long-term use, approval) of these and other solutions by inhabitants. It is not unknown for sound attenuated ventilation openings to be blocked in order to cut out drafts, for example .

## 6.2 Protection measures & control

What is the best strategy to reduce sleep disturbance?
The first thought should always be to reduce the impact, either by reducing the number of events or by reducing the sound levels, or both. In combination with other measures, sound insulation of bedroom windows is an option, but extreme care must be taken to avoid any negative impact on inside air quality. Even then, many people may want to sleep with their windows open, thereby making the insulation ineffective. Although good instruction may go some way to helping to overcome this, it is still a matter well worth taking into account. In warmer climates in particular insulation is not a serious option for residential purposes and excessive exposure must be avoided either by removing the persons exposed or removing the source if source-related measures fail.
Although air-conditioning of houses (or just bedrooms) is not commonplace in the EU, there are indications that its use is increasing, especially in the warmer parts of the Union. Although this still leaves the possibility that people may sleep with their windows open outside the summer season, it is something to consider when discussing measures.

Exposed areas could be a good choice for uses where people have no nightly occupations (offices, schools) or it is physical impossibility to sleep with the windows open (fully airconditioned buildings, for example).
A simple measure is the **orientation** of noise-sensitive rooms on the quiet side of the dwelling (this applies to road and rail traffic noise).
**Zoning** is an instrument that may assist planning authorities to keep noise-sensitive land uses away from noisy areas. In the densely populated areas of the EU this solution must often compete with other planning requirements or plain lack of suitable space.
In the UK, the discussion spawned a milestone research report on sleep[21]. At the end it was decided not to establish a separate night-time limit value, but to install the **Quota Count system** which attributes to aircraft a rating depending on the noise class to which they belong. At the base of this night time restriction policy lies the field study on sleep disturbance[21] . Although the QC-system does not directly control $L_{night}$, in a situation of a fixed number of runways and flight paths, changes in the QC will reflect corresponding changes in $L_{night}$. The QC-system appears[5] to have been quite successful in limiting night-time noise emissions which is perhaps the reason that attempts have been made to copy it elsewhere[26].
The Netherlands has set a limit value for indoor aircraft noise of 26 dB(A) for the $L_{Aeq}$ between 23.00 and 06.00 hrs. This was based on a scrutiny of dose-effect relations for self-reported sleep disturbance, awakening reactions and sleep stage changes. The choice for an exact level was, to a great extent influenced by the estimated cost of insulating existing dwellings (put at €150 million at the time of the decision).

## 6.3 Effectiveness of measures

There are few reliable before-after studies or other study designs which can be used to deduce the effectiveness of measures. The overall impression is that good communication with the population may be important to supplement physical measures such as night-time restrictions and insulation. Insulation of houses may have some benefits if care is taken to ensure that ventilation requirements are met. In an analysis of complaint data[28] there is a suggestion that insulation may help to avoid complaints (figure 10)

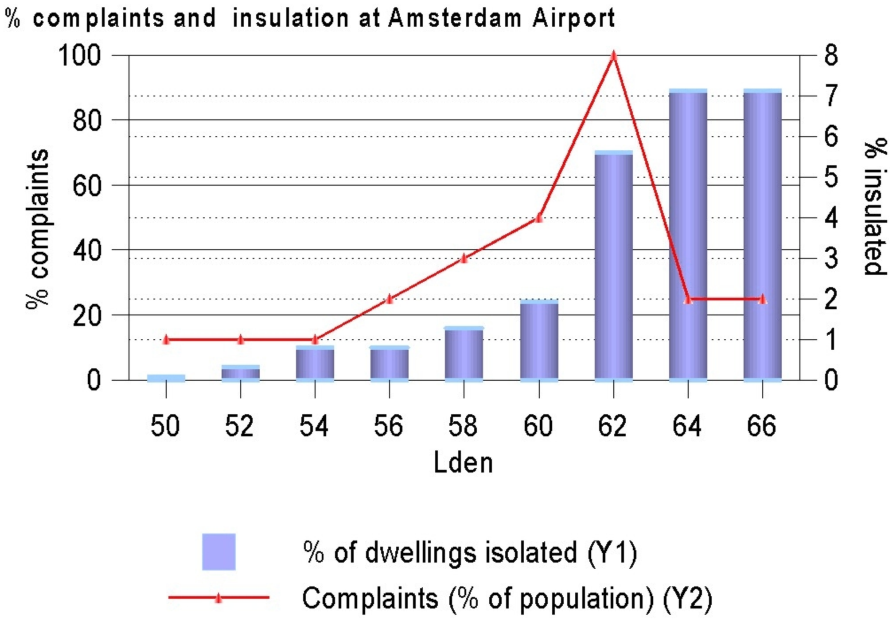



*Figure 10. relation complaints and $L_{den}$ from Schiphol airport (2000 data)*

## 7 Recommendation to Commission and Member States

1. As well exposure data as epidemiological data about night time exposure in the EU is lacking. Although the strategic noise mapping will partly fill this gap, epidemiological data will be needed to assess progress of measures or deterioration due to autonomous developments.

2. Annex III of the END with regard to $L_{night}$ can be amended by incorporating the following dose-effect relationships:
   - Number of awakenings for SEL from aircraft noise (formula [4])
   - Maximum number of expected behavioural awakenings for $L_{night}$ of aircraft noise (formula [5]).
   - Increase in body movements for $L_{night}$ from aircraft noise (Mean motility) (formula [8a])
   - Percentage of population disturbed by noise from aircraft, roads and railways for $L_{night}$ (formula's [9]-[17]). The variation of the aircraft noise relations ([12], [13],[14]) is relatively high, and should be used with care.

   The formula's are numbered in the paper with square brackets: [..]

3. The relations as mentioned in conclusion 2 represent the best available knowledge to date. Attention should be paid to the following limitations and restrictions.
   - the relations refer to a steady state situation. Therefore the relations cannot be used to predict accurately the effect immediately after a major change;
   - the information intends to refer to an average population (the extent of which is not clear; for practical and ethical reasons experiments are carried out in a relatively young and healthy group). Care should be taken for protection for vulnerable or sensitive groups;
   - if local knowledge is available, this may be used if this is shown to be of suitable quality. This should be motivated.

4. Further research
   - as there is (limited) evidence for an increase of blood pressure in the population due to prolonged exposure to night time noise long term studies into the increase of medicine consumption, cardiac failure and blood pressure are desirable
   - awakenings by road traffic noise, railway noise and impulse noise;
   - EU-wide studies on self reported sleep disturbance by transport noise and neighbour noise;
   - reactions at low number of noise events and the distribution of events over the night;
   - effectivity of reduction measures, specifically the relation between insulation and indoor levels.

5. As the current state of control of night time noise in the EU is confusing , it is recommended that Member States review their night noise control systems in the light of the latest evidence presented in this paper.

## 8 References


1 Babisch, W et.al. (2003), Traffic Noise and myocardial infarction , results from the NAROMI study, ICBEN proceedings 2003, Schiedam

2 Berglund, B. & Lindvall, T, Schwela, D. (2000).Guidelines for Community Noise. WHO.

3 Bohny, H.-M., Borgmann, R., Kellner, K.-H., Kühne, R., Müller, H., Vierling, W. & Weigl, P. (1986). Lärmschutz in der Praxis. München: R.Oldenbourg.

4 Diaz, J., Ekelund, M., Gothe, R., Huber, M., Jordan, A., Kallischnigg, G., Kampet, T., Kappos, A., Santiago, C.L., Mansfield, T., Maschke, C., Niemann, H. & Welker, D. (2001). Traffic Noise Pollution. Similarities and differences between European regions. A state-of-the-art-review. Berlin: Technical University.

5 Department for Transport (2003), Review of the quota count (QC) system used for administering the night noise quota's at Heathrow, Gatwick and Stansted airports, London

6 European Communities, (2002) Position paper on dose response relationships between transportation noise and annoyance, Luxembourg: Office for Official Publications of the European Communities, 2002, ISBN 92-894-3894-0

7 European Communities, (2000) Position paper on EU noise indicators Luxembourg: Office for Official Publications of the European Communities, 2002, ISBN 92-828-8953-X

8 Flindell, I.H. & McKenzie, A.R. (2000). An inventory of current European methodologies and procedures for environmental noise management. Copenhagen, DK: European Environment Agency, Technical Report.

9 Dongen, JEF, van, Franssen, EAM, Ruysbroek, JMH, Stellato, RK, Vos, H.(2004). Hinder door milieufactoren en de beoordeling van de leefomgeving in Nederland. RIVM, Bilthoven, TNO-INRO, Delft.

10 Kihlman, T., Öhrström, E. & Skånberg, A. (2002). Adverse health effects of noise and the value of access to quietness in residential areas. InterNoise '02, Paper IN02404.

11 Lambert, J., Simonnet, F. & Vallet, M. (1984). Patterns of behaviour in dwellings exposed to road traffic noise. Journal of Sound and Vibration, 92, 159 -172.

12 Lambert, J. & Plouhinec, M. (1985). Day and night annoyance: a comparison. Proceedings of Inter-Noise '85, 941-944.

13 Lambert, J. & Vallet, M. (1994). Study related to the preparation of a communication on a future EC noise policy. Bruxelles: LEN Report No.9420.

14 Langdon, F.J. & Buller, I.B. (1977). Road traffic noise and disturbance to sleep. Journal of Sound and Vibration, 50, 13-28.

15 Maschke, C (2003), Epidemiological research on stress caused by traffic noise and its effects on high blood pressure and psychic disturbance, ICBEN proceedings 2003, Schiedam

16 Miedema, H.M.E, Passchier-Vermeer, W, Vos, H.(2002) Elements for a position paper on night-time transportation noise and sleep disturbance, TNO-INRO, Delft

17 Miedema, H.M.E, Vos, H. (2004). Self-reported sleep disturbance caused by aircraft noise, TNO-INRO, Delft

18 Passchier-Vermeer, W, (2003) Night-time noise events and awakening, TNO-INRO, Delft

19 Passchier-Vermeer et. al. (2002), Sleep disturbance and aircraft noise exposure, TNO-PG, Leiden

20 E. Öhrström. A. Skånberg and Helena Svensson (2004, to be published), Effects of Road Traffic Noise and the Benefits of Access to Quietness. Dept of Environmental Medicine, Sahlgrenska Academy at Göteborg University

21 Ollerhead et. al., (1992), Report on a field study of Aircraft Noise and Sleep Disturbance, DoT, London

22 Scharnberg, T. (1985). Sleep impairments caused by road traffic noise in cities. Proceedings of Inter-Noise '85, 953-956.

23 Scharnberg, T., Wühler, K., Finke, H.-O. & Guski, R. (1982). Beeinträchtigung des Nachtschlafs durch Lärm. Eine interdisziplinäre Feldstudie der Technischen Universität Berlin und der Physikalisch-Technischen Bundesanstalt Braunschweig. Berlin: Umweltbundesamt, Forschungsbericht 82-10501207.

24 Schreckenberg, D., Schuemer-Kohrs, A., Schuemer, R., Griefahn, B. & Moehler, U. (1999). An interdisciplinary study on railway and road traffic noise: Annoyance differences. 137th ASA Meeting + 25th DAGA Conference.

25 Solberg, S. (2002). Answer to I-INCE questionnaire on national noise policies and laws. http://www.akustisk-selskap.com/nas_nytt_2_2002/ince_questionaire/answer_to_i.htm.

26 Vindevogel, G. (2001). Belgian noise indicators in the light of the EU directive. Workshop "Evaluation et gestion du bruit ambient", Bruxelles: Institut Bruxellois pour la Gestion de l'Environnement.

27 Vos, J (2003). On the relevance of shooting-noise-induced sleep disturbance to noise zoning, ICBEN-proceedings 2003, Schiedam

28 van Wiechen,C, Franssen,E, de Jong,RG, Lebret, E (2002), Aircraft noise exposure from Schiphol airport, relation with complaints, RIVM, Bilthoven

29 Basner, M et al (2004), Effects of nocturnal aircraft noise, Deutsches Zentrum für Luft und Raumfahrt, bericht 2004-07/E

# I. APPENDIX I: relations between $L_{night}$ and instantaneous effects

**Statement 1**

Let f be a function of *SEL* that gives the expected number of instantaneous effects caused by a single event. With a given $L_{night}$ and a given number of events *N*, the expected number of times that an effect occurs in the night, *n*, is maximal if all events have equal *SEL*, provided that $f \circ 10\lg$ is increasing but negatively accelerated.

**Statement 2**

If

$$n_{max} \;=\; 10^{(Lnight-sel+70.2)/10} \,.\, f(sel),$$

has a maximum over *sel* and f is the quadratic function $f(SEL) = a\, SEL^2 + b\, SEL + c$, then the maximum occurs irrespective of $L_{night}$ at

$$sel_0 \;=\; 4.34 - A \pm [(A - 4.34)^2 - (c/a) + 8.68A]^{½},$$

where A = b/(2a). (Only with + at the place of ± the value will come in the realistic range of *sel*)

**Statement 3a**

If the shape of the time pattern of the sound level has a block form, then $SEL = {}_{LAmax} + 10\lg T$, where ${}_{LAmax}$ is the maximum sound level (integrated over 1-s) and *T* is the duration of the noise event in s.

**Statement 3b**

If the sound level increases with rate *a* (in dB(A)/s) and after time point $t = 0$ decreases with rate $-a$, then $SEL \quad L_{Amax} - 10\lg a + 9.4$.

## II. APPENDIX II: Overview of night time noise regulations in the EU

### A. Introduction

The noise abatement laws and standards for night-time noise used in the EU differ in many respects[13]. Even within the same country, different standards may apply, depending on the district[26]. Some member states give separate day-time and night-time levels, some give 24h-levels, while others state $L_{Amax}$-levels. When separate equivalent sound pressure levels are given for day-time and night-time separately, they mostly refer to outdoor situations. Noise limits for dwellings most often result from a compromise between the effects of noise on the population (disturbance and more particularly the effects of noise on sleep) and the costs of implementing noise protection measures. This compromise, most often decided by governmental authorities, tends to evolve over time insofar as populations are more demanding now than they were in the past (it is still debatable whether populations have become more sensitive to noise, or whether there is increased social pressure or perhaps other factors might be at work). Noise limits depend on the sensitivity of the zones where they apply: sensitive areas (hospitals, schools), residential areas, mixed residential and commercial areas, industrial areas as well as the development phase of the infrastructures and buildings (existing, projected or planned). Differences of 10 to 15 dB(A) are frequently encountered between the noise limits of the areas considered to be the most sensitive (hospitals and schools) and the least sensitive areas (industrial zones). The situations are, therefore, extremely diverse and often difficult to compare. Differences of 5 to 10 dB(A) are also commonly observed between noise limits for new situations (preventive actions) and existing situations (corrective actions).

Comparing noise limits at face value is a tricky task; in order to understand what the actual impact of a limit is it is necessary not only to look at technical backgrounds like definitions and computation practices, but also at juridical and financial implications. Sometimes a fairly strict limit will not be enforced and sometimes a higher limit will be facilitated by generous financial compensation.

B. Road traffic noise

Table 6.3 gives night-time outdoor/indoor threshold levels as $L_{Aeq}$ for road traffic noise (new roads with existing receivers) in urban residential areas. Most data are taken from Flindell & McKenzie (2000) [8] who rely heavily on Lambert & Vallet (1994)[13]; the Belgium data are taken from Vindevogel (2001)[25]; the German data partially from Bohny et al. (1986)[3].

**Table 6.3 $L_{Aeq}$ *)for road traffic noise (new roads with existing receivers) in urban residential areas.**

| Member State | Directive | Jurid. Type | Night Time | Outdoor Level night | Indoor Level night |
|---|---|---|---|---|---|
| Belgium (Flemish) | VLAREM | guide | 22-07 | 35 | 28 |
| Finland | Council of State Decision on noise level guidelines 993/1992 . | guide | 22-07 | 45-50 | 30 |
| France | | law | 22-06 | 55-60 | |
| Germany | BImSchG | law | 22-06 | 49 | |
| Germany | VDI 2719 | guide | 22-06 | | 25 – 30 **) |
| Italy | | law (proposal) | 22-06 | 40-60 | |
| Netherlands | Noise Abatement Act | law | 23-07 | 55 | 25-35***) |
| Sweden | | guideline | 24 hrs<br>$L_{Amax}$ | 55 | 30<br>45 |
| Spain | | law | 22-07 | 55 | |

*) Some values may include facade reflections while others may not
**) windows slightly open
***)with sufficient ventilation; 25 is preferred value but allowance up to 35 may be permissible for technical reasons

Note: The significant reduction of outside sound levels by means of windows may reduce the masking of sound from inside (e.g., from plumbing), but residents still complain significantly more about outside noise intrusions than about inside noise intrusions (Scharnberg[23] et al. 1982).

C. Rail traffic noise

As is the case with road traffic, noise limits are applied in many European countries for night-time railway noise. Their main objective is to protect people living near new lines. In this case, $L_{Aeq}$ is the most common index. However, some countries also use $L_{Amax}$, particularly for nightly events to limit the effects of noise on sleep. Table 4 provides further details.

**Table 6.4 Railway noise regulations (or guidelines) in selected European countries**

*Perception side values for new railway lines with existing residential areas*

| Country | Noise index | Reference time period | Outdoor level (1) | Indoor level windows closed |
|---|---|---|---|---|
| Austria | Lr = LAeq - 5 dB | 22.00 - 06.00 | 50 dB (FF) | |
| Denmark | LAeq,24h<br>$L_{Amax}$ | 00.00 - 24.00<br>00.00 - 24.00 | 60 dB (FF)<br>85 dB (FF) | |
| Finland | LAeq | 22.00 - 07.00 | 45-50 (FF) | 30 dB |
| France | Lr = LAeq - 3 dB | 22.00 - 06.00 | 55 dB (F) (speed < 250 km/h)<br>52 dB (F) (speed > 250 km/h) | |
| Germany | Lr = LAeq - 5 dB | 22.00 - 06.00 | 49 dB (FF) | |
| Great-Britain (2) | LAeq | 23.00 - 07.00 | 63 dB (FF) | |
| Italy | LAeq | 22.00 - 06.00 | ° speed < 200 km/h<br>0 - 100 metres: 60 dB (F)<br>100 - 250 metres: 55 dB (F)<br><br>° speed > 200 km/h<br>0 - 100 metres: 55 dB (F)<br>100 - 250 metres: 55 dB (F) | |
| Netherlands | LAeq | 23.00 - 07.00 | 47 dB (FF) | 25/27 dB |
| Norway (3) | $L_{den}$<br>$L_{Amax}$ | 00.00 - 24.00<br>22.00 - 06.00 | 58 dB (FF)<br>75 dB (FF) | |
| Portugal | LAeq | 22.00 - 07.00 | 45 (FF) | |
| Sweden | LAeq,24h<br>$L_{Amax}$ | 00.00 - 24.00<br>23.00 - 07.00 | 60 dB (FF) | <br>45 dB |

(1) FF = freefield ; F = façade (2) For insulation scheme (3) Proposal for a new regulation

The time period to which these limits generally apply ise 10.00 p.m. to 6.00 or 7.00 a.m (and sometimes the evenings: 7.00 to 11.00 p.m.). Sweden, Denmark and Norway use a single 24-

hour period.

Noise limits often depend on the sensitivity of zones affected by noise. When new lines are created in residential areas, night-time noise limits (at the facade) are in the range of 53 to 62 dB(A). Permissible $L_{Amax}$ is generally in the range 75 to 85 dB(A) for night-time events (i.e. 54-64 dB(A) indoors).

D. Aircraft noise

The purpose of fixing noise limits for aircraft noise is to ensure that rules are followed when building new dwellings close to existing airports. Generally, these rules specify whether construction is permitted or not, or whether it is necessary to strengthen insulation depending on the zone of the building exposed to noise.

Unlike road noise and rail noise, the noise indices used in regulations relating to aircraft noise are extremely numerous. In fact, two approaches seem to coexist : one uses the $L_{Aeq}$ (in the UK, Germany and Sweden, for example), the other uses indices which consider both the number of aircraft movements and the peak sound level of each overflight (NNI, IP, Ke, NEF, WECPNL, etc) with different weightings for the different periods during the day. In most cases, two periods are used : daytime (6.00 a.m. - 10.00 p.m.) and night-time (10.00 p.m. - 6.00 a.m.). The UK and the Netherlands adhere to a definition from 23.00 to 07.00 hrs.

Given the diversity of the indices used, it is extremely difficult to compare noise reception limits, particularly when sound levels are either expressed in dB(A) or in EPNDB.

E. Industrial noise

Most industrialised nations apply noise limits when noisy industrial establishments are built. The base index used is the $L_{Aeq}$. It applies particularly for the night-time period and sometimes the evening period. Here again, values depend on zone sensitivity ; in residential zones these are generally 40 to 45 dB(A) at night.
In the Netherlands $L_{Amax}$ is used to protect against noisy events: the value is 60 dB(A) in the night-time period (outside value).