INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

34 Meeting of Experts

Noise Immission

Stockholm, Sweden, November 27-28, 2000

Organised by: FFA

Scientific Coordination:

Sven-Erik Thor
FFA, The Aeronautical Research
Institute of Sweden

CONTENTS

INTRODUCTORY NOTE TO IEA EXPERT MEETING ON NOISE IMMISSION

Sten Ljunggren, KTH, Sweden

The wind turbine market is a very international one. Thus, a substantial number of common rules and guidelines have been developed. This is true also for the noise issue: important examples being the recently accepted IEC standard on source strength (noise emission) measurements and the procedure for the declaration and verification of noise data which will soon be published by the Cenelec.

However, on the immission side, that is, the measurement and assessment of noise at receptor locations, less has been done and several important rules and practices differ significantly from country to country. The IEA believes now is an opportune time to assess the current practices in different countries. Therefore, the IEA is arranging an expert meeting on noise immission.

A primary goal of the meeting is to give the participants a good overall view of the current situation. To this end, the expert meeting will welcome participation from parties who have experience in noise measurement and assessment. Experienced noise immission participants should discuss a variety of topics including but not limited to:

A. Form of immission guidelines/limits
- Form of planning guidelines
- Form of final permission
- The problem of acoustical limits for wind turbines with variable rotor speed

B. Formulation of limits in acoustical terms
- Type of acoustic level (equivalent levels or percentiles)
- Reference conditions (8 m/s and/or other wind speeds)
- Use of day, evening and/or night limits
- Weather conditions
- Treatment of wind turbines with variable RPM

C. Calculation formulae for the immission levels
- Treatment of air absorption
- Ground effect
- Topographical effects (influence on sound generation as well as propagation)
- Certification of prediction methods

D. Experiences from immission measurements (does the IEA document need a revision?)

E. Consequences in cases of limit violation

Correction of source strength

$$L_{WA,corr} = L_{WA,std} + k \cdot \Delta v_h$$

where

$L_{WA,std}$ is the standardised sound power level (IEC)

k is the dependence of L_{WA} on wind speed (at 10 m height) in dB/m/s

Δv_h is calculated according to

$$\Delta v_h = v_h\left(\frac{\ln(H/z_o)}{\ln(h/z_o)} \cdot \frac{\ln(h/0{,}05)}{\ln(H/0{,}05)} - 1\right)$$

where

H is the hub height in m

h is 10 m

z_0 the roughness length in m.

Sound propagation over land

The sound level, L_A, is calculated as

$$L_A = L_{WA,korr} - 8 - 20 \cdot \log(r) - 0{,}005 \cdot r$$

where

r is the distance from the immission point to the wind turbine hub,
$r < 1000$ m

Sound propagation over water

The sound level, L_A is calculated as

$$L_A = L_{WA,korr} - 8 - 20 \cdot \log(r) + \Delta L_a + 10 \cdot \log(r/200),$$

where

$$\Delta L_a = 10 \cdot \log(\Sigma 10^{(L_i + A_i)/10}) - 10 \cdot \log(\Sigma 10^{(L_i + A_i - r \cdot a_i)/10})$$

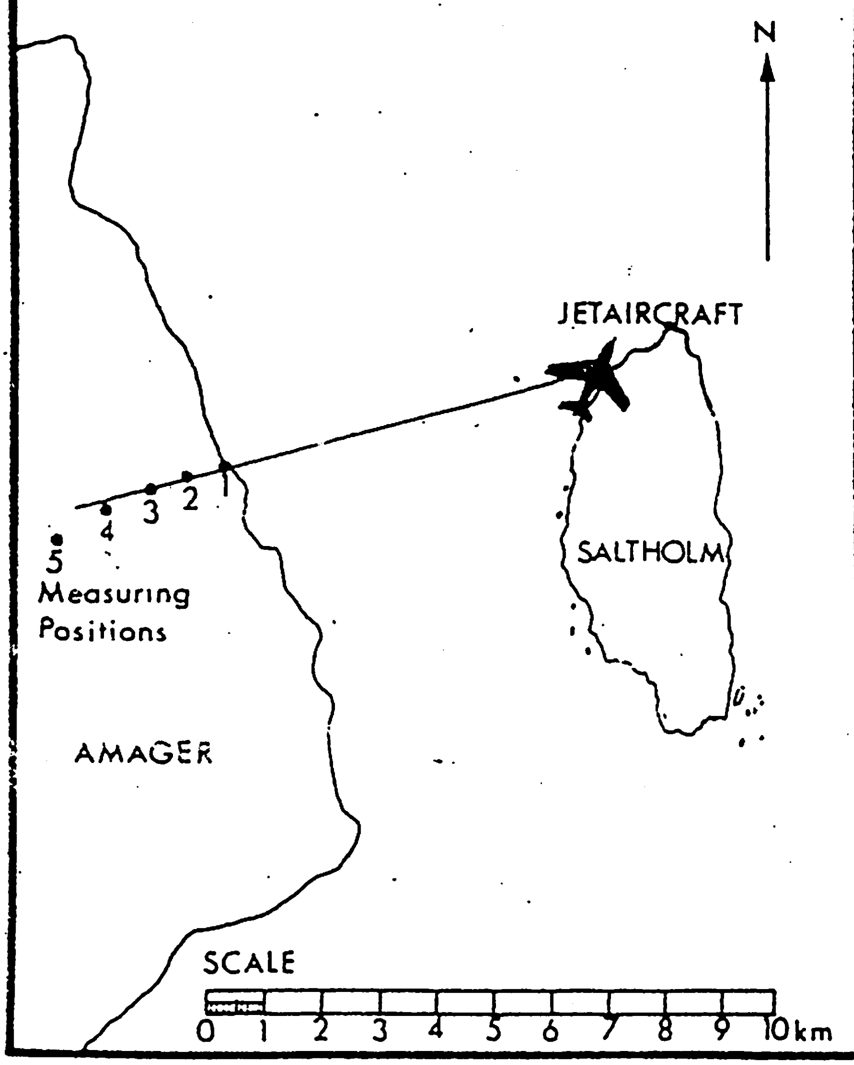
and

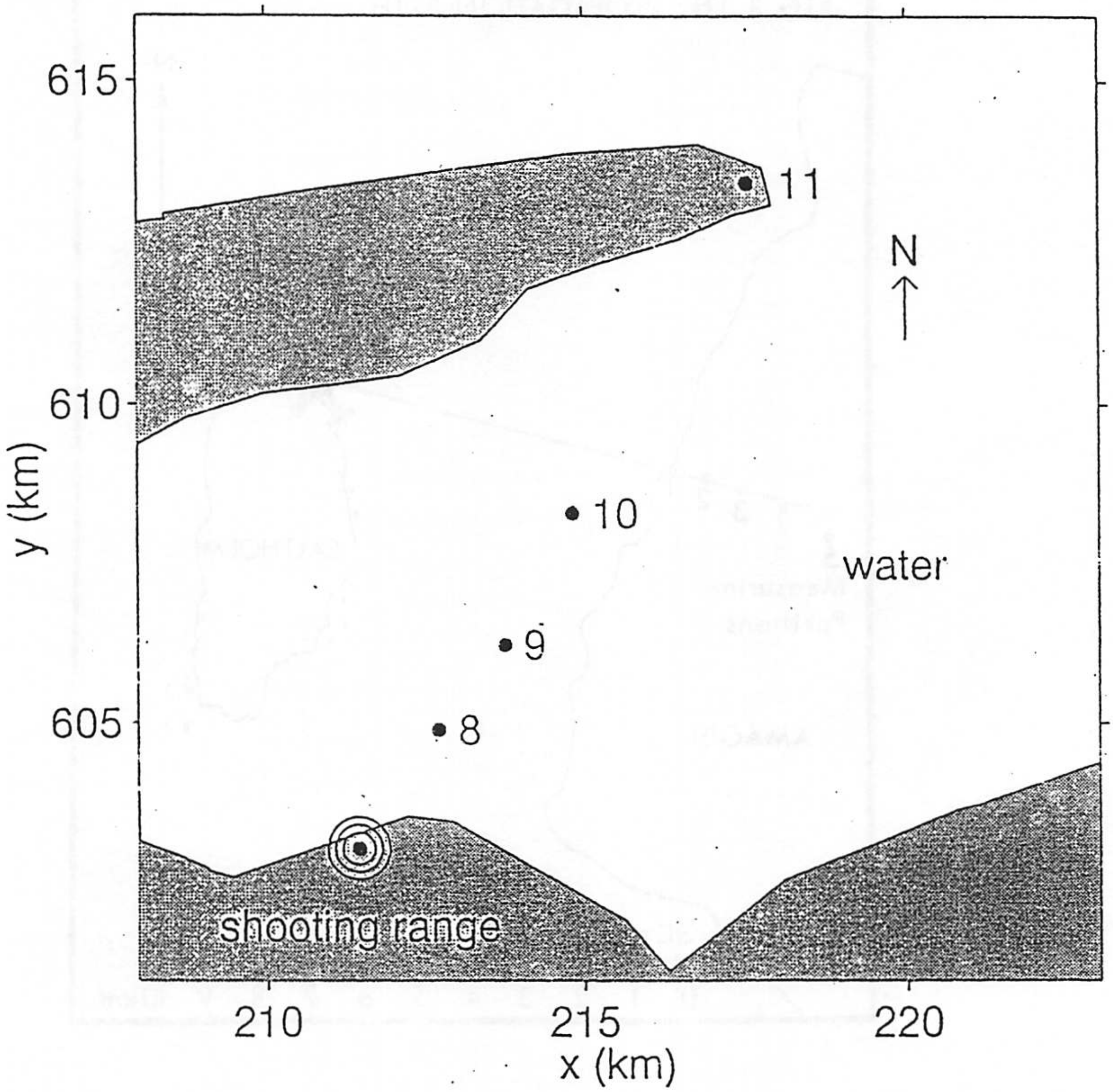
Li are the octave band levels of the sound power

Ai is the A-weigthing

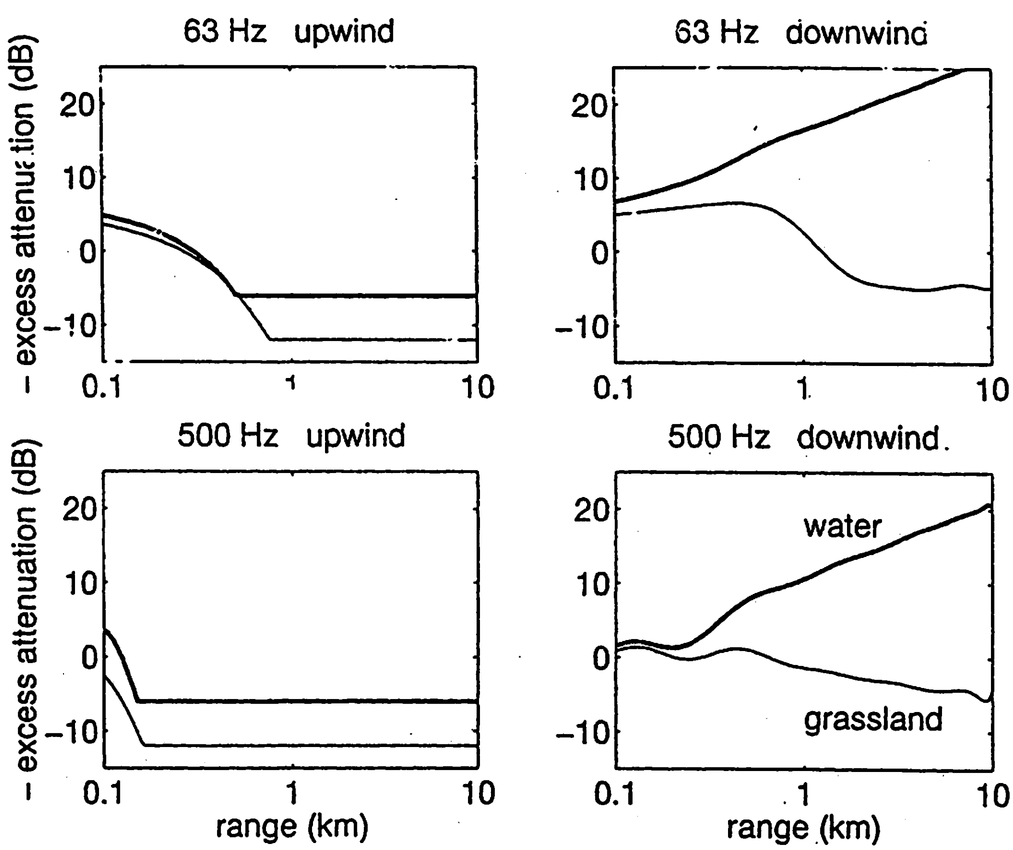
ai is the air absorption according to Conny Larsson

FIG. 3 THE PROPAGATION PATH

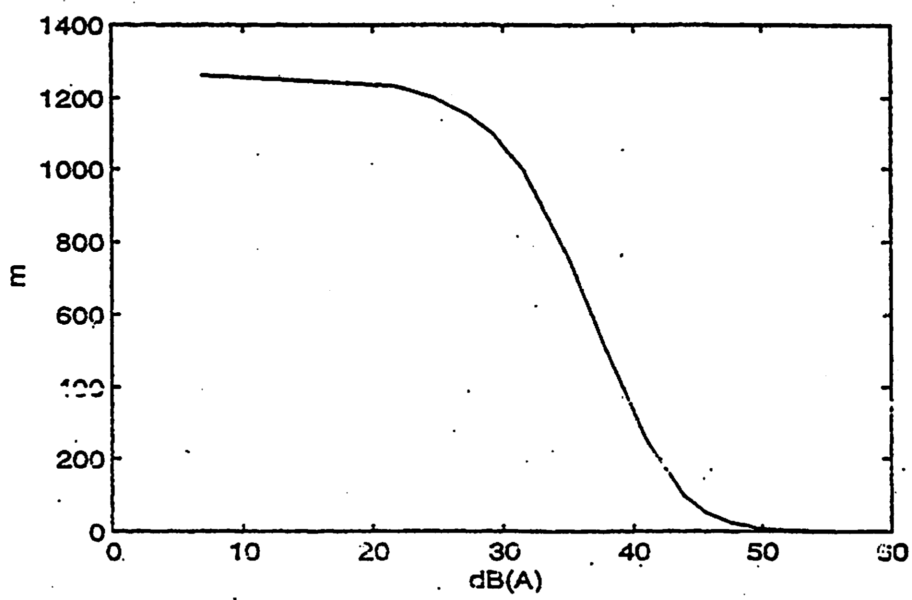




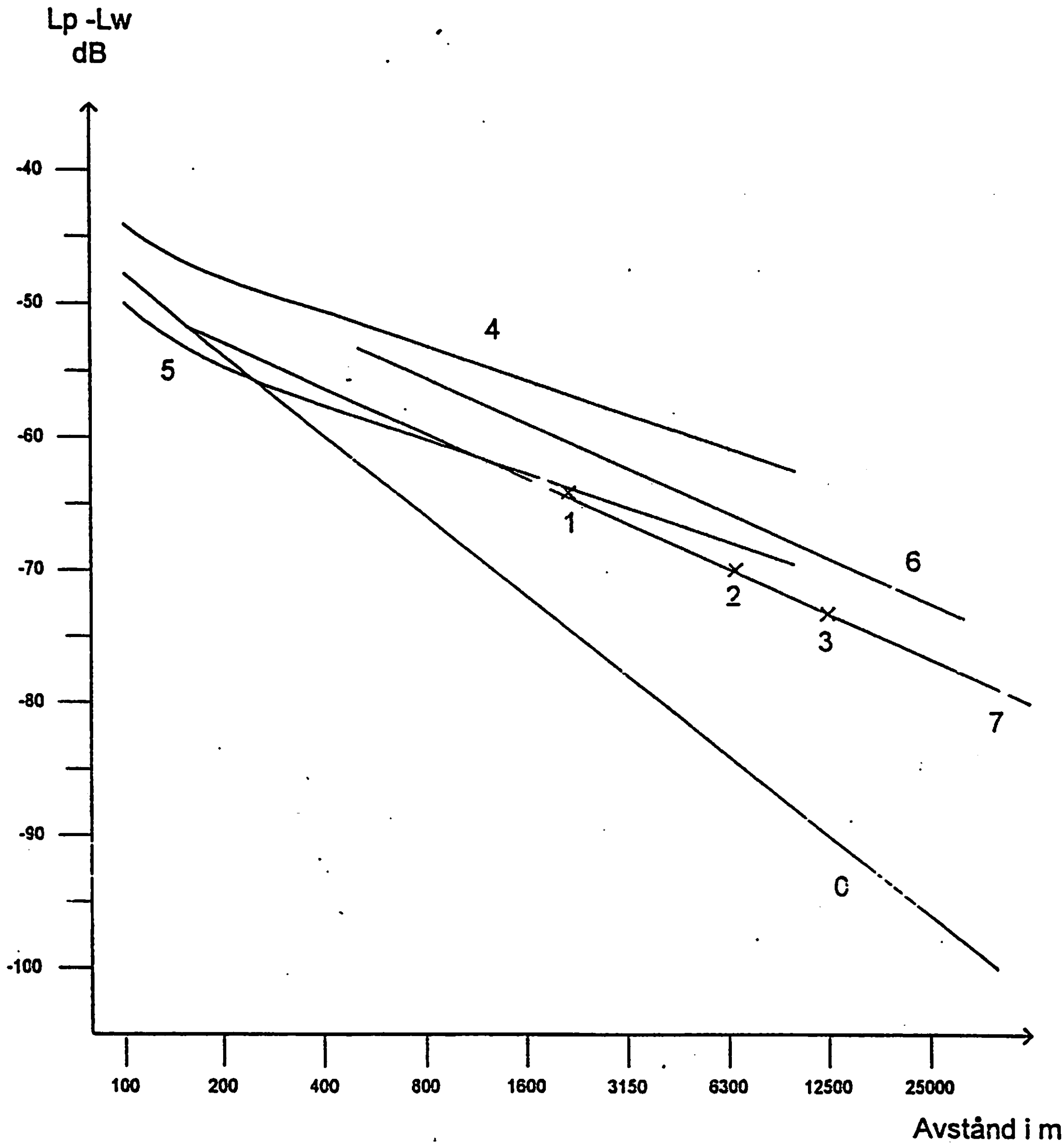
Figur 5. Mätplatsernas läge i TNOs undersökning.



Figur 6. Beräknade data på ljudets spridning kring en punktkälla placerad nära marken. Angivna data avser spridningen relativt sfärisk spridning. Från Referens [7].



1400
1200
1000
800
600
200
0
m
0
10
20
30
40
50
dB(A)



0 Halvsfärisk spridning
1 FFA, mätning
2 DTH, mätning
3 TNO, mätning
4 TNO, 63 Hz, teori
5 TNO, 500 Hz, teori
6 KTH1, teori
7 KTH2, teori

Regulations on wind turbine noise in Norway

IEA-Wind Noise Immission meeting 27-28.11.00
sigurd.solberg@kilde-akustikk.no

Norwegian authorities NVE (Norwegian Waterfall and Energy Directorate) and SFT (National Pollution Agency) have adopted the general noise criteria for industrial noise to cover wind turbine noise. The basis is the night regulation for dwellings, at equivalent noise level 40 dBA for the usual reference operation condition of the turbine: 8 m/s at 10m. In case of a "wind shadow" situation (receiver point in a valley, exposed to low wind induced background noise) or audible pure tones, the criterion has been tightened to 37 dBA.

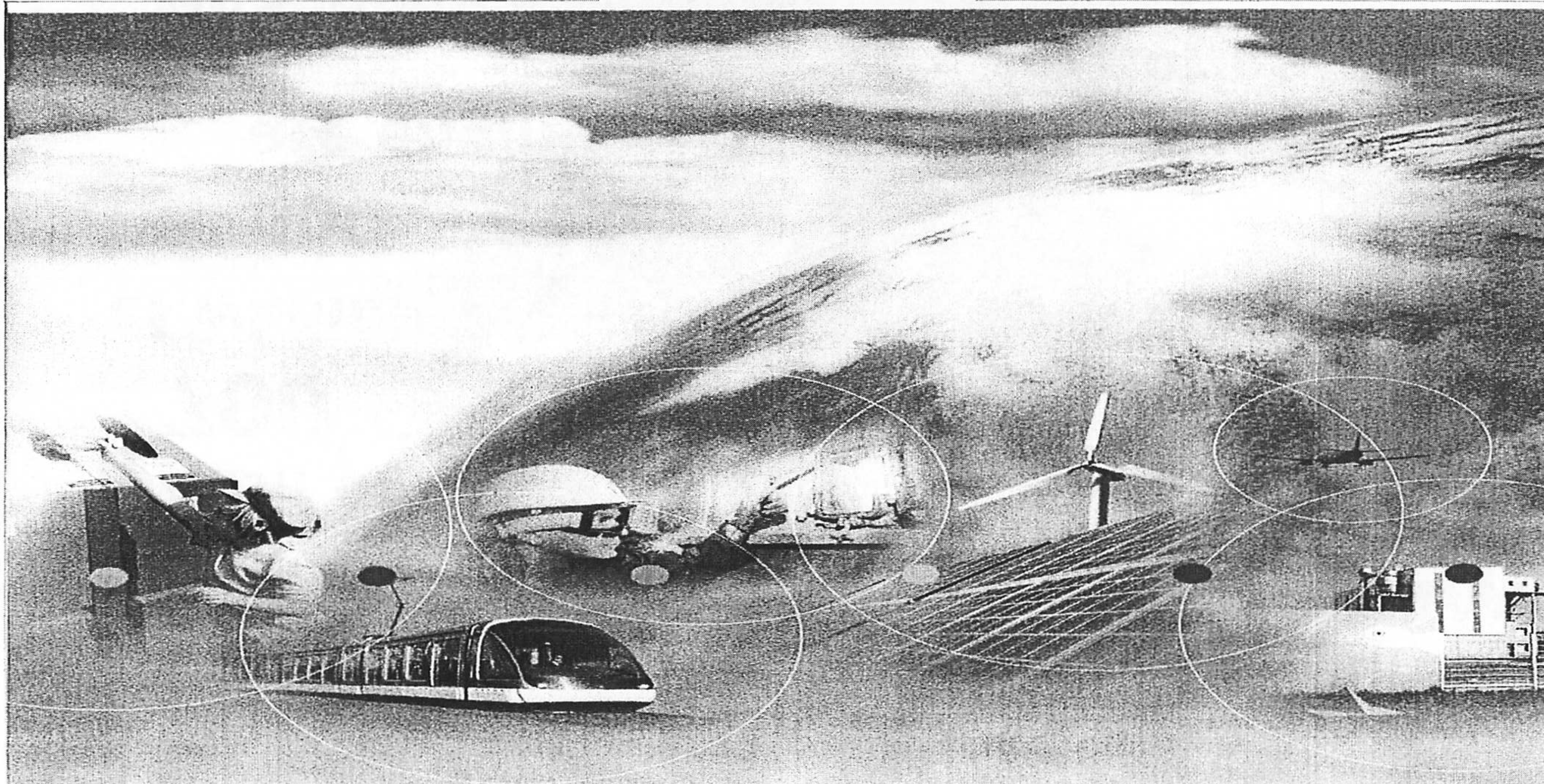
If the calculated noise immission from a wind farm is above 37 dBA at the nearest dwelling or holiday home, a noise report has to be made. How detailed this report must be, is dependent on the situation. At the moment there are no fixed requirements related to the quality of noise emission data or type of control measurements.

At the moment, only 13 MW of wind turbine power is installed in Norway, but actual projects comprise about 900 MW (mostly in parks of 40-160 MW). Most of the installations are planned in coastal or mountain areas, where noise exposure of dwellings is not considered to be an important problem.

French Agency For Environment and Energy Management

ADEME

Presentation



Key figures

A staff of
700
of whom
400
are engineers

Management of
more than
407 MXEU
per year for
incentives

26
regional
branch offices

3 overseas
territories
offices

1 office in
Brussels

ADEME

ADEME 's areas of activity

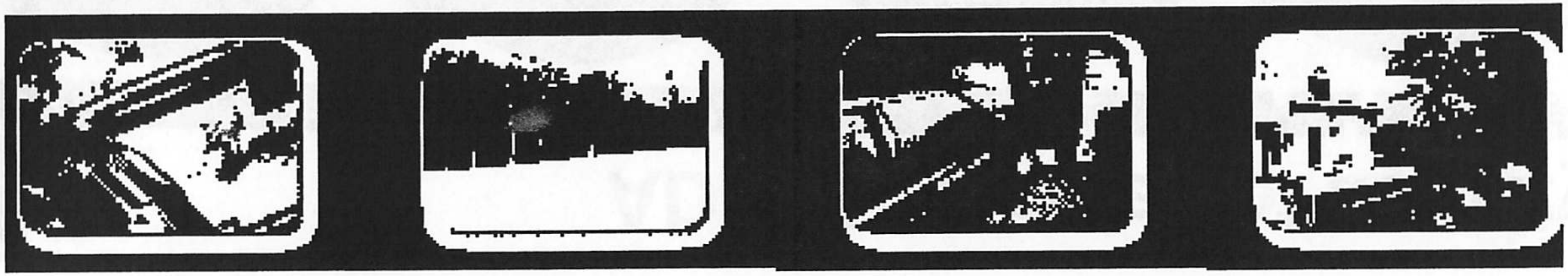
- Protecting air quality
- Reducing the quantity of wastes
- Managing energy
- Developing environmental management
- Rehabilitating polluted sites
- Encouraging use of renewable energy sources
- Reducing noise

ADEME

3 priorities for sustainable development
3 main lines of progress

- **3 priorities:**
  - Developing a **waste economy** with high environment quality
  - Reducing **air pollution**
  - Committing long-term efforts to **energy management**

- **3 main lines:**
  - **Creating** new alliances
  - **Promoting** best practices
  - **Committing** itself to results



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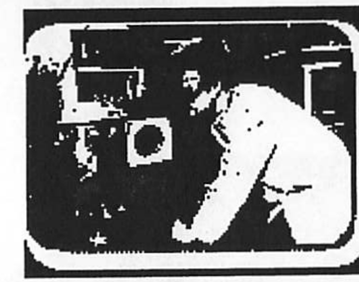
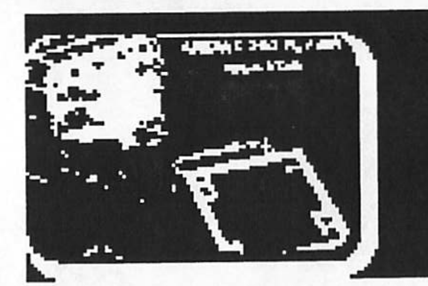
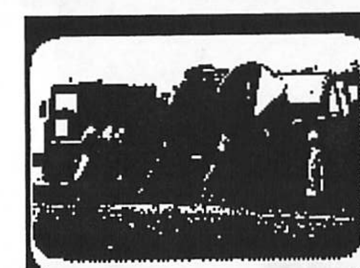
Areas of expertise



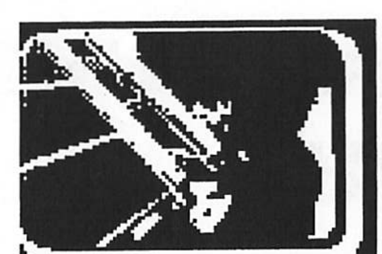


- **Encouraging** research and development:
  - wind turbines
  - photovoltaïc systems and components
  - bio-fuels and bio-materials
  - hot dry rock source (geothermal energy)



- **Providing** advice for decision support

- **Disseminating** best practices



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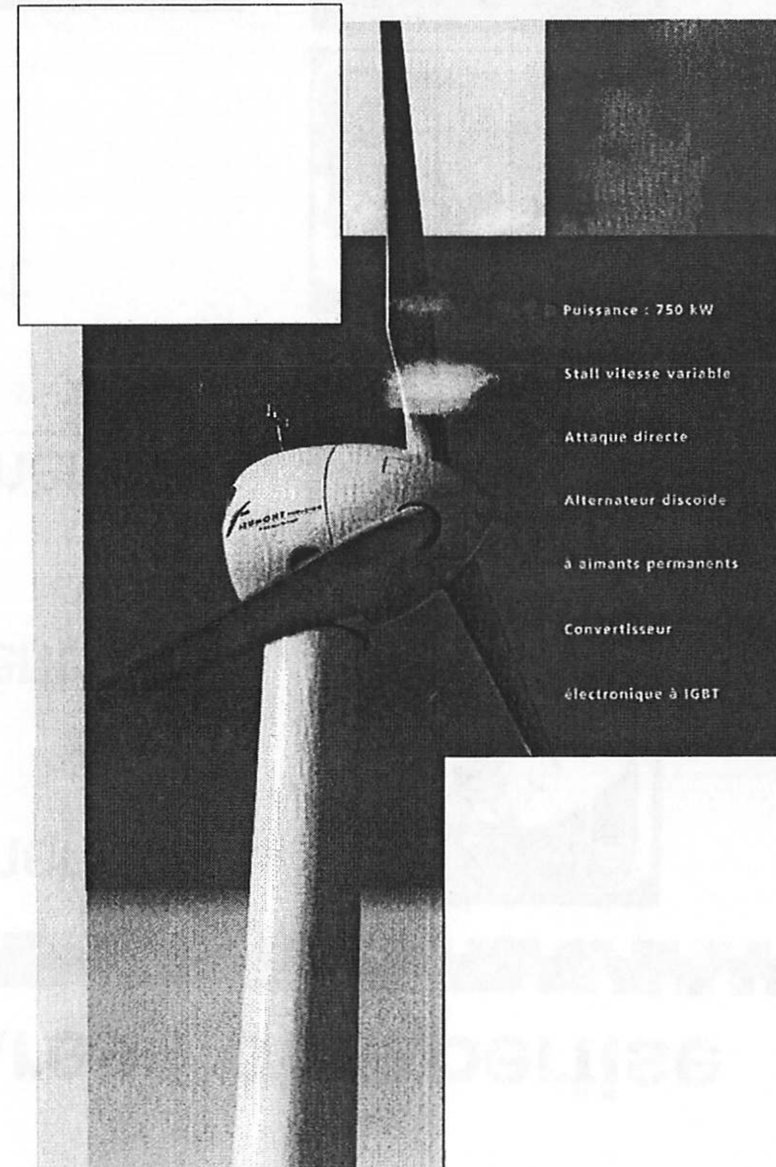
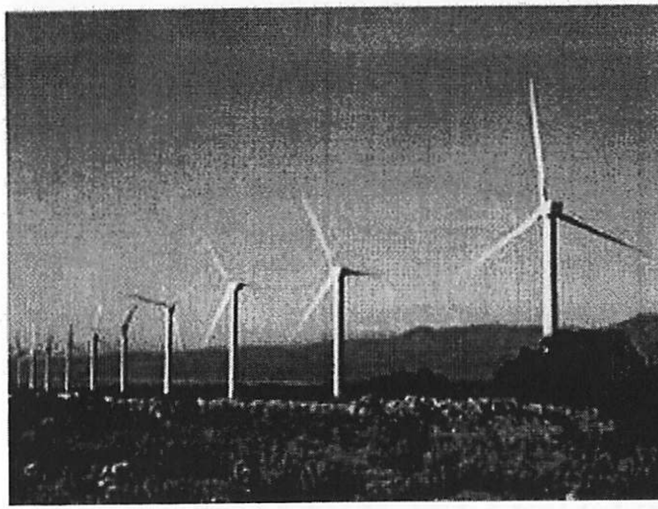
R&D support

- 3 main topics have been identified:
  - **Wind assessment** provided by advanced software:
    - topological aspects to take care in the South
  - **Research and development of wind turbines** and their components:
    - Large machine (Jeumont Industrie) - Small (Vergnet)
  - **Accompanying studies:**
    - ToTem (Addition of wind energy measured): collecting all data about the production of the wind farms installed in France)





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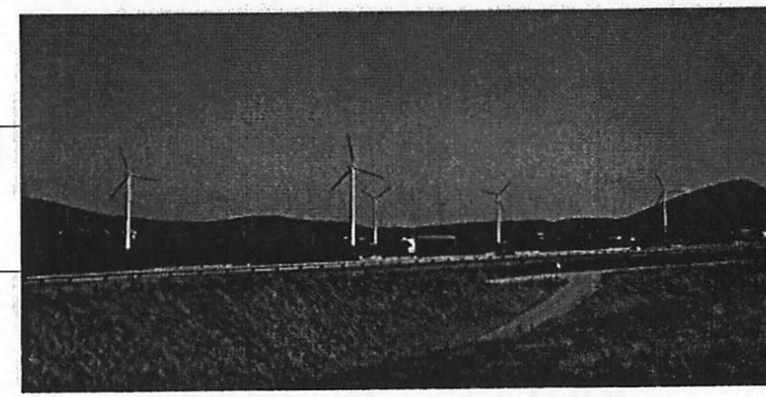
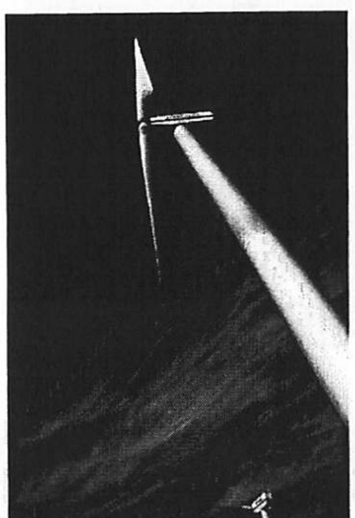
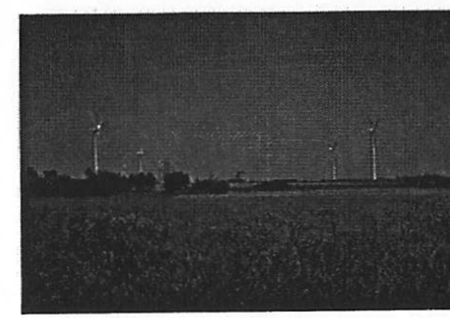


Development of Wind Energy in France
State of the art





Dr Pascal BERLU
R&D wind energy program manager
Renewable Energy Department
ADEME - France

ADEME

National context of the electric market

- Energy policy essentially based on nuclear power stations and large hydro
- For many years, only one major public utility for the electricity production and distribution, EDF
- EDF have to purchase electricity coming from independent producers in the case of a rated power installed less than 8 MW (2,57cXEU/kWh in summer, 6,41 cXEU/kWh in winter)
- On 10 February 2000 opening of the electricity market (UE resolution)

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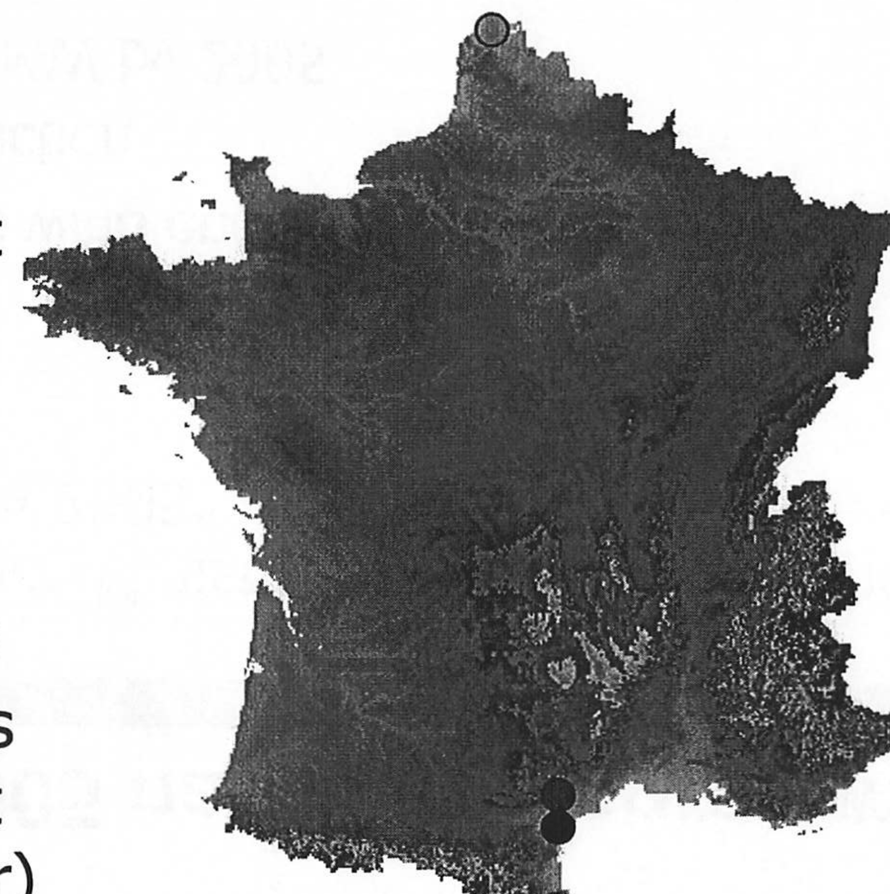
First steps

France has the 2nd wind energy potential in Europe: 66 TWh/year offshore (10 km - 10 m depth) 97 TWh/year onshore

- 3 leading installations:
  - **1993**: Port-la-Nouvelle (Aude) in the Southwest (4x500 kW + 200 kW Vestas)
  - **1996**: Canal des Dunes (Nord) in the north (9x300 kW Windmaster)
  - **1998** : Sallèles-Limousis (Aude) in the Southwest (10x750 kW Windmaster)



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Eole 2005 national programme

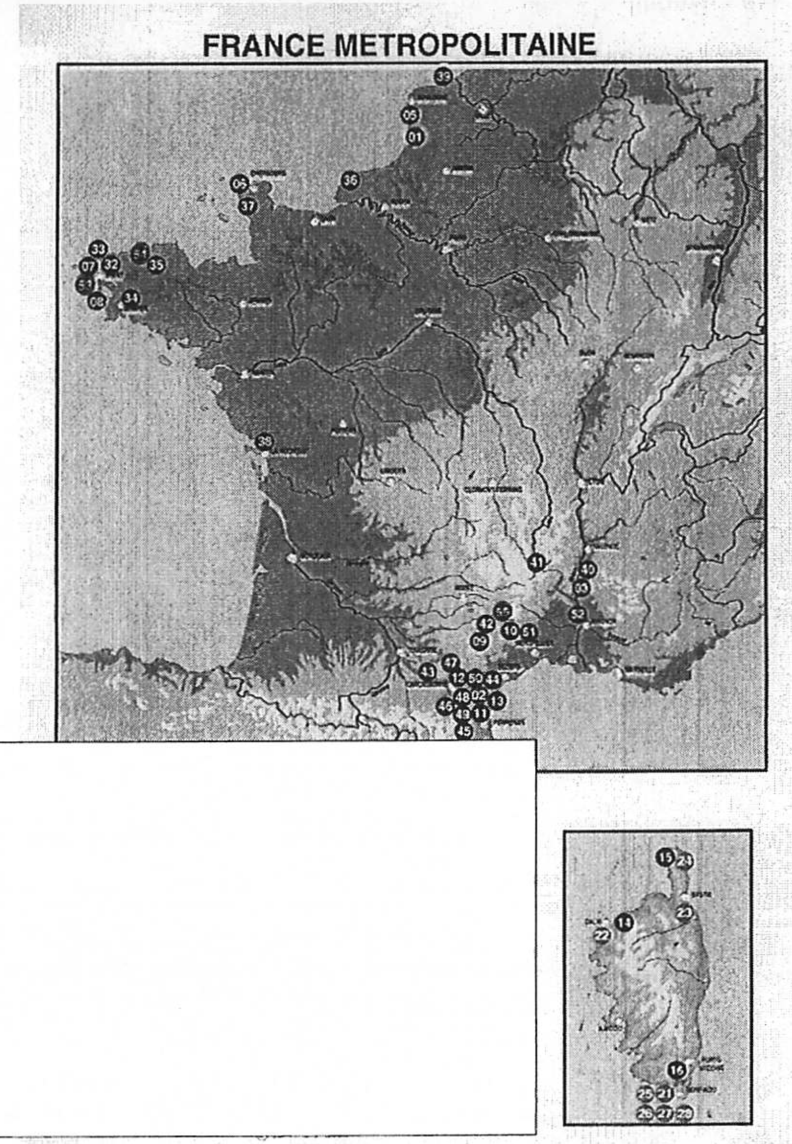
- On 6 February 1996 the French Ministry for Industry launched the national programme "Eole 2005"

- Objectives:
  - To prepare France to use its wind energy resource
  - To diversify electricity production
  - To install between 250-500 MW by 2005
  - To create a new industrial activity

- EDF ran the programme which was launching a series of invitations to tender for private wind-powered electricity producers

Eole 2005 results
Toward an new programme

- 55 projects selected representing 360 MW
- About 48 MW will be installed at the end of the 2000 year (60 MW in overall with the non-Eole2005 installations)
- Eole 2005 has been officially stopped since 10th February 2000
- Works are in process to define a new programme by 2010:
  - fixed tariffs
  - 3 000 - 10 000 MW



Noise & Wind energy in France

Pascal Berlu - ADEME

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Paul Neau - Abies

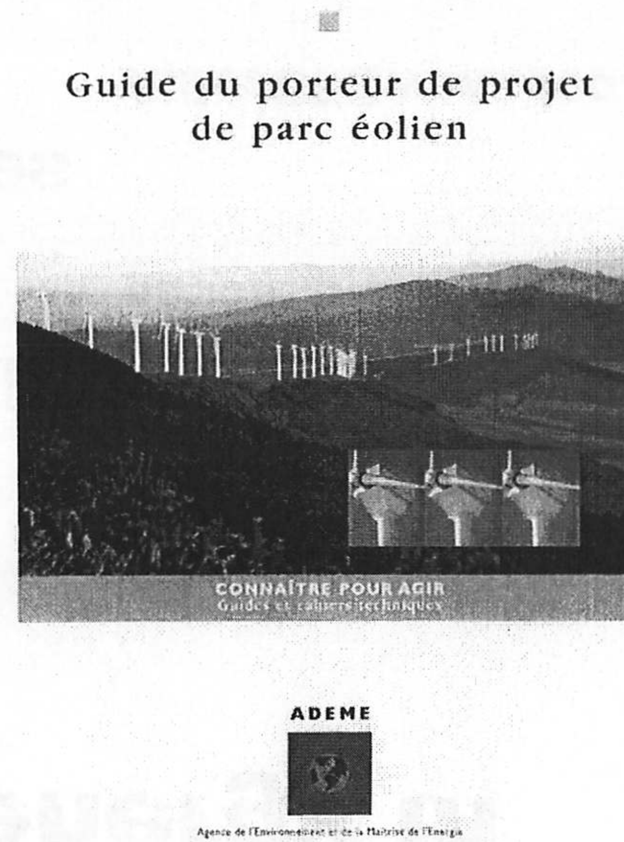
AbiesBE@wanadoo.fr

René Gamba - Acoustique Gamba

gamba@easynet.fr

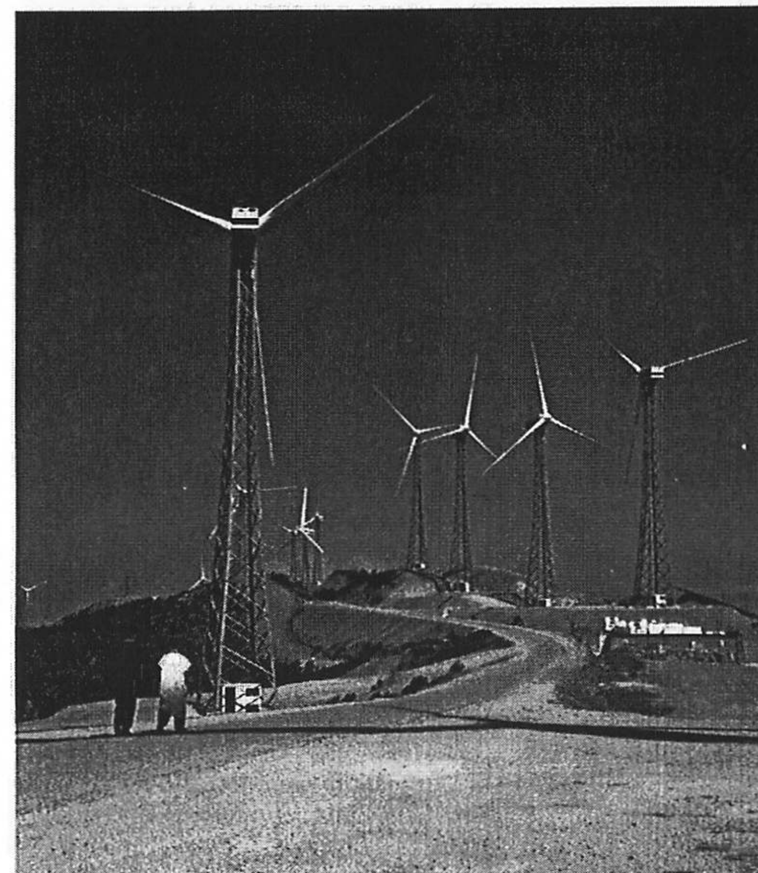
Abies

- Private office (3 persons)
- Wind energy & the environment
- Bird monitoring of Port-la-Nouvelle wind farm
- Guide for developers of wind farms
- Airplanes & wind turbines



Abies

- Environmental Impact Study for « la Compagnie du Vent »:
  - Koudia Al Baïda (Morocco) wind farm: 50.4 MW;
  - 8 French wind farms: 46 MW studied, 10 MW achieved.



Wind energy in France

- Some figures about wind energy in France:
  - End of 1996: 10 MW installed
  - 1st november 1999: 59 MW installed
  - 2005 → 350 MW selected
  - 2010 → 3 000 or 10 000 MW

Environmental Impact Study

- The 3 objectives of an EIS are:
  - to protect the environment (give information to the developer about constraints and sensitivity of the site);
  - to help the developer to design a good wind farm regarding natural and human environments;
  - to give information to the planning authorities (and to the public in case of public enquiry).

Environmental Impact Study

- Example of the content of an EIS:
  - summary;
  - description of the site environnement;
  - description of the project and the reasons of the choices;
  - analysis of the impacts;
  - environmental measures to reduce or compensate the impacts;
  - effects on health;
  - scientific problems encountered.

Noise regulation

- Neighbour noise regulation ;
- Margin above background (noise emergence);
- 3 dB(A) for night-time; 5 dB(A) for daytime;
- No absolute noise limits ;
- Noise measurements: wind speed <5 m/s.

Noise regulation

- Environment Ministry recommandation of a 500 m buffer zone.

First step

- Measurement of noise level.

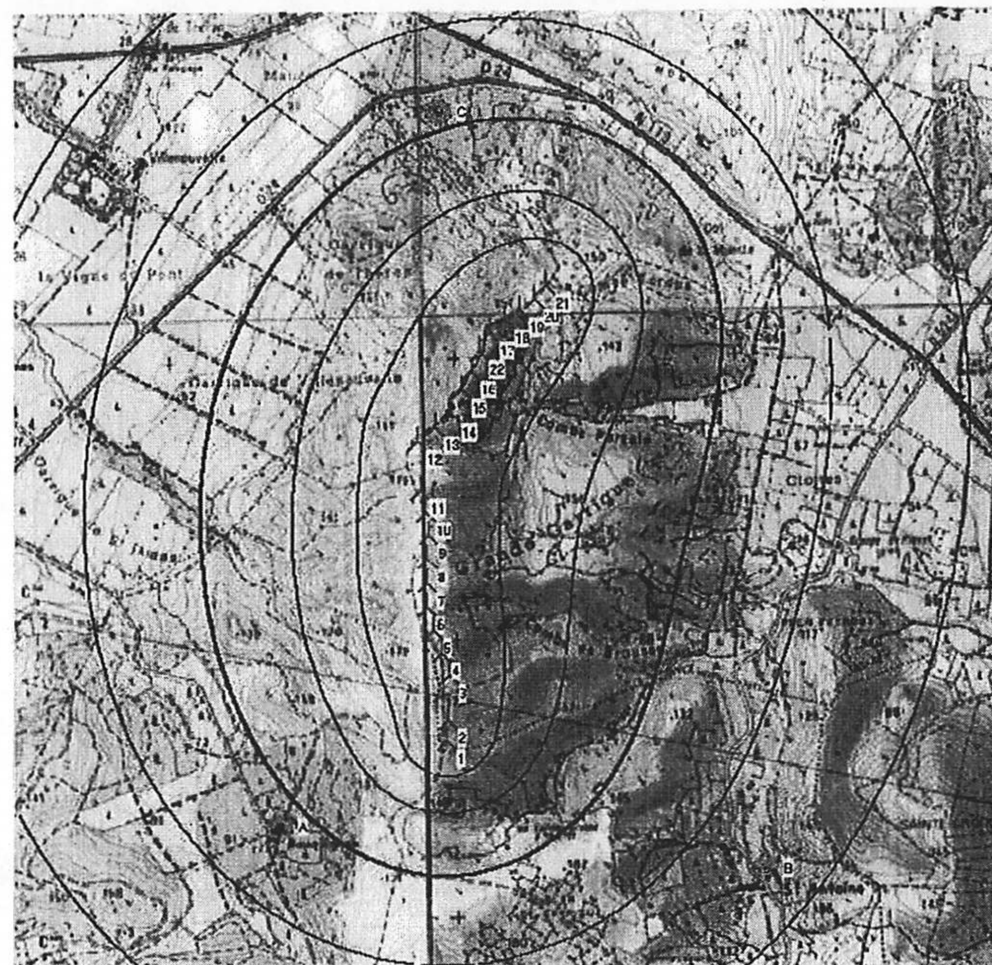
First step

Some results:

	Low wind speed	Moderate wind speed	
Point 1	51 dB(A)	47,5 dB(A)	Downstream
Point 2	41,7 dB(A)	36 dB(A)	Downstream
Point 3	38,9 dB(A)	44,5 dB(A)	Upstream
Point 4	33 dB(A)	34 dB(A)	Upstream

Second step

Diagnosis of sensitivity: example of a noise simulation.



Acoustique GAMBA et Associés

RESEARCH & DEVELOPMENT

SOFTWARES :

- **-AcouS PROPA**
- **-AcouS STIFF ®**
- **-AcouS STRIKE ®**
- **-DIAG Lexd ®**

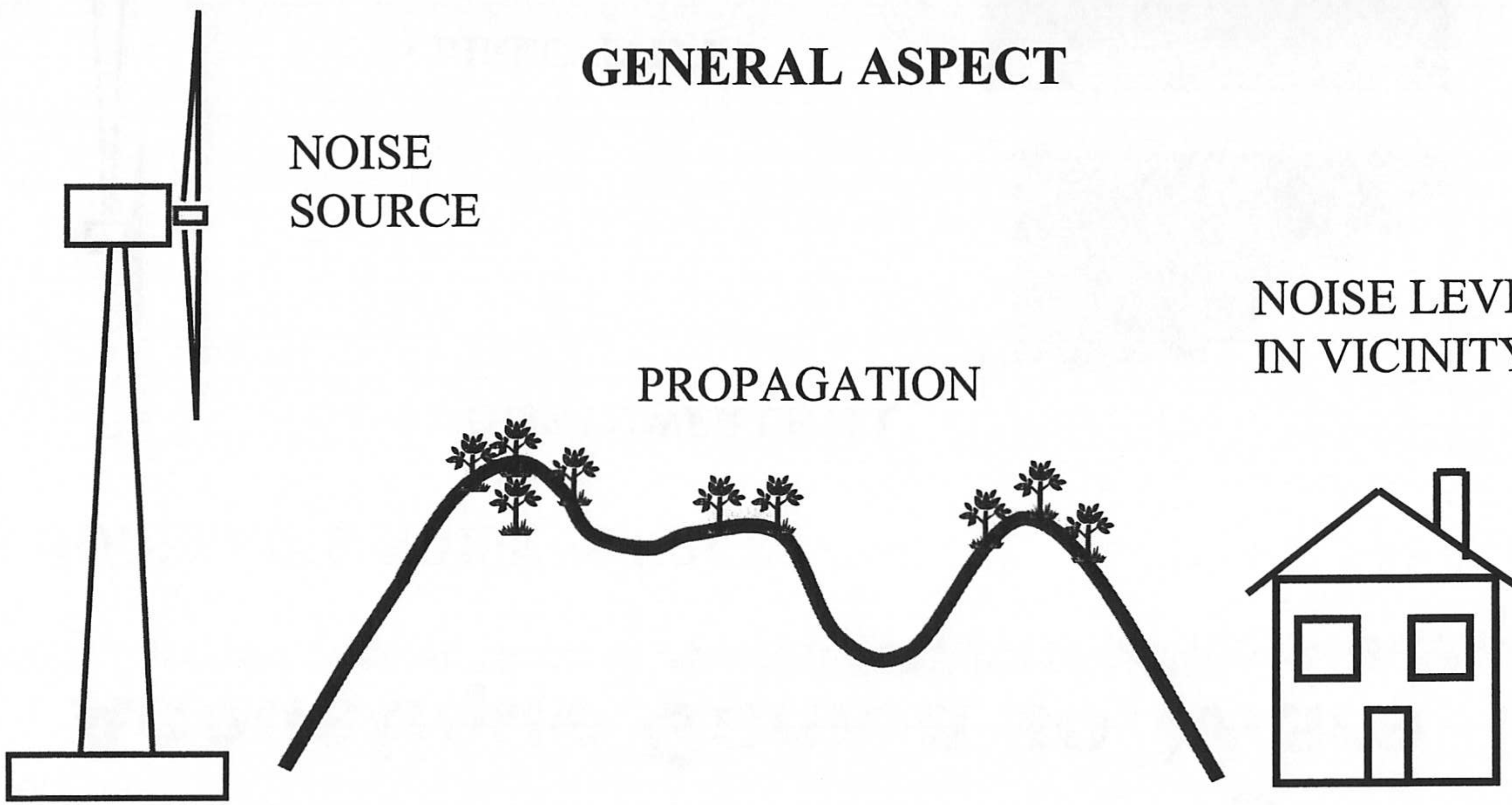
ENGINEERING

- **- ENVIRONMENT**
- **- BUILDING**
- **- WORKPLACE**

TRAINING

Detailed simulation using Acoustique Gamba software

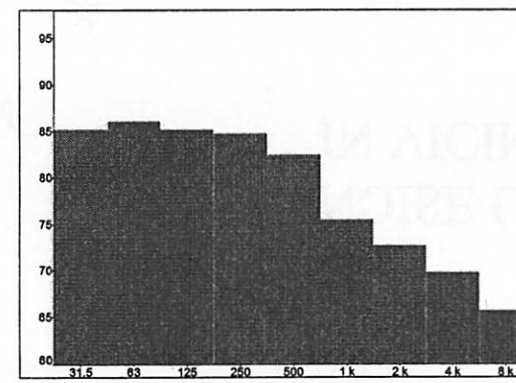
GENERAL ASPECT



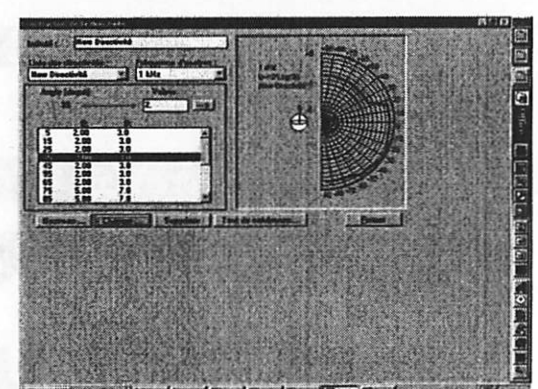
Detailed simulation using Acoustique Gamba software

- MODELLING NOISE SOURCE

• NOISE POWER LEVEL

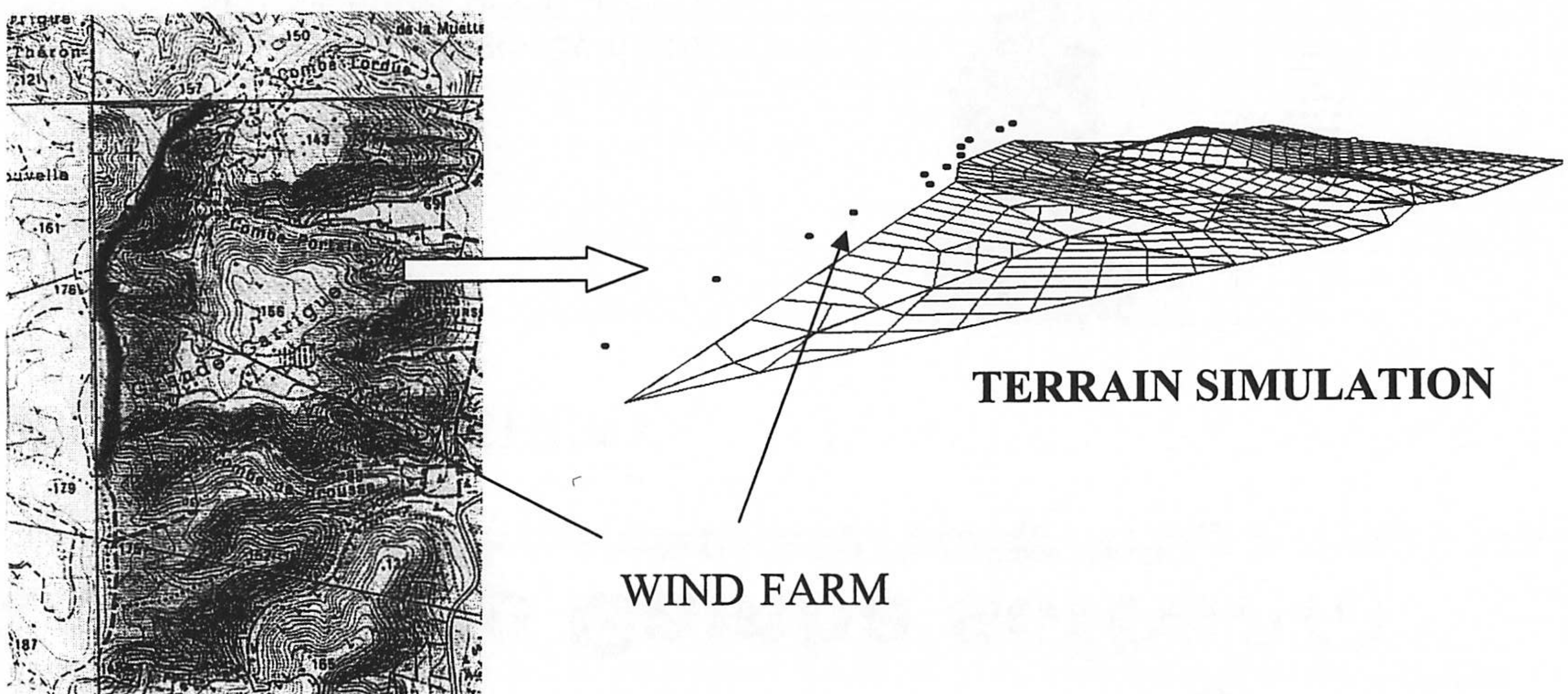


• DIRECTIVITY



Detailed simulation using Acoustique Gamba software

- MODELLING PROPAGATION



Detailed simulation using Acoustique Gamba software

- NOISE LEVEL IN VICINITY

NOISE MAP :

Predicted noise levels in the vicinity of wind farm

Problems encountered

- Conditions of noise measurements : wind speed, noise measurements with wind ;
- Low noise margin above background for night-time, which means high constraint for quiet regions (countryside) ;

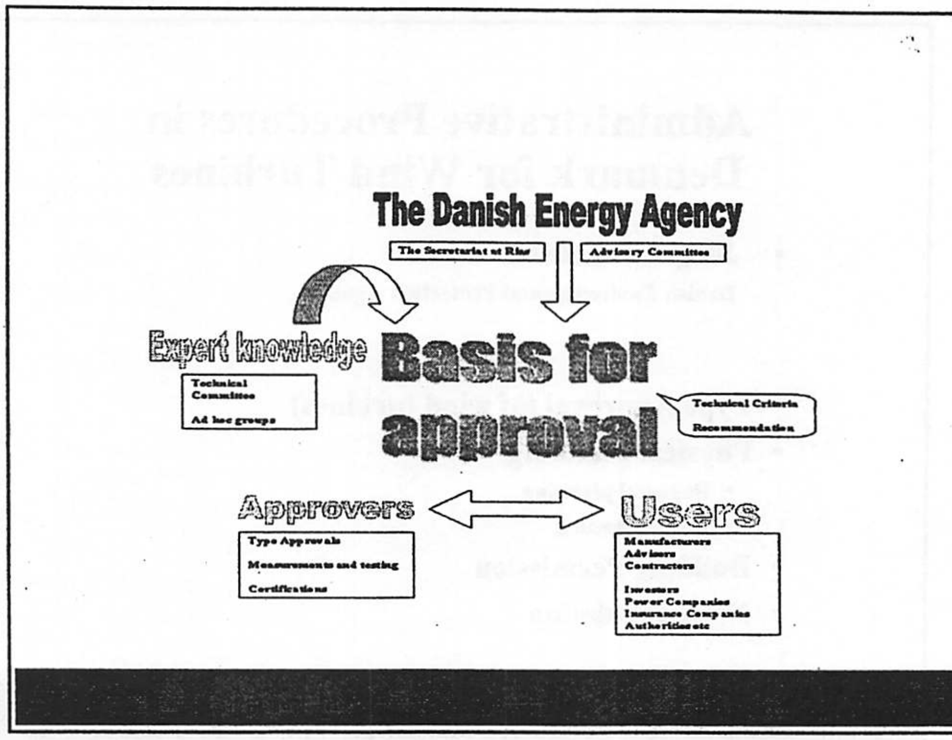
Administrative Procedures in Denmark for Wind Turbines

- **Jørgen Jakobsen**
  Danish Environmental Protection Agency

- **Type Approval (of wind turbines)**
- **Physical Planning**
  - **Regional planning**
  - **Local planning**
- **Building Permission**
- **Noise regulation**

Type Approval for Wind Turbines

- **Type approval is a condition for erection and connection to the utility**
- **Criteria for safety and quality**
- **Technical criteria issued by the Danish Energy Agency (www.ens.dk)**
- **Type approval report shall inform on noise emission**


The Danish Energy Agency
The Secretariat at Risø
Advisory Committee
Expert knowledge
Technical Committee
Ad hoc groups
Basis for approval
Technical Criteria
Recommendation
Approvers
Type Approvals
Measurements and testing
Certifications
Users
Manufacturers
Advisors
Contractors
Investors
Power Companies
Insurance Companies
Authorities etc

Physical Planning for Wind Turbines

- Government Circular (no. 100 of 10. June 1999) gives the Regions the possibility to locate wind turbines in Region Planning. And specifies the rules to follow in the planning.
- Rules for Environmental Impact Assessment of certain installation (groups > four, height > 80m and in 'certain cases')
- Local plans (by the Municipalities) shall be in accordance with Region Planning

Building Permission for Wind Turbines

- Granted by the Municipalities.
- Usually a reference to type approval is sufficient.
- Critereia for height / distance to property

Noise Regulation of Wind Turbines

- Statutory Order no. 304 of 14. May 1991
- Regional authorities are notified and informed of assumed noise impact
- Objection can be made within four weeks

- Noise level must not exceed 45 dB at individual dwellings / 40 dB in residential areas.
- Noise level is calculated assuming 8 m/s wind speed, reflecting ground (formula given).
- Control also applies calculated noise level.

Measurement of Wind Turbine Noise

- Annex to Statutory Order, precursor of IEC method
- Noise level measured on the ground, simultaneously with wind speed, 10 m
- Reference noise level determined at 8 m/s
- Simple calculation scheme for noise at neighbouring residences
- Penalty for clearly audible tones (at neighbouring residences)

Wind energy and environmental legislation in the Netherlands
The (problematic) aspect of noise

Hans Geleijns

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Consulting engineers
Noise control, environmental control, building physics and acoustics

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The Netherlands

Summary and introduction

Many noise assessment problems in the Netherlands are still arising due to the increased use of wind turbines in energy conversion. Dutch law and jurisdiction still states that, when assessing industries, a connection must be made with the sound level of the surroundings. In the case of windfarms this noise is mainly generated by buildings and trees and depends on wind velocity. But the coming amendments to the Environmental Act that subsequently apply will drastically change all this and will create more (noise) space for wind energy in the Netherlands. The basic (acoustical) principles, advantages and disadvantages of the new legislation will be scrutinised in this presentation.

Lichtveld Buis & Partners BV

Content

- Summary/preamble/introduction
- The principles and starting points of environmental legislation (Environmental Management Act)
- New Act 2001+
- Opportunities and obstacles
- Conclusions

Lichtveld Buis & Partners BV

LBP

- Located in Utrecht, The Netherlands
- Founded in 1970
- Quality above quantity
- Continued growth
- Now approx. 35 employees

Website: www.lbp.nl

Lichtveld Buis & Partners BV

Well-mixed team

- Environmental engineers
- Environmental lawyer
- Acoustical engineers
- Architectural engineers
- Mechanical engineers
- Physicists
- General services

Lichtveld Buis & Partners BV

Disciplines

- Environmental control (research, licences, procedures, legislation)
- Industrial noise (large and small industries)
- Traffic noise
- Architectural and Electro acoustics
- Building physics (interior climate)
- Working conditions

Lichtveld Buis & Partners BV

Specific consultancy wind turbines

- Technical environmental matters (including acoustics) and procedures
- Legal (legal proceedings including Council of State)
- National research on wind turbines and noise and amending environmental legislation
- Drawing up new legislation (AMvB)

LBP Lichtveld Buis & Partners BV

Specific consultancy wind turbines

- "Wind energy and environmental legislation. Preliminary research on AMvB Decree on wind turbines and environmental management" dated 14 November 1996
- "Noise standards for wind turbine noise regarding AMvB. Measuring noise and wind velocity. "Technical report dated 18 August 1998 (NOVEM)
- "Noise standards for wind turbine noise. Measuring noise and wind velocity" Main report dated 14 February 1999 (NOVEM)

LBP Lichtveld Buis & Partners BV

The principles and starting points of the environmental legislation and AMvB

Environmental legislation

- Protecting the environment
  - whether to give new companies the go-ahead
  - meeting environmental regulations (relevant environmental aspects)
  - in principle, locally determined, locally authorised municipalities (700)

LBP Lichtveld Buis & Partners BV

The principles ..

- Licence duty and AMvB
  - Licence duty
    - customised
    - lengthy, convoluted procedures
    - large local differences
  - AMvB
    - national, equal treatment
    - short procedures with no participation

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The principles

- Environmental aspect of noise
  - disturbance in surroundings (environmental damage factor out)
  - direct linking to the background noise (surroundings)
  - emission and immission
    - **Noise levels outer wall**
    - **Noise levels interior**

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The principles ..

- Directives and manuals
  - Manual for Measuring and Calculating Industrial Noise (HMRI)
  - Assistance for judging the noise-effects (standards e.g.)

Wind turbines:

'special treatment concerning noise aspects' (visualisation)

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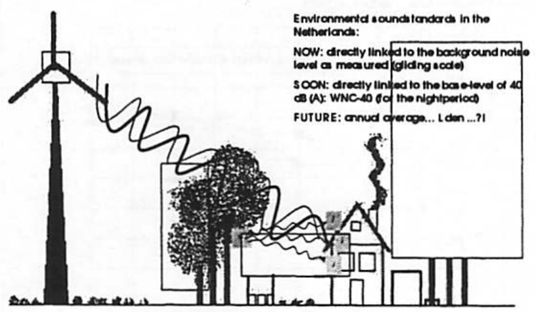
Visualisation



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New Legislation 2001+

- AMvB wind turbines
- Noise regulations
- WNC: the gliding scale

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AMvB: current affairs

- The draft has been drawn up (third version) and it will be published in the middle of 2001 in the Government Gazette (Staatscourant).
- It is expected, with reservations, that the definitive version will come into effect at the end of 2001.

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Content of AMvB Decree

- **Articles**
  scope of effect, definitions, wind turbines type A (part of facility) and type B (independent facility)
- **Specific regulations (type A and B)**
  installation (noise and WNC curve), putting into operation, further requirements
- **General regulations (type B)**
  general noise (basic requirements), other

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Noise regulations

- Measuring the production of noise to determine the source volume relevant to the immission is carried out according to the standard IEC 61400-1 1 "Wind turbine generator systems - part 11: Acoustic noise measurements. Measurements are taken with an average wind velocity of 7 m/s allowing for a maximum deviation of plus or minus 2 m/s. The source volume spectra are measured in octave bands.

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Noise regulations

- Measurements for determining the noise level at the outer wall of a house or other destination sensitive to noise and assessing it, have to be carried out with respect to the WNC in Appendix 3. A measurement as meant in the first sentence can also be carried out at an immission point on condition that it is in agreement with the competent authorities. When measurements are being taken of immissions, the dominating wind velocity on site will be measured at axis level, or if this requirement is unreasonable, at a height of 10 m above ground level.

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WNC: the gliding scale

- Based on national research (NOVEM-assignment)
- It is in alignment with the starting points of the Environmental Management Act (Wm) and its insights on a clean environment
- some examples

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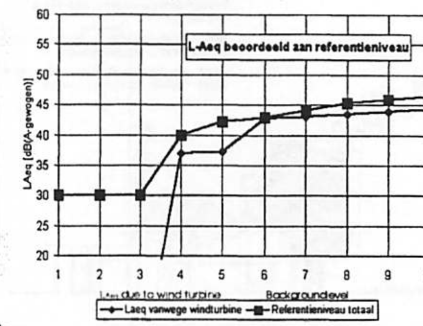
An example: individual project



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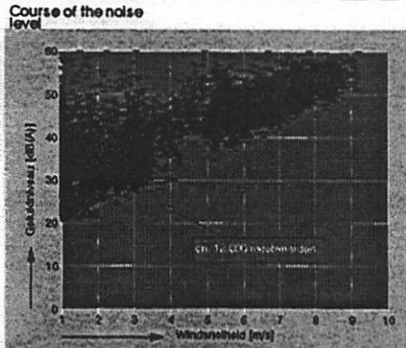
Course of the noise level



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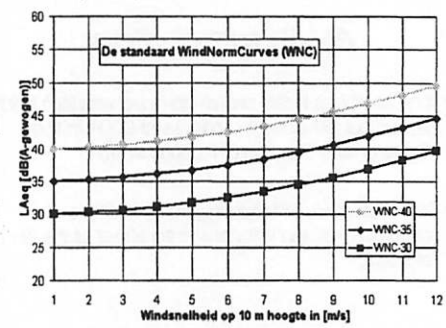
WNC's: -30-35-40



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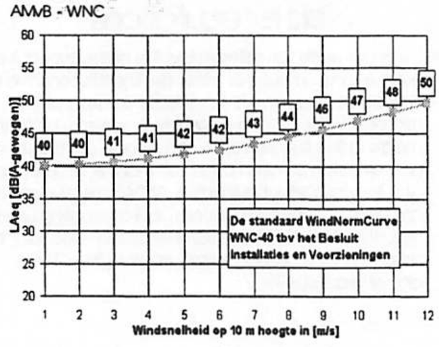
AMvB - WNC



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Opportunities and obstacles for wind energy

Opportunities

- Simplified procedures
- More noise allowance from WNC-system
- countrywide the same approach
- links to the still appearing licences

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Opportunities and obstacles for wind energy

Obstacles

- Resorting to the old system (and jurisdiction)
  - less noise allowance: direct linking to the background soundlevels
  - many procedures for Further Requirements (additional) and still direct linking to background levels, with local differences and no real environmental background

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Conclusions

- Positive developments in legislation
- control obstacles through good national information
- influence new jurisdiction
- More space for wind energy in the Netherlands 2001+

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The End

Questions, discussion..

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Opdrachtgever:	Datum:	Rapportnummer:
NOVEM	17 februari 1999	R52 364A1.TK

Normstelling windturbinegeluid

Metingen geluid en windsnelheid

HOOFDRAPPORT

ir. A.J. Kerkers
ing. J. Geleijns

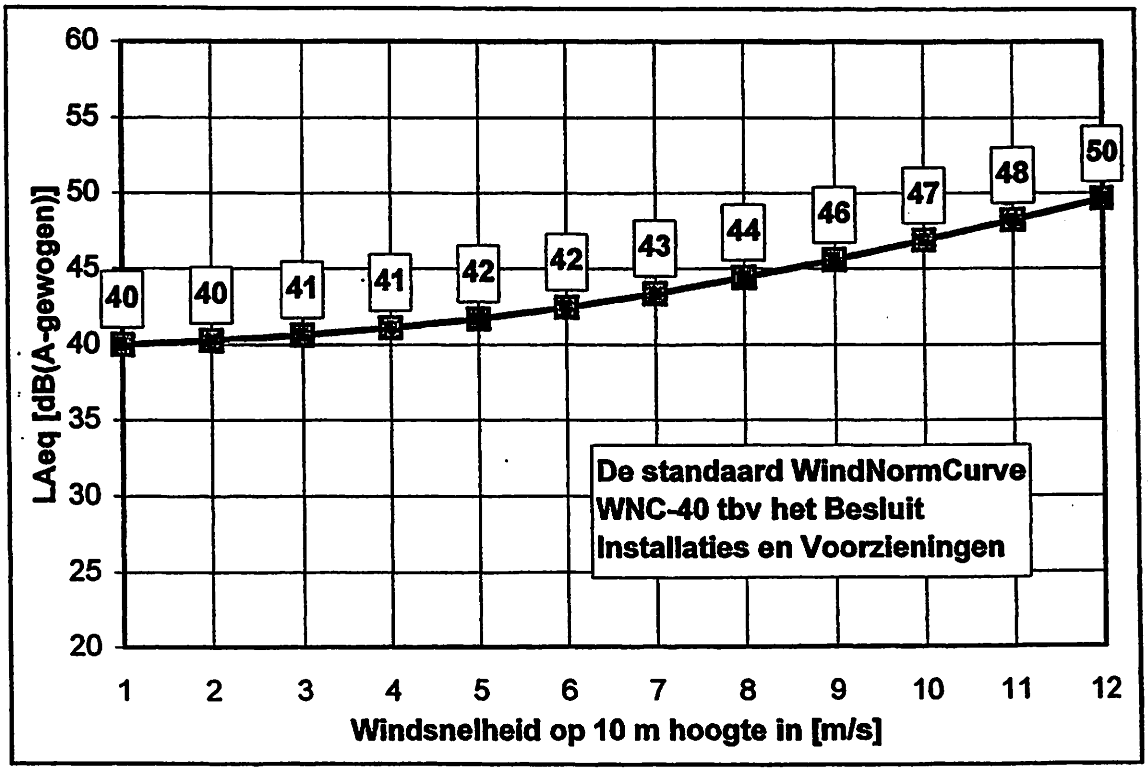
Inhoudsopgave

Samenvatting

In opdracht van de Nederlandse onderneming voor energie en milieu (NOVEM) is in Nederland een groot aantal geluid- en windsnelheidsmetingen verricht aan het achtergrondgeluidniveau van de omgeving bij de diverse windsnelheden.

Het doel van de metingen is de relatie tussen achtergrondgeluid en windsnelheid kwantitatief vast te leggen voor diverse representatieve woningen nabij potentiële windparklocaties, zowel in een winter- als in een zomersituatie.

De metingen laten zien dat het omgevingsgeluid toeneemt vanwege het windgeruis met ca. 1,6 dB per m/s windsnelheidstoename. Dit resulteert in de onderstaande WindNormCurve WNC-40. Voorgesteld wordt om deze curve te hanteren bij de beoordeling van de geluidimmissie vanwege windturbines en/of windparken die vallen onder het toekomstige 'Besluit installaties en voorzieningen milieubeheer'.



1 Inleiding

In opdracht van de Nederlandse onderneming voor energie en milieu (NOVEM) is in Nederland een groot aantal geluid- en windsnelheidsmetingen verricht aan het achtergrondgeluidniveau van de omgeving bij de diverse windsnelheden.

Het doel van de metingen is de relatie tussen achtergrondgeluid en windsnelheid kwantitatief vast te leggen voor woningen nabij potentiële windparklocaties, zowel in een winter- als in een zomersituatie. Aan de hand van de resultaten van de metingen zal een voorstel geformuleerd worden waarmee de geluidimmissie vanwege windturbines in het kader van de Wet milieubeheer even stringent beoordeeld zal kunnen worden als alle andersoortige inrichtingen.

2 Uitgangspunten

Belangrijke uitgangspunten voor het voorliggende onderzoek zijn vermeld in:
- de 'handleiding meten en rekenen industrielawaai IL-HR-13-01' van maart 1981, een publicatie van de interdepartementale commissie geluidhinder;
- Industrielawaai. Richtlijnen voor karakterisering en meting van omgevingsgeluid. 1981, ICG publicatie IL-HR-15-01;
- het 'Besluit horeca-, sport- en recreatie-inrichtingen milieubeheer' van 20 mei 1998, staatsblad nr. 322.

2.1 Wettelijk kader

Windturbines zijn op dit moment in het kader van de Wet milieubeheer (Wm) vergunningplichtig. Momenteel wordt een Algemene Maatregel van Bestuur (AMvB) opgesteld die tot doel heeft om algemene regels te stellen o.a. ten aanzien van de toelaatbare geluidimmissie voor windturbines en (kleine) windparken. Deze voorschriften zullen vastgesteld worden in het 'Besluit installaties en voorzieningen milieubeheer'.

In het kader van de huidige vergunningverlening wordt een relatie gelegd met het zogenaamde referentieniveau. Dit is de laagste waarde van ofwel het wegverkeerslawaai minus 10 dB, ofwel het achtergrondgeluidniveau L_{95}. Dit statistische geluidniveau L_{95} is het geluidniveau dat gedurende 95% van de tijd *overschreden* wordt. Bij de huidige vergunningverleningssystematiek geldt dus in het algemeen dat hoe stiller de omgeving is, hoe strenger de van toepassing zijnde geluidnormen.

In de nieuwe AMvB's, waarvan op dit moment de tekst van het eerste aangepaste Besluit horecabedrijven milieubeheer reeds vastgesteld is, wordt - in afwijking van de huidige systematiek - een vaste grenswaarde van 40 dB(A) voor het toelaatbare equivalent geluidniveau L_{Aeq} van een inrichting tijdens de nachtperiode aangegeven. Dit is de bovengrens van de in de circulaire industrielawaai vermelde indicatieve tabel met referentieniveaus voor verschillende meer of minder landelijke gebieden. Door het ministerie VROM is aangegeven dat deze grenswaarde van 40 dB(A) in alle nog vast te stellen AMvB's opgenomen zal worden. De lokale overheid kan dan door het stellen van nadere eisen deze grenswaarde aanscherpen of verruimen.

Uit overleg met het ministerie VROM is gebleken dat geen afzonderlijke grenswaarden voor de geluidemissie van windturbines in de tekst van het besluit opgenomen zullen worden. Wel zal er in de toelichting van het besluit een nadere uitleg komen hoe de grenswaarde van 40 dB(A) in het geval van windturbines geïnterpreteerd zal kunnen worden.

2.2 Beoordeling van windturbinegeluid

Ten aanzien van de methodiek van het meten, rekenen en beoordeling van de geluidemissie AMvB-inrichtingen, zal worden verwezen naar de IL-HR-13-01 (zie begin van dit hoofdstuk). Het verdient aanbeveling dat op een aantal punten er ten aanzien van het windturbinegeluid e.e.a. wordt verduidelijkt.

Een windturbine vormt een van andere 'inrichtingen' afwijkende geluidbron. Met het toenemen van de windsnelheid neemt ook de geluidemissie van de windturbine toe. Indien de geluidemissie van windturbines conform de systematiek van de huidige vergunningverlening formeel beoordeeld wordt, zou er geconcludeerd kunnen worden dat de representatieve bedrijfssituatie optreedt bij een windsnelheid van bijvoorbeeld 20 m/s (ofwel de meest maximale bedrijfssituatie behoudens incidenten). Bij dergelijke hoge windsnelheden zal echter nimmer sprake zijn van geluidhinder, vanwege het dan zeer sterk toegenomen omgevingsgeluid. Kans op het optreden van geluidhinder treedt in het algemeen slechts op vanaf het moment dat de windturbine in bedrijf komt (ca. 3 m/s op 10 m hoogte), tot een windsnelheid van ca. 10 m/s. Bovendien zal bij deze en hogere windsnelheden het verrichten van geluidmetingen vanwege allerlei praktische beperkingen nagenoeg onmogelijk zijn.

Vanwege het altijd fluctuerende karakter van de windsnelheid, ook gedurende de nachtperiode, is het moeilijk te spreken van één representatieve bedrijfssituatie. Formeel gezien zou je voor elk deel van de nachtperiode het L_{Aeq} dienen te bepalen (bij 4 ± ½ m/s, bij 5 ± ½ m/s, etc. etc.), en dus de bedrijfsduurcorrectie, de geluidimmissie, en het achtergrondgeluidniveau, hetgeen een zeer ingewikkelde rekenexercitie met zich mee zou brengen. Er kan echter ook gekeken worden naar een brede bandbreedte aan windsnelheden, bijvoorbeeld 'Het equivalent geluidniveau L_{Aeq} bij een windsnelheid van 5 ± 2 m/s', ofwel van 3 - 7 m/s. Aangezien binnen deze bandbreedte zowel de geluidimmissie van de windturbine, als het omgevingsgeluid aanzienlijk kunnen variëren, komt dit de nauwkeurigheid vanzelfsprekend niet ten goede.

Aangezien windturbines volcontinu in bedrijf kunnen zijn, zal enkel de nachtperiode beschouwd behoeven te worden, aangezien tijdens de avond- en dagperiode een 5 dB respectievelijk 10 dB ruimere normwaarde van toepassing is. Tijdens de avond- en dagperiode zullen windturbines of windparken overigens geen grotere geluidemissie veroorzaken dan tijdens de nachtperiode.

2.3 De belangrijkste uitgangspunten

Aan het voorliggende onderzoek liggen de volgende uitgangspunten ten grondslag.
- Er wordt een grenswaarde voor het toelaatbare L_{Aeq} gehanteerd van 40 dB(A) (basis-eis; ref: VROM; 2e concept-AMvB Installaties en voorzieningen milieubeheer d.d. juni 1998).
- Een interpretatie van deze basis-eis ten aanzien van de beoordeling van het windturbinegeluid zal opgesteld worden. Aangegeven zal worden welke geluid-eisen gehanteerd dienen te worden bij de hogere windsnelheden zodat de kans op hinder onder alle omstandigheden gelijk beoordeeld kan worden als bij andere AMvB-inrichtingen.
- De voor te stellen beoordelingsmaatstaf wordt '*windnormcurve (WNC)*' genoemd. De bepalende curve is de WNC-40 (met hierin in ieder geval een toelaatbaar equivalente geluidniveau L_{Aeq} van 40 dB(A) bij lage windsnelheden).
- De toelaatbare geluidimmissie zal beoordeeld worden voor windsnelheidsklassen met een bandbreedte van 1 m/s, tot een windsnelheid van 10 m/s (meethoogte 10 m). Bij hogere windsnelheden zal geen beoordeling plaats hoeven te vinden.
- Er zal geen correctie toegepast worden voor de bedrijfsduur per windsnelheidsklasse per etmaalperiode.
- De meteocorrectie C_m zal toegepast worden conform de 'handleiding meten en rekenen industrielawaai IL-HR-13-01'.

De overige uitgangspunten zullen in het volgende hoofdstuk aan de orde komen.

3 Wind-geluidmetingen

Het bij het onderhavige hoofdrapport behorende technische rapport R52 361A2.TK d.d. 18 augustus 1998 (bijlage I) geeft een beschrijving van alle verrichte windsnelheid- en geluidmetingen.

3.1 Geluidbronnen

Bij het verrichten van de geluidmetingen wordt al het geluid door de meetopstelling geregistreerd. Hierin zijn bijdragen te verwachten van:

a. niet bekende, veraf gelegen geluidbronnen;
b. nabij gelegen, herkenbare geluidbronnen, bijvoorbeeld het wegverkeer;
c. windgeruis door de nabij de woning aanwezige begroeiing, bomen, struiken en beplanting;
d. windgeruis om gebouwen en andere bij de woning behorende objecten;
e. windgeruis vanwege de meetopstelling zelf, bijvoorbeeld door het geluid van de wind die in het grid van de microfoon blaast.

De onder a. genoemde niet bekende, veraf gelegen geluidbronnen betreffen het normaliter in het kader van de (huidige) vergunningverlening vast te stellen achtergrondgeluidniveau. Deze waarde is in de resultaten van de nu verrichte metingen te herkennen als zijnde het L_{95} bij lage windsnelheden. Op dat moment spelen namelijk alle door de wind veroorzaakte deelgeluidbronnen nog geen belangrijke rol (zie c., d. en e.).

Nabij de meetopstelling gesitueerde geluidbronnen kunnen een probleem vormen bij de te verrichten onbemande geluidmetingen. We maken hierbij onderscheid in stationaire geluidbronnen zoals bijvoorbeeld ventilatoren (maar ook een regenbui), en het instationaire geluid van het wegverkeer of op het bedrijfsterrein rondrijdende transportmiddelen.
De stationaire geluidbronnen zijn in het algemeen zeer herkenbaar in de meetresultaten, aangezien op dat moment het stochastische karakter van het gemeten geluidniveau verdwijnt. In de grafische weergave van de metingen is dit te herkennen als een verhoogd plateau, zodat hiervoor zonodig eenvoudig gecorrigeerd kan worden.
Het effect van passerende voertuigen zal in het algemeen ook geen probleem opleveren. Nagenoeg alle woningen/boerderijen in potentiële windturbinegebieden zijn op het platteland gelegen, en ondervinden slechts een beperkte geluidbelasting vanwege het wegverkeer. De bijdrage van het wegverkeer op het L_{95} is zelfs geheel te verwaarlozen.

Als voorbeeld: bij 1.000 meetwaarden zal het 50-ste laagste getal de waarde van het L_{95} opleveren, terwijl het verhoogde geluidniveau vanwege een (fictief aangenomen) verdubbeling van het aantal voertuigpassages slechts enkele van de 1.000 meetwaarden zal verhogen. Mogelijk dat dan een zeer geringe fout ontstaat doordat de 49-ste laagste i.p.v. de 50-ste laagste waarde het L_{95} zal geven. De afwijking zal bij voldoende meetwaarden in het algemeen slechts maximaal 0,1 dB bedragen.

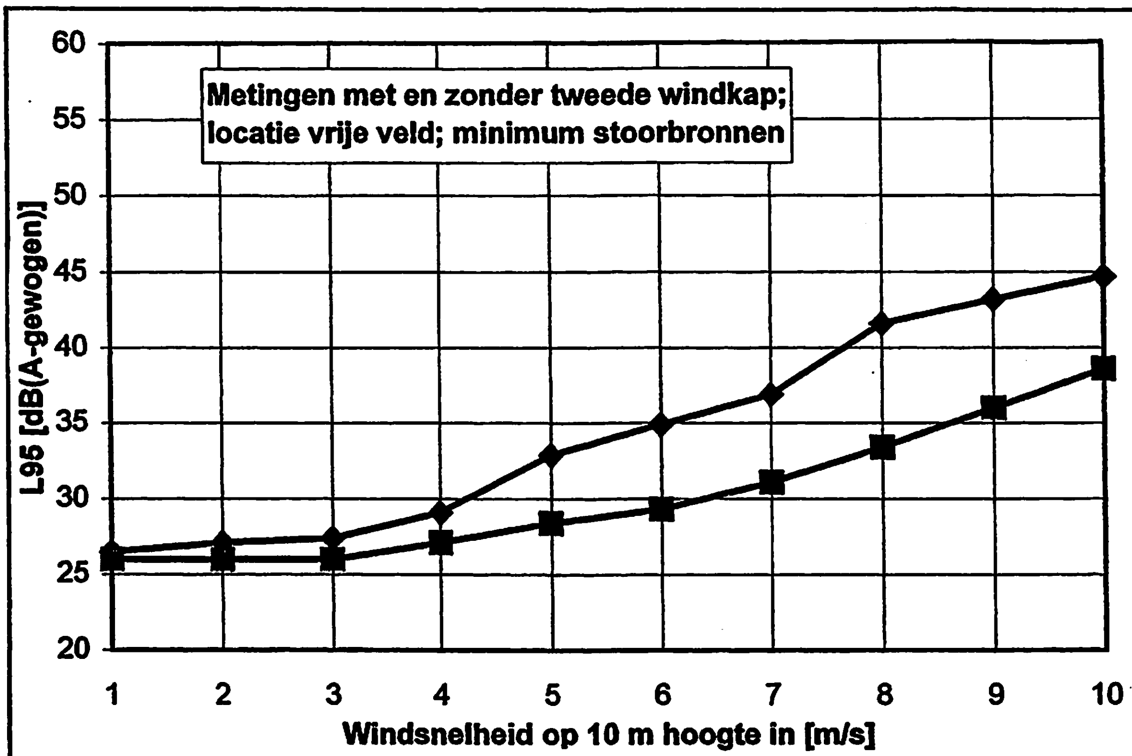
Ook een moedwillige verstoring van het L_{95}, ofwel het nagenoeg laagst te meten geluidniveau, is moeilijk. Hiertoe zou namelijk één van de door het windgeruis veroorzaakte geluidbronnen uitgeschakeld of verzwakt dienen te worden. Daarentegen is het moedwillig verhogen van de meetwaarden wel eenvoudig te realiseren door een stoorgeluidbron in te schakelen (en is daarmee wel herkenbaar doordat alle meetwaarden opgeslagen worden).

3.2 Eigengeluid van de meetopstelling

Het eigengeluid van de meetopstelling is bij de wat hogere windsnelheden nooit geheel te voorkomen. Voorzieningen zijn in ieder geval noodzakelijk om het windgeluid in de microfoon tot een minimum te reduceren. Eén kleine windbol is hiertoe in ieder geval onvoldoende, zodat een tweede, grotere windbol aangebracht dient te worden. De toegepaste windkap is cilindervormig met een diameter van ca. 50 cm. Met name de keuze van de toe te passen opencellige schuimsoorten kan een grote variatie in het eigengeluid opleveren, zodat de materiaalkeuze de nodige aandacht verdient. Daarnaast is het ook van belang om het eigengeluid van het statief waarop de microfoon bevestigd is voldoende te beperken, door bijvoorbeeld scherpe randen e.d. af te ronden en/of te bekleden.

Bij de bepaling van het eigengeluid is een pragmatische oplossing gekozen door de meetopstelling in een onbebouwd open landschap in een stille omgeving te plaatsen, en gedurende meerdere dagen een meetcyclus te laten doorlopen. De bijdrage van de 'normale' achtergrondgeluiden is dan te bepalen uit het L_{95} bij een windsnelheid van 0 - 2 m/s, terwijl de meetwaarden bij de hogere windsnelheden in hoofdzaak door de meetopstelling zelf veroorzaakt worden. De hiernavolgende figuur 3.1 geeft de aldus geregistreerde meetwaarden van een gelijktijdige meting met een meetopstelling met, en één zonder extra windkap. De windkap is verder gecontroleerd op demping/afscherming van het te meten geluidniveau. Er blijkt geen systematische geluidreductie vanwege de windkap op te treden.

Voorafgaand aan alle wind-geluidmetingen dient de beschreven nulmeting altijd uitgevoerd te worden, zodat inzicht verkregen kan worden in de bijdrage van het eigengeluid van de meetopstelling. De hier beschreven methode is eenvoudig praktisch uitvoerbaar en biedt voldoende informatie binnen de van toepassing zijnde nauwkeurigheidsmarges.



Figuur 3.1
De resultaten van de wind-geluidmetingen met en zonder extra windkap op een stille locatie in het open buitengebied op onbebouwd akkerland

3.3 Meetmethode

Bij het vaststellen van grenswaarden dient in de huidige situatie per locatie het L_{95} per windsnelheidklasse bepaald te worden. Aangezien het L_{95} een statistische grootheid betreft, dienen er voldoende L_p-waarden over de gehele etmaalperiode verzameld te worden om een nauwkeurige waarde van het L_{95} te verkrijgen.

Aangezien we echter nu ook per windsnelheidsklasse van 1 m/s meetparen van L_p's en momentane windsnelheden dienen te verzamelen, is het zaak om in ieder geval (bijv.) *minimaal vijf maal zo veel* meetwaarden te verzamelen indien we een L_{95}-curve van (bijv.) 3 t/m 7 m/s willen opstellen. Vanwege de noodzakelijke spreiding in windsnelheden tijdens een meetsessie, blijkt de totale meetsessie in de praktijk minimaal twee etmalen te omvatten. Vanwege de eindige capaciteit van de dataloggers is gekozen voor een sample-interval van 11 sec. Bij een totale opslagcapaciteit van 24.000 meetwaarden kan hiermee gedurende drie volledige etmalen gemeten worden.

Voor de meethoogte van de geluidniveaumeter is ca. 4-5 m gekozen. Bij voorkeur bedraagt de meethoogte 5 m, conform de van toepassing zijnde IL-HR-13-01. Bij hoge windsnelheden in open gebieden blijkt het echter soms raadzaam om hiervan om praktische redenen af te wijken. De afmetingen van de windkap zorgen namelijk voor aanzienlijke belastingen op het statief, terwijl eventuele tuikabels op voldoende afstand van de microfoon bevestigd dienen te worden om onnodig stoorgeluid te voorkomen.

De windsnelheid wordt gemeten op een statief met een hoogte van 10 m. Het L_{95} blijkt in hoofdzaak veroorzaakt te worden door de begroeiing en beplanting rondom de woningen/gebouwen. De gekozen meethoogte is een goede maat voor de 'aanstoting' van het groen door de wind, terwijl ook alle bronsterktegegevens van windturbines gerelateerd worden aan een meethoogte van 10 m. Meteostations hanteren dezelfde meethoogte, terwijl het ook praktisch bezien te hanteren statiefafmetingen oplevert.

3.4 De afstand tussen windsnelheid- en geluidniveaumeter

De afstand van windsnelheidsmeter tot geluidniveaumeter dient vanzelfsprekend zo klein mogelijk gehouden te worden vanwege de looptijd van een windvlaag tussen de beide meetposities. Er is indien mogelijk een maximale afstand van 50 m aangehouden, maar in diverse situaties moest deze afstand vergroot worden tot maximaal 100 m. Weliswaar kan bij stabiele weerscondities met wind uit één hoofdrichting in beperkte mate hiervoor gecorrigeerd worden, maar deze looptijd is nooit voor 100% te corrigeren vanwege het gekozen sample-interval van 11 sec. Bij kleinere sample-intervallen zijn er wel meer correctiemogelijkheden, maar dan nog zal er wel van uitgegaan dienen te worden dat de voortplantingssnelheid van de wind nagenoeg gelijk is aan de momentane windsnelheid op één locatie. Met name bij vlagerige wind is deze aanname op zijn minst twijfelachtig te noemen.

Gekozen is wederom voor een meer pragmatische benadering. In een praktijksituatie is gemeten met een kort sample-interval van 2 sec., waarna vervolgens voor diverse sample-intervallen, 2-4-8-12-16 sec. de L_{95} waarden bepaald zijn. Daarna is er zowel een tijdverschuiving van één sample uitgevoerd, alsof de windsnelheidsmeter en de geluidmeter op grotere onderlinge afstand stonden. Onderstaande tabel 3.1 geeft hiervan de resultaten. Hierbij is bovendien gekeken naar het minimum aantal te hanteren meetsamples.

Tabel 3.1
Variaties van sample-intervallen en het gesimuleerde effect van afstandsvergroting; bij de bepaling van de cursief- en vetgedrukte waarden zijn minder dan 200 samples gebruikt

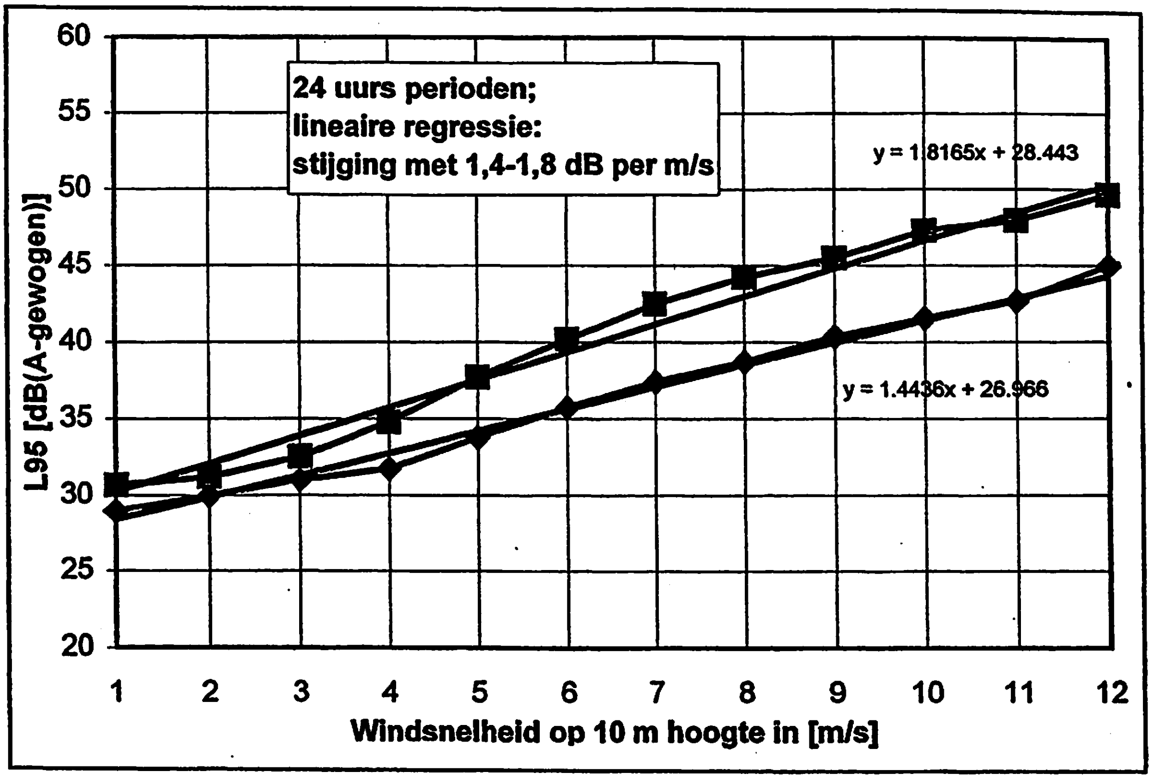
Omschrijving van de meting: sample-interval =	Referentieniveau L_{95} bij een windsnelheid [m/s] van:											
	3	4	5	6	7	8	9	10	11	12	13	14
2 sec.	30	30	30	33	36	39	43	46	48	51	53	56
4 sec.	***30***	30	30	33	36	39	44	46	48	52	54	***56***
4 sec. verschoven:	***29***	30	30	33	36	39	43	46	48	51	52	***55***
8 sec.	***29***	30	30	33	36	39	43	46	49	51	***50***	***56***
8 sec. verschoven	***29***	30	30	33	36	40	43	46	47	51	***54***	***52***
12 sec.	***29***	30	30	33	36	40	43	46	48	***53***	***49***	***49***
12 sec. verschoven	***29***	30	30	33	36	39	43	46	46	***48***	***48***	***50***
16 sec.	***29***	30	30	33	36	39	43	46	48	***54***	***48***	***51***
16 sec. verschoven:	***30***	30	30	33	36	38	42	44	47	***50***	***52***	***48***

De volgende conclusies kunnen voorzichtig hieruit getrokken worden:
- de belangrijkste parameter bij het vaststellen van nauwkeurige L_{95}-waarden is het aantal meetparen; per te berekenen L_{95}-waarde dienen *minimaal* 200 meetparen aanwezig zijn om de nauwkeurigheid niet tot meer dan 2 dB te laten toenemen;
- het verschuiven van de geluid- t.o.v. de windsnelheidssamples begint substantiële afwijkingen te geven in het te berekenen L_{95} bij een tijdverschuiving van meer dan 12 sec.

Vanwege het belang van het verkrijgen van een zo groot mogelijk aantal meetparen is er voor gekozen om bij de metingen niet alleen te kijken naar de tijdens de nachtperioden gemeten waarden, maar ook naar de L_{95} waarden die berekend zijn aan de hand van *alle* per meetpositie ter beschikking staande meetparen (ofwel 24 uur/etmaal). De extra nauwkeurigheid vanwege het grotere aantal meetwaarden weegt onzes inziens op tegen de te verwachten geringe verhoging van de L_{95} waarden bij de lage windsnelheden. Gedurende de dagperiode bedraagt het niet aan de wind gerelateerde L_{95} bijv. ca. 35 dB(A) en voor de nachtperiode ca. 25 dB(A). Effectief zal dan het over het gehele etmaal bepaalde L_{95} ca. 26 dB(A) kunnen bedragen. In het technisch rapport, bijlage I is e.e.a. verder uitgewerkt.

3.5 Seizoensinvloeden

Onderstaande figuur 3.2 geeft de uit alle metingen gemiddelde waarden van het L_{95} voor zowel de zomer, als de winterperiode. De L_{95} waarden zijn bepaald uit de metingen over de complete meetperiode per locatie. Enerzijds blijken er bij de lage windsnelheden geringe verschillen op te treden tussen de beide seizoenen (het L_{95} bedraagt dan ca. 30 dB(A)). Anderzijds neemt het verschil tussen winter en zomer toe met het toenemen van de windsnelheid. In de winterperiode bedraagt de stijging van het L_{95} met de windsnelheid ca. 1,4 dB per m/s windsnelheidstoename, gedurende de zomerperiode ca. 1,8 dB per m/s. Bij een windsnelheid van 5 ± 2 m/s bedraagt het verschil tussen zomer en winter gemiddeld ca. 3 dB.



Figuur 3.2

3.6 Nauwkeurigheidsmarges

De hiernavolgende tabel 3.2 geeft de diverse marges en nauwkeurigheden die geschat zijn voor de individuele wind-geluidmetingen.

Tabel 3.2
Meet- en rekentoleranties

Ten gevolge van toleranties van:	Mogelijke tolerantie:
calibratie van de akoestische meetapparatuur:	0,2 dB
de totale akoestische meetketen:	0,2 dB
vanwege het eindige aantal meetwaarden bij een sample-interval van 11 sec.:	1,5 dB
veroorzaakt door de looptijd tussen de windsnelheidsmeetlocatie en de locatie waar het geluidniveau gemeten wordt, bijvoorbeeld vanwege fluctuaties in de windrichting tijdens één meetsessie:	2,0 dB
de gemeten windsnelheid (uitgaande van een toename van 1,6 dB per m/s):	0,8 dB
De gecombineerde totale meet- en rekentolerantie:	2,6 dB

De gecombineerde onzekerheid van de L_{95} bepaald bij de afzonderlijke windgeluidmetingen, uitgedrukt als één standaarddeviatie bedraagt aldus 2,6 dB.

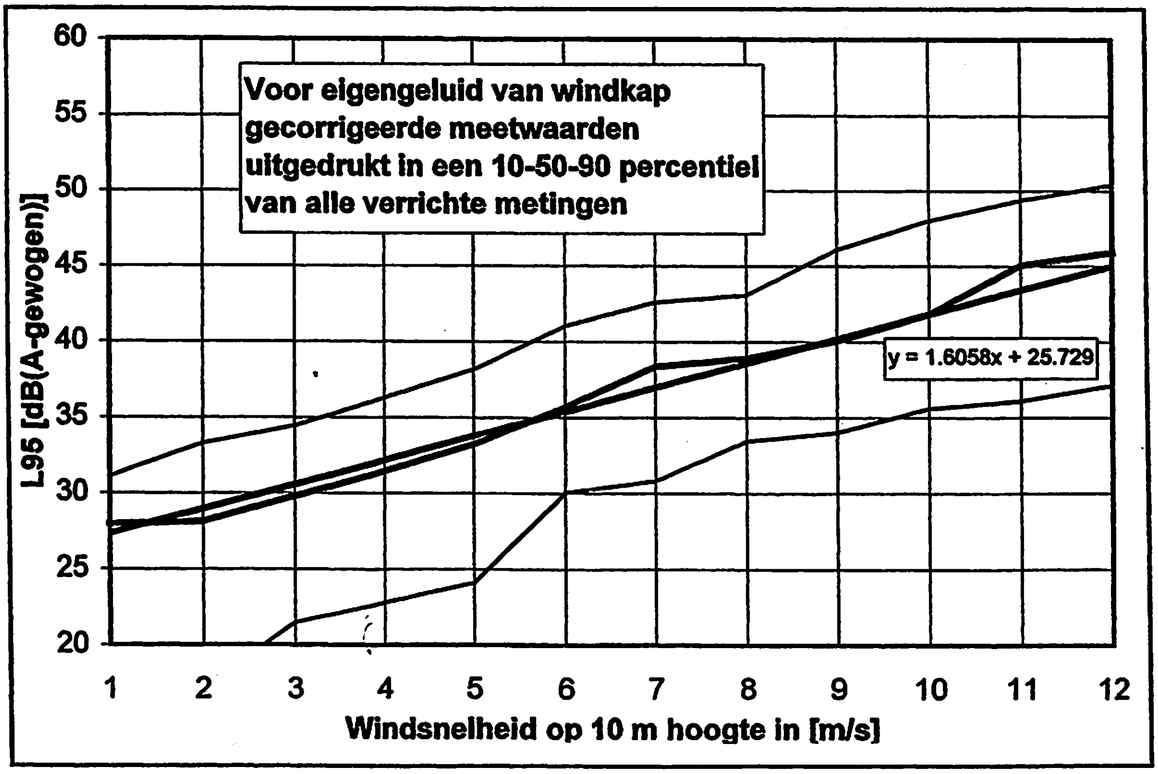
3.7 Samenvatting metingen

Uit de metingen komt een aantal zaken naar voren.

- Zonder toepassing van een tweede windkap om de microfoon zijn geen betrouwbare metingen mogelijk.
- Het eigengeluid van de meetopstelling is op een eenvoudige wijze vast te stellen door middel van een meetsessie op een stille, landelijke locatie met geen of nauwelijks begroeiing.
- Het sample-interval dient maximaal 12 sec. te bedragen. Een korter interval levert enerzijds een grotere betrouwbaarheid, maar anderzijds een kortere tijdsduur van de meetsessie. In het kader van het voorliggende onderzoek is een sample-interval van 11 sec. gekozen.
- Eén meetsessie dient *minimaal* twee volledige etmalen te beslaan om voldoende meetwaarden te verzamelen om zinvol de L_{95} waarden bij voldoende windsnelheden te kunnen bepalen. De windsnelheidfluctuaties gedurende één etmaal zijn veelal te beperkt.
- Bij de bepaling van de L_{95}-waarde voor één windsnelheid dienen *minimaal* 200 meetparen ter beschikking te staan.
- De metingen resulteren niet in grote verschillen tussen alleen de tijdens de nachtperioden gemeten waarden en alle, gedurende het gehele etmaal gemeten waarden. Deze laatste heeft de voorkeur bij de bepaling van de L_{95} waarden vanwege het drie maal zo grote aantal ter beschikking staande meetwaarden.
- De afstand tussen windsnelheids- en geluidmeter dient bij voorkeur maximaal 50 m te bedragen. Indien dit niet mogelijk blijkt te zijn, bijvoorbeeld doordat de windsnelheidsmeter dan mogelijk in een windluw gebied terecht komt, kan deze afstand vergroot worden tot maximaal 100 m.
- De meethoogte voor de windsnelheidsmeting dient 10 m te bedragen. De meethoogte van 5 m voor de geluidniveaumeter kan zonder grote afwijkingen te introduceren wat verlaagd worden bij te verwachten hoge windsnelheden.

4 De WindNormCurve WNC-40

Ten behoeve van het toekomstige 'Besluit installaties en voorzieningen milieubeheer' dient er een nadere interpretatie opgesteld te worden met betrekking tot de te hanteren grenswaarde van 40 dB(A) voor het toelaatbare equivalente geluidniveau L_{Aeq}. De geluidimmissie vanwege windturbines neemt namelijk met het toenemen van de windsnelheid toe met gemiddeld ca. ½ dB per m/s windsnelheidstoename. Daarentegen blijkt de toename van het omgevingsgeluid vanwege het windgeruis met gemiddeld 1,6 dB per m/s toe te nemen (zie figuur 4.1). Indien er geen nadere toelichting komt op de beoordeling van het windturbinegeluid zal er in nagenoeg alle gevallen bij een bepaalde (hoge) windsnelheid een overschrijding van de grenswaarden optreden, terwijl de kans op geluidhinder dan juist sterk afneemt. De interpretatie van de te hanteren geluidgrenswaarde in het kader van de Wet milieubeheer dient een bij alle windsnelheden zo gelijk mogelijke 'hindermaatstaaf' op te leveren.



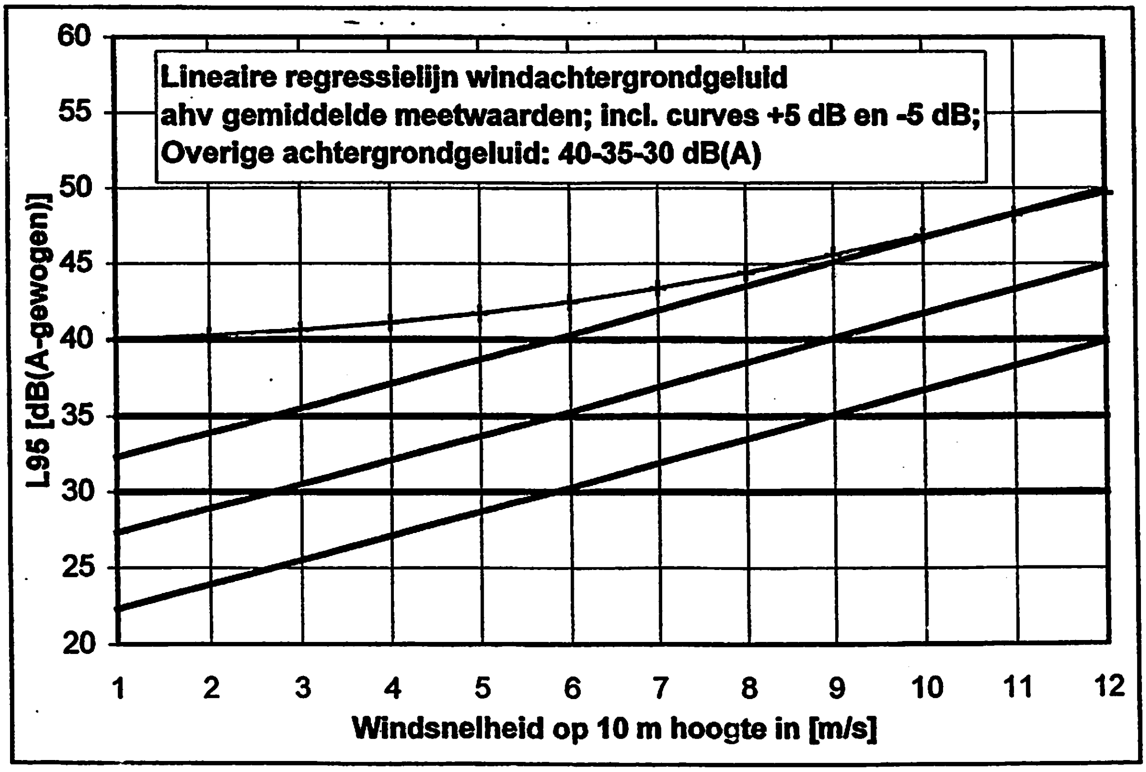
Figuur 4.1

Om nu het windturbinegeluid niet strenger te beoordelen dan andersoortige inrichtingen, dienen deze getoetst te worden aan een van de windsnelheid afhankelijke normcurve.

De te hanteren *WindNormCurves (WNC)* kunnen worden afgeleid uit twee delen.

- Bij lage windsnelheden geldt dat voor alle inrichtingen een grenswaarde van 40 dB(A) van toepassing zal zijn. Deze waarde is afkomstig uit de circulaire industrielawaai, en betreft de voorkeursgrenswaarde en de bovengrens van de indicatieve tabel met achtergrondgeluidniveau voor de diverse meer of minder landelijke gebieden (40-35-30 dB(A) voor de nachtperiode). Overigens zullen windturbines bij de lage windsnelheden tot ca. 3 m/s geen geluidhinder veroorzaken, aangezien ze dan niet in bedrijf zullen zijn.
- Bij hogere windsnelheden zal het omgevingsgeluid enkel nog bepaald worden door het windgeruis. Daartoe wordt de gemiddelde curve van L_{95} waarden van alle verrichte metingen (tijdens de zomer- *en* winterperiode) gehanteerd, samen met daarbij de 5 dB hoger en lager gesitueerde curves.

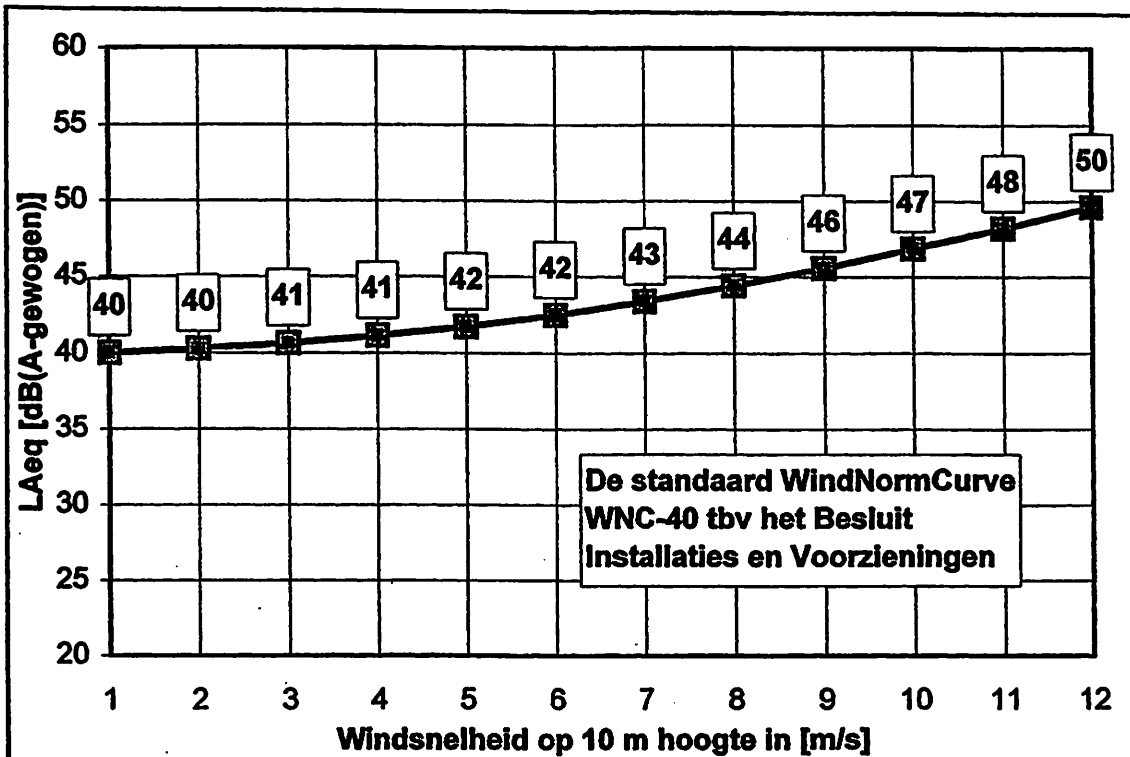
Onderstaande figuur 4.2 geeft de hierboven beschreven curves. De dunne lijn in de figuur geeft hierbij alvast de hieruit afgeleide WNC-40, evenals figuur 4.3.



Figuur 4.2

Conclusie

Voorgesteld wordt de in de onderstaande figuur 4.3 aangegeven WNC-40 te hanteren ten behoeve van de beoordeling van het geluid vanwege windturbines en/of windparken die in de toekomst zullen ressorteren onder het 'Besluit installaties en voorzieningen milieubeheer'. Het hanteren van deze curve zal er toe bijdragen dat in de nabije toekomst de geluidimmissie vanwege windturbines op dezelfde wijze beoordeeld zal worden als bij alle andersoortige inrichtingen in het kader van de Wet milieubeheer.



Figuur 4.3

Lichtveld Buis & Partners BV

ir. A.J. Kerkers

IEA expert meeting on Noise Immission.
Stockholm, 27-28 November 2000
Dimitris Theofiloyiannakos, CRES, Wind Energy Dept.

Note on

Noise Immission from Wind-turbines in Greece

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IEA expert meeting on Noise Immission.
Stockholm, 27-28 November 2000
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Note on noise Immission from W/Ts in Greece

Planning and permission of Wind Energy projects

Greece is one of the European countries possessing high wind energy potential. The legal framework governing the development of the renewable energy sources has been in effect since 1995 and is based on Law 2244/94 and relevant ministerial decrees. The main features of the framework regarding wind energy, are the opening of the market to the private sector and the obligation of the public power corporation of Greece (PPC) to buy the wind-produced electricity. Before the installation of a new wind-farm a request has to be applied at the regional departments of the ministry of development, providing a feasibility study of the project, the total power capacity, the topography and geography of the area. The request is passed to the public power corporation for consulting on technical parameters mainly the electrical grid potential of the area and the Ministry for the environment physical planning and public works, for a preliminary acceptance of the proposed wind-park area.

If the request is accepted, second step is the installation permission. The developer must provide among other things, information on any existed or approved project (mainly wind-parks) that can be influenced by the current in a distance of 5 Km, noise contours around the park and a photo-realistic representation of the wind-park. There are no criteria for the noise propagation model used and no criteria on the treatment of the photo-realistic presentation. Shadow effect is not taken into account.

Finally, the operation permission except other things, which have to do with the operational status of the project, includes also a special permission for high buildings. It has two components. One clear and objective, the static analysis of the turbine and one unclear, which has to do with the architecture of the turbine from a rather aesthetic point of view.

Noise limits.

Till now wind-parks were erected in remote rural areas and although there have been some complaints expressed, none of them has reached the court. It seems that this easy-going situation is changing. During last two years, Greece has experienced a dynamic increase on wind energy projects leading to a total installed capacity of 194 MW, while in 1998 it was 38 MW. 200 MW more, are expected to be added in next two years and as the number of projects is increasing, their distance from residential areas is decreasing.

The national noise legislation imposes acoustical limits at the boundaries of the noise source's area (at the fence), according to the following table:

Note on noise Immission from W/Ts in Greece

Limit in dBA	Zone
70	Industrial
65	Mainly industrial
55	Mixed industrial and residential
50	Mainly residential
45	Inside nearby dwelling

There are no different limits for day, evening or night.

I n cases of limit violation, the wind park owner is obliged to take some action and improve the situation, in a specific period of time. If this is not effective and finally the problem is presented at a court, then the court has the right even to ask the annulment of the wind-park's operation permission. To judge the case, a noise Immission measurement is required and a question that will be imposed in the future, is who shall pay the initial cost. A cost which is relatively high, almost prohibitive in cases where the noise receptor is just an individual. This problem could be by-passed, if measurements for the assessment of environmental impact had been included in the valuation program for the final acceptance and payment of the subsidised projects (all wind-energy projects are subsidised by 40% of the total cost). Moreover valuable data could have been gathered for the evaluation of noise propagation models and as a basis for more effective legislation.

Noise prediction

Due to the complex terrain, there are additional difficulties on the prediction of noise propagation in Greece. However, there are no criteria or a guide for acceptable noise propagation models by the central or local authorities.

The majority of Greek Wind Energy developers use the WINPIV software developed by NTUA (National Technical University), to present the environmental impact information requested by the authorities for the wind-park permission. The noise contours are based on the geometrical divergence of hemispherical noise propagation over a flat, reflective surface. Atmospheric absorption according to ISO 9613-1 is included, with inputs the temperature, relative humidity and air pressure. Ground properties, wind speed, direction and shear, are not taken into account.

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Stockholm, 27-28 November 2000
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Note on noise Immission from W/Ts in Greece

Noise immission measurement.

The procedure for the measurement of noise immission from WTs, is based on the relevant IEA document and described in a draft edited at 1999 by the relevant national working group, but it's unpredictable when it shall be officially accepted.

- Noise levels are described by the equivalent continuous A-weighted sound pressure level.with averaging time 2-10 minutes.
- The broadband noise immission is determined at a wind speed of 8 m/s at the wind turbine site and at a height of 10 m. Tonality is also determined at the same wind speed, except if there are indications that is more prominent at a different wind speed.
- No special treatment has been anticipated for the cases of variable-speed WTs, but the possibility of having tones at wind speeds different from the target 8 m/s, is covered by the requirement to assess the tonality at the wind speed where it's more prominent, as already mentioned.
- The calculated or measured wind speed V_h at a height of h m, should be converted to the wind-speed V_{10} at 10 m height, by using the power wind law :

  $$V_{10} = V_h * (10/h)^{\alpha}$$

  The power law exponent α, can be estimated from the appearance of the upwind terrain.. Some indicative values are 0.14 for open flat terrain, 0.07 for complex terrain ridges, even 0.0 on top of hills.
- The method for the assessment of tonality is identical with the one described in the revision of IEC 61400-11, draft 88/130/CD from 1/9/00 (analyzing twelve 10-seconds periods).

  Deviating from the above, no correction is proposed for the hanning window and no correction for background noise. A two minutes period of background noise is analyzed only to ensure that the tones do not originate from the background noise.

  A correction presented on the table below, is applied on the broadband noise level, depending on the value of the «tonal audibility», which is the difference between the assessed tonality ΔL and the frequency dependent audibility criterion L_{crit} according to the Joint Nordic Method.

Tonal audibility (dB)	Broadband noise level correction (dBA)
$\Delta L - L_{crit} \leq 2$	0
$2 < \Delta L - L_{crit} \leq 8$	$\Delta L - L_{crit} - 2$
$8 < \Delta L - L_{crit}$	6

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Note on noise Immission from W/Ts in Greece

WT on a hill. Sound generation, perception and measurement.

- For a WT on a hill, both the turbulence and the angle of attack for the wind velocity (the inclination of wind speed) are increased. There are some indications that this increase can lead consequently on increased sound power emission, but some relative experiments have resulted in unclear and not generally usable conclusions.
- The wind speed on a hill, is 1.5 - 2 times the wind speed at a receptor's site wind-screened by the hill. Consequently the background noise is less than it would be in a flat terrain and the WT noise appears more prominent.
- The main point on a hill is that the wind shear tends to be uniform and in many cases, it is uniform. When the power curve is used for the sound power determination it's oK, but if we use the wind speed's measurement at 10 m height we under-estimate the sound power output at reference wind speed.. The above refer also to the sound pressure level at receptor's site when the target wind-speed is obtained at the turbine site.

Topics for discussion, revision or clarification, on the IEA document

- Tonality assessment (taking into account the IEC document revision).
- Determination of wind speed from the electric power output (reference to Variable speed WTs).
- Wind speed reduction (reference to complex terrain conditions).

Acoustic performance of a large vertical board

Yoshinori Nii (Mechanical Eng. Lab.)

Objective:

To see sound level distributions along two centerlines on a board by field tests in terms of;

- difference from free-standing microphone,
- shield effect of the board,
- A-weighted level and one-third octave band spectrum.

Presentation:

- Test site and method
- Test results
- Summaries

Summaries:

A-weighted levels were found on wide range along the centerlines of the board;

- exactly 6 dB above from the levels of free standing microphone for both sites ,
- being reduced around 10 dB for the noise back from the board.

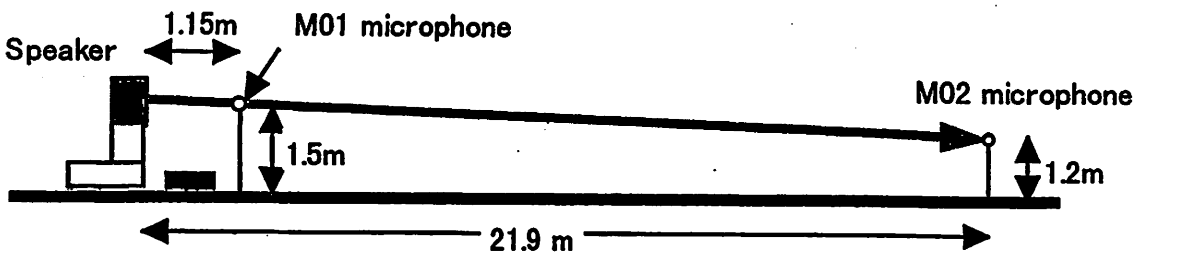
One-third octave band levels;

- didn't show 6 dB difference from the levels of free standing microphone,
- the difference has depended on the frequency such that the higher the frequency the smaller the levels.

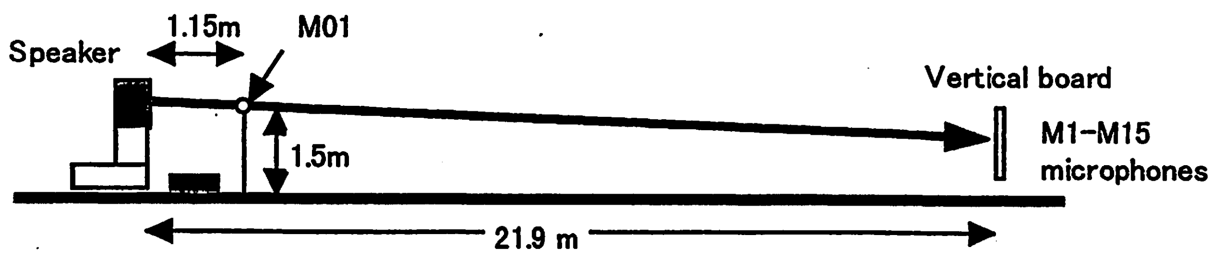
Suggestion;

- Size of the board could be much smaller?

Test description



Set-up for a free-standing microphone.



Set-up for a large vertical board.

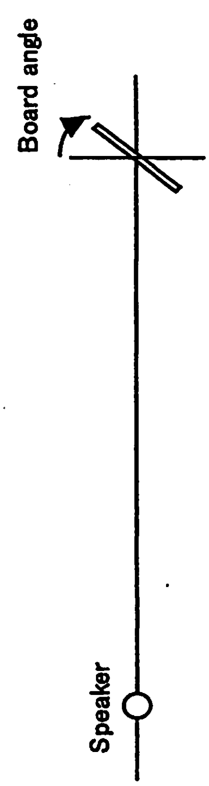
Measurements: One minute linear average

Test sites

A: 200m by 130 m wide asphalt surface

B: Lawn covered surface

Definition of board angle



0 degree: Board is facing to the speaker.

180 degrees: Facing opposite direction from the speaker.

Measured board angle

Site A 0 and 30 degrees

Site B 0, 135 and 180 degrees

One-third octave band response measurements

Relative response (dB) = $SPL_j(M_i) - SPL_j(M02)$

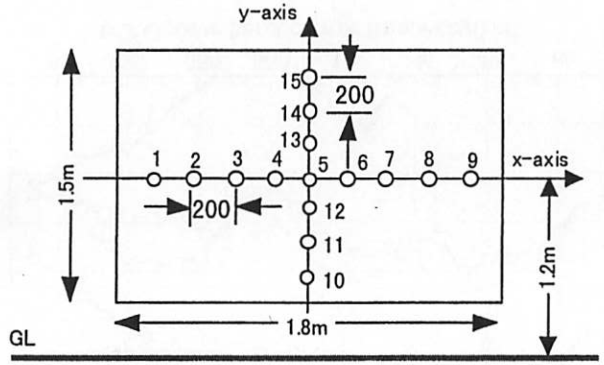
i: microphone number on the board

j: frequency

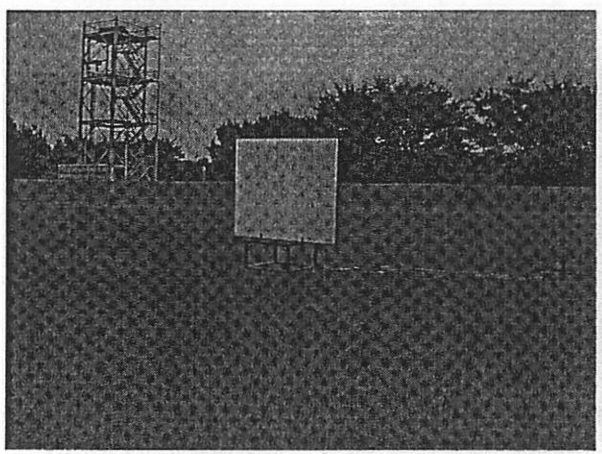
Measurements

One minute linear averaged

Tested vertical board

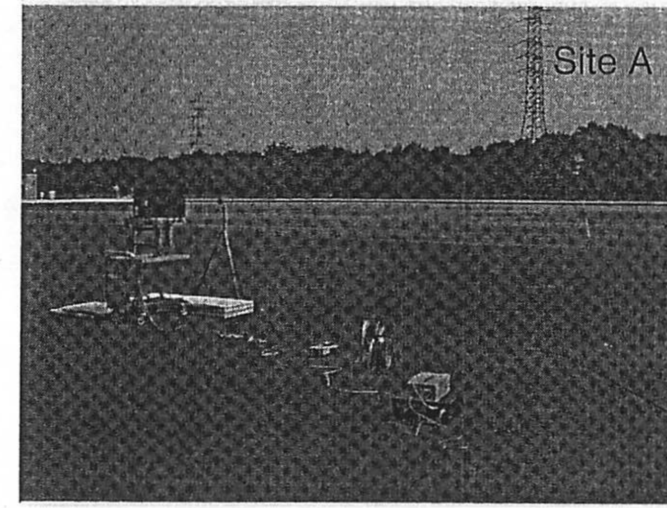


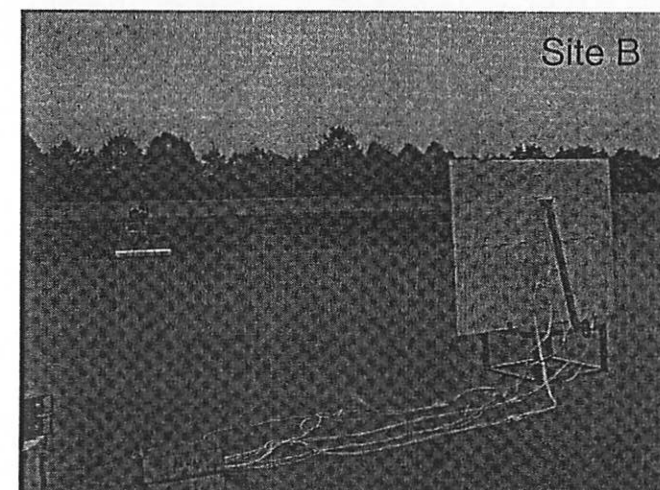
Board dimensions and microphone location.



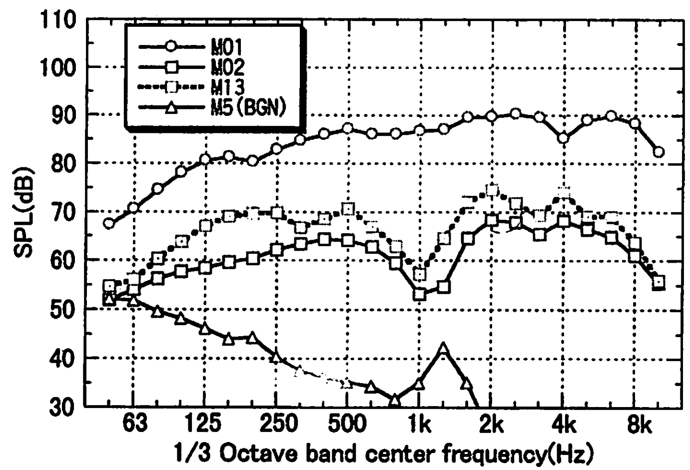
Vertical board at the site B.

Test site and set-up

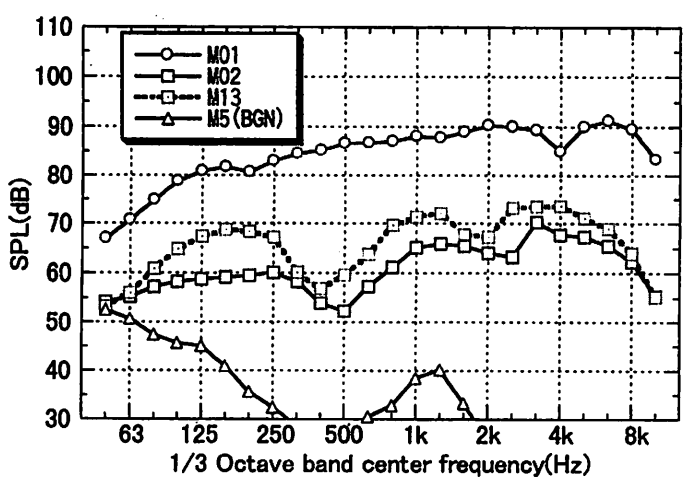




Frequency responses of the M01, M02 and M13 microphones

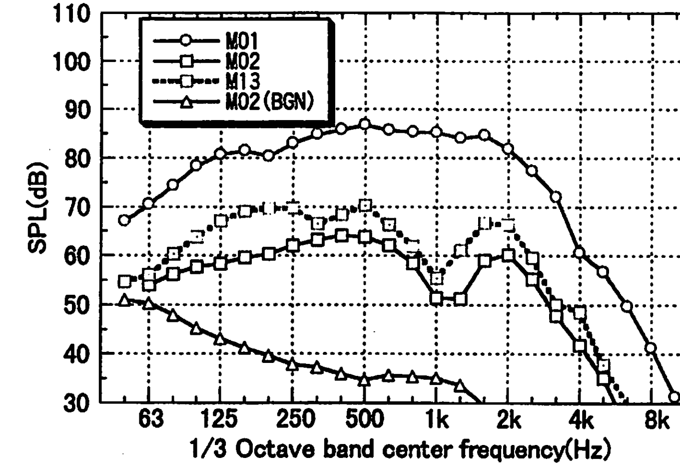


Site A

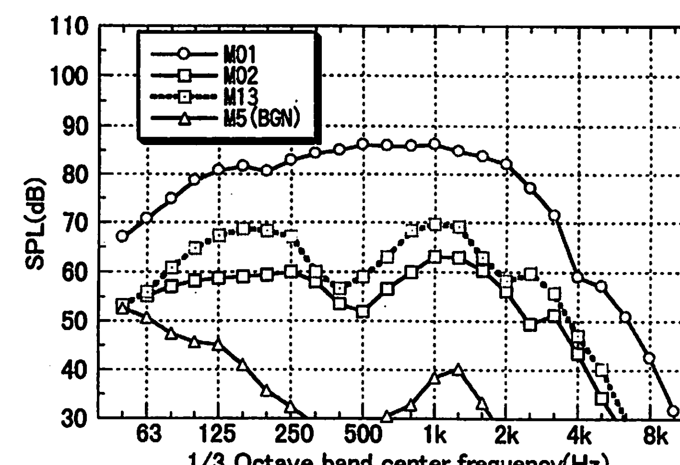


Site B

Examples of frequency response for A-weighted analyses



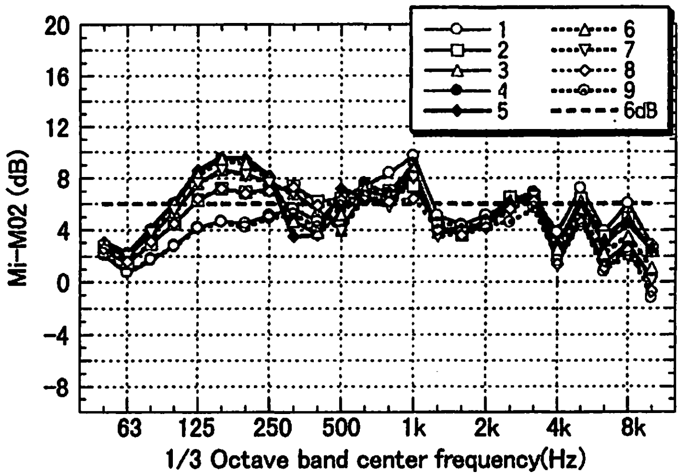
Site A



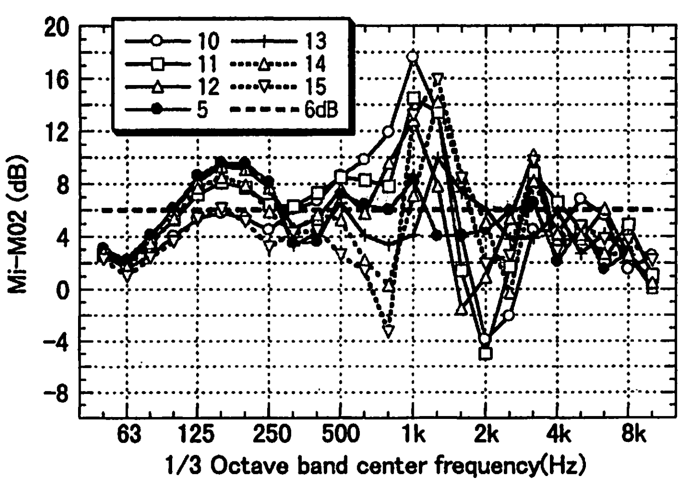
Site B

Relative responses at the site A

Board angle=0 degree



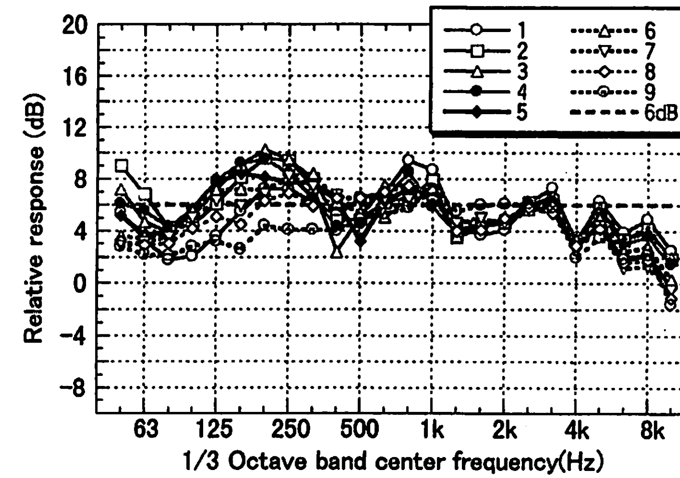
x-axis



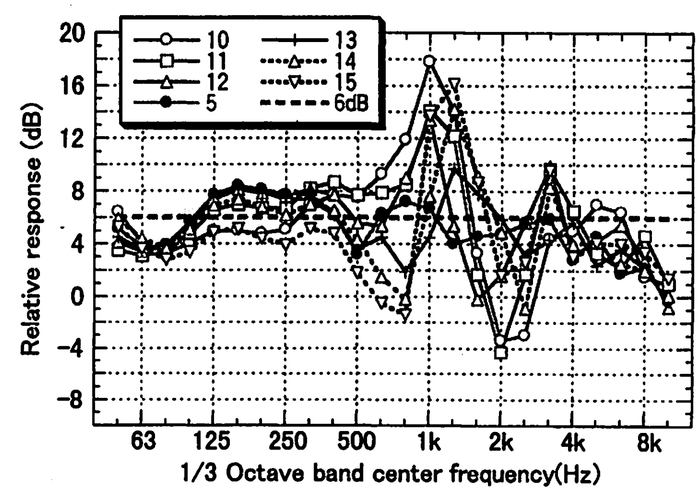
y-axis

Relative responses at the site A

Board angle=30 degree



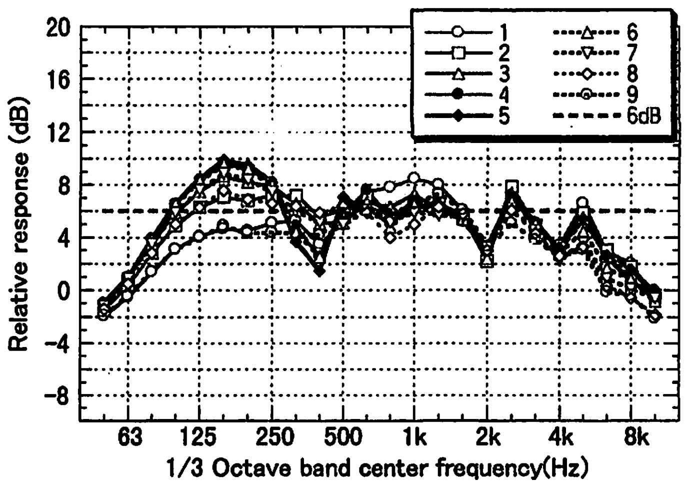
x-axis



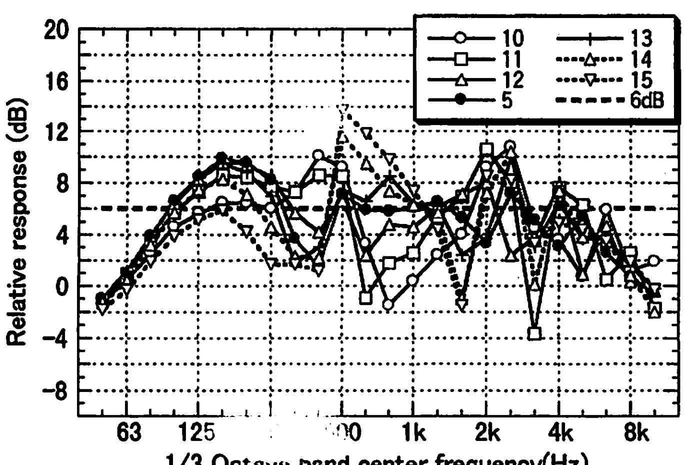
y-axis

Relative responses at the site B

Board angle=0 degree



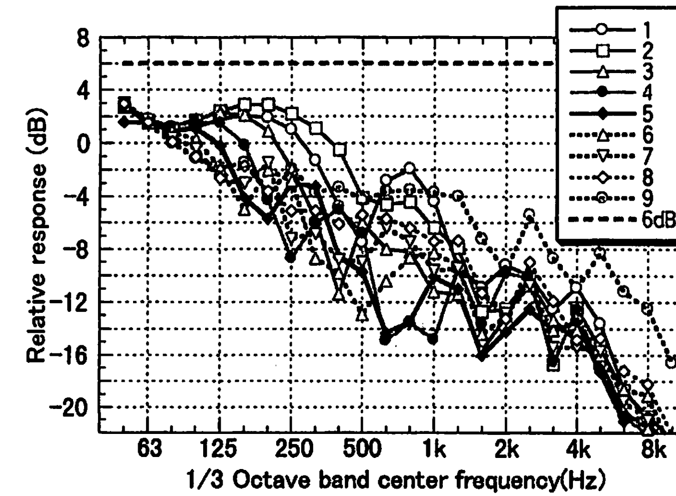
x-axis



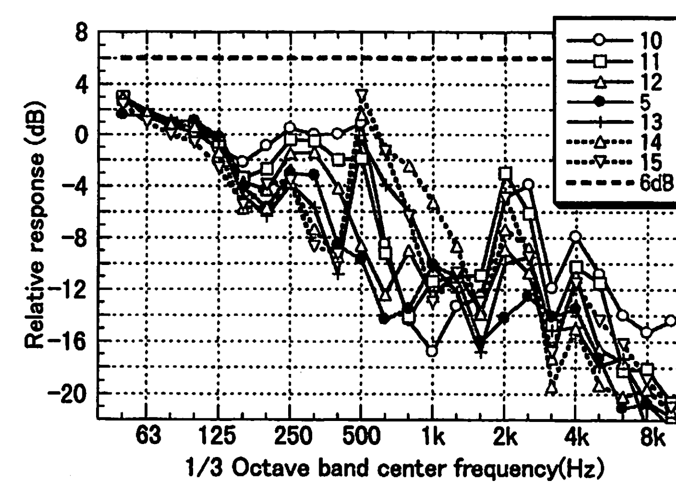
y-axis

Relative responses at the site B

Board angle=135 degrees



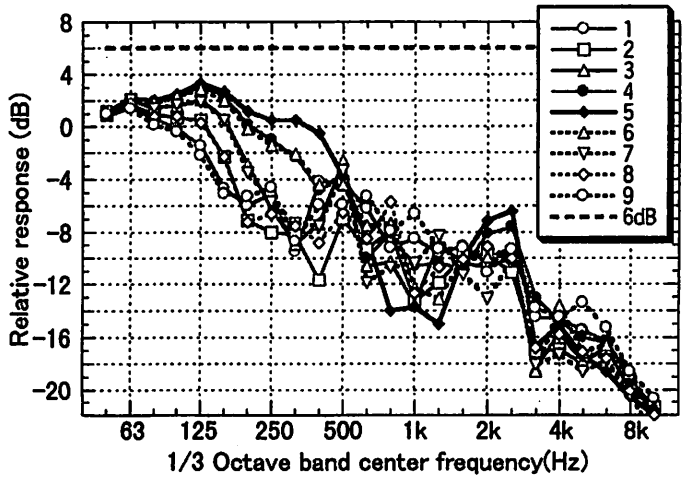
x-axis



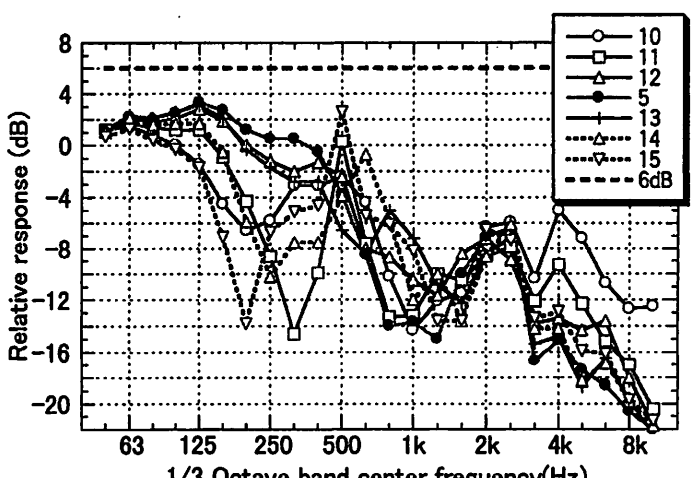
y-axis

Relative responses at the site B

Board angle=180 degrees

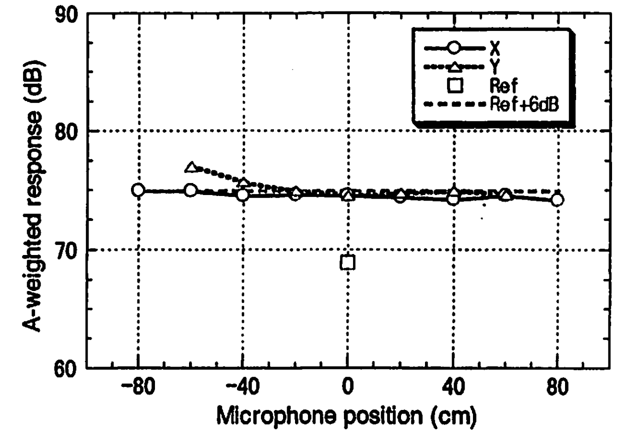


x-axis

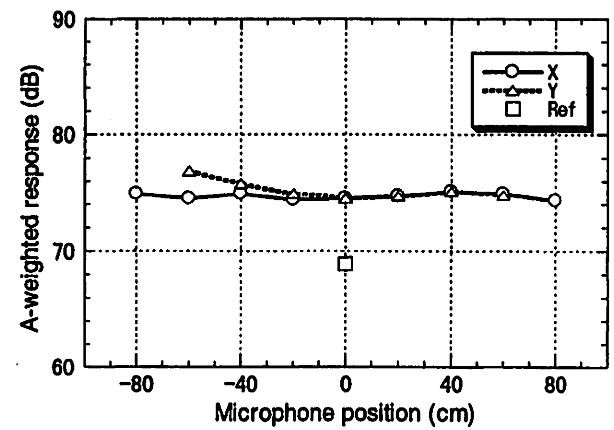


y-axis

A-weighted level on the board at the site A

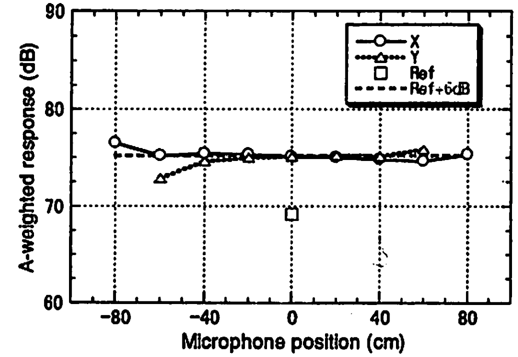


Board angle=0 degree

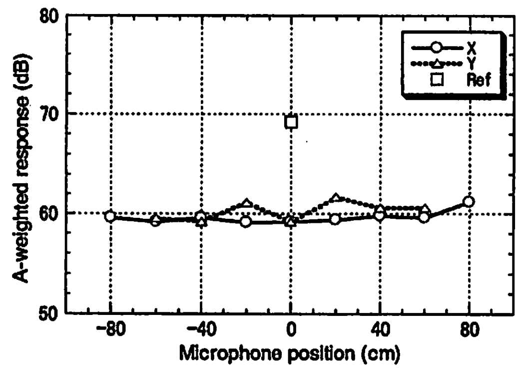


30 degrees

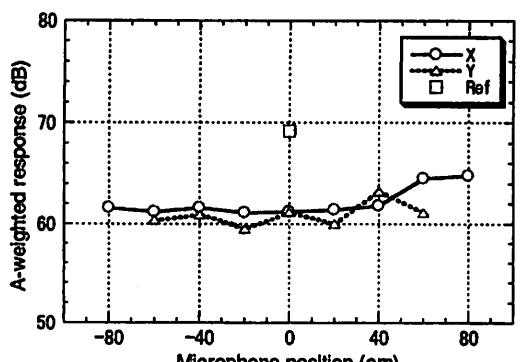
A-weighted level on the board at the site B



Board angle=0 deg



180 degrees



135 degrees

Notes from the IEA Topical Expert Meeting in Stockholm, 27-28 November 2000

By Lisa Johansson, KTH Stockholm

Discussion

The IEA Topical Expert Meeting started with presentations made by the participants. After the presentations the rest of the meeting consisted of discussions. These mainly covered the topics in the agenda given in the invitation. The summary that follows is based on that agenda though slightly different since some other issues, such as offshore wind turbines and indoor noise, was discussed as well.

Form of permissions, guidelines and limits

How the immision guidelines and limits are set in different countries and how wind power developers get permission were covered quite well in the presentations. The topic did however reappear several times during the discussions. A short summary of different limits and regulations follows.

Sweden:
The guideline used when giving permission is the night value for industrial noise of $L_{p,eq}$ = 40 dB(A). In recreational areas and areas with mostly summerhouses there is a reduction of 5 dB (A). The penalty for pure tones is 5 dB. Measurements are made as recommended in the IEA immission document at wind speeds of 8 m/s at 10 m height.

Norway:
Norway has a limit of $L_{p,eq}$ = 40 dB(A) but for cases with pure tones or/and in screened areas the limit is $L_{p,eq}$ = 37 dB(A).

Denmark:
In Denmark the limit is not a measured noise level but a calculated one. The maximum noise immission level at downwind conditions is calculated using the noise power level for a wind speed of 8 m/s at 10 m height. The uncertainty of the emission measurements is assumed to be 2 dB (A).

Immission measurements are rarely done. Instead, if there is a complaint, the noise emission is measured and then the immission level is calculated using the same model as during the planning.

France:
In France there is a neighbourhood noise regulation where the limit is related to the background noise level. The allowed increase in noise level is 5 dB (A) at daytime and 3 dB (A) at night. Hence there is no absolute limit. The noise measurements must be made at wind speeds below 5 m/s.

There is also a recommendation of a 500 meters buffer zone.

Holland:
The Dutch are introducing new regulations. Now the limit is directly linked to the background noise. In the future the limit will follow a wind speed dependent curve. The limit starts at 40 dB (A) (at night) at 1 m/s and increases with the wind speed to 50 dB (A) at 12 m/s. For daytime and evenings there are similar curves starting at 50 dB (A) and 45 dB (A) respectively. In these new regulations the measurements are made according to the IEA immission document.

For the regulations used today a standardised background noise level value is assumed. Though there are quiet places where the noise level from wind power plants will exceed the background noise it is said that the noise level at those places will still be acceptable. In especially quiet areas the local authorities have the right to claim that the background noise level value should be lowered for that area but it is a quite complicated and expensive procedure.

Greece:
There is an indoor limit of 45 dB (A) for nearby dwellings with open windows. In residential areas the outdoor limit is 50 dB (A). The same value is used all day. The noise immission is measured at 8 m/s at 10 m height except for special cases in complex terrain.

Some comments on the regulations:
In quiet areas there is a risk that wind turbine noise will exceed the background level even if it is lower than the immission limit. It will however be quite unpractical to take special notice to such areas and since the immission limit is respected the noise level will still be acceptable. Complaints from neighbours can unfortunately be expected no matter where the wind power plants are built.

The question arose of how many complaints are acceptable for a noise level limit. Jørgen Jacobsen told about a small study in Denmark showing that about 10% of the population will feel disturbed by the immission limits that they have. He thought that this number was quite reasonable.

Whether people will be disturbed or not is a very subjective matter. In Sweden a recently started PhD project will investigate how the public's sensitivity concerning wind turbine noise is affected by their attitude towards wind energy. In Holland there is also an increased interest in subjective, non-technical aspects of how the public experience noise and other environmental disturbances. For example, the odour regulation is already linked to how many people that feel disturbed by the odour.

In several countries there is a special regulation for wind power noise. Some of the participants pointed out that it would be simpler if wind power noise was included in other noise immission regulations.

Within the European Union the Commission has made a proposal for common noise immission level descriptions and evaluation methods. It is primarily intended for traffic noise but can be expanded to include other areas, such as wind power noise. It suggests an equivalent annual average sound level (L_{den}) where the night level has a penalty of 10 dB(A) and the evening level of 5 dB(A). The day is in this case 12 hours, the evening 4 hours and the night 8 hours. At which hour it is day, evening and night is decided by the countries. It should be emphasised that the proposal is not concerned with the specific values of the noise level limits, only with how they are defined.

Formulation of limits in acoustical terms

Type of acoustic level

The noise immission limits are in some countries given as equivalent levels and in some as percentiles. As said above, the new proposal from the European Commission uses equivalent levels. Nothing was said about advantages or disadvantages with the different types of levels.

Bo Søndergaard pointed out that if a maximum value is included in the limits this would give an instrument to force wind power plant owners to repair plants that occasionally makes too much noise.

Use of day, night and/or evening limits

In some countries the limit varies with the time of the day. The night limit is the lowest and therefore the determining value in most cases. Wind turbines with variable RPM can however alter their speed to fit the limits and hence increase the energy output during the day and lower it at night. The result will be that a turbine with variable RPM can produce more energy than a similar one with fixed RPM but still fulfil the noise regulations.

Dimitris Theofiloyiannakos liked the idea with several limits but thought that the authorities in Greece would be reluctant to introduce such regulations.

Sten Ljunggren told about an ETSU-report suggesting that the evening values should be lower than night values since the noise can be louder without being a disturbance when people are asleep. Bent Andersen and Kurt Braun did however not agree with this since a higher noise level at night could be a major problem for night workers and others trying to fall asleep at that hour.

Background noise

Determination of background noise can be a problem. In Holland they use standardised values for the background noise while in France they measure the background noise level on the site. If a model of the background noise is to be fairly detailed it will need many measurements. On the other hand should in situ measurements also be fairly extensive so that they can cover different kinds of weather conditions.

The question arose also of what should be included in background noise. If it is not just natural sound then the background noise in an area will increase as more and more sound sources (industries, roads, other wind turbines etc) are built. Hence, if the background noise is to include other artificial sound sources there must be a maximum limit of the noise immission.

Indoor noise

It was discussed whether it is possible to measure the noise immission indoors or if the indoor noise level most often is too low to be measured correctly. Olivier Fégeant told that he had experience from a person complaining about wind turbine noise indoors, the turbines could be heard very faintly but the noise level indoors could not be measured. In Holland the noise immission level indoors is 15dB(A) lower than the corresponding outdoor limit. However the noise level is not measured indoors, instead they measure it outdoors and then reduce that value with the insulation of the walls.

When the wind blows around a house broadband noise is generated. It is therefore important to measure the noise level at the same wind speed with and without the wind turbines operating. It is also important to measure at different points indoors to avoid resonance effects due to the properties of the room.

Some countries, as Sweden and Holland, have standards for how to measure indoor noise.

Treatment of wind turbines with variable RPM

The issue of wind turbines with variable RPM was discussed throughout the meeting. Though there are not many of these wind turbines installed today the number is likely to increase in the near future.

As said when different day and night limits were discussed, having different immission limits at different hours will increase the possible energy output of a wind power plant with variable RPM. Kurt Braun said that these turbines should be treated fairly and that they therefore also should be allowed to emit more noise at high wind speeds. Due to increased background noise this will not be disturbing. The new regulation in Holland uses a wind speed dependent immission limit and is therefore an advantage for these turbines.

It was said that the plant owners should be able to know how high electric power they could have at different wind speeds without violating the noise limits. The IEA standard states that the noise immission shall be measured at 8 m/s wind speed. This allows for higher sound levels at higher wind speed but it also gives the wind plant owners the possibility to optimise their plants so that they won't emit more than allowed at 8 m/s and not caring for the emission at other wind speeds. Limits at several wind speeds or integration over a range of wind speeds would perhaps be better. This will however require quite a lot of measurements.

Another idea was to relate the noise level to the electric power instead of the wind speed. Then there is no risk of a dishonest owner shutting down the turbine and only letting the blades rotate when measuring the noise level. It would also be easier for the owners to know how much electric power they can produce at different wind speeds. This will however require information from the manufacturer of how the noise changes with electric power.

When dual speed turbines change their RPM there is a risk of high noise levels. Due to this Sten Ljunggren asked if a short-term limit higher than the normal limit is needed. The general opinion was that it isn't since these problems probably can be avoided if the turbines are constructed correctly. Hydraulic control of the turbines should for example be avoided since they always generate noise. Since high noise at speed changes is created by resonance this is also a structural problem, which the manufacturers most probably will correct.

Calculation formulae for the immission levels

During the discussion of this topic Jørgen Jacobsen and Sten Ljunggren told about a program called WiTuProp for calculating sound propagation that is freeware. It has been used in Sweden for upwind conditions. It is based on geometric ray-tracing and assumes ground with finite impedance and homogenous atmosphere. For these conditions it has given good results. There is also a version for refracting atmosphere.

Absorption

The atmospheric absorption can be calculated if the temperature, the pressure and the relative humidity of the atmosphere is known. How to do this is described in the standard ISO 9613-1:1993 and ISO 9613-2:1996. If there are no meteorological data from the specific site there are standard values that can be used. The standard values are however quite rough. In Sweden the absorption has been calculated for different places using meteorological data from several decades, giving more accurate values.

Topographical effects on sound generation

In complex terrain the emission from the same kind of wind turbine will vary much depending on the surroundings. In complex terrain there are vertical movements of the air and quite often turbulence that cause sound generation around the wind turbine blades. When measuring noise immission the wind speed is often only measured at 10 m height, which does not give enough information to predict these effects.

One of the worst cases is if a wind power plant is standing near a slope, then there can be a difference in the noise emission up to 5-6 dB(A) compared with data from the manufacturer. This is due to that the wind flow hits the blades with an angle, which generates more sound than if it hits the blades perpendicularly. This will also create vibrations in the turbine making it not only a noise problem but a structural one as well.

Franco Guidati told that they have been measuring the noise emission for different jaw angles. They found that at a certain angle the noise will increase rapidly and the electric power will decrease. At 45° the power is halved.

It seems however that there is no good model to calculate these effects accurately. There have be efforts trying to relate the noise emission to the wind shear but with no success. It is possible that it is better to try to relate the noise emission to the electric power instead of the wind speed. This will however not solve the problem entirely since the propagation also is affected by complex terrain and turbulence.

Offshore wind turbines

The wind power industry seems to think that noise is not a problem for offshore wind turbines but the fact is that we don't have enough knowledge in this area yet. According to Sten Ljunggren there is an example of offshore wind turbines being heard as far as 100 km from the site at certain weather conditions. The noise immission level was in this case about 30 dB. That sound can travel long distances over water is not surprising tough and other examples was given by Jørgen Jacobsen (a ferry emitting pure tones heard 50 km away) and Hans Geleijns (a shooting site).

When sound is propagated over water in downwind conditions there will be a tunnel effect where the sound energy is trapped between the reflecting water surface and layers of air with high wind speed. The sound level will be highest near the ground. How often this happens is not know yet and we need meteorological data to find that out. The same problem with tunnel effects can be observed under the water where the sound is trapped between layers of different salinity.

Today there is quite few offshore wind turbines and they are relatively small. There are however plans for larger farms in many countries and the wind turbines used there will most likely be larger than land based turbines hence emitting more noise. It is however possible to modify the RPM of the wind power plants and thereby move the noise emission to higher frequencies. This would improve the situation since high frequencies are absorbed more.

The group agreed that above all measurements of long range sound propagation over water is needed, especially due to the industry's unawareness of the problem. Long-term measurements from offshore wind turbines are planned by Sten Ljunggren and Lisa Johansson as a part of Lisa Johansson's PhD project and will hopefully be carried out within a few years.

Certification of prediction models and measurements

There are three areas in which certification and accreditation could be needed; when calculating expected noise immission level, when measuring noise immission and when manufacturers specify noise emission.

In Sweden there has been a discussion if prediction models should be certified since some developers have used models and programmes that didn't agree with Swedish recommendations. In Denmark they do not have that problem since they have a calculation method within their regulations. They also have a system for accrediting those who make measurements, so have also some of the other countries.

The discussion came to concentrate on how to certify the manufacturers specifications. When measuring noise emission from prototypes the conditions are often perfect and the prototypes optimised. The noise level will therefore most probably be as low as it can be for that type of turbine. An emission level of about 2-3 dB compared to more realistic conditions is quite common. Some authorities also always assume that the turbines will emit 2-3 dB more than stated while others warn developers who are to close to the regulation limit that measurements will be done after the installation. There is also an ageing effect that needs to be considered; a wind turbine will often emit more noise some time after the installation.

Today the manufacturers often only measure on one turbine. If they measured the emission from 2-3 turbines the result could be a bit more accurate but the measurements would still be done at unrealistic conditions. Franco Guidati suggested that an artificial roughness could be applied to the blades to obtain a more correct emission. Random measurements during the production are also an idea.

It was concluded that it would be beneficial for both the manufacturers themselves and others to know the production uncertainty for emission from wind turbines.

Experiences from immission measurements

Sweden and Germany use the IEA document for measuring noise immission and Hans Geleijns said that he thought that the Dutch standard agreed with it. In France they had not heard of it until this meeting. They measure the noise immission at less than 5m/s but the IEA standard can probably still be used though it says that the target wind speed should be 8 m/s.

The measurement of pure tones is quite complicated and will be rewritten if there is a new revision. In the emission document (for which there is a new version) the tonality is given as a RMS average. It was not agreed on whether this would be good idea for immission measurements as well since the tones are masked during the propagation. However it did not seem as a new version of the immission document is needed just to change this.

No specific simplification was asked for but there was a discussion of how to measure immission from offshore wind turbines. When this has been done a method should be included in the document. Dimitris Theofiloyiannakos also asked for more on how to measure in complex terrain and how to do with turbines with variable RPM.

Consequences in case of limit violation

Different ways of dealing with limit violations were discussed it seems as the most common methods are fees and (partial) closure of the wind turbines. There are quite many examples of turbines that have to be closed during night or that a few turbines in a group are closed.

In some countries the owner of the turbines can make an agreement with the neighbours and the local authorities to compensate the neighbours with better house insulation. If such agreement is made the immission level can be raised.

Jørgen Jacobsen told of a case where a neighbour complained of the noise from a wind turbine. Since he was the only resident in the area a power switch was installed in his house so that he himself could shut down the turbine when he felt disturbed. He did however never use the switch. Though this was a quite extraordinary case it is common that if the public is included in the discussions and offered some kind of compensation their attitude will change and there will be less complaints.

Though it is the laws in the different countries that decide the punishments for violations it could be beneficial if representatives for the countries were to exchange experiences in this area.

IEA R&D Wind Expert Meeting on Noise Immission in Stockholm November 27-28 2000

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