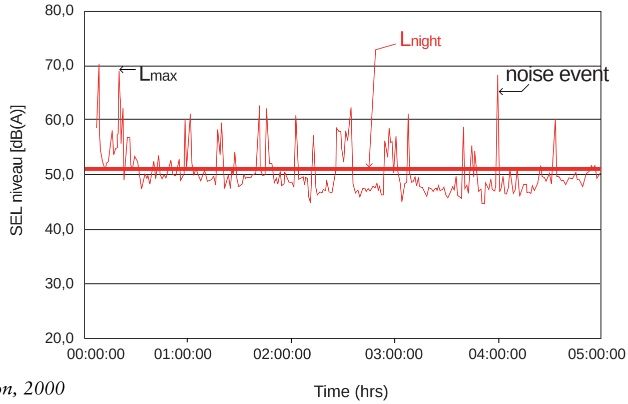
use and health complaints, in particular, requires a combination of a number of events and their level instead of just the average L_{Amax} or average SEL. For events with a similar time pattern there is a relatively simple relation between L_{Amax} and SEL, and therefore between L_{Amax} and L_{night} (night-time noise indicator as defined

Fig. 1.6
Relation between L_{night}, L_{Amax} and SEL



Source: European Commission, 2000

by the END – see paragraph 1.3.4 below). Appendix 2 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.

Fig. 1.6 is based on 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). In reality the L_{night} is the average over all nights in one year. 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 long-term health status, whereas a sustained sufficiently high level over a long period may.

1.3.3 NUMBER OF EVENTS

There is no generally accepted way to count the number of (relevant) noise events. Proposals range from the number of measured L_{Amax}, the number of units (vehicles, aeroplanes, trains) passing by, to the number exceeding a certain L_{Amax} level (commonly indicated by NAxx; NA70 is the number of events higher than 70 dB).

1.3.4 CONVERSION BETWEEN INDICATORS

1.3.4.1 Introduction

L_{night} is defined as the 1 year L_{Aeq} (exposure to noise) over 8 hours outside at the most exposed facade. For the purpose of strategic noise mapping and reporting the height is fixed at 4 metres. As L_{night} is a relatively new definition and because the studies rarely cover such a long period, the research data are rarely expressed in 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 L_{night}. There are four 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 façade.

Further background information on these issues is provided in section 1.3.5. This section details the conversions that are actually carried out.

1.3.4.2 SEL to L_{Amax}

SEL is only used for aircraft noise in this report and, according to Ollerhead et al. (1992) from ground-based measurements, the following relation was found:

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

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 $SEL \approx L_{Amax} + 10lg\ t$, 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 from 3 to 30 seconds, then SEL is 5–15 dB higher than L_{Amax}. 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 increases with rate a (in dB per second), and thereafter is at its maximum for a short duration before it decreases with rate -a, then $SEL \approx L_{Amax} - 10lg(a) + 9.4$. 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 per second up to 5 dB per second. When (a) is in the range from 9 dB to 1 dB per second, then SEL is 0–9 dB higher than L_{Amax}.

1.3.4.3 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:
$L_{night} = 10*lg\ \Sigma_i\ 10^{SEL_i/10} - 10*lg\ (T)$.

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

$$L_{night} = SEL + 10*lg(N) - 70.2 \qquad [2],$$

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 notation adheres to the END where the L_{night} is defined as a year average at the most exposed facade. Any reference to an inside level is noted as such, that is, as $L_{night,inside}$. In order to avoid any doubt the notation $L_{night,outside}$ may be used, for instance in tables where both occur.

1.3.4.4 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 results about effects are expressed with indoor (that is, inside bedrooms) exposure levels, 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 dB has been chosen, as this takes into account that even in well-insulated houses windows may be open a large part of the year. In general:

the instantaneous noise-induced motility. Other factors influencing the relationships between instantaneous motility and L_{Amax} or SEL are the point of time in the night, and time since sleep onset. For example, after 7 hours of sleep, noise-induced motility is about 1.3 larger than in the first hour of sleep. Age has only a slight effect on noise-induced motility, with younger and older people showing a lower motility response than persons in the age range of 40–50 years.

3.1.7 BEHAVIOURAL AWAKENING IN ADULTS

Passchier-Vermeer (2003a) published a review of nine 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_{indoor} 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:

$$\text{Percentage of noise-induced awakenings} = -0.564 + 1.909 * 10^{-4} * (SEL_{inside})^2 \quad [4],$$

where SELinside is the sound exposure level of an aircraft noise event in the bedroom.

This relation is confined to commercial aircraft noise over the intervals $54<SEL<90$ ($37<L_{Amax}<82$) and the number of events per night $1< N< 10$.

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. Fig. 3.1 represents the results of this worst case approach (converted to L_{night}, see Chapter 1, section 1.3.4), and so gives the maximum number of awakenings n_{max} that may be expected.

$$n_{max} = 0.3504 * 10^{(L_{night}-35.2)/10} \quad [5].$$

- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening.
- There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.
- While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia), it also leads to further consequences for health and well-being.
- There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.
- There is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.

In the next section threshold levels are presented for the effects, where these can be derived.

5.2 THRESHOLDS FOR OBSERVED EFFECTS

The NOAEL is a concept from toxicology, and is defined as the greatest concentration which causes no detectable adverse alteration of morphology, functional capacity, growth, development or lifespan of the target organism. For the topic of night-time noise (where the adversity of effects is not always clear) this concept is less useful. Instead, the observed effect thresholds are provided: the level above which an effect starts to occur or shows itself to be dependent on the dose. This can also be an adverse effect (such as myocardial infarcts) or a potentially dangerous increase in a naturally occurring effect such as motility.

Threshold levels are important milestones in the process of evaluating the health consequences of environmental exposure. The threshold levels also delimit the study area, which may lead to a better insight into overall consequences. In Tables 5.1 and 5.2 all effects are summarized for which sufficient or limited evidence exists (see Table 1.2 in Chapter 1 for a definition). For the effects with sufficient evidence the threshold levels are usually well known, and for some the dose-effect relations over a range of exposures could also be established.

5.3 RELATIONS WITH $L_{NIGHT,OUTSIDE}$

Over the next few years, the END will require that night exposures are reported in $L_{night,outside}$. It is therefore interesting to look into the relation between $L_{night,outside}$ and the effects from night-time noise. The relation between the effects listed in Tables 5.1 and 5.2 and $L_{night,outside}$ is, however, not straightforward. Short-term effects are mainly related to maximum levels per event inside the bedroom: $L_{Amax,inside}$. In order to express the (expected) effects in relation to the single EU indicator, some calculation needs to be done.

5.7 RELATION WITH THE GUIDELINES FOR COMMUNITY NOISE (1999)

The *Guidelines for community noise* (WHO, 1999) have been quoted a number of times in this paper, so one could rightfully ask what the relation is between the 1999 guidelines and the present NNG.

Impact of night-time exposure to noise and sleep disturbance is indeed covered in the 1999 guidelines, and this is the full statement (WHO, 1999):

> "If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with L_{Amax} and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep."

It should be noted that the noise indicators of the 1999 guidelines are L_{Aeq} and L_{Amax}, measured inside for continuous and non-continuous noise, respectively. The present night noise guidelines adopt an harmonized noise indicator as defined by Environmental Noise Directive (2002/49/EC): L_{night} measured outside, averaged over a year.

It should also be borne in mind that the 1999 guidelines are based on studies carried out up to 1995 (and a few meta-analyses some years later). Important new studies (Passchier-Vermeer et al., 2002; Basner et al., 2004) have become available since then, together with new insights into normal and disturbed sleep.

Comparing the above statement with the recommendations, it is clear that new information has made more precise statements possible. The thresholds are now known to be lower than L_{Amax} of 45 dB for a number of effects. The last three sentences still stand: there are good reasons for people to sleep with their windows open, and to prevent sleep disturbances one should consider the equivalent sound pressure level and the number of sound events. The present NNG allow responsible authorities and stakeholders to do this. Viewed in this way, the *Night noise guidelines for Europe* complements the 1999 guidelines. This means that the recommendations on government policy framework on noise management elaborated in the 1999 guidelines should be considered valid and relevant for the Member States to achieve the guideline values of this document.