Assessing noise exposure for public health purposes

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Health Council of the Netherlands:
Committee on Uniform environmental noise exposure metric

to:

the Minister of Health, Welfare and Sport

the Minister of Housing, Spatial Planning and the Environment

the Minister of Defence

the Minister of Transport, Public Works and Water Management

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Executive summary

In this report, the 'Uniform environmental noise exposure metric' Committee of the Health Council of the Netherlands proposes a system of environmental noise exposure metrics for risk assessment of and policy decision-making on the adverse effects of environmental noise on the health and well-being of residential communities.

Request for advice and background

The Minister of Health, Welfare and Sport and the Minister of Housing, Spatial Planning and the Environment requested the Health Council to recommend a system of environmental noise exposure metrics. This system should be simple, transparent, in agreement with binding international regulations, and applicable to all environmental noise sources outside the home. The request is to be viewed against the background of the present use of a variety of source-dependent noise metrics associated in different ways with noise-induced health effects.

The present report, which answers the Ministers' request, is part of the national policy project MIG: Modernisering Instrumentarium Geluidbeheer (Modernization of Policy Tools for Noise Management). This project should result in a policy revision that aims at simplifying the environmental noise regulations by introducing more transparency, flexibility and delegation to provincial and municipal authorities.

Specification of adverse effects

The request for advice was limited to exposure to environmental noise. The former Health Council Committee on Noise and Health showed in its report that noise-induced general annoyance and sleep disturbance are the most widespread effects of environmental noise on the population of the Netherlands. The system of noise metrics is developed in such a way as to be able to assess these effects within communities in residential areas independent of the type of noise source. This is done by adjusting physical noise exposure metrics, using exposure-response relationships based on empirical data, in such a way that source-dependent differences in the exposure-response relationships disappear.

In surveys it is common practice to specify the degree of general annoyance in a population by the ‘percentage of the population that is highly annoyed’ (*%HA*). A subject is considered to be highly annoyed if he (or she) rates his (or her) degree of general annoyance on a scale from 0 to 100 with a score of 72 or over. (‘Not at all annoyed’ is at the lower end of the scale and ‘extremely annoyed’ at the upper end.) This measure of general annoyance is also used in this report.

Sleep disturbance is specified here by two measures of effect, one for sleep-disturbance annoyance and another for awakening. Similarly to general annoyance, sleep-disturbance general annoyance is assessed by the percentage of people highly annoyed by noise-induced sleep disturbance (*%HS*). Awakening is specified, only for situations involving isolated noise events during sleeping time, by a count of the number of noise-induced awakenings in an adult person.

Basic concept of the system

The Committee proposes a system of two metrics to quantify long-term environmental noise exposure in communities:

- *EEL*: environmental exposure level, associated with general annoyance due to long-term exposure to environmental noise during the 24-hour daily cycle
- *ENEL*: environmental night-time exposure level, associated with sleep disturbance (annoyance and awakenings) due to long-term night-time exposure to environmental noise.

These metrics are specified in such a way that, irrespective of the type of noise source, situations in residential areas with the same *EEL* lead to approximately the same level of general annoyance in a community. Similarly, in situations with the same *ENEL*, communities would experience approximately the same level of noise-induced sleep disturbance.

The available data are insufficient to complete the full specification of *EEL* and *ENEL*. Therefore the Committee starts the uniforming process with the introduction of the noise metrics $L_{adjusted,den}$ and $L_{adjusted,23\text{-}07h}$. These metrics are explained below. The Committee indicates the actions that should be undertaken to specify the system completely.

Determination of *EEL*

The determination of the *EEL* for a specific environmental noise source starts by expressing exposure to noise from that source during a part of the day by means of the equivalent sound level during that period. Then differences in general annoyance which depend on special characteristics of the noise (e.g. tonal and impulsive components, the period of the 24-hour daily cycle in which the noise occurs and the type of noise source) are taken into account.

In the first step for determining the *EEL,* adjustments are applied to the equivalent sound level to account for special noise characteristics. These adjustments are appropriate in the following situations:

- non-impulsive continuous industrial noise: adjustments are tentatively proposed for application which vary from 0 to 10 dB(A)
- situations with audible tones in the noise: adjustments are tentatively proposed for application which vary from 0 to 5 dB(A)
- situations with (highly) impulsive components: adjustments are 5 or 12 dB(A).

Adjustments for tones and impulses are generally not deemed necessary for situations involving common modes of present-day transport. The Committee recommends that the need for adjustments for tonal or impulsive components be the subject of a study for new modes of transport.

In the next step, the three (adjusted) equivalent sound levels over the three periods of the 24-hour daily cycle (day-time: 07.00 - 19.00 hours ; evening-time: 19.00 - 23.00 hours; night-time: 23.00 - 07.00 hours) are determined and adjusted with respect to the time of occurrence of the noise,, by adding 5 dB(A) to the adjusted equivalent sound level during the evening and 10 dB(A) to the adjusted equivalent sound level during the night. In addition to this, an exponential average of the three adjusted equivalent sound levels is calculated to determine a value representative for the full 24-hour period ($L_{adjusted,den}$).

The final step in the derivation of *EEL*, the uniform environmental noise exposure metric related to general annoyance, would be to adjust the adjusted equivalent sound level for the 24-hour daily cycle in such a way that the exposure-response relationships for aircraft and rail (train and tram) traffic noise coincide with those for road traffic noise and stationary noise sources, such as industries, shooting ranges and shunting yards. However, the Committee stops short of making this final step, the main reason being that agreement must be reached on the most appropriate measure of effect. Although *%HA* is widely used, other measures are prescribed in some regulations. As the decision on this matter is largely of a political nature, the Committee presents its derivation of the *EEL* as an example.

Determination of *ENEL*

To determine the *ENEL,* the noise exposure from 23.00 to 07.00 hours is considered. As specified for the determination of the *EEL*, the equivalent sound level is adjusted to account for special noise characteristics to obtain $L_{adjusted,23\text{-}07h}$. Then adjustments that take into account the type of noise source should be applied. The Committee is not able to make this final step, since the exposure-response relationships for the various noise sources require further evaluation before they can be taken as sufficiently stable for specifying *ENEL*. The report presents preliminary exposure-response relationships for sleep-disturbance annoyance for situations involving transport noise and noise from stationary sources, and a preliminary relationship for the maximal number of noise-induced awakenings in adult persons which is limited to situations with isolated noise events during sleeping time. From these relationships an indication of the adjustments required is obtained.

Discussion of the proposed system

The Committee is of the opinion that, to a large extent at least, the system meets the requirements put forward in the request for advice.

Transparency The system has a high degree of transparency. Using the two proposed metrics *EEL* and *ENEL*, in many relevant situations of environmental noise exposure the expected general annoyance and sleep disturbance can be estimated from simple relationships, irrespective of the noise source. Also, the system with $L_{adjusted,den}$ and $L_{adjusted,23\text{-}07h}$ is much more transparent that the present Dutch system.

International agreements The proposed system is to a large extent in accordance with the authoritative ISO document 1996-2 on the description and measurement of environmental noise pertinent to land use. The system is also in line with the conclusions of the international conference on future EU noise policy, held in May 1997 in the Netherlands (The Hague).

Simplicity of assessment and measurement The proposed noise metrics are based on the equivalent sound levels during specific parts of the 24-hour daily cycle. These equivalent sound levels can in principle be easily used in noise emission and immission calculation models and measured with simple, relatively inexpensive acoustical equipment. The Committee recognizes that measuring environmental noise in practical situations is complicated due to e.g. (noise from) intervening human activities, variations in noise situations from day to day and requirements for noise-source specific measurement results. In most instances, the determination of special characteristics of noise requires advanced acoustical instrumentation. However, a proper assessment of these special characteristics, which is relevant in only a minority of cases, is necessary and unavoidable to prevent underestimation of the levels of general annoyance and sleep disturbance.

The noise metrics have been specified as values representative for a year. It is common practice to determine noise exposure for national, regional or local purposes either by using calculation methods or by extrapolating the results of (representative) samples of measurement results. In both instances this requires specific expertise which is sometimes beyond the knowledge of the users of the system. However, any other system of metrics for the reliable estimation of noise-induced adverse effects would also require such expertise.

Applicability It is expected that the system will be applicable to the large majority of situations involving environmental noise exposures, such as situations with exposure to noise from road, rail and aircraft traffic and from industries, shunting yards and shooting ranges. It is important to note that the system of metrics is designed to assess health effects due to long term environmental noise exposure, and not to assess health effects shortly after the noise levels show a sudden change, e.g. due to noise reduction measures in the neigbourhood or the use of a new railway line.

Exposure to infrequently occurring noise from, for example, the occasional passage of a helicopter (for rescue purposes), ultra-light aircraft and small aircraft (for advertising purposes), or pop concerts and sporting events cannot be assessed using the proposed metrics. The Committee recommends further research on this subject.

The Committee recognizes that noise from neighbouring dwellings and from activities in the near vicinity is an important cause of general annoyance. However, non-acoustical factors play a role in people's appraisal of such noises to a larger extent than in the case of traffic noise. Therefore it is considered unlikely that the proposed system, even with amendments, will be able to predict general annoyance in these situations. Further psycho-acoustical surveys may be able to reveal important acoustical, psychological and social variables in this respect.

It has been found that people's reactions to low-frequency noise, once they perceive this type of noise in their living environment, are usually so severe as to suggest that appropriate adjustments may be in the order of 40 dB(A). The Committee recommends further investigation on this subject before applying the proposed system of metrics (with incorporation of the appropriate adjustments) in such situations.

The Committee is of the opinion that inclusion of a detailed recommendation for rating high-energy impulsive noises such as sonic booms, was beyond the scope of the present report.

The Committee discussed the possibility of using the proposed system of metrics for assessing the combined effect of two or more different noise sources, each producing similar general annoyance or sleep disturbance. As yet, there is no generally accepted method to assess this effect. Also taking into account the limited available time, the committee considered it not possible to formulate a proposal for this complicated subject at this moment.

Samenvatting

In dit advies doet de Commissie 'Uniforme geluiddosismaat' van de Gezondheidsraad een voorstel voor een stelsel van maten voor blootstelling aan omgevingslawaai. Het stelsel moet dienen voor de risicobeoordeling en beleidsondersteuning met betrekking tot de schadelijke gevolgen van die blootstelling voor de gezondheid en het welzijn van mensen in de woonomgeving.

Adviesaanvraag en achtergrond

De Ministers van Volksgezondheid, Welzijn en Sport en van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer hebben de Gezondheidsraad gevraagd een stelsel van maten voor de blootstelling aan omgevingsgeluid aan te bevelen. Dat stelsel moet, aldus de adviesaanvraag, eenvoudig en inzichtelijk zijn, passen binnen bindende internationale afspraken en bruikbaar zijn voor alle geluidbronnen buiten de woning. Het huidige bestaan van een grote diversiteit van bronspecifieke geluiddosismaten die, elk op eigen wijze, verband houden met gezondheidseffecten, vormt de achtergrond van de adviesaanvraag.

Het voorliggende advies is een antwoord op het verzoek van de beide ministers. Het maakt deel uit van het nationale beleidsproject Modernisering Instrumentarium Geluidbeleid (MIG) dat moet resulteren in een op sterke vereenvoudiging van het huidige normstelsel gerichte herziening van het overheidsbeleid. Belangrijke doelstellingen zijn: het bewerkstelligen van meer inzichtelijkheid en flexibiliteit alsmede het overhevelen van meer bevoegdheden naar provinciale en gemeentelijke overheden.

Specificatie van gezondheidseffecten van blootstelling aan geluid

De adviesaanvraag heeft betrekking op blootstelling aan omgevingsgeluid. In een eerdere publicatie van de Gezondheidsraad toonde de Commissie 'Geluid en Gezondheid' aan dat, op populatieniveau, hinder en slaapverstoring de meest voorkomende effecten van deze blootstelling zijn. Het in het voorliggende advies beschreven stelsel is zodanig opgezet dat het een mogelijkheid biedt om, onafhankelijk van de aard van de geluidbron, de omvang van deze effecten in woongebieden vast te stellen. Om dat doel te bereiken worden, op geleide van empirische gegevens, gangbare fysische blootstellingsmaten aangepast teneinde bronspecifieke verschillen tussen blootstelling-responsrelaties op te heffen.

Als maat voor de hinder in een populatie wordt in wetenschappelijk onderzoek gewoonlijk het 'percentage ernstig gehinderde personen' gebruikt, aangeduid als *%HA* ('highly annoyed'). Als ernstig gehinderd wordt beschouwd iedereen die op een schaal van 0 tot 100 (respectievelijk: 'geheel niet gehinderd' en 'uitermate gehinderd') 72 of hoger scoort. Ook in dit advies wordt deze hindermaat gehanteerd.

Met betrekking tot het effect 'slaapverstoring' is er een onderscheid tussen enerzijds de hinder die voortvloeit uit aantasting van de slaapkwaliteit door geluid en anderzijds het ontwaken uit de slaap ten gevolge van geluid, kortheidshalve aangeduid als, respectievelijk, slaaphinder en ontwaken. Analoog aan hetgeen voor hinder is gezegd, geldt als maat voor slaaphinder in de populatie het 'percentage mensen met ernstige slaaphinder' in die populatie (*%HS*). De maat voor 'ontwaken' is het aantal malen dat een doorsnee volwassene gedurende diens nachtrust uit de slaap gehaald wordt. Deze maat is alleen gespecificeerd voor situaties met geïsoleerd van elkaar optredende geluidgebeurtenissen.

Basisconcept

Voor de langdurige blootstelling van een bevolkingsgroep aan geluid stelt de commissie twee maten voor:

- de *EEL* ('environmental exposure level'), geassocieerd met de hinder die, op lange termijn, veroorzaakt wordt door dagelijkse blootstelling aan omgevingsgeluid
- de *ENEL* ('environmental night-time exposure level'), geassocieerd met de slaapverstoring (slaaphinder en ontwaking) die op lange termijn teweeggebracht wordt door blootstelling aan nachtelijk omgevingsgeluid

Beide maten worden zodanig gespecificeerd dat, onafhankelijk van de aard van de geluidbron, eenzelfde waarde van *EEL* respectievelijk *ENEL* leidt tot eenzelfde niveau van hinder respectievelijk slaapverstoring.

De beschikbare gegevens zijn ontoereikend voor een volledige specificatie van *EEL* en *ENEL*. De commissie specificeert wel de twee geluidmaten $L_{adjusted,den}$ en $L_{adjusted,23\text{-}07h}$. Deze geluidmaten zijn te beschouwen als tussenstappen naar *EEL* en *ENEL*. De commissie geeft in dit advies aan wat nog gedaan moet worden om *EEL* en *ENEL* volledig te specificeren.

Bepaling van de *EEL*

De bepaling van *EEL* voor een bepaalde bron van omgevingsgeluid begint met het uitdrukken van de mate van blootstelling aan het geluid gedurende een gedeelte van een etmaal in het zogeheten 'equivalente geluidniveau'. Vervolgens worden verschillen die voortvloeien uit speciale kenmerken van het geluid (bijvoorbeeld: de aan- of afwezigheid van tonale of impulscomponenten), de tijd van de dag en de aard van de geluidbron in rekening gebracht.

De eerste stap in de bepaling van een *EEL* behelst aanpassen van het equivalente geluidniveau in samenhang met speciale fysische kenmerken van het geluid. Dergelijke aanpassingen zijn gewenst als er sprake is van:

- niet-impulsief industrieel geluid van laag niveau (voorlopig wordt de volgende aanpassing voorgesteld: verhoging van het equivalente geluidniveau met 0 tot 10 dB(A))
- hoorbare tonen in het geluid (voorlopig wordt de volgende aanpassing voorgesteld: 0 tot 5 dB(A))
- impulscomponenten in het geluid (de aanpassing: 5 of 12 dB(A)).

Voor het geluid van de tegenwoordig gebruikelijke vormen van transport zijn aanpassingen voor tonale en impulscomponenten volgens de commissie niet noodzakelijk. Onderzoek terzake is echter gewenst voor eventuele nieuwe vormen.

De tweede stap van de *EEL*-bepaling behelst een aanpassing voor de deelperiode van optreden van het geluid binnen een etmaal (de commissie onderscheidt dag: 07.00 - 19.00 uur; avond: 19.00 - 23.00 uur; nacht: 23.00 - 07.00 uur). Die aanpassing is een verhoging met 5 dB(A) voor de 'avond' en met 10 dB(A) voor de 'nacht'. Ter verkrijging van de blootstellingsmaat voor een heel etmaal ($L_{adjusted,den}$) worden de drie aldus aangepaste equivalente geluidniveaus exponentieel gemiddeld.

De laatste stap in de bepaling van de *EEL* zou nu een zodanige aanpassing van het zojuist bedoelde etmaal-gemiddelde moeten zijn dat de voor de onderscheiden types van geluidbronnen (vliegtuigen, weg- en railverkeer, niet mobiele bronnen zoals fabrieken) geldende blootstelling-responsrelaties met elkaar samenvallen. Voornamelijk wegens het ontbreken van algemene consensus over de meest geschikte maat voor hinder, acht de commissie het echter nog niet mogelijk die stap definitief te zetten. Weliswaar wordt *%HA* veelvuldig als maat voor hinder gebruikt, maar in sommige wetten en voorschriften in binnen- en buitenland komen ook andere maten voor. Het maken van een keuze is grotendeels een politieke kwestie. Daarom beschrijft de commissie de hier bedoelde laatste stap bij wijze van voorbeeld.

Bepaling van de *ENEL*

De *ENEL* dient als maat voor de blootstelling aan geluid gedurende de nachtelijke periode, dat wil zeggen tussen 23.00 en 07.00 uur. Zoals bij de bepaling van de *EEL*, wordt het equivalente geluidniveau gedurende die periode aangepast voor speciale kenmerken van het geluid. Het resultaat is $L_{adjusted,23\text{-}07h}$. Vervolgens zijn dan aanpassingen aan $L_{adjusted,23\text{-}07h}$ nodig wegens verschillen tussen brontypes. Deze laatste stap kan de commissie nog niet zetten omdat daartoe nader onderzoek noodzakelijk is naar de algemene geldigheid van de beschikbare gegevens over blootstelling-responsrelaties voor onderscheiden types van bronnen. De in het advies gepresenteerde blootstelling-responsrelaties voor slaaphinder van verkeerslawaai en lawaai van stilstaande bronnen is derhalve als voorlopig te beschouwen. Hetzelfde geldt voor de gepresenteerde blootstelling-responsrelaties voor ontwaken ten gevolge van geïsoleerde nachtelijke geluidgebeurtenissen. Aan beide blootstelling-responsrelaties valt wel inzicht in de omvang van de nog noodzakelijke aanpassingen te ontlenen.

Discussie

De commissie meent dat haar voorstellen in belangrijke mate voldoen aan de eisen die in de adviesaanvraag zijn geformuleerd.

Inzichtelijkheid Het door de commissie ontwikkelde stelsel is in hoge mate inzichtelijk. Het gebruik van zowel de *EEL* als de *ENEL* betekent dat voor veel relevante blootstellingssituaties, aan de hand van eenvoudige formules en ongeacht het type van de geluidbron, een goede schatting te maken is van de mate van hinder en slaapverstoring door omgevingsgeluid. Ook het gedeeltelijk gespecificeerde systeem met $L_{adjusted,den}$ en $L_{adjusted,23\text{-}07h}$ is veel inzichtelijker dan het huidige Nederlandse systeem.

Internationale afspraken Het in dit advies gepresenteerde stelsel is vergaand in overeenstemming met ISO-document 1996-2 over het beschrijven en meten van omgevingsgeluid in de woonomgeving. Ook is er goede aansluiting bij de conclusies van een internationale conferentie over de toekomstige Europese regelgeving op het gebied van geluid, gehouden in mei 1997 in Den Haag.

Eenvoud van meting en beoordeling De voorgestelde blootstellingsmaten berusten op de equivalente geluidniveaus gedurende bepaalde gedeelten van een etmaal. Deze niveaus zijn in principe eenvoudig te gebruiken in berekeningsmodellen en met relatief eenvoudige en goedkope apparatuur te meten. De commissie erkent dat het meten van woonomgevingsgeluid een gecompliceerde zaak is, bijvoorbeeld door (geluid van) menselijke activiteiten in de buurt, variaties in de geluidsituaties van dag tot dag en eisen die bestaan om meetresultaten te verkrijgen die bron-specifiek zijn. De bepaling van specifieke geluidkarakteristieken — vereist om onderschatting van hinderniveaus te voorkomen — vraagt weliswaar meer geavanceerde apparatuur, maar is slechts zelden nodig.

Omdat het stelsel berust op de beschikbaarheid van de numerieke waarden van blootstellingsniveaus die representatief zijn voor het gehele jaar, moet de gebruiker over een zekere kennis van bepaalde reken- en extrapolatietechnieken beschikken die niet altijd aanwezig zal zijn. De commissie erkent dat dit een complicatie betekent, maar wijst erop dat geen enkel systeem voor betrouwbare schatting van effecten van blootstelling hieraan kan ontkomen.

Toepasbaarheid De commissie verwacht dat het stelsel in de meeste blootstellingssituaties toepasbaar is. Te denken valt aan het geluid van weg-, rail- en luchtverkeer, fabrieken, schietbanen en rangeerterreinen. Het is in dit verband belangrijk op te merken dat het stelsel is ontworpen voor het schatten van mogelijk optredende schadelijke gezondheidseffecten op de lange termijn. Het stelsel is derhalve niet geschikt voor het schatten van veranderingen in de mate van hinder of slaapverstoring die teweeg worden gebracht door plotselinge wijzigingen, bijvoorbeeld de invoering van geluidwerende maatregelen of het in gebruik nemen van een nieuwe spoorlijn.

Evenmin is het stelsel geschikt voor de kwantificering van blootstelling aan geluid dat zich betrekkelijk weinig voordoet, zoals dat van overvliegende helicopters (voor reddingsdoeleinden), ‘ultra-light’- en reclamevliegtuigjes, popconcerten en sportmanifestaties. De commissie beveelt verder onderzoek op dit gebied aan.

De commissie beseft dat burengerucht en het geluid van incidentele gebeurtenissen in de directe omgeving van de eigen woning veel hinder kunnen veroorzaken. Omdat echter een grote diversiteit van niet-akoestische factoren een rol speelt in de menselijke perceptie van dit soort geluiden, is het onwaarschijnlijk dat, zelfs na eventuele verdere aanpassingen, het beschreven stelsel de schatting van hinder in die situaties mogelijk kan maken. Wellicht kan nader psycho-akoestisch onderzoek licht werpen op de in het geding zijnde akoestische, psychologische en sociale variabelen.

Gebleken is dat mensen relatief heftig kunnen reageren als ze zich bewust worden van laagfrequent geluid in hun leefomgeving. De reactie kan dermate sterk zijn dat een geschikte aanpassing al snel in de grootteorde van 40 dB(A) zou liggen. Voor een dusdanige aanpassing van het stelsel is volgens de commissie meer onderzoek nodig.

Aanbevelingen inzake de kwantificering en de effecten van blootstelling aan hoog-energetisch impulsgeluid (bijvoorbeeld dat van het doorbreken van de geluidsbarrière door een vliegtuig) gaan, zo meent de commissie, de reikwijdte van dit advies te buiten.

In haar beraad over de toepasbaarheid van het stelsel, heeft de commissie eveneens de mogelijkheid besproken om het geschikt te maken voor het schatten van het gecombineerde effect van twee of meer gelijktijdig optredende geluidbronnen, die elk ongeveer een gelijke mate van hinder en slaapverstoring veroorzaken. Zij heeft, mede gezien de haar toegemeten tijd, geen kans gezien om op basis van de beschikbare onderzoekgegevens over dit gecompliceerde onderwerp thans een voorstel te doen. Daardoor is het in feite nog niet mogelijk om *EEL*-waarden en *ENEL*-waarden van verschillende bronnen te aggregeren tot één gecombineerde blootstellingsmaat.

Chapter 1

Noise as a public health problem

1.1 Introduction

In the Netherlands, as well as in other countries, regulations have been issued to limit environmental noise exposure. The Health Council of the Netherlands has provided the Dutch government with scientific information with which to underpin these regulations (GR71, GR91, GR94). In this report a committee of the Health Council proposes a system of environmental noise exposure metrics that meets certain scientific and policy-based criteria.

The Health Council was requested to prepare this advisory report within the framework of a national policy project (the project MIG: Modernisering Instrumentarium Geluidbeheer; Modernization of Policy Tools for Noise Management) in which several government departments participate. The uniform environmental noise exposure metrics system is to play a role in a new policy on noise abatement in the Netherlands. The policy revision being prepared at present aims to simplify the regulations based on the 1979 Noise Nuisance Act by introducing more flexibility for achieving policy goals and delegating authority to provincial and municipal government. The present regulations in the Netherlands with respect to the assessment of environmental noise are rather complicated, based as they are on several noise exposure metrics.

The present report may also be of interest in the light of ongoing discussions within the European Union (EU96). In the Conclusions of the Conference on EU Future Noise Policy, held on 21 and 22 May 1997 in The Hague, it was suggested that policy decisions with respect to a noise metric system be left until the publication of the Health Council recommendations on this matter (VROM97).

1.2 Request for advice and the Committee

In a letter dated 3 February 1997, the Minister of Health, Welfare and Sport and the Minister of Housing, Spatial Planning and the Environment requested the President of the Health Council to prepare an advisory report on a uniform noise exposure metrics system.

In order to answer the Ministers' questions, the vice-president of the Health Council invited experts from the Netherlands and abroad to participate in the Committee on Uniform environmental noise exposure metric, hereafter referred to as the Committee.

The members of the Committee were interviewed by the scientific secretaries of the Committee (February 1997). The two main aims of the interviews were to determine priorities for further consideration and to determine criteria for a thorough literature study and analysis of available information.

Drafts of the report were the subject of meetings of the Committee in Oegstgeest (the Netherlands) on 18 and 19 April 1997 and on 6 September 1997. The Committee members approved the final text of the report by post.

1.3 Structure of the report

The report is structured as follows. In Chapter 3, the proposed system of environmental noise exposure metrics is specified. Chapter 3 is preceded by an overview of the current level of knowledge as regards effects of environmental noise exposure on populations. Chapter 2 also summarizes specifications for environmental noise metrics in current environmental noise regulations in the Netherlands and abroad. In Chapter 4 the proposed system is discussed.

Much of the background information and all the analyses of available information is contained in the Annexes, which are an integral part of this report. Annex A contains the text of the request for advice, Annex B lists the members of the Committee, Annex C explains technical terms and Annex D provides information about activity patterns of the Dutch population during the 24-hour daily cycle. Annexes E to G present additional information for the derivation of the metrics in the system, while Annex H gives a stepwise determination of the noise metrics.

Chapter 2

Environmental noise metrics and effects of environmental noise exposure

2.1 Characterization of noise exposure in present regulations

Basic quantities

For many purposes noise exposure during a part of the day is specified by the *equivalent sound level* during that part of the day (Ger96, Lam894, Got95, ISO87, Val96)*. The formal definition of the equivalent sound level over a period T ($L_{Aeq,T}$) is given in Annex C (definition 1). Environmental noise exposure may consist of exposure to separate noise events, such as aircrafts flying over or trains passing. Such a noise event can be characterized by its *SEL*-value** (see Annex C, definition 7). To obtain the equivalent sound level for noise, consisting of isolated noise events over a period of time, the *SEL* values for all events of that noise source during that period of time are

* The equivalent sound level for a period T is by definition a metric in which the sound levels occurring during that period are averaged exponentially and is therefore not a simple average of these sound levels. The consequence of this exponential averaging is that higher sound levels are weighted more heavily than lower ones.

** *SEL* is the equivalent sound level of a noise event normalised in a specific way to a reference time of one second. E.g., if a noise event lasts for 60 s, and the equivalent sound level over these 60 s is equal to 80 dB(A), the *SEL*-value of this noise event is equal to 80 + 10 lg 60 = 80 + 17.8 = 97.8 dB(A).

added exponentially in a specific way.*

Characterization in present regulations

Some regulations outside the Netherlands are based on the 24 hour equivalent sound level ($L_{Aeq,24h}$) (definition 2 in Annex C) (Got95). In several other regulations an adjustment is applied to the equivalent sound level during the night, after which an exponential average over 24 hours is computed (ANSI96). An example of such a metric is L_{dn} (definition 3 in Annex C).** In addition, regulations exist in which an adjustment is also applied to the evening-time equivalent sound level, as in L_{den} (definition 4 in Annex C) (DEL95b, Kra95a, Kra95b). Most noise exposure metrics (e.g., L_{etmaal}, see definition 5 in Annex C) specified in present Dutch legislation (Noise Nuisance Act, Aviation Act and Environmental Management Act) are based on adjusted equivalent sound levels***.

* The exponential summation of *SEL* values to obtain the equivalent sound level over a period of time T takes into account the fact that the *SEL* values are normalised to a reference time of one second by adding 10 lg (1/*T*) to the result of the exponential summation of *SEL* values. E.g. for 10 noise events, each with a SEL value of 97.8 dB(A), the exponential sum of the *SEL* values is 107.8 dB(A). If these 10 noise events occur during a period of 600 s, the equivalent sound level during this period is equal to 107.8 + 10 lg (1/600) = 107.8 - 27.8 = 80 dB(A).

** 'dn' is the abbreviation of day-night and 'den' of day-evening-night. In both metrics a 10 dB(A) adjustment is applied to night-time noise (night in several regulations being defined as the period from 22.00 to 07.00) and in L_{den} a 5 dB(A) adjustment is applied to evening-time noise (evening usually being defined as the period from 19.00 to 22.00).

*** In the Netherlands, for road and rail traffic and industrial noise, the Noise Nuisance Act specifies noise exposure by an L_{etmaal} value. L_{etmaal} is not a weighted average of the adjusted equivalent sound levels but the maximum of the following three values in the case of rail traffic and industrial noise: $L_{Aeq,07\text{-}19h}$, $L_{Aeq,19\text{-}23h}$ +5 and $L_{Aeq,23\text{-}07h}$ +10, and the maximum of $L_{Aeq,07\text{-}19h}$ and $L_{Aeq,23\text{-}07h}$ +10 in the case of road traffic noise. Aircraft noise in the vicinity of 'larger' airports in the Netherlands is expressed by the quantity *B* in the Kosten Unit (Kosteneenheid, Ke) (see definition 6 in Annex C). *B* is determined from the maximum sound levels of the overflights, the number of overflights and varying adjustments for evening and night-time flights. The maximum adjustment to be applied for the period from 24.00 to 06.00 is equivalent to 10 dB(A) in a conventional equivalent sound level procedure. The quantity *B* is not an equivalent sound level, since only the maximum sound levels of overflights are taken into account and the lower levels during the overflights do not affect *B*. Noise exposure from small aeroplanes in the Netherlands is expressed in *BKL* values. *BKL* is the abbreviation of 'Belasting Kleine Luchtvaart' (Exposure caused by Small Aircraft). With a view to sleep disturbance, night-time exposure to aircraft noise in the Netherlands is also characterized by the equivalent sound level during 7 hours of the night-time period, usually defined as the period indoors from 23.00 to 06.00. Nearly all of the metrics are determined on a yearly basis.

2.2 Effects of environmental noise exposure on people

2.2.1 The 1994 Health Council report on Noise and Health

In 1994 the international Committee on Noise and Health of the Health Council reviewed the data on the adverse effects of long-term exposure to noise on health and well-being (GR94).

It concluded that there is sufficient evidence for causal relationships between noise exposure and the following effects:

- hearing loss
- general annoyance
- stress-related somatic health effects: hypertension and ischaemic heart disease
- sleep disturbance
- performance.

Since the present report is concerned with environmental noise exposure, no further consideration is given here to noise-induced hearing loss: this effect is supposed not to be caused by environmental noise (GR94).

General annoyance

Noise-induced general annoyance can be described as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with a person's thoughts, feelings or activities (GR94, Sch94a, Sch94b). The extent to which people are annoyed by a noise source is assessed by means of surveys in which questions about noise annoyance are presented to (a sample of) individuals in a community. In many instances these questions allow a range of answers (e.g. from 'not at all annoyed' to 'very much annoyed'). After quantification of the response, parameters of this distribution in a community are determined. These include the mean of the responses and the percentage of responses exceeding various cut-off points. The theoretical background of quantifying the responses and suggestions for harmonization are described in a paper by De Jong and Miedema (Jon95). Many surveys use a cut-off point at 72 on a scale from 0 ('not at all annoyed') to 100 ('very much annoyed') and label the percentage of responses in a population exceeding this cut-off point as 'percentage highly annoyed persons' (*%HA*) (Mie92, Mie96, Sch78, Sch83a, Sha96, Vos85a, Vos85b, ANSI96).

With regard to the quantification of 'exposure' in exposure-response relationships for general annoyance, the Committee on Noise and Health pointed to relationships derived by Miedema (Mie92). In these relationships, noise exposure is expressed in noise metrics that are frequently used in noise regulations. The Committee on Noise and Health, however, did not express a preference for any of these metrics.

Hypertension and ischaemic heart disease

As regards hypertension and ischaemic heart disease, very little is known about exposure-response and exposure-effect relationships: meaningful associations could only be derived for road and aircraft traffic noise.

Sleep disturbance

The Committee on Noise and Health considered several aspects of sleep disturbance: awakenings, sleep stage changes, general annoyance due to sleep disturbance, changes in heart rate and mood next day.

For awakenings and sleep stage changes, the former Committee stated that provisional exposure-effect relationships were only available for the effect of isolated night-time noise events and referred to work by Passchier-Vermeer (Pas94a).

Annoyance caused by sleep disturbance is, again, assessed by responses to questionnaires, usually as part of surveys which cover general annoyance and sometimes disturbance of specific activities. As with general annoyance these responses are quantified in order to determine parameters of their distribution. For exposure-response relationships of sleep-disturbance annoyance the Committee on Noise and Health made reference to preliminary results presented by Miedema (Mie93).

For heart rate changes and mood next day the Committee on Noise and Health did not present exposure-response relationships.

Performance

Children exposed to high levels of aircraft or road traffic noise at school show impaired performance in cognitive tasks: they are more easily distracted and make more mistakes.

In adults, there is only limited evidence for a causal relationship between noise exposure in the living environment and decreased performance of cognitive tasks, although significant acute effects on the performance of test subjects in laboratory studies have been demonstrated.

2.2.2 *Other information*

During the last seven years the Environment and Health Section of TNO Prevention and Health (Leiden, the Netherlands), has been building up an archive* (the TNO database) of original data sets from surveys about general annoyance and specific disturbances caused by environmental noise (Fie94b). The surveys concern noise from different modes of transport (aircraft, road and rail traffic) and some stationary sources (industries, shunting yards, shooting ranges), and were carried out in Europe, North America and Australia in the period from the early seventies up to last year. Much effort has been devoted to the determination of variables from data in different surveys so that the studies can be compared with each other. Methodological considerations (Fid91, Fie82, Fie94, Kry82, Kry83, Sch78) have been taken into account as much as possible. At present the database contains over 60 000 general annoyance ratings and over 35 000 sleep-disturbance ratings with noise-exposure values to match. The database was described in 1993 at the Fifth Congress on Noise as a Public Health Problem in Nice (Mie93). Miedema and Vos published the results of the first stage of an analysis of the general annoyance data (Mie96) and a publication on exposure-response relationships for general annoyance due to *transport noise* has been finalized (Mie97, submitted for publication). The Committee will make use of these relationships in this report. More detailed information is given in Annex E. At the request of the Committee some additional analyses were performed to determine appropriate evening-time and night-time adjustments for obtaining a scientifically appropriate noise exposure metric with respect to general annoyance. These results are also included in Annex E.**

Typical examples of types of *stationary, non-transport noise sources* in the environment are industrial premises, transformers, fans, cooling towers, small-arms shooting ranges, shunting yards, aircraft test facilities, and drop forges and pneumatic hammers used in activities such as harbour maintenance. For some of these noise sources, data are available in the TNO database but have not yet been fully analysed. The Committee has therefore employed a number of strategies in collecting information about the relationships between general annoyance and noise exposure for stationary noise sources (Fin80, Kür89, Tay87). In Annex E exposure-response relationships are reviewed for general annoyance due to industrial noise with and without impulse components. Research on the general annoyance caused by impulse

* This project was made possible with financial support from the Dutch Ministry of Housing, Spatial Planning and the Environment.
** These analyses were financially supported by the Ministry of Housing, Spatial Planning and the Environment.

sounds produced by small fire-arms (pistols, rifles) has been reviewed by Vos (Vos95a). A summary of his review is also given in Annex E.

Also at the request of the Committee, exposure-response relationships for sleep-disturbance annoyance and night-time noise exposure were derived from the TNO database. These relationships are reviewed in Annex G.1. In Annex G.2 information on noise-induced awakenings is used to estimate the number of awakenings due to night-time noise events (Fid95a, Fid95b, Pea89, Pea96, Oll92).

Chapter 3

A system of environmental noise exposure metrics

3.1 Use of the system

The design of a system of environmental noise exposure metrics is to a large extent determined by its intended purpose and its prospective users. It is to be expected that, in the Netherlands, the system will be used for:

- revision of the present regulations on noise in residential areas
- policy decisions by local authorities on the siting of activities with noise exposure implications
- policy decisions on the effectiveness and efficiency of noise reduction measures
- national policy discussions and decisions on large-scale projects that have a major impact on the noise exposure of the Dutch population
- noise mapping for international (EU), national and regional purposes
- public information issued by local and national governments on existing and future noise situations and their consequences for communities in the Netherlands.

The system should, among other things, enable the assessment of health effects on exposed populations. Furthermore, it has to be manageable by local authorities and be transparent for politicians.

3.2 Requirements

In the request for advice, the Health Council has been asked to propose a system of environmental noise exposure metrics which is as simple as possible. Detailed preconditions for a system of this kind have been specified in the request:

- transparency with respect to the relationship between the noise exposure metrics and effects on populations with regard to (severe) annoyance and sleep disturbance, and the possible inclusion of other effects
- observation of international agreements insofar as they are binding
- the metrics should be relatively simple to set or measure
- the system should be applicable to all noise sources outside the home.

In the discussion of the proposed system, the Committee will return to these criteria in Chapter 4. It has taken the assessability of annoyance and sleep disturbance in noise-exposed populations as the main criterion for the proposed system. The Committee has, in line with the request for advice, limited itself to effects of noise in residential environments. Neither noise-induced health effects in recreational situations, nor health effects of occupational noise have been taken into account. Noises due to neighbours' activities and noises from neighbouring dwellings (e.g. people shouting, slamming of car doors, noise from car horns and lawn mowers) have an impact on populations. These noises show a large variability and their effect is determined by various non-acoustic factors to a larger extent than environmental noises (Job88, Jon94, Kür89). The Committee considers these noise sources to be outside the field of application of the proposed system.

3.3 Approach

The system envisaged by the Committee consists of two metrics to be used to assess annoyance and sleep disturbance, respectively, as induced by long-term environmental noise exposure in communities. These two metrics are denoted, respectively, by *EEL* ('environmental exposure level') and *ENEL* ('environmental night-time exposure level'). Ideally, both metrics should be specified in such a way that, irrespective of the type of noise source, different long-lasting situations in residential areas with the same *EEL* result in approximately the same level of annoyance in a community. Similarly, in different long-lasting situations with the same *ENEL*, communities would experience approximately the same level of noise-induced sleep disturbance.

The Committee's considerations of this subject reveal that the available data are insufficient to complete the full specification of *EEL* and *ENEL*. Below, the Committee will propose the steps which should be taken in order to specify the metrics on a scientific basis and will indicate the actions that should be taken to specify the system completely. A model used by the Committee to construct an environmental exposure metric is presented first. Then the Committee discusses the steps in the model for the construction of the *EEL* and of the *ENEL* separately.

In the construction of uniform noise exposure metrics, the Committee uses *adjusted* noise metrics. The adjustment concept can be explained theoretically as follows.

Let us consider a situation involving exposure to road traffic noise during a part of the day and a situation involving noise exposure from a small-arms firing range during the same part of the day, and let us take the first situation as a reference. If the noise from the firing-range is more annoying than that from road traffic, the curves showing annoyance as a function of the relevant noise metric — in this example taken as the equivalent sound level over the time specified — for the two sources will differ. Findings indicate that the annoyance caused by noise from small-arms firing ranges equals that caused by road traffic noise, with equivalent sound levels over the exposure time that are 12 dB(A) higher. Therefore, in defining an adjusted equivalent sound level over the exposure time considered, which in the case of road traffic noise is equal to its (unadjusted) equivalent sound level over that time and which in the case of a small-arms firing range is equal to its equivalent sound level plus 12 dB(A) over the same time, the curves giving annoyance as a function of the *adjusted* equivalent sound level for the two sources over this time will be identical. In cases where differences between exposure-effect relationships are more complicated (i.e. not the same over the whole noise metric range), adjustments dependent on the noise exposure level may be necessary.

3.4 Model for constructing an environmental noise exposure metric

To construct an environmental noise exposure metric, the following model specifying five steps can be used. The five steps concern one ‘frequency’ step, three ‘time’ steps and one ‘source’ step.

In the first step, the instantaneous sound pressure levels at the various frequencies, due to the presence of a specific noise source at a given moment of time and at a given location, are combined into one instantaneous value.

The second step combines the instantaneous values during a part of the 24-hour daily cycle into a value representative for that period of time. The periods of time over which the instantaneous values are combined, are specified by the Committee as day-time (07.00 - 19.00 hours), evening-time (19.00 - 23.00 hours) and night-time (23.00 - 07.00 hours). For each period it has to be considered whether the noise during (a part of) that period has special characteristics, which would result in a different level of annoyance and sleep disturbance compared to these effects from a reference situation with the same noise level.

The third step combines the values representative for the periods of the full 24-hour daily cycle into one value representative for the full 24 hours.

The fourth step combines the values representative for the 24 full hours into a value representative for a longer period of time, in this report a year.

In the fifth step, the value representative for a year for a specific noise source is adjusted so that it accounts for differences in exposure-response relationships for various noise sources.

Another step might be envisaged in which values representative for different noise sources are combined. It is not clear whether this step would be appropriate as a last or as an intermediate step. The Committee will come back to this step in Chapter 4.

3.5 Construction of the *EEL*

In this section the steps for constructing the *EEL* are specified.

3.5.1 Step 1: Frequency-weighting of instantaneous values

The Committee considers it justifiable to use the A-weighting for the frequency-weighting of the instantaneous sound pressure levels. The A-weighting is standardised, used in the large majority of environmental noise regulations, including those of the Netherlands, acoustical measuring equipment usually includes the A-weighting network, environmental noise emission and immission calculation models are based on it, and in most surveys noise exposure is expressed in A-weighted noise metrics. The instantaneous A-weighted sound pressure level is called the sound level (ISO87).

3.5.2 Step 2: Combining instantaneous values and assessing the result for special characteristics

Combining instantaneous sound levels

The way in which people spend their time during the day shows distinct patterns at the population level. From Dutch data (Annex D) the Committee concludes that defining ‘day-time’ as the period from 07.00 to 19.00, ‘evening-time’ as the period from 19.00 to 23.00 and ‘night-time’ as the remaining period from 23.00 to 07.00 suitably reflects the periodicity in the activity patterns of the Dutch population.

The instantaneous sound levels are considered for each period of the 24-hour daily cycle. The Committee considers it justifiable to quantify exposure to noise from a specific environmental noise source during such a period of the day by means of its *A-weighted equivalent sound level* during that period. This view conforms to specifications in authoritative documents (see e.g. ISO87 and EU96) and is also in line with most of the environmental noise exposure metrics specified in current Dutch legislation (Noise Nuisance Act, Aviation Act (night-time regulations) and Environmental Management Act).

Applying adjustments for special characteristics

The Committee takes noise exposure from present-day common modes of road transport as a reference situation. This choice is based on the fact that noise from road transport is most prominent in causing annoyance in the Netherlands and in populations elsewhere (Jon94, Lam94).

If communities are exposed to noise which has (during a part of the 24-hour daily cycle) special characteristics that are usually absent from road traffic noise, a larger percentage of people in an exposed community will be highly annoyed than would be estimated from the exposure-response relationships for road traffic noise (Ber83, Bis89, Buc90, Buc93, Bul91, CHA96, Fli89, Hal81, Hal84, Job95, Mie92, Moh83, Por93a, Por93b, Ric83, Ric89, Sch83a, Sch94c, Sch95a, Vos85a, Vos85b, Vos87, Vos92a). Therefore the Committee considers it appropriate to apply adjustments in deriving the *EEL* metric to account for this increase in general annoyance in case of:

- low-level non-impulsive industrial noise
- situations involving audible tones in the noise
- situations involving (highly) impulsive noise components.

Annex G contains detailed information on the determination of appropriate adjustments to be applied to the equivalent sound levels during the time-intervals the characteristics are present. In Annex F the values of the adjustments are given. Taking into account the limited information available, the adjustments for low-level non-impulsive industrial noise and for tones are tentatively proposed for application.

Adjustments for tones and impulses are not deemed necessary for the large majority of situations involving common modes of present-day transport. The Committee recommends that the question whether adjustments for tonal or impulsive components are warranted, should be answered with regard to new modes of transport. In addition to these considerations, special circumstances might exist in which adjustments would also be justified for present-day transport, though the Committee feels that such circumstances are exceptional. An example of such a situation is the vicinity of a bend in a rail- or tramline, causing squealing noise during the passage of trains or trams.

The system does not cover situations in which one of the following two special characteristics are present: high-energy impulsive sound and low-frequency noise. Examples of high-energy impulsive sound are quarry and mining explosions, sonic booms, industrial processes involving explosives and artillery fire (ISO97). Although rating procedures for high-energy impulsive sounds have recently been revised (ANSI96; CHA96) and promising alternative procedures have been suggested (Buc96, Vos96; also see Vos97) the Committee feels that inclusion of a detailed recommendation for rating these impulsive sounds is beyond the scope of the present report.

As mentioned above, the Committee considers the system inappropriate for use in predicting adverse effects in situations in which low-frequency noise prevails*. People's reactions to low-frequency noise, once they perceive this type of noise in their living environment, are usually severe (ANSI96, DEL95b, Ver89). There are indications that appropriate adjustments for low-frequency noise may be in the order of 40 dB(A). The Committee recommends further investigation on this subject.

In cases where the environmental noise exposure is caused by separate noise events, such as trains passing and aircrafts flying over, the *SEL* values of these events may be used for the combination of the instantaneous sound levels and for the application of adjustments for special noise characteristics. An alternative metric sometimes used to specify a noise event is the maximum sound level ($L_{A,max}$) occurring during the event.** The Committee has considered various aspects of this subject and consulted the limited amount of relevant scientific literature available. It concludes that the use of *SEL* to describe a single noise event is to be prefered to describe such an event by means of a maximum value, for the following reasons:

- it is improbable that the duration of noise events will not have an impact on annoyance. In the case of helicopter noise, for example, it has been shown (Atk83, Fie85, Fie87, Oll82, Pas94b, Sch79, Sch81a, Sch81b) that annoyance is not only determined by the maximum levels during overflights but also by the total duration of the time the helicopter noise is heard

* Low-frequency noise is noise within the 10 third-octave bands from 10 to 80 Hz. Low-frequency noise is almost exclusively an indoor problem. It occurs when the difference between the C-weighted equivalent sound level and the A-weighted equivalent sound level exceeds 20 dB, measured indoors.

** Such a maximum depends upon the time constant (S, F, I or peak) of the measuring device with which it is determined. ISO 3891 (ISO79), for example, specifies that time constant S (1 second) shall be used to measure the maximum sound level of the overflight of an aeroplane. To obtain the maximum level of a noise event of (very) short duration, such as noise from impulses (fire-arms), a much shorter time constant may be required to fully specify the noise event.

- results of field studies on awakenings due to noise events show a higher correlation between *SEL* and awakening than between $L_{A,max}$ and awakening (Fid94, Fid95a, Fid95b, Oll92, Pea89, Pea96)
- the few surveys which have specifically dealt with the subject have shown that the correlation between general annoyance and (a combination of) *SEL* values is significantly higher than between general annoyance and (a combination of) $L_{A,max}$ values (Bro85, Cri90, Oll82, Sch79, Sch81)
- there is a straightforward method of measurement for determining a combination of *SEL* values for a series of noise events, viz. the determination of the equivalent sound level for the period in which the events occur, whereas there is not one for the combination of $L_{A,max}$ values
- the application and concept of $L_{A,max}$ in situations with more or less constant noise is unclear.

3.5.3 Step 3: Combining (adjusted) equivalent sound levels for parts of the 24-hour daily cycle into a value representative for the whole cycle

At present, noise metrics containing adjustments for evening or night are in regulatory use. This could be interpreted as taking into account increased annoyance during the evening and especially during the night at equal equivalent sound levels.

The impact of time of exposure on noise annoyance during the day has been studied in several surveys (Bir80, Deu74a, Fie85b, Fie86a, Fie86b, Fin80, Hal84, Job88, Kür89, Mie93, Pas93, Pas95a, Por95, Sch83b, Sch95b, Sch96). The Committee was fortunate to have the results from an analysis of data in the TNO database (Pas97, see Annex E). Unfortunately, the field surveys are not very discriminatory with respect to the question at hand. This is partly due to the strong correlation between day-, evening- and night-time equivalent sound levels in the surveys.

The Committee is of the opinion that the data contain some indication of differences in annoyance depending on the time of day of the exposure, at least for road traffic noise. The data are consistent with the suggestion that night-time road traffic noise is as annoying as day-time noise that has an equivalent sound level 10 dB(A) higher. Results are much less unequivocal for other types of noise and for noise during evening-time.

It appears that the data cannot provide sufficient guidance for making a firm recommendation on evening- and night-time adjustment factors. However, the Committee feels that — given more discriminatory data — differences might be expected. It therefore considers it reasonable to adhere to the adjustments of 5 dB(A) for evening-time and 10 dB(A) for night-time, which are widely used at present

(Ger96, Got95). The Committee has concluded from the analysis of the data in the TNO database that the empirical data do not invalidate use of this procedure.

The Committee also considered the possibility of applying no evening- and night-time adjustments. Such an approach would greatly simplify the system of metrics and would not appear to be in disagreement with scientific evidence, judging from the evaluation of the data in the TNO database. Nevertheless, as pointed out above, the Committee eventually decided to develop its system of metrics using evening-time and night-time adjustments. A further argument for this approach is that it is closer to people's general experience.

At the next stage, consideration is given to the question of how to combine these three adjusted equivalent sound levels to obtain a value which is representative for a 24-hour period. The Committee has considered two possibilities:

- using the exponential average of the three adjusted equivalent sound levels
- taking the maximum of the three adjusted equivalent sound levels, as specified in the Dutch metric L_{etmaal} (see footnote in Section 2.1).

From the preliminary results of the analysis of data in the TNO database the Committee concludes that using the exponential average of the three adjusted equivalent sound levels gives a noise metric that has a higher correlation with annoyance than the maximum of the three equivalent sound levels. Therefore, the Committee adopts the exponential averaging method of the three adjusted equivalent sound levels in order to specify the noise metric for annoyance. The adjusted day-time, evening-time and night-time equivalent sound levels are thus combined, by means of exponential averaging, to produce an adjusted 24-hour equivalent sound level, the so-called $L_{adjusted,den}$ ('adjusted' means adjusted for special noise characteristics; 'den' means adjusted for day-time, evening-time and night-time differences in annoyance).

3.5.4 *Step 4: Combining values for daily exposures into a value representative for a year*

The Committee has interpreted the Ministers' request as pertaining to stable noise exposure situations. It has selected, in accordance with legal requirements in a majority of countries, an exposure period of one year as representative for such situations. Data on the effects of sudden changes in noise exposure and of exposure to infrequently occurring noises are lacking. Therefore these situations could not be incorporated in the system.

Annoyance may to a certain extent be influenced by the time at which the exposure takes place, such as during working days or at the weekend, in summer or winter, and so on. During the weekends, more people are at home, they stay in bed longer, and their appraisal of the noise situation may be influenced by recreational activities or activities outdoors (Vos95b). Seasons of the year may have an influence on annoyance owing to the windows that are closed more during winter than during summer. Research has shown that noise exposure during weekdays and during weekends, experienced indoors and outdoors, all contribute to the evaluation of the noise situation at home (Bir80, Fie92, Fie93). Information on this aspect of noise exposure is scarce, however, and the Committee therefore opted not to include season and time of the week as variables in the scheme for the development of a environmental noise exposure metric system. In the Committee's view, these effects are of secondary importance.

The consequence is that in the construction of the noise metrics, no adjustments are applied to take into account possible period of the year and day of the week effects. With respect to the combination of all the 24-hour values in a year, the Committee proposes to base the *EEL* on an exponential average of all the 24-hour (adjusted) equivalent sound levels in a year.

3.5.5 Step 5: Source-related adjustments to obtain a uniform metric

Exposure-response relationships

Environmental noise can be divided into two main categories: noise from transport sources and noise from stationary sources. The Committee distinguishes three categories of transport noise sources: road, rail (trains and trams) and aircraft traffic, since exposure-reponse relationships for these three noise sources differ if the noise exposure is expressed in terms of $L_{adjusted,den}$. Detailed information on exposure-response relationships for annoyance due to transport noise is given in Annex E. It has been shown that exposure to aircraft noise results in a higher percentage of highly annoyed people than exposure to road traffic noise with the same value of $L_{adjusted,den}$, while exposure to rail traffic noise with the same value results in a lower percentage of highly annoyed people. For noise from stationary sources, special characteristics have been taken into account in $L_{adjusted,den}$ such that the relationship between $L_{adjusted,den}$ and *%HA* for these noises co-incides with the relationship for road traffic noise.

Figure 1 presents exposure-response relationships for the different types of noise sources using $L_{adjusted,den}$ as a noise metric. The measure of effect used is the percentage highly annoyed persons (*%HA*). The curves are based on analyses of the data in the TNO database (Annex E). The Committee reviewed the results in detail and concluded that these relationships represent the current level of knowledge. Given the wide coverage of the TNO data base, the Committee expects the relationships to be quite

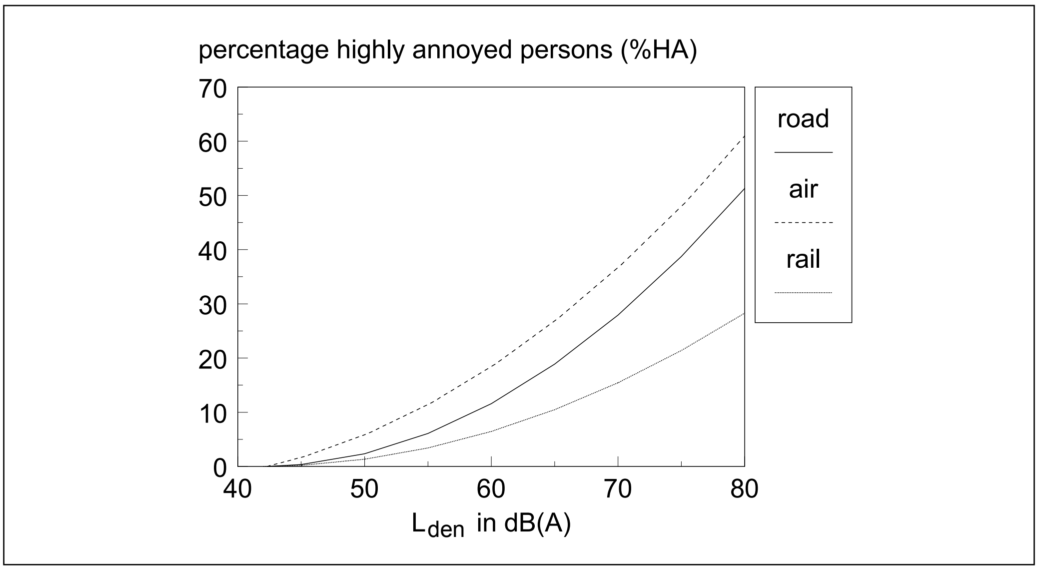

Figure 1 The percentage highly annoyed persons (*%HA*) as a function of L_{den} for road, air and rail traffic. If no adjustments for special noise characteristics have to be applied: $L_{den} = L_{adjusted,den}$

stable and does not expect that new data will significantly change the relationships obtained.

There is considerable variation between exposure-response relationships derived from different studies. The available methods to calculate confidence intervals for the curves presented in Figure 1 analytically or by resampling methods do not take variation *between* studies into account, or do not produce intervals based on curves. Therefore, it was not possible with the available statistical methods to calculate confidence intervals on the basis of the curves presented. The Committee has been informed that work on adapting these methods is in progress in order to obtain the desired confidence intervals.

The final step in the construction of a uniform environmental noise exposure metric, related to general annoyance, would be to adjust the $L_{adjusted,den}$ in such a way that the various exposure-response relationships coincide with that for road traffic noise. However, the Committee stops short of taking this final step, the main reason being that agreement must be reached on the most appropriate measure of effect. Although the *%HA* is widely used, other measures are prescribed in some regulations. As the decision on this matter is largely of a political nature, the Committee presents the derivation of *EEL* as an example. The adjustments to be made are specified in Annex H (see also Fin80, Hal81, Kür89, Mie92, Moh83). The final result is an exposure metric *EEL*, equal to $L_{adjusted,den}$ for road traffic noise, and related to *%HA* by the expression:

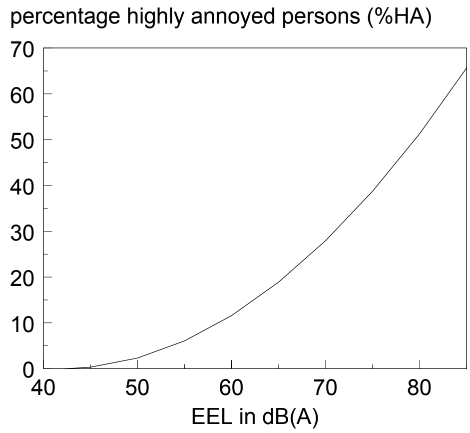

Figure 2 Example of a uniform environmental noise metric *EEL*. Percentage highly annoyed persons (*%HA*) as a function of *EEL*.

$\%HA = 0.0353 \times (EEL - 42.3)^2 + 0.03 \times (EEL - 42.3)$

This result is depicted graphically in Figure 2.

The Committee recommends that the necessary steps be undertaken to reach agreement on the appropriate measure of effect in order to be able to establish a definitive uniform environmental noise exposure metric.

3.6 A metric for the assessment of sleep disturbance (*ENEL*)

3.6.1 Step 1: Frequency-weighting of instantaneous values

The Committee specified in 3.5.1 the use of A-weighting for the frequency weighting of the instantaneous sound pressure levels.

3.6.2 Step 2: Combining instantaneous values and assessing the result for special characteristics

The Committee defines the beginning and end of night-time as 23.00 and 07.00 respectively. At 23.00 approximately 50% of the adult Dutch population have gone to bed and 7.00 is about the time by which 50% have got up in the morning. For populations with other social habits, determined by such factors as climate or working times, an alternative definition of night may be more relevant.

The Committee also quantifies exposure to noise from a specific environmental noise source during night-time with respect to sleep disturbance by means of its *A-weighted equivalent sound level* during this period.

The Committee has considered whether adjustments similar to those for general annoyance are required for sleep disturbance. Although scientific evidence is lacking, the Committee considers it likely that night-time exposure to noise with the characteristics listed above would result in increased sleep disturbance. It therefore considers it prudent to provisionally apply these adjustments also in deriving the *ENEL* metric, and recommends further research on this matter.

The noise metric representative for a 24-hour daily cycle with respect to sleep disturbance is therefore taken as $L_{adjusted,23\text{-}07h}$.

3.6.3 *Step 3: Combining (adjusted) equivalent sound levels for parts of the 24-hour daily cycle into a value representative for the full cycle*

This step is irrelevant with respect to sleep disturbance, since there is only one period in the 24 hours to be considered.

3.6.4 *Step 4: Combining values for daily exposures into a value representative for a year*

Similarly, the Committee proposes for a night-time noise exposure representative for a year, to take the exponential average over all the adjusted night-time equivalent sound levels during a year.

3.6.5 *Step 5: Source-related adjustments to obtain a uniform metric*

Effect measures

The Committee considers two measures of noise-induced sleep disturbance in populations exposed to environmental night-time noise: percentage of persons highly sleep-disturbance annoyed, and number of noise-induced awakenings of the adult individual.

Exposure-response relationships for sleep-disturbance annoyance

Detailed information on exposure-response relationships for sleep-disturbance annoyance from transport noises is given in Annex G.1. Figure 3 presents the

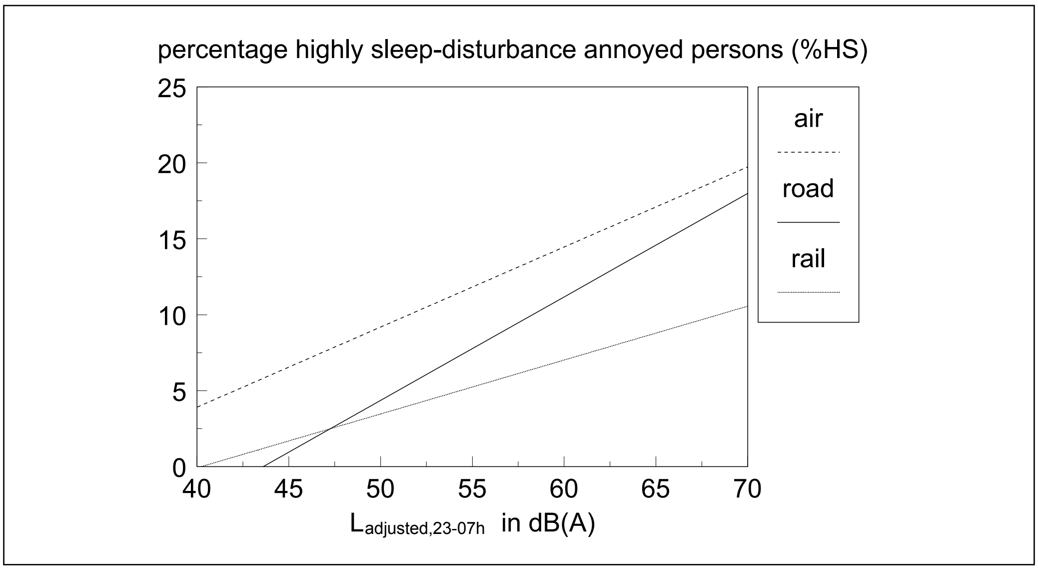

Figure 3 The percentage of people who are highly sleep-disturbance annoyed (*%HS*) as a function of $L_{adjusted,23\text{-}07h}$ for road, air and rail traffic.

exposure-response relationships for the different types of transport noise sources, with $L_{adjusted,23\text{-}07h}$ measured outside the dwellings as a noise metric. The measure of effect is the percentage of people highly sleep-disturbance annoyed (*%HS*). The curves are based on analyses of the data in the TNO database (see Annex G.1). The Committee reviewed the results in detail and concluded that these relationships represent the current level of knowledge. However, the Committee feels that the analyses should be further evaluated before they can be taken as sufficiently stable and reliable for specifying a uniform noise exposure metric related to sleep-disturbance annoyance.

Exposure-response relationships for awakenings

In Annex G.2 it is shown that, given an equivalent sound level for the night-time, it is possible to estimate *a worst case* noise exposure pattern for specific types of noise sources, which would represent the maximum number of noise-induced awakenings per night occurring on average in an adult person (Pas95). This maximum number of noise-induced awakenings increases with the equivalent sound level during the night. The Committee bases its considerations on several field studies (Fid94, Fid95a, Fid95b, Oll92, Pea89, Pea96). The maximum number of noise-induced awakenings is estimated for situations in which people are exposed to noises of outside events which are ‘normal’ in their environment. If *y* is the number of awakenings and *z* is the number of sleeping adults exposed to noise of isolated events during the night-time, the total number of awakenings for the *z* persons is *y* times *z*, as determined by EEG recordings.

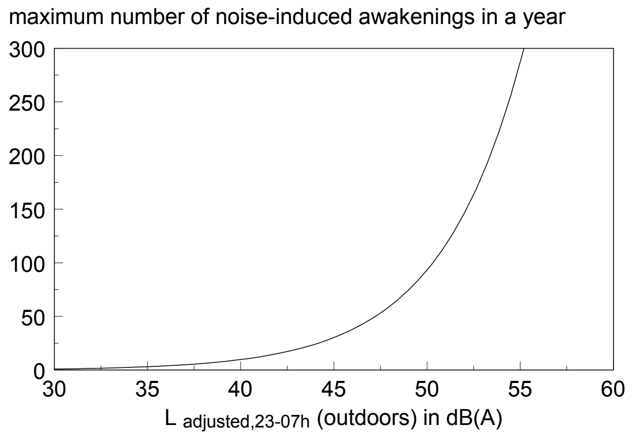

Figure 4 Estimate of the number of noise-induced awakenings as determined by EEG recordings, per year, as a function of $L_{adjusted,23\text{-}07h}$, measured outdoors. (Indoor values are approximately 20 dB(A) lower assuming closed windows.) The estimate is applicable to situations involving isolated noise events and to adult persons that are exposed to these night-time noise events for longer periods of time.

To obtain the maximum number of noise-induced awakenings during a calendar year, the number of noise-induced events has to be multiplied by 365. In Figure 4 the estimate of this maximum number of noise-induced awakenings that occur on average in an adult person is given as a function of $L_{adjusted,23\text{-}07h}$.

The final step in the derivation of a uniform environmental noise exposure metric related to sleep disturbance *(ENEL)* would be to adjust $L_{adjusted,23\text{-}07h}$ in such a way that the various exposure-response relationships coincide with that for road traffic noise. This step cannot be made as yet. Apart from the verification of the analyses mentioned above, a decision still has to be taken on the appropriate measure of effect, as is the case with the *EEL*.

Chapter **4**

Discussion of the proposed environmental noise exposure metrics system

4.1 Preconditions specified in the request for advice

The Health Council was asked to recommend a simple system of environmental noise exposure metrics. In this chapter, the Committee discusses the extent to which the proposed system meets the requirements specified in the request for advice (see also 3.2).

Transparency between the system and effects on communities

The Committee is of the opinion that the system meets the transparency requirement to a large extent. It is important to note that the Committee proposes a system of noise exposure metics which is able to assess annoyance and sleep disturbance for each environmental noise source by the same noise metric. Also, it needs the application of simple formulas only, to obtain from a value of *EEL* (or $L_{adjusted,den}$) of a noise source in a specific situation the percentage highly annoyed people in that situation. The same is true for the percentage of highly sleep-disturbance annoyed people and the number of awakenings in a community and *ENEL* (or $L_{adjusted,23\text{-}07h}$).

Since *EEL* (or $L_{adjusted,den}$) covers a 24 hour period and performance of children at school is limited to only a few hours during day-time, this is not the most appropriate metric in relation to performance. Nor is a high correlation expected between this metric and specific disturbances, such as reduced speech intelligibility in specific situations during specific periods of time. The Committee expects that the use of non-adjusted equivalent sound levels or more specific metrics will demonstrate a more meaningful relationship with such effects than the application of *EEL* (or $L_{adjusted,den}$).

International agreements

The proposed system is largely in accordance with ISO document 1996-2 (ISO87) on the description and measurement of environmental noise pertinent to land use, and with Addendum 1 to this document. The Committee considers itself justified in deviating from ISO 1996-2 by allowing adjustments of 5 and 10 dB(A) to the equivalent sound levels during evening-time and night-time respectively. The proposed system also matches the conclusions of the Conference on EU Future Noise Policy held in May 1997 in The Hague, The Netherlands (VROM97).

Simplicity of assessment and measurement

The Committee has specified that the equivalent sound levels on which the noise metrics are to be based should be representative for the noise exposure accumulated over one year. It is common practice to determine noise exposure for national, regional or local purposes either by using calculation methods or by extrapolating the results of (representative) samples of measurement. In both instances this requires specific expertise which may be beyond the knowledge of the users of the system. However, any other reliable system for assessing noise-induced adverse health effects would also require such expert input. The equivalent sound levels during specific parts of the 24-hour daily cycle can in principle be measured nowadays with simple, relatively inexpensive acoustic equipment. The Committee recognizes that measuring environmental noise in practical situations is complicated due to e.g. intervening human activities, variation in noise situations from day to day and requirements for noise source specific measurement results. Advanced acoustic equipment is sometimes required in determining special noise characteristics. However, such specialized measurements are only necessary in a minority of cases, since these special characteristics are not present in the majority of environmental situations.

Applicability to all environmental noise sources

Although it turned out to be impossible to include all sources and situations in the recommended system, it does cover the vast majority of situations in residential areas. The following considerations illustrate the main limitations of the system.

The Committee recognizes the special nature and the variety of non-acoustic factors that play a role in people's appraisal of noise from neighbouring dwellings and from activities in the near vicinity. Therefore the Committee considers it unlikely that the proposed system, constructed for assessment of community response, will be able to predict annoyance and sleep disturbance in individual cases. Further psycho-acoustic research may be able to reveal important acoustic, psychological and social variables in this respect.

Of a special character are also other infrequently occurring sound exposures in the neighbourhood, such as from occasional outdoor mass gatherings and the use of ultra-light aircraft and small aircraft (for advertising purposes). On one hand, these noise sources usually have only a small value of $L_{adjusted,den}$ on a yearly basis, but on the other hand are considered to be a real nuisance. Apart from non-accoustic factors that may play a role, presumably the relevant noise exposure metric should not be taken on a yearly basis when predicting general annoyance and sleep disturbance from these sources but be related to more limited time periods. The Committee recommends further research on this subject.

The proposed system is not suitable for the prediction of short-term changes in general annoyance and sleep disturbance brought about by a sudden change in noise levels, e.g. due to the introduction of noise reduction measures, such as noise barriers, and due to the origination of a new noise source in the neighbourhood. The long-term effect of such changes on general annoyance and sleep disturbance may, however, be estimated using *EEL* or *ENEL*. The Committee feels that the recommended metrics should not be used to predict the effect of changes in noise situations occurring within one year of these changes.

4.2 Further considerations

Specific features of residential properties

The exposure-response relationships have been determined with the noise metrics which represent the outdoor noise levels determined in a specific way (incident sound) and at a specified distance from the most exposed facade of dwellings. They also relate to respondents, most of whom were living in dwellings for which no special sound insulation measures (e.g. double glazing) had been taken. The Committee is not able to take into account any beneficial effects of a much lesser exposed facade and of extra sound insulation of dwellings on general annoyance and sleep-disturbance annoyance, since there are as yet insufficient data to allow such effects to be estimated with the required reliability (Mie93).

Effect of the presence of another noise source on general annoyance from a specific noise source

In an extensive meta-analysis, Fields examined general annoyance due to a specific noise source in the presence of another noise source (Fie96). He showed a small effect which the Committee considers negligible for practical applications. In real life situations, environmental noise from a specific source is presumably not (completely) masked by another environmental noise because of differences in the time at which the different noises occur and because of differences in noise spectra when the noises do occur simultaneously. Habituation to the characteristics of a noise and directional effects may also have an impact of the ability to distinguish a specific noise source while it is partly masked by another noise source.

Effects from a combination of noise sources

Communities may be exposed to noise from several environmental noise sources, instead of one. In cases where one source dominates, that source is primarily responsible for the total general annoyance and sleep disturbance, and the recommended system of metrics can be used in predicting these total effects from the noise metric values of that dominant source.

The Committee discussed the possibility to derive aggregation rules to obtain a metric that would, once again, be a predictor of the general annoyance and sleep-disturbance annoyance in a community exposed to two or more noise sources which, taken separately, would cause approximately similar effects (DEL95a, Gus97, Kra97, Mie87, Ron97, Sch97, Sch78, Sch96, Tay82, Vos92a). A generally accepted method to combine noise exposure from two or more sources is, as yet, not available. Also taking into account the limited time available to the Committee to prepare the report, the Committee considered it not possible to formulate a proposal for this complicated subject. The Committee recommends that the problems in deriving uniform noise exposure metrics for single sources are solved first, before considering aggregation of sound exposure levels from several sources.

4.3 Comparison with the present Dutch regulations

With regard to road traffic, rail traffic and industrial noise, various similarities exist between the specifications in the proposed system of the noise metric for assessing general annoyance and the specifications in the Netherlands Noise Nuisance Act. These similarities include night-time and evening-time adjustments, the definition of evening-time and night-time and the use of the equivalent sound level during the three periods of the 24-hour daily cycle. There is a difference in the way these three equivalent sound levels are taken into account: *EEL* is specified as the exponential average, whereas in the present Dutch regulations the maximum of the three values is used.

With respect to aircraft noise in the vicinity of larger airports, differences between the proposed metric *EEL* (or $L_{adjusted,den}$) and the presently used quantity *B* in the 'Kosten Unit' are considerable. To determine *B*, $L_{A,max}$ values are taken to characterize an aircraft noise event, while *SEL* is used in the proposed metrics. In *B* the number of noise events during 24 hours are also rated differently from the rating used in the proposed system and there are small differences in the evening-time and night-time adjustments. Another important difference is that in the calculation of *B* only aircraft noise events are taken into account with $L_{A,max}$ equal to 65 dB(A) or more, and all aircraft noise events contribute to $L_{adjusted,den}$. For exposure to small aircraft the difference between *BKL* and *EEL* concerns mainly differences in aspects, related to the noisiest weeks and months of the year.

The proposed night-time metric conforms to a large extent with the night-time regulations on aircraft noise currently into force in the Netherlands. In both instances the equivalent sound level during the night is taken as the metric. Differences lay in the definition of night-time, defined as 23.00 to 07.00 in the system and as 7 consecutive hours between the times of 23.00 and 07.00 in the current Dutch regulations and in the use of the adjusted equivalent sound level.

Rijswijk, 20 October 1997,
for the Committee

W Passchier-Vermeer, HGM Bouman, T ten Wolde, technical secretary technical secretary chairman

References

ANSI96 Quantities and procedures for description and measurement of environmental sound - Part 4: Noise assessment and prediction of long-term community response. Draft 6b ANSI S12.9-1996-Part 4

Atk83 Atkins CLR, Brooker P, Critchley JB. 1982 Helicopter Disturbance Study:Main Report. London: Civil Aviation Authority 1983: DR Report 8304.

Ber79 Berry BF . The rating of helicopter noise: development of a proposed impulse correction. Teddington 1979: NPL Reprt Ac 93.

Ber83 Berry BF. LAeq and Subjective Reaction to Different Noise Sources: A Review of Research. Proc Inter-noise 1983: 993-6.

Ber85 Berry BF. Evaluation of impulsive environmental noise: laboratory studies of annoyance reactions. Proc Inter-noise 1985; 2: 921-4.

Ber87 Berry BF. The evaluation of impulsive noise. Teddington 1987: NPL Rpt. Ac 111.

Ber88 Berry BF, Bisping R. CEC Joint project on impulse noise: physical quantification methods. Proceedings 5th International Congress on noise as a public health problem. Stockholm 1988: 153-8.

Ber89 Berry BF. Recent advances in the measurement and rating of impulsive noise. Proceedings 13th ICA. Belgrade 1989; 3: 147-50.

Ber94 Berry BF, Porter ND. The evaluation of acoustic features in industrial noise. Proc Inter-noise. Yokohama 1994: 803-8.

Bir80 Birnie SE, Hall FL, Taylor SM. The contribution of indoor and outdoor effects to annoyance at noise in residential areas. Proc Inter-noise 1980: 975-8.

Bis89 Bisping R. Steady versus impulsive noises: spectral parameters and subjective ratings. Proceedings 13th ICA. Belgrade 1989; 3: 143-6.

Bra90 Brambilla G, Carretti MR. Evaluation of annoyance due to impulse noise. NoiseCon 1990: 279-84.

Bro85 Brooker GR, *et al*. United Kingdom Aircraft. Noise Index Study: main report. London: Civil Aviation Authority 1985: DR Report 8402.

Bro97 Broek A van den. Calculation on sleeping time Dutch population 1995. Sociaal Cultureel Planbureau, Rijswijk, 1997.

Buc83 Buchta E, Buchta C, Koslowsky L, Rohland P. (1983). Lästigkeit von Schiesslärm (Umwelt Bundes-amt: Berlin, Germany). Report no. 82-10501314.

Buc90 Buchta E, *et al.* A field survey on annoyance caused by sounds from small firearms. J Acoust Soc Am 1990; 88(3): 1459-67.

Buc93 Buchta E. A review of the penalty for impulse noise. In: Vallet M (ed.). Noise as a public health problem. Arcueil Cedex France: INRETS 1993; 3: 420-7.

Buc96 Buchta E. Annoyance caused by shooting noise - determination of the penalty for various weapon calibers. Proc Inter-noise 1996; (5): 2495-2500.

Bul91 Bullen RB, *et al*. Community reaction to noise from an artillery range. Noise Control Eng J 1991; 37(3): 115-28.

Bul96 Bullen R, Hede A, Williams T. Sleep disturbance due to environmental noise: a proposed assessment index. Acoustics Australia 1996; 24: (3) 91-97.

CHA96 Community response to high-energy impulsive sounds: An assessment of the field since 1981. Committee on Hearing, Bioacoustics and Biomechanics (CHABA), National Research Council, National Academy of Science, Washington, DC, 1996.

Cri90 Critchley JB, Ollerhead JB. The use of Leq as an aircraft noise index. London, Directorate of Operational Research and Analysi 1990: DORA Report 9023.

DEL95a DELTA Acoustics & Vibration. Assessment of annoyance from combined noise sources. DELTA Acoustics & Vibration 1995: report no. AV 1213/95a.

DEL95b DELTA Acoustics & Vibration. Metrics for environmental noise in Europe. Danish comments on INRETS Report LEN 9420. DELTA Acoustics & Vibration 1995: Report no. AV 837/95.

DEL97 DELTA Acoustics & Vibration. Objective measurements of audible tones in noise. Detection and assessment of tones. Copenhagen, 1997.

Deu74 Deutsche Forschungsgemeinschaft 1974. Fluglärmwirkungen: Eine interdisziplinäre Untersuchung über die Auswirkungen des Fluglärms auf den Menschen. Boppart: Bolt, 1974.

Dym77 Dym DL. Sources of industrial impact noise. Noise Control Eng J 1977; 8: 81-7.

Ebe87 Eberhardt JL. Akselsson KR. The disturbance by road traffic noise on the sleep of young male adults as recorded in the home. J Sound & Vibr 1987; 114: 417-34.

EU96 European Union. DG XI. Draft proposal for a Council directive on the assessment and reduction of environmental noise exposure. EU, Brussels, February 1996.

FIC92 Federal Interagency Committee on Noise (FICON) (1992). Final report: airport noise assessment methodologies and metrics. Washington, DC 1992.

Fid91 Fidell S, Barber D, Schultz TJ. Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise. J Acoust Soc Am 1991; 89(1): 221-33.

Fid94 Fidell S, Pearsons K, Howe B *et al.*Noise-induced sleep disturbance in residential settings. Canogan Park: BNN Systems and Technologies Corporation 1994: BNN Report 7932.

Fid95a Fidell S, Pearsons K, Tabachnick B *et al*. Field study of noise-induced sleep disturbance. J acoust Soc Am 1995; 98: (2:1) 1025-33.

Fid95b Fidell S, Howe R, Tabachnick B *et al*. Noise-induced sleep disturbance in residences near two civil airports. NASA Contractor Report 198252. Hampton VA: NASA Langley Research Center 1995.

Fie82 Fields JM. Effects of errors in specifying noise environments on results from community response surveys. Proc Inter-noise 1982: 609-12.

Fie85a Fields JM, Powell CA. A Community Survey of Helicopter Noise Annoyance Conducted Under Controlled Noise Exposure Conditions. Washington DC: NASA 1985: Publ NASA TM-86400.

Fie85b Fields JM. The timing of noise-sensitive activities in residential areas. Washington DC: NASA 1985: Publ NASA CR-177937.

Fie86a Fields JM. The relative effect of noise at different times of day. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, Washington DC: NASA 1986: Publ NASA CR-3965.

Fie86b Fields JM. Cumulative airport noise metrics: an assessment of evidence for time-of-day weightings. DOT/FAA/EE-86/10. US Department of Transportation, Federal Aviation Administration, Washington DC, 1986 (1989 revised printing).

Fie87 Fields JM, Powell CA. Community Reactions to Helicopter Noise: Results from an experimental study. J Acoust Soc Am 1987; 82: 479-92.

Fie92 Fields JM. Effect of personal and situational variables on noise annoyance: with special reference to implications for en route noise. Washington DC: 1992: Publ NASA CR-189676, FAA Report number FAA-EE-92-03. Federal Aviation Administration.

Fie93 Fields JM. Effect of personal and situational variables on noise annoyance in residential areas. J Acoust Soc Am 1993; 93: 2753-63.

Fie94 Fields JM. Review of an updated synthesis of noise / annoyance relationships. Atlanta GA: Gergia Institute of Technology, Washington DC: 1994: Publ NASA CR 194950.

Fie96 Fields JM. An analysis of residents' reactions to environmental noise sources within an ambient noise context. DOT/FAA/EE-96/08. US Department of Transportation, Federal Aviation Administration, Washington DC: 1996.

Fin80 Finke HO, Guski R, Rohrmann B. Betroffenheit einer Stadt durch Lärm. Umweltforschungsplan des bundesministers des Innern 1980, Forschungsbericht 80-10501301.

Fin94 Finegold LS, Harris CS, von Gierke HE. Community annoyance and sleep disturbance: updated criteria for assessing the impacts of general transportation noise on people. Noise Control Eng J 1994; 42(1): 25-30.

Fli86 Flindell IH, Rice, CG. ISVR-Rep. No. 86/22 (ISVR: Southampton, England). 1984-1985 Joint CEC project on annoyance due to impulse noises: laboratory studies, 1986.

Fli89 Flindell IH, *et al*. Human response to impulse noise - impulsivity and annoyance. Proceedings 13th ICA. Belgrade 1989; 3: 155-8.

Fre97 Freijer JI, Loos S de. Analyse van tijdbestedingspatronen van de Nederlandse bevolking tbv een uniforme geluidsdosismaat. RIVM Bilthoven 1997, Report no. 715120 002.

Ger96 Gerretsen E. Environmental noise descriptors in Europe - Comparison of definitions and prediction methods. Delft, TNO-TPD 1996: Report TPD-HAG-RPT-960059.

Got95 Gottlob D. Regulations for Community Noise. Noise/News International 1995: 223-36.

GR71 Gezondheidsraad: Geluidhinder. Rapport Gezondheidsraad Commissie Geluidhinder en Lawaaibestrijding. Den Haag: Gezondheidsraad 1971; publikatie nr 1971/24.

GR91 Gezondheidsraad: Commisie Vliegtuiglawaai en slaap. Vliegtuiglawaai en slaap. Den Haag: Gezondheidsraad 1991; publikatie nr 1991/05.

GR94 Gezondheidsraad. Noise and health. Den Haag: Gezondheidsraad, 1994; Report 1994/15E

Gro81 Groeneveld Y, Verboom WC. Karakterisering en beoordeling van industrielawaai. Delft: IMG-TNO Rep. D54 1981.

Gus97 Guski R. Interference of activities and annoyance by noise from different sources: some new lessons from old data. Seventh Oldenburg Symposium on Psychological Acoustics. Ed Schick & Klatte. University of Oldenburg 1997: 239-58.

Hal81 Hall FL, Birnie SE, Taylor SM, Palmer JE: 1981. Direct Comparison of Community Response to Road Traffic Noise and to Aircraft Noise. J Acoust Soc Am 1981; 70(6): 1690-8.

Hal84 Hall FL. Community response to noise: is all noise the same? J Acoust Soc Am 1984; 76(4): 1161-8.

Hei80 Heintz, P. (1980). Sozio-psychologische Schiesslärmuntersuchung Bundesamt für Umweltschutz: Bern, Switzerland.

Ike93 Ikeda I, Flindell IH. Subjective tests of impulse noise annoyance and the listening environment. Proc Inter-noise 1993; II: 1133-6.

Isi93 Ising H, Rebentisch E. Comparison of acute reactions and long-term extra-aural effects of occupational and environmental noise exposure. In M. Vallet (ed). Noise as a public health problem. Frame, INRETS, 1993; 3: 331-8.

ISO78 International Organization for Standardization. ISO 3891-1978. Acoustics - Procedure for describing aircraft noise heard on the ground. Geneve: ISO, 1978.

ISO87 International Organization for Standardization. ISO R 1996-2. Acoustics - Description and measurement of environmental noise. Part 2: Acquisition of data pertinent to land use. Geneva: ISO, 1987.

ISO97 International Organization for Standardization. ISO R 1996-2. Acoustics - Description and measurement of environmental noise. Part 2: Acquisition of data pertinent to land use. (Draft) Addendum 1. ISO, 1997.

Job88 Job RFS. Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. J Acoust S Am 1988; 83: 991-1001.

Job95 Job RFS, Peploe P, Cook R. Factors influencing reaction to individual impulsive events experienced in the home. Proceedings 15th International Congress on Acoustics 1995; 2: 295-8.

Jon94 Jong de RG, Opmeer C, Miedema HME. Hinder door milieuverontreiniging in Nederland: effecten van geluid, geur, trillingen, stof, verlichting en onveiligheid.; peiling 1993. Leiden: TNO-PG, 1994: Rapport 94.056

Jon95 Jong RG de, Miedema HME. Comparing results of community response surveys. In: Newman M, ed. Proceedings of the 15th International Congress on Acoustics. Trondheim, Norway 1995: 61-4

Jur83 Jurriëns AA, Griefahn B, Kumar A, e.a. An essay on European research collaboration: Common results from the project on traffic noise and sleep in the home. In: Rossi G, ed. Proceedings IVth International Congress on Noise as a Public Health Problem. Milan: Centro Ricercha E Studi Amplifon 1983; 2: 929-37.

Kra95a Kragh J. Technical note. Informal note on quantities used to describe some types of environmental noise in Scandinavia. AV 669/95, Copenhagen, DELTA Acoustics & Vibration 1995.

Kra95b Kragh J. Technical note. Nordic comments on proposed EC noise policy. Copenhagen, DELTA Acoustics & Vibration 1995. AV 1214/95.

Kra97 Kragh J. Assessment of various kinds of environmental noise occurring at the same time. A proposal for a practical method. Seventh Oldenburg Symposium on Psychological Acoustics. Ed Schick & Klatte. University of Oldenburg 1997: 221-38.

Kry82 Kryter KD. Community annoyance and aircraft and ground vehicle noise J Acoust Soc Am 1982; 72: 1212-42.

Kry83 Response of Kryter to modified comments by Schultz on KD Kryter's paper: 'Community annoyance and aircraft and ground vehicle noise'. J Acoust Soc Am 1983; 73: 1066-8.

Kür89 Kürer R, *et al*. Umweltbundesamt. Lärmbekämpfung '88. Lärmwirkungen - Tendenzen - Probleme - Lösungen. Berlin: Erich Schmidt Verlag GmbH, 1989.

Lam94 Lambert J, Vallet M. Study related to the preparation of a communication on a future EC Noise Policy. Final Report. INRETS Report LEN No. 9420, Lyon 1994.

Lar76 Large JB, Ludlow JE. Community reaction to noise from a construction site. Noise Control Eng J 1976; 6(2): 59-65.

Lee81 Leeuw R, Berg R van den. Impulse noise in the Netherlands industry. Delft: IMG-TNO Report B 472 August 1981.

Mie87 Miedema HME. Beoordelingsmethode voor hinder in de woonomgeving door cumulatie van omgevingsgeluid. Leidschendam: VROM, 1987: Rapport nr GA-HR-08-03.

Mie92 Miedema HME. Response functions for environmental noise in residential areas. Leiden: NIPG- TNO 1992: Publ.nr. 92.021.

Mie93 Response functions for environmental noise. Vallet M, ed. In: Proceedings of the 6th International Congress on Noise as a Public Heath Problem. Nice, France: Noise & Man 1993: 428-33.

Mie96 Miedema HME, Vos H. Exposure response relationships for transportation noise. Leiden: TNO-PG, 1996: Report no. 96.070.

Mie97 Miedema HME, Vos H. Exposure response relationships for transportation noise. Submitted for publication.

MIG96 Projectplan Modernisering Instrumentarium geluidbeleid. Den Haag, VROM 1996.

Moh83 Möhler U, Knall V. Correlation of Acoustic Indices and Disturbance Reaction Factors on Railway and Road Traffic Noise. Proc Inter-noise 1983: 989-92.

Ohr93 Ohrström E. Research on noise and sleep since 1988. Present state. In M. Vallet (ed). Noise as a public health problem. Frame, INRETS 1993; 3: 331-8.

Oll82 Ollerhead JB. Laboratory Studies of Scales for Measuring Helicopter Noise, Washington DC: 1982: Publ NASA CR 3610.

Oll92 Ollerhead JB, Jones CJ, Cadoux RE, *et al*. Report of a field study of aircraft noise and sleep disturbance. London: Civil Aviation Authority 1992.

Pas93 Passchier-Vermeer W. Noise and Health. Den Haag: Gezondheidsraad 1993; publikatie nr A93/02E.

Pas94a Passchier-Vermeer W. Sleep disturbance due to nighttime aircraft noise. Leiden: TNO-PG 1994. Publ.nr. 94.077.

Pas94b Passchier-Vermeer W. Rating of helikopter noise with respect to annoyance. Leiden: TNO-PG 1994. Publ.nr. 94.061.

Pas95 Passchier-Vermeer W. Road traffic noise and annoyance. Leiden, 1995: TNO-PG 1995. Publ.nr. 95.078.

Pas97 Passchier-Vermeer W, Vos H, Miedema HME. Adjustments for evening- and night-time. Leiden: TNO-PG 1997. Information presented to the Committee.

Pea89 Pearsons K, Barber DS, Tabachnick BG. Analysis of the predictability of noise-induced sleep disturbance. Canogan Park: BNN Systems and Technologies Corporation 1989. Report AD-A220.

Pea96 Pearsons K. Recent field studies in the United States involving the disturbance of sleep from aircraft noise. Proc Inter-noise 1996: 2271-6.

Por93a Porter ND, Flindell IH, Berry BF. An acoustic feature model for the assessment of environmental noise. Acoustics Bulletin 1993: 40-8.

Por93b Porter ND, *et al*. An acoustic feature model for the assessment of environmental noise. Proc Inst Acoust 1993; 15(4): 1015-24.

Por95a Porter ND. The assessment of industrial noise - a review of various national practices. National Physical Laboratory, report no. RSA (EXT) 0057C, May 1995.

Por95b Porter ND. The assessment of industrial noise - subjective listening tests and objective assessment procedures. National Physical Laboratory, Report RSA (EXT) 0057C, May 1995.

Por95c Porter ND. The detection of complex tones in noise. Proc Inst Acoust 1995; 17(5): 19-26.

Ric83 Rice CG. CEC Joint research on annoyance due to impulse noise. Proceedings 4th International Congress on noise as a public health problem 1983; 2: 1073-84.

Ric89 Rice CG. Human response to impulse noise - CEC studies: Review of 1987/1989 research programme. Proceedings 13th ICA. Belgrade 1989; 3: 135-8.

Ron97 Ronnenbaum T, Schulte-Fortkamp B, Weber R. Evaluation of combined noise sources. Seventh Oldenburg Symposium on Psychological Acoustics. Ed Schick & Klatte. University of Oldenburg, 1997: 171-90.

Sch78 Schultz TJ. Synthesis of social surveys on noise annoyance. J Acoust Soc Am 1978; 64(2): 377-405.

Sch79 Schomer PD. The Growth of Community Annoyance with Loudness of Events and with Frequency of Occurrence of Events. Champaign: U.S.Army Corps of Engineers, 1979. TM N-38.

Sch81a Schomer PD. Community Reaction to Impulse Noise; Initial Army Survey. Champaign: Construction Engineering Research Library, 1981. TR N-100.

Sch81b Schomer PD. The Growth of Community Annoyance with Loudness and Frequency of Occurrence of Events. Noise Control Engineering 1981; 17(1): 30-7.

Sch83a Schümer-Kohrs A, Schümer R, Knall V, Kasubek W. Interdisziplinäre feldstudie über die besonderheiten des Schienverkehrlärms gegenüber dem Strassenverkehrslärm, Planningsburo Obermeyer, München 1983.

Sch83b Schomer PD. Time of day adjustments on "penalties". J Acoust Soc Am 1983; 73(2): 546-55.

Sch94a Schulte-Fortkamp B. Loudness judgements on the background of subjecitive experience with environmental sounds. Proceedings Internoise 94. Yokohama, Japan 1994: 791-6.

Sch94b Schulte-Fortkamp B. Geräusche beurteilen im Labor. Enwicklung interdisziplinärer Forschungsmethoden und ihre forschungssoziologische Analyse. Düsseldorf: VDI-Verlag, 1994.

Sch94c Schomer PD, Wagner LR, Benson LJ *et al*. Human and community response to military sounds: Results from field-laboratory tests of small arms, tracked-vehicles and blast sounds. Noise Contr Eng J 1994; 42(2): 71-84.

Sch95a Schomer PD, Wagner LR. Human and community response to military sounds - Part 2: Results from field-laboratory tests of small arms, 25 mm cannon, helicopters and blast sound. Noise Contr Eng J 1995; 43(1): 1-13.

Sch95b Schulte-Fortkamp B. Loudness judgements of environmental sounds. Validation by a study in laboratory and field. Proc Inter-noise. Newport Beach, California, USA 1995: 889-92.

Sch96 Schulte-Fortkamp B. Combined methods to investigate effects of noise exposure and subjective noise assessments. Proc Inter-noise. Liverpool 1996: 2351-6.

Sch97 Schulte-Fortkamp B, Weber R, Ronnebaum Th, *et al*. Literaturstudie zur Gesamtgeräuschbewertung. Oldenburg; University of Oldenburg, 1997.

Sha96 Shaw EAG. Noise environments outdoors and the effects of community noise exposure. Noise Contr Eng J 1996; 44(3): 109-19.

Sör79 Sörensen S, Magnusson J. Annoyance caused by noise from shooting ranges. J Sound Vib. 1979; 62: 437-42.

Tay82 Taylor SM. A comparison of models to predict annoyance reactions to noise from mixed sources. J Sound Vib 1982; 81(1): 123-38.

Tay87 Taylor SM, Hall FL, Birnie SE. Transportation noise annoyance: testing of a probabilistic model. J Sound Vib 1987; 117(1): 95-113.

Val78 Vallet M, Gagneux JM, Simonnet F. Effects of aircraft noise on sleep: an in situ experiment. ASHA reports 10. Proceedings Third International Congress on Noise as a Public Health Problem 1978: 391-6.

Val83 Vallet M, Gagneux JM, Blanchet V, *et al*. Long term sleep disturbance due to traffic noise. J Sound Vib 1983; 90: 173-91.

Val91 Vallet M, Vernet I. Night aircraft noise index and sleep research results. In: Lawrence A (ed.). Proc Inter-noise. The cost of noise. Poughkeepsie, NY 1991: Noise Control Foundation; 1: 207-10.

Val96 Vallet M. Caracteristiques et indicateurs de la gene due au bruit des avions. Synthese INRETS no. 29, June 1996.

Ver89 Vercammen MLS. Setting limits for low frequency noise. Proc. 5th Int.Conf. on low frequency noise and vibration. Oxford, 1989.

Vos83 Vos J, Smoorenburg G.F. Annoyance ratings for impulse and traffic sounds presented in quiet. TNO-TM: Soesterberg 1983: IZF-Rep. 1983-23.

Vos85a Vos J, Smoorenburg GF. Penalty for impulse noise, derived from annoyance ratings for impulse and road-traffic sounds. J Acoust Soc Am 1985; 77(1): 193-201.

Vos85b Vos J. A review of field studies on annoyance due to impulse and road-traffic sounds. Proc Inter-noise 1985: 1029-32.

Vos87 Vos J, Geurtsen FWM. L_{eq} as a measure of annoyance caused by gunfire consisting of impulses with various proportions of highre and lower sound levels. Journal of the Acoustical Society of America 1987; 82(4): 1201-6.

Vos90 Vos J. On the level-dependent penalty for impulse sound. J Acoust Soc Am 1990; 88(2): 883-93.

Vos92a Vos J. Annoyance caused by simultaneous impulse, road traffic, and aircraft sounds: a quantitative model. J Acoust Soc Am 1992; 91(6): 3330-45.

Vos92b Vos J. Noise annoyance around irregularly employed shooting ranges. Proceedings 6th International FASE-congress 1992. Zürich, 1992.

Vos95a Vos J. A review of research on the annoyance caused by impulse sounds produced by small firearms. Proc Inter-noise 1995: 875-8.

Vos95b Vos J. Technical note: On the comparability of community responses to noise from artillery and rifle ranges, as determined in two Australian studies. Noise Contr Eng J 1995; 43 (2): 39-41.

Vos96 Vos J. Annoyance caused by impulse sounds produced by small, medium-large, and large firearms. Proc Inter-noise 1996; (5): 2231-6.

Vos97 Vos J. A re-analysis of the relationship between the results obtained in laboratory and field studies on the annoyance caused by high-energy impulsive sounds. Noise Control Eng J 1997; 45 (3):123-31.

VROM97 Conclusions of the Conference on EU-future policy on 21 and 22 May 1997. VROM, The Hague 1997.

Annexes

Annex **A**

The request for advice

The President of the Health Council of the Netherlands received the following letter from the Minister of Health, Welfare and Sport, dated 3 February 1997, Nº BRO-97186.

On behalf of the Minister of Housing, Spatial Planning and the Environment, Mrs M de Boer, and myself, I request advice with regard to a uniform noise exposure metric. Before detailing the aspects which the advisory report should cover, allow me to first to provide you with information on the background to this request.

Background

The system of noise exposure regulations in the Netherlands has become very complicated over the years. Noise exposure regulations are contained in the Aviation Act, the Noise Abatement Act and the Environmental Management Act. These acts and items of subordinated legislation often contain separate (and different) noise exposure regulations for each source of noise. I refer you to the enclosed table for an overview of the current situation. In many cases, there are also different metrics for determining noise exposure. It goes without saying that this does not benefit the transparency, implementation or enforceability of the system. The call for extensive simplification has become manifest in the advisory report on the Noise Abatement Act from the Working Party on Market Forces, Deregulation and Legislative Quality. This advisory report recommends the extensive simplification of the entire system of noise abatement legislation.

The government had the following to say about a uniform noise exposure metric in its response in June 1996 to the Working Party's report on the Noise Abatement Act (Lower House, '95-'96, 24 036, no. 16):

As such, the government considers the idea of one and the same noise exposure metric for all environmental noise sources appealing. This idea will be examined further and will be elaborated as part of the MIG project (MIG - Modernization of Instruments for Noise Abatement Policy). An additional issue which will be examined is the extent to which the exposure metric for aircraft noise can be included in the uniform exposure metric, given European developments relating to calculation methods and standard setting.

The principal appeal of such a uniform noise exposure metric is the simplification which can be achieved.

Links to other projects

As a part of the MIG project, a working party on a system of uniform noise exposure metrics was formed with Prof. C. Gouwens as chair. The working party is due to submit policy recommendations to the MIG Management Group in September 1997 about the simplification of the regulations . The Lower House will then be informed about the results of the MIG project as a whole. We would wish to make the following observations about the link between this working party and the request for a report by the Health Council.

The task of the MIG Working Party referred to above is to produce policy advice about options for an extensive simplification of the current system of noise exposure metrics. There is a strong emphasis here on the practical problems. The basic principle is that the levels of protection afforded by current standards should not change.

Ideally, the working party's policy recommendations should be made available after the publication of the Health Council's scientific advice about possible uniform noise exposure metrics and the public health consequences of possible simplifications of the present system. However, since the working party has to publish its recommendations in September 1997, the two studies will have to be conducted in parallel. Accordingly, the scientific and the policy aspects will have to be very well coordinated and clarity is needed before the studies of possible options begin.

Request for a report

The Health Council is asked to describe a system of environmental noise exposure metrics which is as simple as possible and to examine the relationship between the new metrics and effects on health. Preconditions for a system of this kind are as follows:

- transparency with respect to the effects of noise on health in this system, at least as far as (severe) general annoyance and sleep disturbance are concerned
- observation of international agreements insofar as the latter are binding

- it should be relatively simple to set or measure the metrics in this system
- the system should be applicable to all noise sources outside the home.

Other issues which may be covered are effects on social behaviour, performance, ischaemic heart diseases and blood pressure.

Timetable

The MIG policy document will be sent to the Lower House in early 1998. This means that sub-projects (including that on simplification of noise exposure metrics) must be completed well before then in order to be incorporated in the discussion. Therefore, I would appreciate it if I could receive the Health Council's advisory report no later than September 1997.

In order to ensure optimal coordination with the MIG project, the Minister of Housing, Spatial Planning and the Environment suggests that the committee be attended by an observer from her Ministry.

Yours sincerely,
(signed)
Dr E. Borst-Eilers
Minister of Health, Welfare and Sport

Enclosed: overview of present Dutch environmental noise metrics

Table: Overview of present noise exposure standards, slightly simplified.

Preferred and maximum permissible limits in dB(A) for several environmental noise sources
(+..) = temporary elevation due to expected lower noise emission in the future

noise source	preferred value for spatial planning	maximum permissible in new situations	maximum permissible in existing situations	criteria for demolition	inside the dwelling (new situations)
Noise Abatement Act: etmaal					
local road traffic: road and dwellings new	50 (+5)	60 (+5)			35
local road traffic: other situations	50 (+5)	65 (+5)	70 (+5)	65	35
new highways	50 (+3)	60 (+3)			35
highways: other situations	50 (+3)	55 (+3)	70 (+3)	65	35
industry	50	55	55 to 65	55	35
impulse / tonal noise	50 (-5) [a]	55 (-5)		55	35
railways	57 (+3)	70 (+3)	70 (+3)	65	35/37
Environmental Management Act					
industry (category A), L_{etmaal}	40* to 50* (depending on reference level)	50*	?	—	—
industry (category A), L_{max}	70 dB(A), day-time 65 dB(A), evening 60 dB(A), night	—	—	—	—
Aviation Act + art 108 Noise Abatement Act, Kosten Unit					
military and civil aircraft	20 Ke	35 Ke	65 Ke	40 Ke	35 à 40 dB(A)
Small aircraft	47 (+3)	57 (+3)	—	—	—
Night-time value	—	—	—	—	26

[a] With definite impulse or tonal components in the noise, a penalty of 5 dB(A) should be added to the calculated or measured value.

De adviesaanvraag

De Voorzitter van de Gezondheidsraad ontving onderstaande adviesaanvraag van de Minister van Volksgezondheid, Welzijn en Sport d.d. 3 februari 1997, nr BRO-97186.

Hierbij verzoek ik u, mede namens de Minister van VROM, mevrouw M de Boer, ons advies uit te brengen over een uniforme geluiddosismaat. In het volgende schets ik enige achtergronden van deze materie en vervolgens de details van het gevraagde advies.

Advies

Het geluidnormstelsel in de Nederlandse wetgeving is in de loop der jaren behoorlijk ingewikkeld geworden. Geluidnormen zijn opgenomen in de Luchtvaartwet, de Wet geluidhinder en de Wet Milieubeheer. In ieder van deze wetten en de daarop gebaseerde uitvoeringsbesluiten zijn voor iedere geluidbron vaak afzonderlijke (en van elkaar verschillende) geluidnormen vastgelegd. Voor een overzicht verwijs ik naar bijgaande tabel. In veel gevallen is daarbij ook nog eens sprake van verschillende maten waarmee de geluiddosis bepaald dient te worden. Dit komt de inzichtelijkheid van het systeem, en daarmee de uitvoerbaarheid en de handhaafbaarheid natuurlijk niet ten goede. De roep om vergaande vereenvoudiging is manifest geworden in het advies van de Werkgroep Marktwerking, Deregulering en Wetgevingskwaliteit over de Wet geluidhinder. In dit advies wordt aanbevolen om het hele stelsel van geluidwetgeving vergaand te vereenvoudigen.

In de reactie (TK, ’95-’96, 24 036n nr 16) op het rapport van de MDW-werkgroep Wet geluidhinder van juni 1996 heeft het Kabinet het volgende gezegd over de uniforme dosismaat:

Het idee van één en dezelfde dosismaat voor alle geluidbronnen vindt het Kabinet op zich zelf aantrekkelijk. In het kader van het project MIG zal deze gedachte verder worden onderzocht en uitgewerkt. Tevens zal bezien worden in hoeverre de dosismaat voor luchtvaartgeluid, rekening houdend met Europese ontwikkelingen ten aanzien van rekenmethodieken en normstelling, bij de uniforme dosismaat kan worden betrokken.

De aantrekkelijkheid van een dergelijke geluiddosismaat is vooral gelegen in de vereenvoudiging die dan bereikt kan worden.

Relatie met andere projecten

In het kader van het MIG-project (Modernisering Instrumentarium Geluidbeleid) is een werkgroep "Uniformering dosismaten" in het leven geroepen, onder voorzitterschap van prof. dr. C. Gouwens, die zich over de aspecten van een uniforme dosismaat gaat buigen. Deze werkgroep zou september 1997 beleidsmatig advies over het uniformeren van het normstelsel aan de Regie groep MIG moeten uitbrengen, waarna de Tweede Kamer geïnformeerd wordt over de uitkomsten van het MIG-project als geheel. Over de relatie tussen deze werkgroep en de adviesaanvraag het volgende.

De MIG-werkgroep "Uniformering dosismaten" heeft tot taak een advies te geven over de mogelijkheden om te komen tot een sterke vereenvoudiging van het huidige normstelsel. Hierbij ligt sterk de nadruk op de praktische problemen. Uitgangspunt daarbij is dat de door de huidige normen geboden beschermingsniveaus niet veranderen. Idealiter zou dit beleidsmatig advies van de werkgroep volgen op het advies van de Gezondheidsraad over mogelijke dosismaten en de invloed van mogelijke vereenvoudigingen op gezondheidseffecten.

Gezien het feit echter dat de werkgroep september 1997 advies moet uitbrengen, betekent dat in aanzienlijke mate parallel gewerkt zal moeten worden. Dit maakt het noodzakelijk dat het advies-traject en het beleidsmatige traject zeer goed op elkaar afgestemd wordt en dat aan het begin van deze trajecten duidelijkheid wordt geschapen over de te onderzoeken mogelijkheden.

Adviesaanvraag

De raad wordt gevraagd om een zo eenvoudig mogelijk stelsel van geluiddosismaten te beschrijven en daarbij in ieder geval in te gaan op de relatie tussen het nieuwe stelsel en de gezondheidseffecten. Randvoorwaarden bij een dergelijk stelsel zijn:

- inzicht in de relatie met effecten van geluid op de gezondheid van dit stelsel, in ieder geval voor wat betreft (ernstige) hinder en effecten op de slaap;
- passend binnen internationale afspraken voor zover deze bindend zijn;
- de maten van dit stelsel moeten op (relatief) eenvoudige wijze bepaalbaar of meetbaar kunnen zijn;
- het maatstelsel moet bruikbaar zijn voor alle geluidbronnen buiten de woning.

Tabel: Overzicht huidig geluidnormstelsel, enigszins vereenvoudigd.

Grenswaarden voor geluid van diverse bronnen in dB(A) (+..) = tijdelijke correctie ivm stiller worden bron					
bron	voorkeur/ planningswaarde	maximaal toelaatbaar in nieuwe situaties	maximaal toelaatbaar in bestaande situaties	criteria voor saneringssituaties	binnen (nieuwe situaties)
WGH: $L_{Aeq,etmaalwaarde}$					
wegverkeer lokaal: weg én woningen nieuw	50 (+5)	60 (+5)			35
wegverkeer lokaal: overige situaties	50 (+5)	65 (+5)	70 (+5)	65	35
wegverkeer: nieuwe autowegen	50 (+3)	60 (+3)			35
wegverkeer autowegen: overige situaties	50 (+3)	55 (+3)	70 (+3)	65	35
industrie	50	55	55 to 65	55	35
impuls / tonaal lawaai	50 (-5) *	55 (-5)		55	35
rail	57 (+3)	70 (+3)	70 (+3)	65	35/37
Wet Milieubeheer					
vergunningsplichtige inrichtingen, L_{etmaal}	40* to 50* (afhankelijk referentieniveau)	50*	?	—	—
vergunningsplichtige inrichtingen, L_{max}	70 dB(A), dag 65 dB(A), avond 60 dB(A), nacht	—	—	—	—
Luchtvaartwet+art 108 WGH Kosten-eenheid					
militaire en civiele luchtvaart	20 Ke	35 Ke	65 Ke	40 Ke	35 à 40 dB(A)
Kleine luchtvaart	47 (+3)	57 (+3)	—	—	—
nachtnorm	—	—	—	—	26

* Indien het geluid een duidelijk impuls- of tonaal (muziek)karakter heeft dient bij het rekenresultaat een straffactor van 5 dB(A) geteld te worden.

Aspecten die mogelijk ook betrokken kunnen worden zijn effecten op (sociaal) gedrag, prestatie, hart- en vaatziekten en bloeddruk.

Planning

De verzending van de beleidsnota MIG aan de Tweede Kamer is voorzien begin 1998. Dit houdt in dat de deelprojecten (waarvan het project “uniforme dosismaat” er een is) ruim voor die tijd gereed dienen te zijn om een rol te kunnen spelen in de discussie. Mede met het oog daarop stel ik het op prijs om uw advies uiterlijk september 1997 te ontvangen.

Ten einde optimale afstemming met het MIG (deel)project te garanderen, stelt de Minister van VROM voor een medewerker van haar Ministerie als waarnemer te laten deelnemen in de commissie.

Hoogachtend,
(w.g.)
de Minister van Volksgezondheid, Welzijn en Sport,
dr. E. Borst-Eilers

Bijlage: overzicht huidig geluidnormstelsel

Annex **B**

Members of the Committee

The Committee comprised the following persons:

- T ten Wolde, *chairman*
  TNO Institute of Applied Physics, Delft, the Netherlands
- M van den Berg *adviser*
  Ministry of Housing, Spatial Planning and the Environment, The Hague, the Netherlands
- BF Berry
  National Physical Laboratory, Teddington, Middlesex, England
- JM Fields
  Silver Spring, Maryland, United States of America
- D Gottlob
  Federal Environmental Agency, Berlin, Germany
- J Kragh
  DELTA Acoustics & Vibration, Lyngby, Denmark
- HME Miedema
  TNO Prevention and Health, Leiden, the Netherlands
- WF Passchier, *advisor*
  Health Council of the Netherlands, Rijswijk, the Netherlands
- B Schulte-Fortkamp
  Carl von Ossietzky University, Oldenburg, Germany
- M Vallet, *corresponding member*
  INRETS, Lyon, France

- J Vos
  TNO Human Factors Research Institute, Soesterberg, the Netherlands
- HGM Bouman, *scientific secretary*
  Health Council of the Netherlands, Rijswijk, the Netherlands
- W Passchier-Vermeer, *scientific secretary*
  Health Council of the Netherlands, Rijswijk and TNO Prevention and Health, Leiden, the Netherlands

Administrative support: CA Fortman, M van Kan.

Annex **C**

Terms and definitions

1 Equivalent sound level over a time period T

The equivalent sound level, determined from the actual sound levels during a period *T* is mathematically expressed as follows:

$$L_{Aeq,T} = 10 \lg \frac{1}{T} \int_0^T 10^{L(t)/10} dt \text{ dB(A)}$$

with: *L(t)*: the A-weighted sound level at time *t*
T: duration in s of the exposure period considered.

2 Equivalent sound level over 24 hours ($L_{Aeq,24h}$)

The equivalent sound level over 24 hours is the equivalent sound level due to an exposure of 24 consecutive hours from 07.00 to 07.00 the next day.

3 Day-night level (L_{dn})

$$L_{dn} = 10 \lg\left[\frac{15}{24} 10^{L_{Aeq,d}/10} + \frac{9}{24} 10^{(10+L_{Aeq,n})/10}\right] \text{ dB(A)}$$

in which:
d: day-time - the period from 07.00 to 22.00
n: night-time - the period from 22.00 to 07.00

This definition conforms to the definition in ANSI96.

4 Day-evening-night level (L_{den})

$$L_{den} = 10\,\lg[\tfrac{12}{24}10^{L_{Aeq,d}/10} + \tfrac{4}{24}10^{(5+L_{Aeq,ev})/10} + \tfrac{8}{24}10^{(10+L_{Aeq,n})/10}]\text{dB(A)}$$

in which:
d: day-time - the period from 07.00 to 19.00
e: evening-time - the period from 19.00 to 23.00
n: night-time - the period from 23.00 to 07.00

This definition is conform to definitions in regulations in Scandinavian countries (Kra95a).

5 Full day value (L_{etmaal})

$$L_{etmaal} = \text{maximum of } L_{Aeq,d}, L_{Aeq,ev} + 5 \text{ and } L_{Aeq,n} + 10 \text{ dB(A)}$$

in which:
d: day-time - the period from 07.00 to 19.00
e: evening-time - the period from 19.00 to 23.00
n: night-time - the period from 23.00 to 07.00

This definition is conform to definitions in the Netherlands Noise Abatement Act.

6 Aircraft noise exposure measure B

$$B = 20\ \lg\sum_{i=1}^{N}(n_{ti} \times 10^{L_i/15}) - 157 \text{ Ke (Kosten Units)}$$

in which:
N: number of overflights per year with $L_{A,max}$ of at least 65 dB(A)
L_i: the maximum sound level during an overflight *i*
n_{ti}: a weighting factor, dependent upon the part of the 24 hour period

This definition is conform to definitions in the Aviation Act.

7 Sound exposure level of a noise event (*SEL*)

$$SEL = \int_0^t 10^{L(t')/10} dt' \text{ dB(A)}$$

in which:
t: the duration of the noise event in seconds

The equivalent sound level over a time period *T* during which *n* isolated noise events occur can be expressed in the *SEL* values of these noise events by:

$$L_{Aeq,T} = 10 \lg \frac{1}{T} \sum_i 10^{SEL_i/10}$$

in which
SEL_i: the *SEL* value of noise event *i*
T: duration in seconds of the period considered.

Annex **D**

Activity pattern of the Dutch population

1 Introduction

In this Annex the Committee presents information on the day-, evening- and night-time activity patterns of the Dutch population in 1985 and 1995 and the activity patterns of a population in the United States in 1975 (Fie85). The Dutch data were gathered by the SCP: Dutch Office for Social and Cultural Planning (Bro97; GR91), and the RIVM:

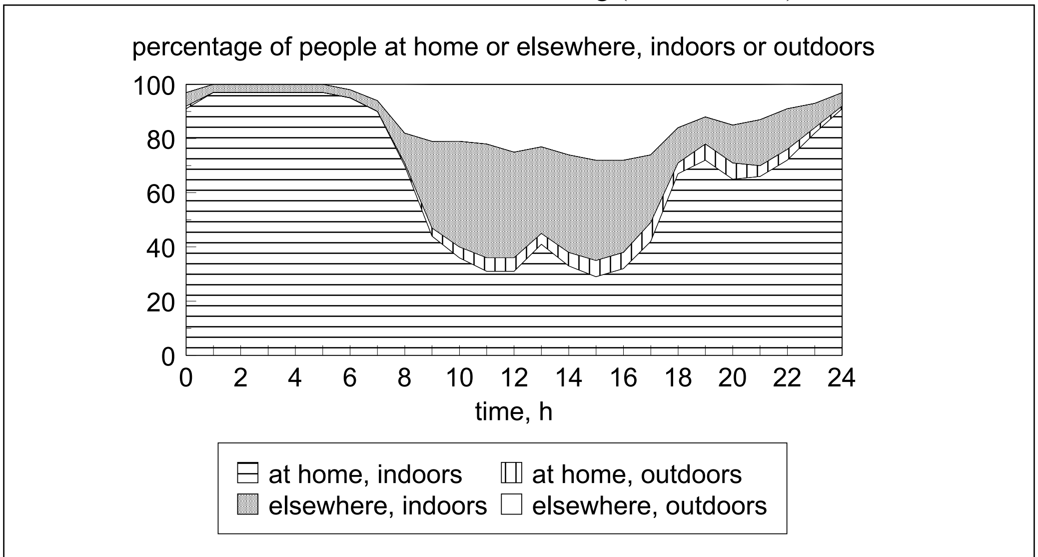

Figure D.1 Percentage of the adult Dutch population at home or elsewhere, indoors or outdoors during working days as a function of the time of the day (n = 2 096). RIVM data, 1994/1995 (Fre97).

National Institute of Public Health and the Environment (Fre97). The Committee used these data to delineate day-, evening- and night-time periods.

2 The evaluated data

The SCP data

The SCP data originate from a 1985 study (GR91) and a 1995 study (Bro97). In these studies information on day-, evening- and night-time activities of Dutch citizens was collected by means of diaries. Participants in the studies kept a diary for one week, that spanned the last days of September and the first days of October. During the week people recorded their most marked activity every 15 minutes. One of these activities

Table D.1 Percentage of the adult population (18 years and older) that is 'sleeping', as a function of the time of the day (n = 2 096). RIVM data, 1994/1995 (Fre97).

percentage of the adult population	sleeping at (h):	sleeping at (h):
25	23.00	08.00
50	23.30	07.15
60	23.30	07.00
70	00.00	07.00
80	00.00	06.30
90	00.45	06.00

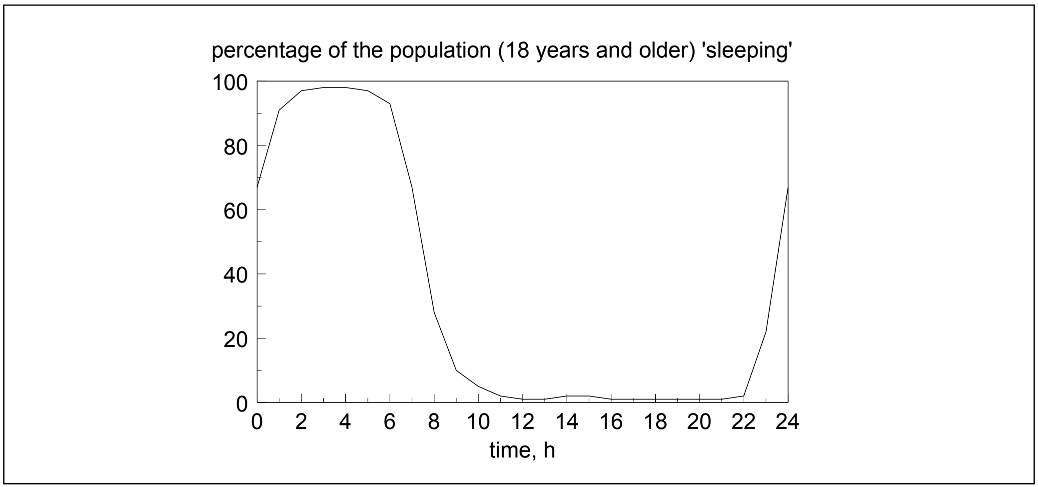

Figure D.2 Percentage of the adult population (18 years and older) 'sleeping' during working days as a function of the time of the day (n = 2 096). RIVM data, 1994/1995 (Fre97).

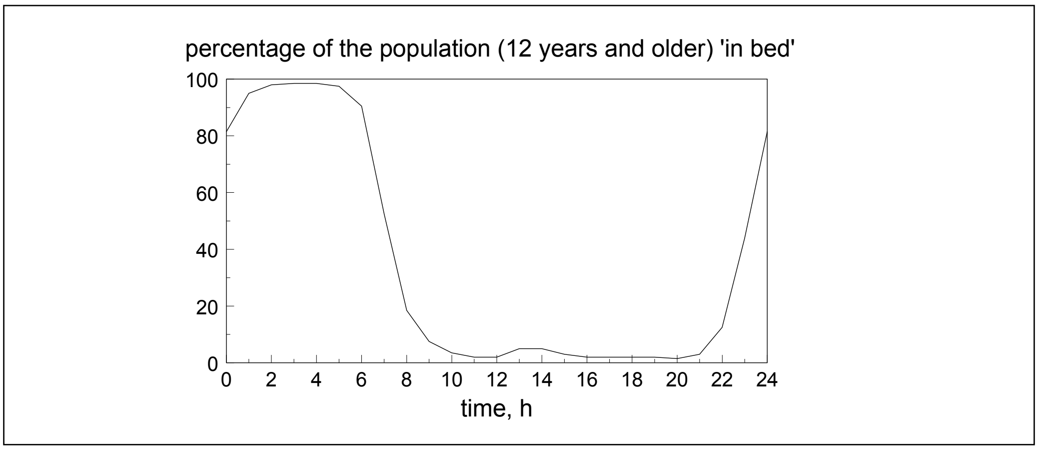

Figure D.3 Percentage of the population (12 years and older) 'in bed' during working days as a function of the time of the day (n = 3 227). SCP data, 1995 (SCP97).

was 'night rest'. The 1985 data on this night rest activity take into account three different age categories: 12 to 17 (n = 295), 18 to 64 (n = 2 635) and 65 years and over (n = 333). The total number of people included in the study was 3 263. In the 1995 data report, 'in bed' is defined as 'night rest', 'sleeping during the day', 'resting' and 'catnapping'. Age categories are 12 to 19 (n = 382), 20 to 34 (n = 961), 35 to 49 (n = 868), 50 to 64 (n = 557) and 65 years and over (n = 459). The total number of people included in the study was 3 227. The study recorded the number of people who were 'in bed' for one weekday (Tuesday), every hour on the hour.

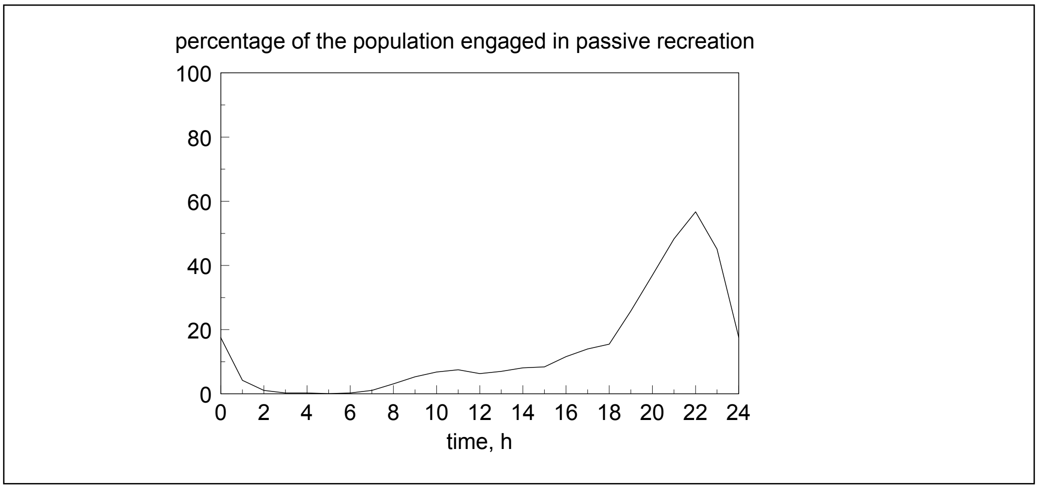

Figure D.4 Percentage of the (adult) population engaged in 'passive recreation at home' during working days (n = 2 096).

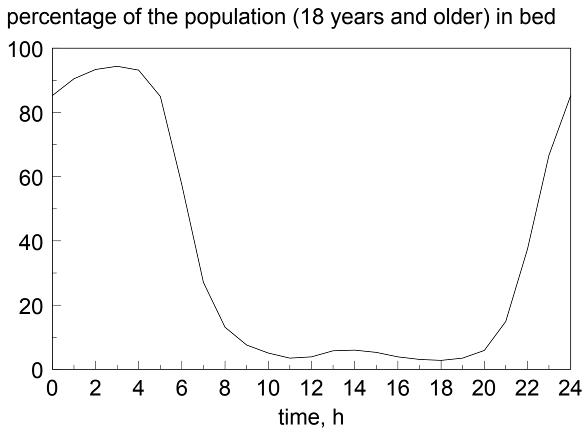

Figure D.5 Data on sleeping time of adults (18 years and older) during weekdays. USA, 1975/1976; Fie85).

In this Annex only SCP data on sleeping times are presented. Other data on day or night-time activity were not available in a form which allowed division of the 24-hour daily cycle into clearly recognizable time periods.

The RIVM data

The RIVM data are available in a format that enabled to distinguish activities like being 'asleep', being 'at home' or 'elsewhere' and participating in 'social activities' as a function of the time of the day (Fre97). The RIVM made use of data (the 'Intomart SQL data base') that resulted from a study designed to determine the indoor and outdoor exposure to air pollutants of the general population. For this purpose, activity patterns were determined during two different periods in the year:

- a sample survey of days during the winter ('winter period')
- a sample survey of days during the summer ('summer period').

4 216 people were asked to record during one day for every 15 minutes their presence in so-called 'micro environments' and their activity. In the data analysis the micro environments were defined as being 'at home' or 'elsewhere', 'indoors' or 'outdoors' and activities were defined as 'sleeping' (in bed and about to sleep) and being engaged in 'passive recreation at home'. Data were grouped according to sex (men: n = 2 160, women: n = 2 056), day of week (working days: n = 2 975, or weekend days: n = 1 241), season (summer: n = 2 043, or winter: n = 2 173), and age (0 to 6: n = 496, 7 to 12: n = 434, 13 to 17: n = 331, 18 to 34: n = 1 076, 35 to 54: n = 1 347, and 55 years and over: n = 532).

Data from a US study

The US study was a longitudinal ‘Time Use Survey’ performed between October 1975 and September 1976.The sample of people interviewed was designed to represent the adult population. People were questioned about their activity patterns during four periods within the above mentioned time span; activities were recorded as being at home, sleeping (the time people are ‘preparing to go to sleep’, ‘in bed and about to fall asleep’, and ‘are asleep’) and participating in ‘noise-sensitive’ activities (e.g. talking, reading, watching TV, listening to the radio or other audio equipment, eating or caring for children). Data were grouped as a function of the hour of the day, according to age (18 to 24, 25 to 44, 45 to 64 and 65 years and over), sex, season (November, March, May and September), day of week (Monday to Thursday, Friday, Saturday and Sunday), degree of urbanization and region.

3 Results

At home or elsewhere, indoors or outdoors

In Figure D.1 the fraction of the adult population 18 years and older being at home or elsewhere, indoors or outdoors during working days is presented. The data are taken from the RIVM study.

According to the data, people spend most of their time indoors, at home. Between about 17.30 and 08.00, more than 50% of

the people are at home, indoors. The place where people spend their time differs to a certain extent with season, day of week and age. In summer people spend more time outdoors than in winter (especially in the evening). During weekdays, the total time spend at home is less than during weekend days.

Sleeping time

Table D.1 and Figure D.2 show the times at which certain percentages of the population are sleeping on weekdays, based on the RIVM data (Dutch population, 1994/1995; Fre97) on adults (18 years and older).

The SCP data resemble the RIVM data with respect to the fraction of the population that is ‘in bed’ as a function of the time of the day (Figure D.3; Dutch population, 1995; SCP97). A comparison between the SCP data from 1985 and 1995 reveals that not much has changed in the course of time with respect to the times that people are ‘in bed’.

Participating in social activities

According to the RIVM data participation in ‘passive recreation at home’ mainly takes place in the evening (for all ages). Around 22.00 the fraction of the adult population that is ‘passive recreative’ shows a maximum (approximately 50%). See Figure D.4.

During the weekends the fraction of the population engaged in passive recreation at home is higher than during weekdays.

Comparing Dutch data and data from the USA

The times at which certain fractions of the population are sleeping, are generally quite similar in the Dutch and the American studies. Main differences between the Dutch and American data seem to relate to the time of getting up and the maximum percentage of people at the same time in bed at night. See Figure D.5. Given the fact that the Dutch and American studies were performed almost twenty years apart (in 1994/1995 and in 1975/1976 respectively), the Committee considers these findings as indicative for the possibility that activity patterns in industrialized countries change only slightly in the course of the years.

The American pattern of ‘being at home’ or elsewhere in the mid-70s strongly resembles the Dutch pattern in the mid-80s or mid-90s. Both in the Dutch and American studies, aspects such as sex, age and day of week influence ‘being at home’ more markedly than aspects such as season, residential district or degree of urbanisation.

4 Day, evening, and night-time

The Committee has decided to divide the day into three time periods:

- the day-time from 07.00 to 19.00
- the evening-time from 19.00 to 23.00
- the night-time from 23.00 to 07.00.

From the data presented in this Annex it can be seen that this division reflects the periodicity in activity pattern of the Dutch population and probably that of other populations (in industrialized countries) as well. One might argue that younger children are also sleeping during the ‘evening-time’ (only the night-time sound level is used to estimate sleep disturbance). However, the Committee took into account the finding that children are less sensitive to noise during their sleeping period than adults. Children were shown to be as liable to disturbances during their night-time sleep as adults at equivalent sound levels of about 10 dB(A) higher (Ebe87).

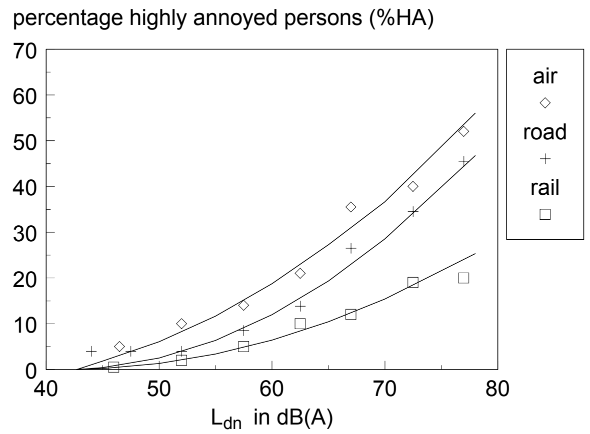

Figure E.1 The relationship between *%HA* and L_{dn} for aircraft, road and rail traffic noise in residential areas. L_{dn} was determined at 1.5 m distance from the most exposed facade of a dwelling.

Annex **E**

Exposure-effect relationships for general annoyance

1 Transport noise sources

Introduction

From an analysis of the data in the TNO database, relationships between measures of general annoyance and several noise metrics have been derived (Mie93, Mie96, Mie97). The database contained more data based on L_{dn} than on other metrics. Therefore in this annex first the results of the analysis to determine the relationships between general annoyance (*%HA*) and L_{dn} are given. The Committee decided to develop the noise metric system by using the metric L_{den} with an adjustment of 5 dB(A) for evening-time and 10 dB(A) for night-time. Therefore the relationships between L_{dn} and *%HA* have been converted to relationships between L_{den} and *%HA*. This procedure is specified in Figure E.3, taking into account differences between L_{den} and L_{dn}.

Relationships between *%HA* and L_{dn}

From the data in the TNO database for general annoyance, the relationships between the percentage highly annoyed respondents (*%HA*) and L_{dn} (with night-time specified as 22.00 - 07.00) have been determined separately for the three transport noise sources (air, road and rail traffic). The relationships are based on the following numbers of respondents:

- aircraft noise: 34 214 (20 surveys)

Table E.1 Differences between L_{den} and L_{dn} as a function of L_{dn} for air, road and rail traffic noise.

L_{dn} in dB(A)	L_{den} - L_{dn} in dB(A)		
	air	road	rail
50 - 55	+0.40	+0.30	-0.01
55 - 60	+0.40	+0.31	-0.01
60 - 65	+0.31	+0.32	+0.02
65 - 70	+0.29	+0.31	-0.05
70 - 75	+0.27	+0.22	-0.08
average value	+0.33	+0.29	-0.03

- road traffic noise: 21 228 (26 surveys)
- rail traffic noise: 8 527 (9 surveys).

For each survey included in the analysis the L_{dn} values were divided into classes of 5 dB(A) width. For each source a quadratic regression was performed on all of the data points of each of the surveys included in the analysis. The following equations were obtained:

aircraft traffic noise $\%HA = 0.0285(L_{dn} - 42)^2 + 0.53(L_{dn} - 42)$

road traffic noise: $\%HA = 0.0353(L_{dn} - 42)^2 + 0.03(L_{dn} - 42)$

rail traffic noise: $\%HA = 0.0193(L_{dn} - 42)^2 + 0.01(L_{dn} - 42)$

The results are plotted in Figure E.1. The data points in the figure have been determined by taking the data of all respondents with L_{dn}-values in a 5 dB(A) class together.

There is a considerable variation between curves derived from *different* studies. Due to this large variation between studies it was not possible to calculate confidence intervals for the curves presented in Figure E.1. The available methods to calculate confidence intervals analytically or by resampling methods do not take variation *between* studies into account, or do not produce intervals based on curves. At TNO work is in progress to adapt the available statistical resampling techniques to arrive at a method with which the desired confidence intervals based on curves can be obtained.

Relationships between *%HA* and L_{den}

To determine the relationship between *%HA* and L_{den} (with evening-time defined as 19.00 to 23.00 and night-time as 23.00 to 07.00) the relationships between L_{dn} (with night-time defined as 22.00 to 07.00) and *%HA* have been converted to relationships between L_{den} and *%HA,* taking into account differences between L_{dn} and L_{den}. To determine whether these differences are, in practice, a function of L_{dn}, a statistical analysis has been carried out on these differences in the exposure situations for which general annoyance data were available in the TNO database. The calculations have been carried out for each of the three noise sources separately. The average values of the differences between L_{dn} and L_{den} are given in Table E.1.

As can be seen, these average differences decrease only marginally as L_{dn} increases and are rather small. Therefore the value averaged over the five L_{dn} categories is used for each noise source in the conversion of the relationship between *%HA* and L_{dn} into the relationship between *%HA* and L_{den}. These relationships then become:

aircraft traffic noise: $\%HA = 0.0285(L_{den} - 42.3)^2 + 0.53(L_{den} - 42.3)$

road traffic noise: $\%HA = 0.0353(L_{den} - 42.3)^2 + 0.03(L_{den} - 42.3)$

rail traffic noise: $\%HA = 0.0193(L_{den} - 42.0)^2 + 0.01(L_{den} - 42.0)$

2 Stationary noise sources

Introduction

Stationary noise sources present in the environment constitute a large variety of types, such as industries, transformers, fans, shooting ranges, and shunting yards. General annoyance from transport noise is much more widespread in the Netherlands and other countries (Jon94, Lam94) than general annoyance caused by noise from stationary sources. Surveys to determine exposure-response relationships for general annoyance due to noise from stationary sources is scarce. Moreover, the larger part of the surveys dealing with noise from stationary sources have been conducted to investigate the effect of special noise characteristics, such as impulsiveness. The results of those investigations have been used in the determination of adjustments for special characteristics. An example of this is the specification of an adjustment for (highly) impulsive noise in (draft) Annex 1 to ISO 1996-2 (ISO97), which has been based on such investigations. Below the Committee presents information on exposure-response relations for three types of stationary noise sources: non-impulsive industrial noise, industrial noise with impulse components and noise from small-arms firing ranges.

Non-impulsive industrial noise

Industrial noise sources constitute a far more heterogeneous group with respect to frequency content and time patterns than any type of transport noise sources. Furthermore, even for a single factory, different special noise characteristics may play a role at different times, due to different aspects of the manufacturing processes.

The Committee has considered the scarce data on relationships between non-impulsive industrial noise and general annoyance. Emphasis was on publications by Finke (Fin80) and on an analysis presented by Miedema (Mie92), containing information on industrial noise which has been categorized by acoustics experts as being noise in which no clearly observable impulse and tonal components are present. Such noise would therefore be perceived by the population as more or less constant with minor variations, comparable to road traffic noise. However, the Committee considers it indisputable that at low levels (L_{dn} values between 40 and 55 dB(A)) non-impulsive industrial noise is more annoying than transport noise. Comparing the exposure-response relations for road traffic noise with the results for low-level non-impulsive industrial noise, exposure to the latter noise at a L_{dn} value of 40 dB(A) results in a similar percentage of highly annoyed persons as road traffic noise at 50 dB(A). At L_{dn} values of over 60 dB(A), general annoyance scores for industrial noise are comparable to those for road traffic noise at the same L_{dn} value. Therefore, the Committee proposes, given the current level of knowledge, to apply the exposure-response relationships for road traffic noise to non-impulsive industrial noise at higher levels from 60 dB(A) upwards and to adjust this relationship tentatively by 10 dB(A) at 40 dB(A) and by 5 dB(A) at 50 dB(A). The Committee acknowledges that further research is necessary in order to arrive at more definite conclusions.

Impulsive noise produced by industrial sources

Many noises found in industrial situations are impulsive in nature, *i.e.* they consist of impacts of metal on metal, surges of compressed air, noise from diesel engines etc*. Extensive reviews of the kind of sources involved have been published (Dym77; Lee81). In this section a summary is given of the relevant text in ISO 1996, reference is made to a review of national practices in the rating of industrial noise, including the

* Impulsive sound is defined in ISO 1996 as sound characterized by brief excursions of sound pressure (acoustic impulses) that significantly exceed the ambient environmental sound pressure. The duration of a single impulsive sound is usually less than one second.

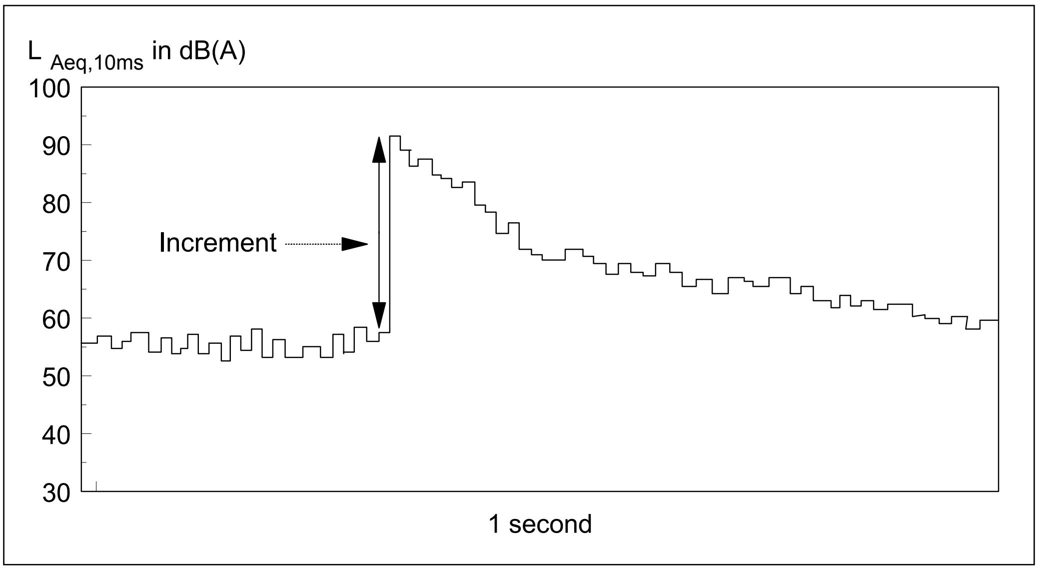

Figure E.2 The increment descriptor.

assessment of impulsive components (Por95a), a brief review of previous research on the assessment of impulsive industrial noise is presented and a selection of methods by which industrial impulse noise in the environment may be assessed is given.

International standardization and national practices The relevant International Standard, issued in 1987, is ISO 1996-2 (ISO87). The general principle of ISO 1996 is the use of a rating level based on $L_{Aeq,T}$ with the addition of adjustments, where tone or impulse characteristics are present. In the case of noise with impulse characteristics, the adjustment is set out as follows: "If impulse is an essential characteristic of sound within the specified time-interval, an adjustment may be applied, for this time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated." A numerical value for the impulse adjustment is lacking in ISO 1996-2 as well as a method to assess impulse noise. Since the issuing of ISO 1996, several investigations have been undertaken and based on the results of these investigations a draft-amendment to ISO 1996-2 has been prepared (ISO97). The draft-amendment states in a note that "currently, no mathematical descriptor exists which unequivocally can define the presence of impulsive sound, or can separate impulsive sounds into the categories given below. Thus the sources of sound listed, are used to define the category." The following definitions are given in the amendment*:

* The text has been reproduced from the latest version of the draft-amendment (August, 1997).

Highly impulsive sound: A sound from one of the following enumerated categories of sound sources: small arms fire, metal hammering, wood hammering, drop-hammer, pile driver, drop forging, pneumatic hammering, pavement breaking, metal impacts of rail-yard shunting operations, or a sound with a comparable characteristic and degree of intrusiveness.

High-energy impulsive sound: A sound from one of the following enumerated categories of sound sources: quarry and mining explosions, sonic booms, demolition and industrial processes that use high explosives, explosive industrial circuit breakers, military ordnance (eg, armor, artillery and mortar fire, bombs, explosive ignition of rockets and missiles, any other explosive source where the equivalent mass of dynamite exceeds 25g), or a sound with a comparable characteristic and degree of intrusiveness.

Ordinary impulsive sound: An impulsive sound that is not a highly impulsive sound or a high-energy impulsive sound.' Examples of ordinary impulsive sound sources are in specific situations low-flying military aircrafts and near-by high speed trains.

For highly impulsive sounds, the impulse adjustment is specified in the draft-amendment by 12 dB(A), and for ordinary impulsive sounds by 5 dB(A). Thus, even after this revision, there is no standardised physical method of determining whether a noise is impulsive, and therefore requires an adjustment.

In 1995, a review was published of national practices in the rating and assessment of environmental noise (Por95a). This was designed to establish how ISO 1996 had been adopted by the 19 countries included in the review, and also to establish the treatment of noise with specific characteristics within the relevant national standards. Examination of the review report shows that 6 of the countries surveyed (Australia, France, Germany, Hong Kong, Italy, Japan) used an objective method of some sort to determine whether adjustments for impulse noise were required. Substantial differences between the various methods could be observed.

Research on the assessment of impulsive noise In 1987, the results were published of an extensive programme of research, designed to evaluate systematically a number of methods proposed to describe the impulsiveness of noise (Ber87, Ber88). Parts of the research had been published earlier (Ber83). A series of related experiments were conducted in which subjective general annoyance reactions to controlled noise environments were obtained under simulated domestic listening conditions. The noise environments, which included recorded real impulsive noise as well as synthesised noises, were then quantified by six objective methods and the results compared with the general annoyance ratings. The optimum method, for the noises used in the experiments, was one which had been developed in earlier work on the rating of helicopter noise (Ber79).

During the above programme of research, special techniques were developed to measure L_{Aeq} over very short time intervals, as short as 10 milliseconds ($L_{Aeq,10ms}$). Between 1987 and 1989 a major research project was conducted, with funding from the EC, in which studies were conducted in various countries to determine the subjective impulsivity and general annoyance of a range of noises, and in addition, physical measurement procedures were developed for the detection and quantification of impulse noise. The opportunity was taken to refine a range of objective descriptors based on the analysis of the time series of short term L_{Aeq}. The optimum results from this work were obtained with a descriptor based on the maximum value of positive differences between consecutive values in the time series. This was termed the 'Increment' descriptor and is illustrated in Figure E.2. The result that noises can be sorted into 'impulsive' or 'non-impulsive' depending on whether or not the value of the increment descriptor exceeds 10 dB(A) was confirmed by Brambilla (Bra90). The overall results of the EC Joint Project are described by Rice in 1989 (Ric89).

In 1990, work started with the overall aim of refining methods of rating industrial noise (Ber89, Ber94, Por95b). Among various activities, a programme of subjective listening tests was conducted on the judged annoyance of specific types of industrial noise with the aims of exploring the effect of impulsiveness and tonality on annoyance, and of assessing objective assessment methods. The emphasis in present work is on developing the objective methods to deal with complex impulsive and tonal noises (Por95c, Ike93).

Possible methods to rate impulsive components in noise Since there is no internationally standardised objective method of determining whether a noise is impulsive, and since it is beyond the scope of the present report to arrive at such a method, only suggestions are made for the assessment of impulse noise. They concern:

- A note (which only has an informative status) in ISO 1996-2 states that: A method of describing the impulse characteristic of the sound within a specified time interval *T* is to measure the difference between the A-weighted sound pressure level, determined with time-weighting I, averaged over time interval *T*, and $L_{Aeq,T}$. The sound pressure levels should be determined simultaneously. The character of the noise may be further illustrated by determining the peak level and the number of impulses during a specified time period. A difference thus obtained could be used in the determination of a value of the impulse adjustment, if appropriate assessment models would be available. The method was found to have serious shortcomings (Ber87, Ber89)
- A method in which the impulse Increment descriptor specified above is used
- The onset rate of impulsive sound. The onset rate of a sound can be described as the average rate of change of sound level during the onset of a noise event.* In

ANSI96 the onset rate (R) is divided into three categories: $R < 15$ dB/s, $15 < R < 150$ dB/s and $R > 150$ dB/s. Adjustments specified in ANSI96 are 0, 11 lg $R/15$, and 11 dB(A) respectively. In ANSI96, however, onset rate is not used to characterize impulse noise, but it is a supplementary characterization of noise events providing a supplementary adjustment. Miedema (Mie92) also divides the onset rate into three categories, without explicitly presenting adjustment values. The values, presented in Mie92, that specify the three categories are about the same as those given in ANSI96

- A method of taking into account the impulse characteristic of a sound is to measure the sound with time weighting characteristic I, and use the measuring result in equations developed for F and S time weighting characteristics.

Impulse noise produced by small fire-arms (pistols, rifles)

In this section information on annoyance caused by impulse sounds produced by small fire-arms is summarized. For more details the reader is referred to a publication by Vos (Vos95a). Spectrally, these sounds are characterized by relatively high sound pressure levels in a broad frequency range between about 50 and 3,000 Hz. In contrast, the sounds produced by heavy fire-arms are characterized by a spectral peak between 20-80 Hz and a high frequency skirt of about -6 dB per octave. This summary considers the results from surveys and experimental studies. In all studies the general annoyance caused by the impulse sounds is compared to that caused by road traffic sounds. This comparison was made possible by expressing both the exposures to road traffic noise and the exposures to the impulse sounds in $L_{Aeq,t}$, with t the period during which both types of sounds are present. The extent to which general annoyance caused by the impulse sounds is different from that caused by road traffic sounds is expressed in the summary by Vos (Vos95a) as an adjustment to be added to $L_{Aeq,t}$ for the impulse sounds to find the $L_{Aeq,t}$ for equally annoying road traffic sounds.

Surveys In a review paper (Vos85b), the yearly average sound level was computed solely on the basis of those time periods during which the sounds were produced. Recent research on the general annoyance in areas around irregularly employed shooting ranges (Vos92a, 92b) has shown that it might be more appropriate to average the yearly sound level over a time period which includes both the days during which

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* More accurate definitions exist: onset rate is the rate of change of the A-weighted event sound level between the time the event sound level first exceeds the ambient sound level by 10 dB, and the time the event sound level first exceeds a level that is 10 dB less than the event's maximum fast-time-weighted sound level. Onset rate is defined for those event sound levels for which the maximum A-frequency-weighted, fast-time-weighted sound level exceeds the ambient sound level by at least 30 dB (ANSI96).

shooting takes place and the quiet days which are free from shooting noise. This means that for a number of field studies the average sound levels for shooting noise would have to be reduced, resulting in a small increase in the adjustment given in the 1985 review (Vos85b). In both the latter review and the newer publication from 1995, the community response to the shooting and road traffic sounds was expressed as the percentage highly annoyed *(%HA)*. The impulse noise adjustment in the review was derived from the difference between $L_{Aeq,t}$ for road traffic and $L_{Aeq,t}$ for shooting noise at which 33% of the respondents were highly annoyed. For lower percentages between 0% and, e.g., 15%, the estimation of the adjustment would be less reliable because of a much weaker relationship between the exposure and the response. In only one survey (Buc83; Buc90) exposure-response relationships were determined for both shooting and road traffic noise. In the other surveys the relationships for shooting noise are compared to a 'standard relationship' for road traffic noise which is based on seven surveys described in more detail (Sch78). That standard relationship predicts 33% of respondents being highly annoyed at an average sound level of 73 dB(A).

The adjustments estimated from Swedish (Sör79), Swiss (Hei80), German (Buc83), and Australian (Bul91) studies were 13, 14, 12, and 12 dB(A), respectively. The mean adjustment of 13 dB(A) for shooting noise can be compared with the adjustment estimates obtained for other types of impulse noise, *i.e.* from an English survey in the area of a construction site (Lar76) and a Dutch survey in the vicinity of an industrial area (Gro81). For comparable criteria of the community response, both the adjustment for the industrial impulses and that for the impulses produced at the construction site were equal to 11 dB(A). Overall, the adjustment was not related to sound level in a systematic way: in the Swedish and the Australian studies, the adjustment for shooting sounds decreased slightly and in the Swiss, Dutch, and English studies, the adjustment (shooting or industrial impact sounds) increased as the level increased. In the German study, the adjustment was independent of level for a wide range of community response.

Experimental studies In laboratory studies from a joint research project on the effects of impulse sounds on human beings (initiated by the Commission of the European Communities), annoyance caused by pistol shots was related to that caused by free-flowing road traffic noise (Bra90, Fli86, Ric83, Vos83, Vos85, Vos90, Vos92b). The results consistently showed that, at relatively low values of $L_{Aeq,t}$, road traffic noise was rated as less annoying than the impulse sounds, whereas this difference decreased as the level of the noises increased. This indicated that the adjustment for impulse noise was level dependent. An overall adjustment of 12 dB(A) was obtained at an indoor value of 30 dB(A) for $L_{Aeq,t}$, decreasing to 1 dB(A) at an average level of 65 dB(A).

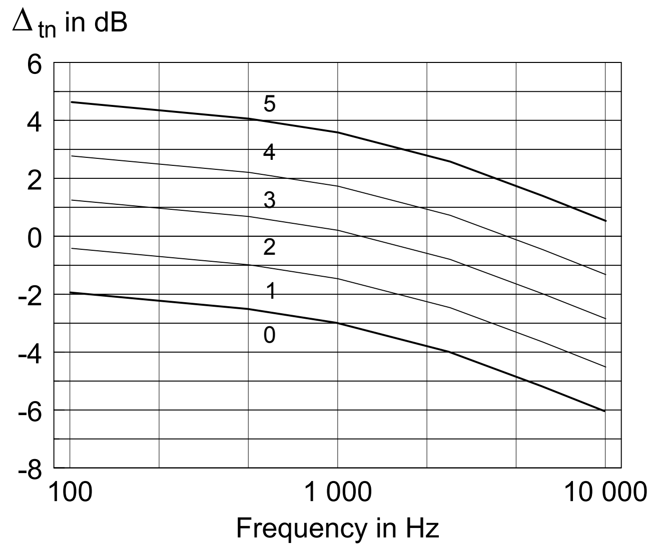

Figure F.1 Curves for the determination of tone adjustment values as a function of frequency of the tone and Δ_{tn}.

In field-laboratory studies in or in front of real houses close to un-used military training fields, hundreds of listeners were presented with sounds that were produced by small fire-arms, wheeled vehicles and other sources (Sch94c, Sch95a). The studies were designed as paired comparison tests where the listeners were presented with the impulse and vehicle sounds and were asked, for each pair, to indicate which sound was more annoying, the first or the second. The level as well as the spectral content of the impulse sounds were varied by the use of various distances between the firing position and the test location (100-400 m), while the level of the vehicle sounds was changed by the use of different vehicles such as a petroleum-engine van, a diesel Jeep, a cargo truck, a 4-wheel-drive pick-up truck and so on.

On the basis of the responses of the subjects, the average *SEL* value of the vehicle sound was determined at which this sound was as annoying as a specific kind of impulse sound. For each of these conditions, there were three listening conditions: indoors with windows closed, indoors with windows partially open and outdoors. The impulse noise adjustments ranged between 4 and 14 dB(A) and were not systematically related to either sound level or listening condition. On the basis of outdoor levels, which are normally used to measure and assess environmental noise exposure, essentially the same range of adjustments was found.

Conclusion In the surveys, the average impulse noise adjustment of 13 dB(A) was derived from the difference between $L_{Aeq,t}$ for road traffic and shooting noise at which

33% of the respondents reported being highly annoyed. In the pertinent surveys, this degree of community response was obtained for values of $L_{Aeq,t}$ for the impulse sounds between 50 and 60 dB(A). In the CEC laboratory studies, indoor noise levels between 30 and 40 dB(A), which were assumed to correspond with outdoor noise levels between 50 and 60 dB(A), yielded an overall mean adjustment of 10 dB(A) (s.d.=2.1 dB(A)). In the field-laboratory studies, the 12 conditions with outdoor levels between 50 and 61 dB(A) resulted in a mean adjustment of 9 dB(A) (s.d.=3.5 dB(A)). The results of the review therefore strongly suggest that, at least for shooting noise produced by small fire-arms, the 5-dB adjustment for impulse sounds recommended by ISO/R 1996 is too small (ISO87). For environmental assessment purposes, applying an adjustment of 12 dB(A) is considered to be most appropriate.

Annex **F**

Adjustments for special characteristics

1 Noise with audible tonal components

Introduction

In ISO 1996 - part 2 (ISO87), the adjustment for the presence of an audible tone in noise is set at 5 dB(A). This adjustment is, although widely used in regulations, not based on results from epidemiological surveys. Due to the absence of an epidemiological basis, the method specified below is proposed tentatively.

There are several methods to assess whether a noise consists of one of more tones or whether there are tones audible in a more broad-band noise (Joint Nordic Method; DEL97, method specified in DIN 45 681, method specified in Draft ANSI S12.9-1996-Part 4; ANSI96). The Committee has considered the similarities and discrepancies in the methods and these considerations are reflected in the method specified below.

Method

In some cases an aural examination of the audibility of a tone present in a noise may be sufficient to decide whether a tone is present. If so, the adjustment is set at 5 dB(A), as specified in ISO 1996-part 2. In other cases, measurements are necessary to determine the value of the adjustment to be applied to the equivalent sound level during the time the tone is present. This method is applicable in the frequency range from 100 to 12 500 Hz.

Measurements are taken indoors. The microphone is placed at a position where, from an aural judgement, the tone(s) is (are) most prominent. The sound pressure level L_t of the tone is determined and, disregarding the energy of the tone, the sound pressure level L_n of the noise in the critical band centered at the frequency of the tone, is also determined. The difference Δ_{tn} between L_t and L_n determines the adjustment to be added to the outdoor equivalent sound level. To that end, Δ_{tn} is compared with the curves given in Figure F.1. If Δ_{tn} is below the curve indicated by 0, the adjustment is equal to 0 dB(A). If Δ_{tn} is above the curve indicated by 5, the adjustment is equal to 5 dB(A), irrespective how much Δ_{tn} lies above the curve. If Δ_{tn} lies between two curves, the adjustment is equal to the lowest number of these two curves.

The bandwidth of a critical band is 100 Hz for tone frequencies below 500 Hz and 20% of the tone frequency above 500 Hz. If multiple tones are present in a single critical band, the tone level of these multiple tones is found by root mean square addition of all tone components within a critical band. The critical band is chosen in such a way that it includes the largest possible number of the most prominent tones. If tones in separate critical bands are present, then the largest value of Δ_{tn} is the decisive value. In the case of non-stationary conditions: for amplitude-modulated tones L_t is based on the maximum values measured with time-weighting F. If the tone level and the noise level change in the course of time, both the tone level and the noise level are measured as equivalent sound levels over 10 minutes.

2 Noise with (highly) impulsive components

The specifications from ISO 1996-2 (including (draft) Annex 1) are used. The adjustment for the enumerated categories of highly impulsive sounds is 12 dB(A) and is 5 dB(A) for impulsive sound.

3 Low-level industrial noise

The following adjustments are tentatively proposed for application to non-impulsive levels of industrial noise:

- equivalent sound level equal to 40 dB(A): 10 dB(A)
- equivalent sound level equal to 60 dB(A): 0 dB(A).

Provisional adjustments for other equivalent sound levels between 40 and 60 dB(A) are obtained by linear interpolation.

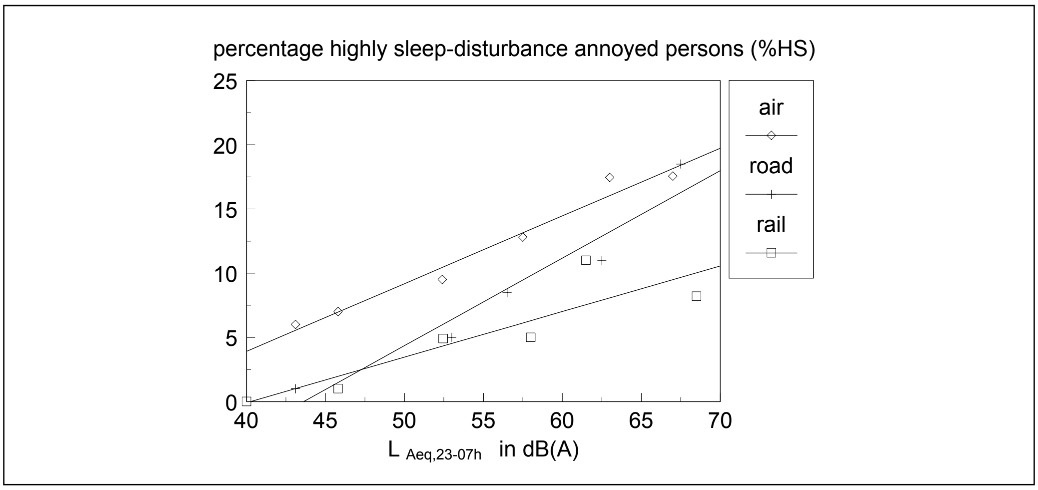

Figure G.1 Percentage of people that are highly sleep-disturbance annoyed (*%HS*) as a function of the equivalent sound level during the night.

Annex **G**

Exposure-effect relationships for sleep disturbance

1 Sleep-disturbance annoyance

Relationships

From analyses performed on the TNO database, relationships between sleep-disturbance annoyance and night-time equivalent sound level have been determined (Pas97, in preparation). Night-time has been defined as the period between 23.00 and 07.00. Surveys with questions regarding sleep disturbance, considered over the whole night-time period were selected from the database. From these surveys data on individual respondents were excluded if the $L_{Aeq,23\text{-}07h}$ value was either above 70 dB(A) or below 45 dB(A). These procedures considerably reduced the amount of data available for analysis. The remaining number of respondents was:

- 6,228 respondents exposed to aircraft noise (5 surveys)
- 4,684 respondents exposed to road traffic noise (4 surveys)
- 2,558 respondents exposed to rail noise (2 surveys).

The calculations performed pertain to aircraft, road and rail traffic noise separately. Results are given for the percentage of highly sleep-disturbance annoyed respondents (*%HS*). The label 'highly annoyed' is specified by a cut-off point at 72 on a scale from 0 ('not at all annoyed') to 100 ('very much annoyed'). The relationships between *%HS* and $L_{Aeq,23\text{-}07h}$ obtained are linear in form and described by:

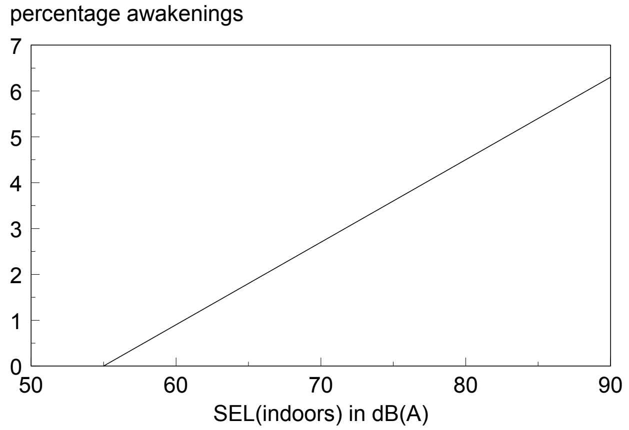

Figure G.2 Preliminary relationship between the percentage of awakenings (as determined from EEG recordings) in an adult person and *SEL* of an isolated night-time noise event measured indoors. The relation has been derived from results of field research in which residents participated who are usually exposed in their bedroom to these noise events.

aircraft traffic noise: $\%HS = 0.48\ (L_{Aeq,23\text{-}07h} - 32.6)$

road traffic noise: $\%HS = 0.62\ (L_{Aeq,23\text{-}07h} - 43.2)$

rail traffic noise: $\%HS = 0.32\ (L_{Aeq,23\text{-}07h} - 40.0)$

The results are presented graphically in Figure G.1. Together with the first order regression lines specified above, the data points derived from the results of all selected respondents are also shown, divided up by their night-time noise exposure into classes of 5 dB(A). A comparison of the data points and the straight lines show that a linear relationships is appropriate and that there is no indication for using second order regression lines.

Considerations by the Committee

The relationships presented above are based on $L_{Aeq.23\text{-}07h}$, determined outdoors in a specific way (incident sound) at a specified distance from the *most exposed facade* of the dwellings. The Committee expects that in many of the situations with the higher night-time equivalent sound levels at this side of the dwelling, people do not have their bedrooms at that side. Therefore, the Committee expects that, if the equivalent sound levels measured at the facades of the bedrooms would have been taken as noise metric, the relationships at the higher equivalent sound levels would be different. The Committee is of the opinion that the analyses should be further evaluated.

Table G.1 Maximum number of awakenings in an adult person as a function of the indoor equivalent sound level.

$L_{Aeq,8h}$ (indoors) in dB(A)	maximum number of awakenings per night for exposures to isolated noise events
15	0.008
20	0.03
25	0.08
30	0.26
35	0.77
40	2.62

2 Awakening

Awakening due to night-time noise is considered one of the most acute adverse effects of exposure to noise (Fin94, Jur83, Pas94a). It is hypothesized that sleep impaired for a long time in particular contributes to the development of stress-related noise-induced somatic effects (Isi93, Ohr93, Val83, Val91). In this Section it will be shown that, given a specific equivalent sound level over the night, it is possible to define *a worst case* noise exposure pattern and to estimate for that exposure pattern the maximum number of awakenings per night occurring on average in an adult person.

Relationship between noise-induced awakening and noise exposure in the case of an isolated noise event

Awakenings may be assessed by a number of methods, including:

- EEG recordings during the sleeping period
- subjects pressing a button after awakening during the sleeping period
- subjects reporting awakening the following morning
- recordings of physical activity by actimeters.

Each of these methods assesses awakening in a different way. Results of recordings by actimeters can be transformed into EEG awakenings by using a conversion rule (Oll92). Bullen *et al.* state that in situations without noise exposure, an EEG typically records 7 to 9 awakenings per night, whereas only one or two awakenings are remembered or are recorded by pushing a button (Bul96). However, other results indicate that the number of EEG awakenings due to noise is approximately equal to the number of remembered awakenings due to noise (Ebe87). In other words, although

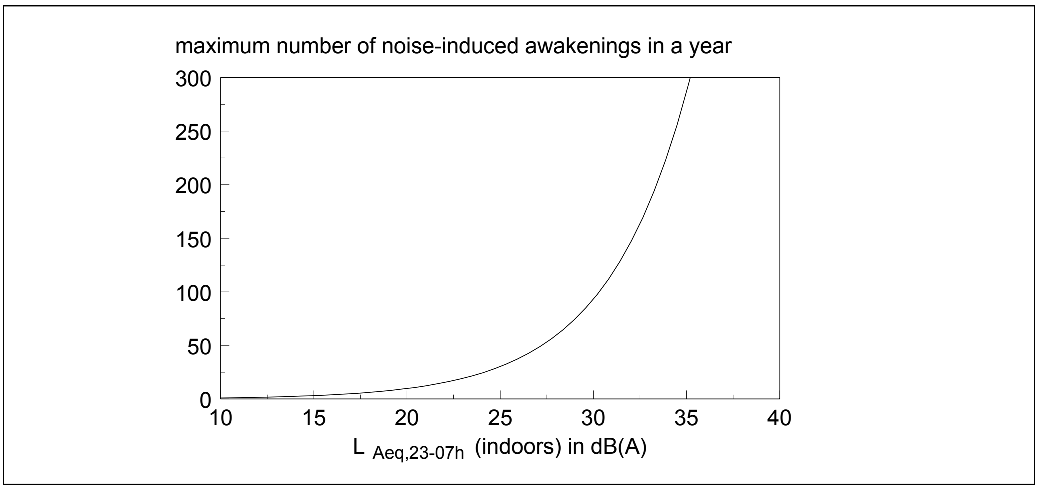

Figure G.3 Estimate of the number of noise-induced awakenings in a year as a function of $L_{Aeq,23\text{-}07h}$ measured indoors. (Outdoor values are approximately 20 dB(A) higher.) The estimate is applicable to situations involving isolated noise events and situations in which residents are usually exposed to the night-time noise source.

most EEG awakenings are not remembered the following morning, those which are caused by a noise event are generally remembered. This result allows data from various studies using different methodologies to be combined, giving greater confidence in the results.

Given a certain level of night-time noise exposure, Pearsons showed that there is a large discrepancy between the percentage of awakenings among subjects tested in laboratory situations and the percentage of awakenings among subjects in field investigations in which residents are exposed for a long time to the specific night-time noises in their bedroom (Pea89). Therefore the Committee only considered field studies in specifying the relationship between noise exposure metrics and noise-induced awakenings, as opposed to the approach in the report by FICON (Federal Interagency Committee on Noise) (FIC92).

The Committee bases its conclusions on several field studies on the relationships between awakening and night-time noise exposure in environmental situations (Fid94, Fid95a, Fid95b, Oll92, Pea89, Pea96). From this information it derived a preliminary relationship between a measure of awakening and a metric for night-time noise exposure consisting of single noise events (an aircraft flying over, the passing of a train or the passing of a truck in a street with a low traffic density). The noise exposure is specified by *SEL*, determined inside the bedroom.* This metric gives a higher

* In research carried out to determine relationships between night-time noise exposure and awakenings, noise exposure is usually expressed by indoor values. In surveys in which annoyance is taken as effect measure, environmental noise exposure is usually expressed in outdoor values. Differences between outdoor and indoor values are dependent upon the sound insulation of the dwelling. Usually a difference of about 20 dB(A) between outdoor and indoor equivalent sound

correlation with measures of awakening than the alternative noise metric $L_{A,max}$ (Fid95a, Pea89). The effect is expressed in percentage of awakenings defined as follows: *x*% awakenings means that if sleeping adult persons are exposed during the night to the noise from one of the 'normal' noise events which is intruding in their bedroom, *x*% of them are awakened by the noise of the event, as determined by EEG recordings. This percentage is an average determined from field studies in which noise events occurred during various periods of the night and in which the exposed people constituted a sample which had not been selected with respect to a special vulnerability for noise-induced awakenings.

The relationship between the percentage of awakenings in an adult person and the *SEL* of an isolated noise event, as derived from the studies referred to above, is given by:

$$P_w = 0.18\ (SEL_{ind} - 55) \text{ for } SEL_{ind} > 55 \text{ dB(A)}$$

in which:

- P_w: the percentage of awakenings, as specified above
- SEL_{ind}: the *SEL* value of a noise event determined in the bedroom.

The relationship is depicted in Figure G.2. The Committee concluded that this relationship represents the current level of knowledge, but that further information is necessary before more definitive relationships and conclusions can be presented.

Relationship between noise-induced awakenings and a noise exposure metric in the case of a series of noise events

If *n* events occur during the night the average percentage of awakenings in an adult person can be estimated from the formula:

$$P_{w,n} = 0.18\Sigma_i(SEL_{ind,i} - 55), \text{ for } SEL_{ind,i} > 55 \text{ dB(A)}$$

in which:

- $P_{w,n}$: the average of the percentages of awakenings due to *n* noise events during a night
- $SEL_{ind,i}$: the *SEL* value determined in the bedroom for noise event *i*.

The definition of $P_{w,n}$ given above can be explained as follows. A percentage of $P_{w,n}=y$ awakenings means that if *z* sleeping adult persons are exposed during the night to the

levels is used to estimate outdoor levels from indoor values.

noise of *n* events which are ‘normal’ in their environment, the total number of awakenings in the *z* persons is ($y \times z$)/100, as determined by EEG recordings.

From this expression relating the percentage awakenings to the noise of isolated noise events during the night-time, the average number of noise-induced awakenings of an adult person during a night can be calculated for any series of events and *SEL* values of these events, provided that any interaction between the various awakenings due to each of the separate events is the same as in the surveys from which the relation between *SEL* and awakenings has been derived. From the various *SEL* values during the night-time, the equivalent sound level during the night can also be calculated (e.g. $L_{Aeq,23\text{-}07h}$). The average number of awakenings of an adult person is not uniquely related to $L_{Aeq,23\text{-}07h}$, but will vary from 0 (all noise events have SEL_{ind} values below 55 dB(A)) up to a maximum which represents the so-called *worst case* situation. This *worst case* situation can be shown to occur if the *SEL* values of the night-time noise events are each equal to 55 + 4.3 = 59.3 dB(A). Any other situation will result in a smaller average number of awakenings in an adult person at the same night-time equivalent sound level.*

In Table G.1 the average of maximum number of noise-induced awakenings in an adult person per night is given as a function of the indoor equivalent sound level over 8 hours.

The last two rows in the table do not represent realistic values, since in the calculations it had to be assumed that the number of isolated night-time noise events would be equal to 107 and 338 events respectively and at the same time that there are no interactions between the various awakenings, which is highly improbable. For 30 dB(A) the number of isolated noise events had to be taken equal to 34.

To estimate the number of night-time awakenings on a yearly basis, the figures in the table should be multiplied by 365 and the maximum number of awakenings in an adult person during an exposure of one year would then become 3, 11, 29 and 95 at indoor equivalent sound levels of, respectively, 15, 20, 25 and 30 dB(A) (see Figure G.3). If the outdoor equivalent sound levels are estimated from the indoor values by adding 20 dB(A) to the indoor values, the calculations indicate that awakenings at an outdoor $L_{Aeq,8h}$ value of 35 dB(A) may occur for a maximum of 3 times a year in an

* The following example is given to illustrate this statement. Suppose the equivalent sound level during the night (8 hours) is equal to an indoor value of 30 dB(A). Such an exposure may consist of 34 SEL values of 59.3 dB(A) each. The average number of noise-induced awakenings per night in an adult person is equal to 0.26: this is the maximum number of noise-induced awakenings in an adult person per night if the indoor equivalent sound level during the night is equal to 30 dB(A) and the exposure consists of isolated noise events. Suppose the night-time exposure consists of 5 events each with a value of SEL equal to 67.6 dB(A) (night-time equivalent sound level over 8 hours again equal to 30 dB(A)) then the average number of noise-induced awakenings in an adult person is equal to 0.11. Another possibility is a SEL value of 56 dB(A), which would need 72 events to give a equivalent sound level of 30 dB(A) during the night. The average number of noise-induced awakenings in an adult person would in this case be 0.13.

adult person and increases up to a maximum of 29 times at an outdoor $L_{Aeq,8h}$ value of 45 dB(A). Figure G.1 shows that sleep-disturbance annoyance starts from outdoor $L_{Aeq,8h}$ values of about 33 to 40 dB(A) for transport noise sources consisting of isolated noise events (aircraft and rail traffic noise). Both results therefore indicate approximately the same outdoor level from which noise-induced night-time noise effects start to occur.

In the derivation of the relations between awakenings and night-time noise exposure, indoor equivalent sound levels have been used to characterize the noise exposure. Research on the sound insulation of dwellings in the Netherlands has shown that this sound insulation is on average about 20 dB(A) for dwellings with windows closed. This average value somewhat depends upon the type of dwelling (apartment, detached house), the quality of the building and on the type of noise source. The value is also only representative for dwellings for which no extra sound insulation measures have been taken. In the relationships presented in Chapter 3, to the relationships specified in this Annex an adjustment of 20 dB(A) has been applied to account for differences between indoors and outdoors equivalent sound levels.

3 Adjustments

In 3.6.2 the Committee considered the application of adjustments for special noise characteristics to specify a noise metric for sleep disturbance. It considers it prudent to provisionally apply these adjustments also in deriving the *ENEL* metric. Therefore, in Chapter 3 these adjustments have been taken into account in the presentation of the relationships as specified in this Annex.

Annex **H**

Stepwise determination of noise metrics

1 Stepwise determination of *EEL*

In this section the steps to be taken to determine the *EEL* in a situation with environmental noise from a noise source are specified.

Step 1: Frequency-weighting of instantaneous values

Use the A-weighting.

Table H.1 Values of *EEL* for aircraft and rail traffic noise as a function of $L_{adjusted,den}$.

$L_{adjusted,den}(x)$ in dB(A)	*EEL* in dB(A)	
	air traffic noise	rail traffic noise
45	48	44
50	54	47
55	60	50
60	64	54
65	70	58.5
70	74	62
75	78.5	66.5

Step 2: Combining instantaneous values and assessing the result for special characteristics

Determine whether it is appropriate to apply adjustments for the following special characteristics:

- low-level non-impulsive industrial noise
- audible tones in the noise
- (highly) impulsive noise components.

To arrive at the equivalent sound level adjusted for these special characteristics during a period *i* of the 24 hour period, first consider the time *s* during which a special noise characteristic prevails within a period *i* and then apply the following formula:

$$L_{Aeq,adj,s} = L_{Aeq,s} + c_j$$

with:

- $L_{Aeq,adj,s}$: the adjusted equivalent sound level during time *s* within period *i*
- $L_{Aeq,s}$: the equivalent sound level during time period *s*
- c_j: the adjustment for special characteristic *j* present during time *s* within period *i*. The values of these adjustments and the methods to determine these values have been specified in F.

During the time (within period *i*) that more than one special characteristic is present, the equivalent sound level is to be adjusted with the highest adjustment value of any of the characteristics present during that time.

The 24-hour daily cycle is divided into three periods: 07.00 to 19.00, 19.00 to 23.00 and 23.00 to 07.00.

To determine the adjusted equivalent sound level for each of these three periods apply the following formula:

$$L_{Aeq,adj,i} = 10\lg 1/t[(s10^{L(s,i)/10} + (t-s)10^{L(t-s,i)/10})]$$

with *t* the duration of period *i*, *s* the time during which the special characteristic is present, *L(s,i)* the adjusted equivalent sound level during time *s* and *L(t-s,i)* the equivalent sound level during time *t-s*. The formula implies that if a special characteristic is present during the total period *i,* the adjustment can be applied to $L_{Aeq,t}$ during that period. If, within period *i,* there is more than one period *s* during which a special characteristic is present in the noise, the formula should be applied with an exponential average of the adjusted equivalent sound levels during each of these times.

If for a period *i* no special noise characteristic is present, $L_{Aeq,adj,i}$ is equal to $L_{Aeq,i}$.

Step 3: Combining (adjusted) equivalent sound levels for parts of the 24-hour daily cycle into a value representative for the whole cycle

$L_{adjusted,den}$ is determined according to:

$$L_{adjusted,den} = 10 \lg 1/T(\textstyle\sum_i t_i 10^{L(x,i)+a(i)/10})$$

with *L(x,i)* equal to $L_{Aeq,adj,i}$ during period *i*, t_i the duration of period *i* in hours, *a(i)* the adjustment factor for period *i* and *T* equal to 24 hours. The values of *a(i)* and t_i are:

- $a(1) = 0$ for day-time and t_1 is equal to 12 hours
- $a(2) = 5$ for evening-time and t_2 is equal to 4 hours
- $a(3) = 10$ for night-time and t_3 is equal to 8 hours.

Step 4: Combining values for daily exposures into a value representative for a year

Determine the exponential average of all 365 $L_{adjusted,den}$ values of a year.

Step 5: Determination of *EEL*

The derivation of *EEL* from $L_{adjusted,den}$ is given as an example. *EEL* is determined by using the formula:

$$EEL = L_{adjusted,den}(x) + x_j\,(x, L_{adjusted,den}(x))$$

with adjustment x_j for source *j*. x_j is dependent upon the noise source and the value of $L_{adjusted,den}(x_j)$ exponentially averaged over a year. The value of x_j is 0 for road traffic noise and stationary noise sources, since for road traffic noise and noise from stationary noise sources *EEL* has been constructed in such a way that it is equal to $L_{adjusted,den}$. For aircraft noise and rail traffic noise *EEL* is given as a function of $L_{adjusted,den}$ in Table H.1.

2 Stepwise determination of *ENEL*

This section specifies the steps to be taken to determine, as far as possible, the *ENEL* in a situation with environmental noise from a noise source.

Step 1: Frequency-weighting of instantaneous values

Use the A-weighting.

Step 2: Combining instantaneous values and assessing the result for special characteristics

Follow step 2, specified in H.1, for the period 23.00-07.00.

Step 4: Combining values for daily noise exposures into a value representative for a year

Determine the exponential average of all the 365 $L_{adjusted,23\text{-}07h}$ values of a year.

Step 5: Determination of *ENEL*

This step can not yet be taken.