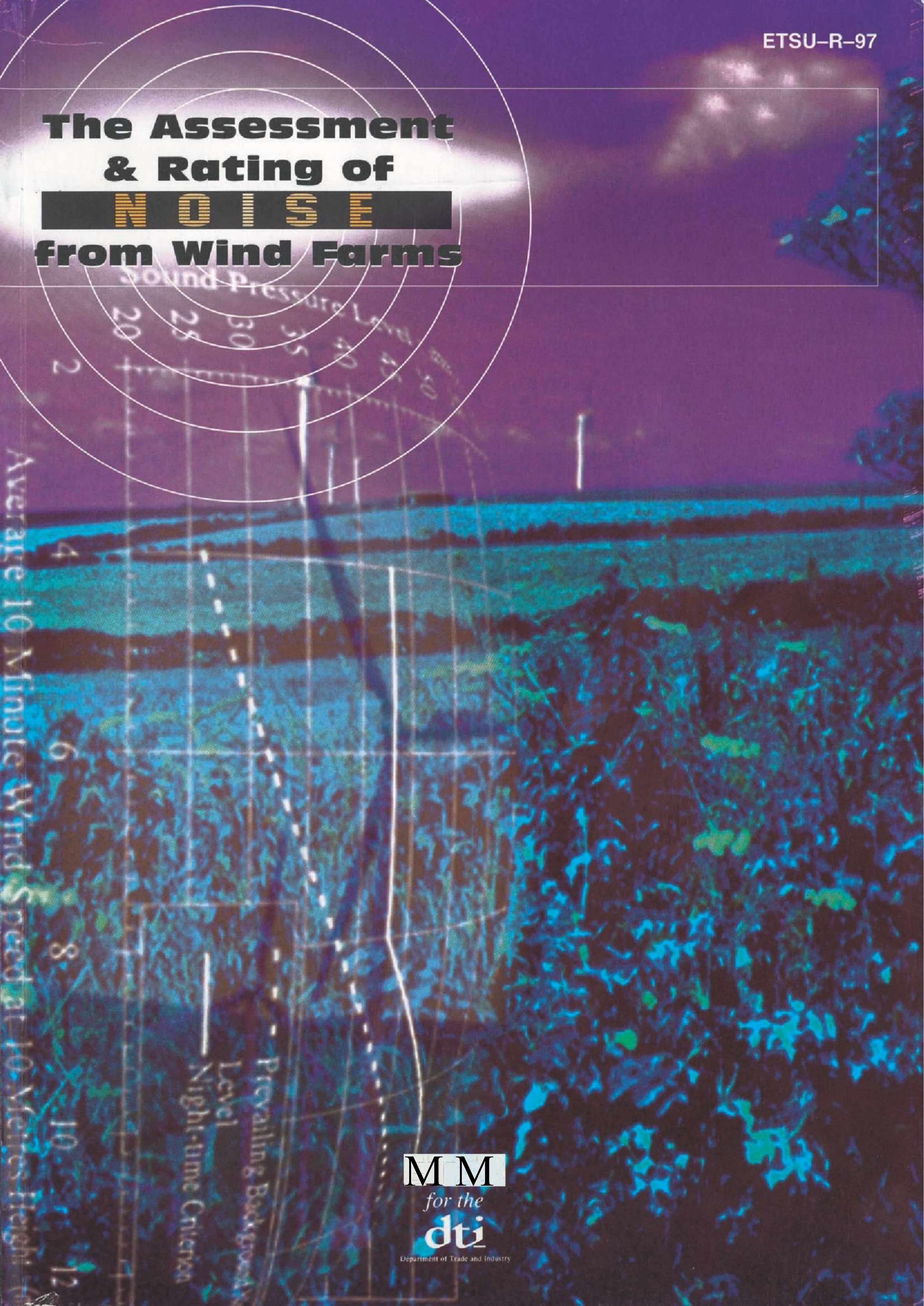
ETSU–R–97

The Assessment & Rating of NOISE from Wind Farms



MM
for the
dti
Department of Trade and Industry

ETSU-R-97

THE ASSESSMENT AND RATING OF NOISE FROM WIND FARMS

The Working Group on Noise from Wind Turbines

Final Report
September 1996

PREFACE

This report describes the findings of a Working Group on Wind Turbine Noise. The aim of the Working Group was to provide information and advice to developers and planners on the environmental assessment of noise from wind turbines. While the DTI facilitated the establishment of this Noise Working Group this report is not a report of Government and should not be thought of in any way as replacing the advice contained within relevant Government guidance.

The report represents the consensus view of the group of experts listed below who between them have a breadth and depth of experience in assessing and controlling the environmental impact of noise from wind farms. This consensus view has been arrived at through negotiation and compromise and in recognition of the value of achieving a common approach to the assessment of noise from wind turbines.

Members of the Noise Working Group:

Mr R Meir, Chairman	DTI
Dr M L Legerton, Secretary	ETSU
Dr M B Anderson	Renewable Energy Systems
Mr B Berry	National Physical Laboratory
Dr A Bullmore	Hoare Lea and Partners
Mr M Hayes	The Hayes McKenzie Partnership
Mr M Jiggins	Carrick District Council
Mr E Leeming	The Natural Power Company Ltd
Dr P Musgrove	National Wind Power Ltd
Mr D J Spode	North Cornwall District Council
Mr H A Thomas	Isle of Anglesey County Council
Ms E Tomalin	EcoGen Ltd
Mr M Trinick	Bond Pearce Solicitors
Dr J Warren	National Wind Power Ltd

EXECUTIVE SUMMARY

INTRODUCTION

1. This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. The suggested noise limits and their reasonableness have been evaluated with regard to regulating the development of wind energy in the public interest. They have been presented in a manner that makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.

2. The noise limits suggested have been derived with reference to:

- existing standards and guidance relating to noise emissions
- the need of society for renewable energy sources to reduce the emission of pollutants in pursuance of Government energy policy
- the ability of manufacturers and developers to meet these noise limits
- the researches of the Noise Working Group in the UK, Denmark, Holland and Germany
- the professional experience of members of the Working Group in regulating noise emissions from wind turbines and other noise sources
- the discussion of the issues at meetings of the Noise Working Group and with others with appropriate experience.

3. The Noise Working Group has sought to protect both the internal and external amenity of the wind farm neighbour. Wind farms are usually sited in the more rural areas of the UK where enjoyment of the external environment can be as important as the environment within the home.

4. The guidance contained within this report refers to the operation of the wind farm and is not appropriate to the construction phase.

NOISE LIMITS

5. The Noise Working Group recommends that the current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment.

6. Given that one of the aims of imposing noise limits is to protect the internal environment, one might consider it appropriate to set these limits and hence monitoring locations at positions within the building. There are, however, some practicalities to take into consideration which lead us to believe that the current practice of setting external limits on noise is the more sensible approach; these factors are described in detail in Chapter 6 of the full report.

7. The noise limits applied to protect the external amenity should only apply to those areas of the property which are frequently used for relaxation or activities for which a quiet environment is highly desirable.

8. The Noise Working Group considers that absolute noise limits applied at all wind speeds are not suited to wind farms in typical UK locations and that limits set relative to the background noise are more appropriate in the majority of cases.

9. Only by measuring the background noise over a range of wind speeds will it be possible to evaluate the impact of turbine noise, which also varies with wind speed, on the local environment.

10. The Noise Working Group is of the opinion that one should only seek to place limits on noise over a range of wind speeds up to 12m/s when measured at 10m height on the wind farm site. There are four reasons for restricting the noise limits to this range of wind speed:

- Wind speeds are not often measured at wind speeds greater than 12m/s at 10m height

- Reliable measurements of background noise levels and turbine noise will be difficult to make in high winds

- Turbine manufacturers are unlikely to be able to provide information on sound power levels at such high wind speeds for similar reasons

- If a wind farm meets noise limits at wind speeds lower than 12m/s it is most unlikely to cause any greater loss of amenity at higher wind speeds

11. The recommendation of the Noise Working Group is that, generally, the noise limits should be set relative to the existing background noise at nearest noise-sensitive properties and that the limits should reflect the variation in both turbine source noise and background noise with wind speed. We have also considered whether the low noise limits which this could imply in particularly quiet areas are appropriate and have concluded that it is not necessary to use a margin above background approach in such low-noise environments. This would be unduly restrictive on developments which are recognised as having wider national and global benefits. Such low limits are, in any event, not necessary in order to offer a reasonable degree of protection to the wind farm neighbour.

12. Separate noise limits should apply for day-time and for night-time. The reason for this is that during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. Day-time noise limits will be derived

from background noise data taken during quiet periods of the day and similarly the night-time limits will be derived from background noise data collected during the night.

Quiet day-time periods are defined as:

All evenings from 6pm to 11pm,
plus Saturday afternoon from 1pm to 6pm,
plus all day Sunday, 7am to 6pm.

Night-time is defined as 11pm to 7am.

13. Consideration has also be given to circumstances where a more simplified approach, based on a fixed limit, may be appropriate.

14. The Noise Working Group is agreed that the $L_{A90,10min}$ descriptor should be used for both the background noise and the wind farm noise, and that when setting limits it should be borne in mind that the $L_{A90,10min}$ of the wind farm is likely to be about 1.5-2.5dB(A) less than the L_{Aeq} measured over the same period. The use of the $L_{A90,10min}$ descriptor for wind farm noise allows reliable measurements to be made without corruption from relatively loud, transitory noise events from other sources.

15. The limits to be proposed relate to free-field (except for ground reflections) measurements in the vicinity of noise-sensitive properties.

16. The Noise Working Group is of the opinion that absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area contributing to the noise received at the properties in question. It is clearly unreasonable to suggest that, because a wind farm has been constructed in the vicinity in the past which resulted in increased noise levels at some properties, the residents of those properties are now able to tolerate higher noise levels still. The existing wind farm should not be considered as part of the prevailing background noise.

17. Wind turbines operate day and night dependent upon wind speeds. It will be necessary to acquire background noise data for both day- and night-time periods because:

- the absolute lower limit is likely to be different for day- and night-time operation
- the noise limits are to be related to the background noise levels
- background noise levels may be different in the day than during the night.

18. It is proposed that the background noise levels upon which limits are based and the noise limits themselves are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions.

19. The variation in background noise level with wind speed will be determined by correlating $L_{A90,10min}$ noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data.

20. The wind farm noise limits proposed below refer to rating levels in a similar manner to that proposed in BS 4142 in respect that additions are made to the measured noise to reflect the character of the noise.

21. Noise from the wind farm should be limited to 5dB(A) above background for both day- and night-time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different.

22. In low noise environments the day-time level of the $L_{A90,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). The actual value chosen within this range should depend upon a number of factors:

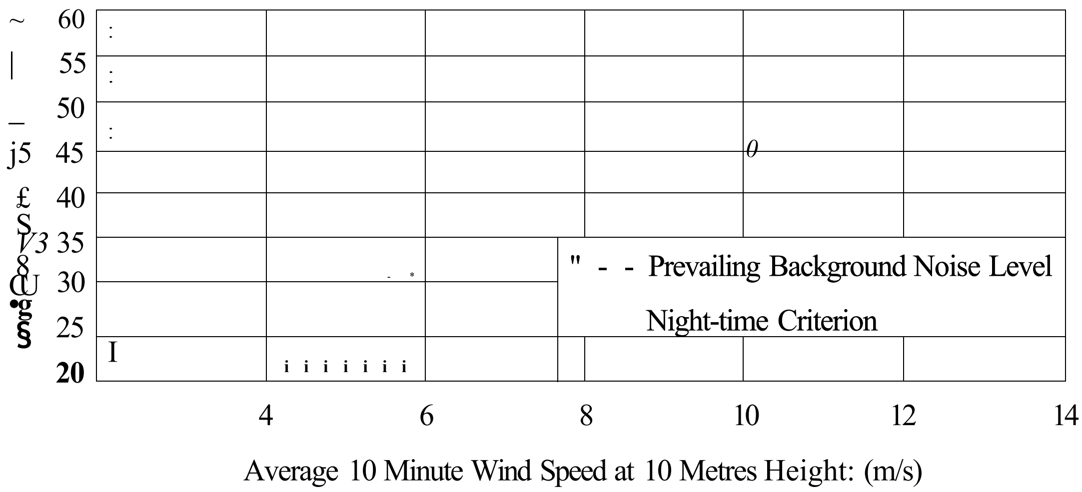
- the number of dwellings in the neighbourhood of the wind farm
- the effect of noise limits on the number of kWh generated
- the duration and level of exposure.

23. The Noise Working Group recommends that the fixed limit for night-time is 43dB(A). This limit is derived from the 35dB(A) sleep disturbance criteria referred to in Planning Policy Guidance Note 24 (PPG 24). An allowance of 10dB(A) has been made for attenuation through an open window (free-field to internal) and 2dB subtracted to account for the use of $L_{A90,10min}$ rather than $L_{Aeq,10min}$.

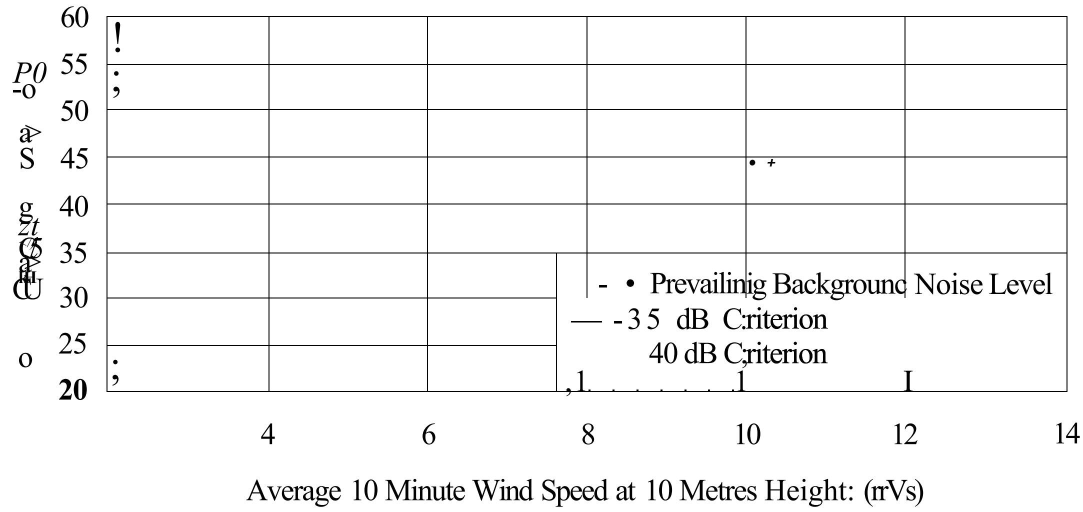
24. The Noise Working Group recommends that both day- and night-time lower fixed limits can be increased to 45dB(A) and that consideration should be given to increasing the permissible margin above background where the occupier of the property has some financial involvement in the wind farm.

25. For single turbines or wind farms with very large separation distances between the turbines and the nearest properties a simplified noise condition may be suitable. We are of the opinion that, if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height, then this condition alone would offer sufficient protection of amenity, and background noise surveys would be unnecessary. We feel that, even in sheltered areas when the wind speed exceeds 10m/s on the wind farm site, some additional background noise will be generated which will increase background levels at the property.

26. Graphical representations of the recommended limits appear in the figures overleaf based upon a fairly typical background noise curve. Both background levels and turbine noise are determined by best-fit curves through representative data.



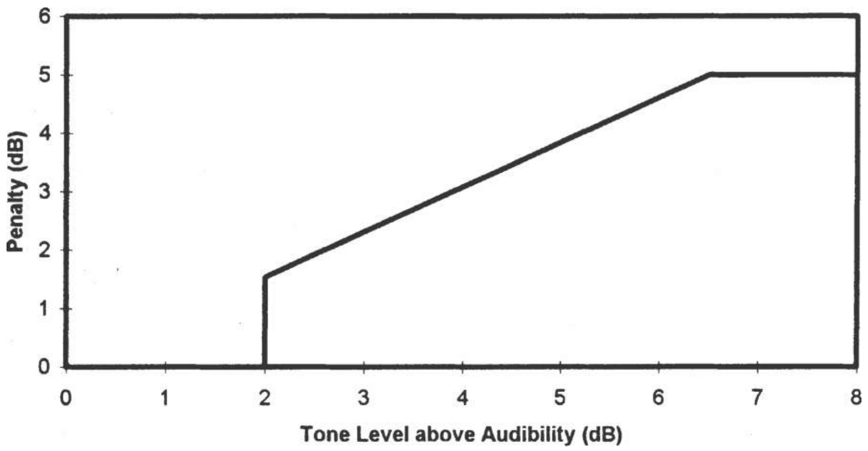
Example of night-time noise criterion



Example of day-time noise criterion

27. The noise levels recommended in this report take into account the character of noise described as blade swish. Given that all wind turbines exhibit blade swish to a certain extent we feel this is a common-sense approach given the current level of knowledge.

28. The Noise Working Group recommends that a tonal penalty is added to the measured noise levels in accordance with the figure below. The penalty incurred is related to the audibility of any tones produced by the wind turbines when measured using a prescribed method as represented graphically below.



Penalties for tonal noise

29. The Noise Working Group thought that it would be beneficial to present its recommendations in a form which might be useful to developers and planners. We therefore considered drafting planning conditions, but came to the conclusion that the necessary definitions of terms which would be required would make planning conditions too complicated. Therefore, it was decided to produce covenants for inclusion within an Agreement between a developer and a local authority. Conditions and Agreements (known as Planning Obligations) are discussed in Chapter 2. The Planning Obligation produced by the Noise Working Group is reproduced in Chapter 8 where it is supplemented by some Guidance Notes to which it refers. These Guidance Notes also serve as a useful summary of the proposed measurement procedure.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

A Planning Policy Guidance Note on Renewable Energy, PPG 22 [1], was published by the Department of the Environment and the Welsh Office on 3 February 1993. PPG 22 contains an Annex on Wind Energy which includes some discussion on noise from wind turbines. This annex includes a description of the sources of noise from wind turbines, a discussion on the limitations on the use of BS 4142: 1990, "Method for rating industrial noise affecting mixed residential and industrial areas" [2], and advice on noise-related information that could usefully accompany a planning application. At the time of writing there was insufficient relevant experience of noise from wind farms in the UK environment and public reaction to the noise to be able to provide more specific guidance.

A literal interpretation of how BS 4142 should be applied to wind turbine noise assessment is difficult and its use may be inappropriate and problematical. These difficulties are discussed in Chapter 6 of this report.

With no generally agreed procedure for determining noise levels that provide acceptable protection to the amenity of local residents, planners and developers have been required to use their own experiences to bring forward workable solutions by reference to the particular character and sensitivity of the area. Many wind farms, though not all, have had conditions relating to noise levels from the wind farm specified in the planning consents. These have varied in noise level and measurement units (eg L_{A90} or L_{A50}) from site to site but generally fall in to two classes: either an absolute noise level which shall not be exceeded at the nearest residences or a margin above the existing background noise which shall not be exceeded.

It was, however, recognised that there was still a degree of uncertainty among planners and developers. Planners did not have much experience of noise from wind turbines in rural areas. Developers had no noise targets for guidance when selecting sites for wind farms or deciding upon turbine layout. Therefore, in August 1993, the DTI facilitated the establishment of a Working Group on Noise from Wind Turbines, consisting of experts with experience in the environmental assessment of noise from wind turbines. The objectives of the Noise Working Group were:

- To review recent experience in the field of wind turbine noise. This was to include an attempt to relate measured data to complaints and provide an expert assessment of the issues relating to wind turbine noise.

- To define a framework which can be used to measure and rate the noise from wind turbines. This was to include parameters to be measured, measurement methods, units and measurement periods and was to fulfil all the necessary criteria required for planning conditions or covenants within Planning Conditions.

- To provide indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours and encourage best practice in turbine design and wind farm siting and layout.

- To encourage the widespread adoption of the Working Group's recommendations.

The Working Group was asked to address the issues of broadband noise, tonal content and blade swish (the modulation of broadband noise at blade passing frequency). The following report describes the findings and recommendations of the Noise Working Group. These recommendations are intended to serve as an informative guide to assessing the environmental impact of the noise from wind turbines.

The report was drafted in the light of the best information available at the time. However it is acknowledged that as more experience and information become available and as circumstances develop it may become necessary to revise and improve the contents of this report. The Noise Working Group therefore suggests this report and its recommendations are reviewed in two years time. To this end, any comments on the usefulness of the report would be most welcome, including any suggestions for improvement with any supporting evidence where possible. Any such suggestions should be sent to the Noise Working Group Secretariat at the following address:

Noise Working Group Secretariat
c/o Dr M L Legerton
ETSU
Harwell
Didcot
Oxfordshire 0X11 ORA

2. THE PHILOSOPHY AND PRACTICE OF NOISE EMISSION CONTROL

Introduction

The way in which a society controls man-made noise sources reflects a variety of complex influences. These influences are social, economic, intellectual and political. They also reflect the limits of technical ability in the measurement of the noise source in question.

That the position is complex is reflected by the way in which those in the UK who live close to wind farms have reacted to noise generated by the wind turbines. An individual's reaction to the receipt of noise may reflect, at the same time, physical sensitivity to noise, local political attitudes to wind turbines, perceptions of the economic worth of wind energy generation, attitudes to wind energy development and development in the countryside, and the individual's own perception of wind turbines.

These complexities are not unique to the UK. Attitudes to noise emissions vary between and throughout all countries. However, certain patterns emerge both within Europe and within the UK. From the researches of the Working Party it seems that attitudes towards noise emissions, particularly with regard to wind turbines, are generally more rigorous in the northern countries of Europe where the most extensive deployment of wind turbines has taken place. In particular, Swedish and Dutch attitudes to the control of noise from wind turbines are strict, and the same could probably be said of the UK. Again, in Denmark there is a Statutory Order which specifically regulates noise from wind turbines, although perhaps less strictly than in Holland.

History of noise emission control in the UK

Modern noise control in the UK derives in spirit from the Wilson Report of 1964 [3]. One of the fundamental findings of the Wilson Report was that as a guiding principle noise regulation authorities should seek to control existing ambient noise at current levels. The existing noise environment should be maintained. This principle can be seen in DOE Circular 10/73 [4], now withdrawn in England in favour of Planning Policy Guidance: Planning and Noise, PPG 24, [5] issued in September 1994.

There can be little surprise at the findings of the Wilson Report or at the way it became transmitted into formal Government advice. The UK is relatively densely populated. Intensive and extensive developments in and adjoining towns and cities have over the years produced ambient noise levels much higher than might be desirable by any objective standard. At the same time, perhaps because of noise-generating development in towns and cities, those able to do so have sought the peace and quiet of the countryside for their leisure time. They have become commuters. It is to be expected that such persons will be exceptionally sensitive to any intrusions on the peace and quiet which they have obtained by moving to live in the countryside, whatever the reasons for the noise-generating activity which may prove to be such an intrusion.

Given the findings of the Wilson Report, and the advice in DOE Circular 10/73, it was logical that control of new noise emissions should have developed on the basis of a level of exceedence over the background noise level existing prior to the introduction of the new noise source. This approach is reflected in a well known advisory document on noise control, BS 4142. BS 4142 was first issued in 1967 and was most recently reissued in revised form in 1990. At the date of this report a further revision is in train.

PPG 24 and other advisory documents which include BS 4142: 1990 seek to control the noise environment by limits on the levels by which new development may cause the background noise level to be exceeded. However, there is a recognition that new development must take place because of the needs of the economy and of society. The aim of the guidance contained within PPG 24, as stated in the opening paragraph, is:

> *"..... to provide advice on how the planning system can be used to minimise the adverse impact of noise without placing unreasonable restrictions on development or adding unduly to the costs and administrative burdens of business."*

In the context of wind energy, the planning system must therefore seek to control the environmental impact from wind farms whilst at the same time recognising the national and global benefits that will arise through the development of renewable energy sources, and not be so severe that wind farm development is unduly stifled.

Special considerations are given to some types of development, such as road, rail and airport developments where the balance advised in PPG 24 is particularly difficult to achieve. In recognition that such developments must take place, but that they will cause significant changes to the noise environment of neighbours, a statutory compensation code has been developed. The statutory framework for this code is within the Land Compensation Act 1973. Developments covered by this Act possess a statutory immunity from action by regulatory authorities or by citizens who feel aggrieved at the noise created. Instead, citizens can claim compensation under the Act. The provisions of the Land Compensation Act 1973 do not apply to anything other than the sort of infrastructural development recorded in the previous paragraph.

The Government and planning authorities have also had to produce advisory standards for noise-generating developments which in the interests of the economy, society, and indeed the environment must take place. An example of a form of development falling into this category is mineral exploitation. Specific advice on noise emissions from mineral operations is contained in Mineral Planning Guidance Note 11 [6]. It is perhaps no coincidence that the Mineral Planning Guidance Notes issued by the Secretaries of State form an entirely separate body of advice from general Planning Policy Guidance Notes. Minerals are recognised in a variety of ways, not least noise emissions, to be a special case. Society requires a variety of minerals, and there is an inevitable environmental cost in their extraction and distribution.

Turning to wind energy, the Government has advised in a variety of documents, most recently Planning Policy Guidance Note 22 (February 1993) [1] and DTI Energy Paper 62 (March 1994) [7], that its policy is to encourage the exploitation of renewable energy resources in appropriate circumstances. The reasons for this advice relate to the need to promote a diversity of energy resources and to assist in meeting the UK's international environmental obligations. The Government's policy towards renewable energy development has been evidenced in the case of wind by over 30 planning permissions for wind farms, with many more planning permissions for single wind turbines. These developments have been permitted in rural areas where more established forms of development, except perhaps for mineral extraction, would be unlikely to be permitted.

No development is without an external cost. The external cost of wind energy generation derives mainly from the visual effect of the turbines, and such noise emissions that impact to any degree on those who live and work nearby.

Methods of noise control in the UK

While the Wilson Report was issued over 30 years ago, the emergence of noise emissions as a core environmental concern is relatively recent. While quite separate law relating to statutory nuisance derives from the Public Health Act 1936, the first relevant advice in a planning context can be seen within DOE Circular 10/73. At a statutory level the Control of Pollution Act 1974 contained detailed provisions concerning statutory nuisances. European Community (EC) Directives of the mid-1980s, and rapidly increasing concerns about a wide variety of environmental issues, culminated in the Environmental Protection Act 1990. Part I of the 1990 Act contains provisions (formerly within the Control of Pollution Act 1974) relating to the statutory nuisances which include noise. At the advisory level Planning Policy Guidance Note 24: Planning and Noise has replaced DOE Circular 10/73. In terms of renewable energy development the wind annex to Planning Policy Guidance Note 22 contains some fairly general thoughts on noise emissions.

Chapters 4 and 6 of this report include discussion on the difficulties in theory and in practice of applying the advisory documents recorded in the paragraph above to wind energy development.

There are three principal methods available to local authorities and to citizens who wish to control noise emissions from wind generators. Local authorities may secure compliance with planning conditions by serving a planning Enforcement Notice, by serving a Breach of Condition Notice, or by taking injunctive action in the Courts. Local authorities can enforce covenants given within Planning Obligations by taking injunctive action. Both local authorities and citizens can pursue complaints in the Magistrates Courts alleging statutory nuisance.

Planning conditions

When a local authority grants planning permission for a development they may impose such planning conditions as they think fit. This discretion is not unlimited. To be valid a planning condition has to satisfy certain tests, and these are advised in paragraph 14 of DOE Circular 11/95 (Welsh Office Circular 35/95) [8]. These tests are:

- relevance to planning
- relevance to the development in question

- necessity
- precision
- enforceability
- reasonableness in all the circumstances.

There is no doubt that the control of noise is relevant to planning, almost certainly relevant to any wind energy development and, if only for this reason, very probably necessary. It remains for a local authority to ensure that the condition as drafted is precise, enforceable and reasonable. If a planning condition fails any one of these three tests the local authority would have little prospect of successful enforcement.

The invalidity of a planning condition because of a failure to comply with any of the tests outlined above helps neither the developer nor the local authority if a problem should arise. With a well drafted and enforceable condition both parties know where they stand both against each other and, within the planning jurisdiction, with regard to any complainant. If a noise condition has been carefully thought out, correctly phrased, and is in all other respects valid then two beneficial consequences follow. Firstly, the wind farm operator will be able to establish if he is in breach of the condition, and what he has to do in order to secure compliance. Secondly, if despite a well drafted and reasonable condition, and compliance with that condition, a citizen brings a complaint before the Magistrates Court under the Environmental Protection Act 1990, the fact of compliance with a reasonable and well thought out condition may prove to be an effective defence to an action in the Magistrates Court. The defence of best practicable means is discussed below.

On the other hand, if the planning condition drafted does not secure the proper control of noise emissions, and could readily be perceived to be unfair to neighbouring occupiers, the Magistrates Court might have little hesitation in imposing a noise regime, through an abatement notice, under the statutory nuisance provisions of the Environmental Protection Act 1990. This regime would take precedence over the planning condition and would then be enforceable in the Courts even if more onerous than the planning condition.

Returning to the enforcement powers available to local planning authorities, the Enforcement Notice is a well established instrument used to proceed against breaches of planning control, including breaches of planning conditions. There is a right of appeal, and the appeal process may take a year or more. This position has for some years been extremely unsatisfactory for local authorities because irresponsible developers can flout the planning system, knowing that a considerable period of grace can be obtained by the lodging of an appeal.

It was and still is open to local authorities to serve Stop Notices. These require the immediate cessation of the activity alleged to be unlawful, but the Stop Notice has to be accompanied by an Enforcement Notice, and there is a right of appeal. Compensation for certain economic losses may be payable if the Stop Notice is withdrawn or quashed on appeal (unless quashed on the basis that the planning permission, which permitted increased noise levels, is granted).

Therefore local authorities very rarely use Stop Notices unless they are convinced of winning the appeal that may follow.

The Planning and Compensation Act 1991 introduced the Breach of Condition Notice. If local authorities detect a breach of a planning condition they can serve a notice requiring the developer to remedy the breach within the minimum period of 28 days. There is no right of appeal, and the only option for the developer is to make an application to vary or discharge the planning condition. This is a very effective means of control, and emphasises the need for developers to negotiate conditions that are not only comprehensible and valid, but to which they can adhere. Developers need to bear in mind the economic consequences of shutting down or restricting the operation of a wind farm in order to secure compliance with a Breach of Condition Notice.

Finally, local authorities may take injunctive action to secure a remedy for any breach of planning control, and therefore they may in theory take such action to secure an end to a breach of a planning condition. The principles for deciding such actions in the Court will broadly follow those in an action relating to breach of a covenant described below, but it is unlikely that the local authority would take injunctive action to prevent a continuing breach of the planning condition given the alternative, cheaper and equally effective remedies available, which are discussed above.

Planning Obligations

A Planning Obligation made under Section 106 Town and Country Planning Act 1990 (as amended) is a contractual document in which a developer gives covenants which are enforceable by the local planning authority. A Planning Obligation may take the form of an agreement between a developer and the local authority, or, a unilateral undertaking given by the developer to the local authority. The scope of a Planning Obligation is defined in Section 106 and guidance on the use of Planning Obligations is given in DOE Circular 16/91 (WO Circular 53/91). This Circular is under review at the time of writing. The present Circular 16/91 advises that Planning Obligations should be sought only where they are necessary to the granting of planning permission, relevant to planning, and relevant to the development to be permitted. Where a local planning authority seeks a Planning Obligation from a developer Circular 16/91 advises on the tests of the reasonableness of seeking a Planning Obligation.

If the developer breaches the covenants within the agreement then the local authority can take action through the Courts to secure an injunction requiring him to adhere to the terms of the Obligation. In such an action the burden of proof is on the planning authority to prove the breach alleged. However, once the breach has been proved there are severe limits to the mitigating circumstances which the developer can advance, and which may persuade the Court to stay its hand and refrain from granting an injunction. There is a substantial body of law relating to the limits of the Court's discretion in deciding whether or not to grant an injunction following an initial finding that a breach of covenant has occurred.

Statutory nuisance

As to the jurisdiction of the Environmental Protection Act any citizen who feels himself to be adversely affected by noise emission can bring an action in the Magistrates Court in order to secure what is known as a noise abatement order. Again, a local authority can act directly as a prosecutor and issue a noise abatement notice. An abatement notice or order may require the abatement of the alleged noise nuisance or prohibit or restrict its occurrence or recurrence. It may also require the execution of specified works and the taking of other specified steps. The abatement notice or order will specify the time within which the requirements are to be complied with. The wind farm operator can appeal, on specified grounds, to the Magistrates Court, and ultimately to the Crown Court and higher Courts, against noise abatement orders and notices.

It is not the role of this report to discuss in detail the defences available to a developer faced with an allegation of statutory nuisance under the Environmental Protection Act which has resulted in the issue of a noise abatement order or notice. However, it can be noted that the defence of "best practicable means" is available, can be very effective and may be essential. If a wind farm operator cannot reduce noise emissions without jeopardising the viability of the operation, then the defence of best practicable means will be the last line of defence against potentially disastrous economic consequences.

In considering the merits of the defence of best practicable means the Magistrates Court will have regard to three principal factors: local circumstances, the technology being deployed by the developer, and some sort of cost-benefit analysis. With regard to the first factor, the Court cannot require the developer to take abatement action which will involve the use of land not under his control. An acoustic barrier may be appropriate in a particular case, but if it can only be placed on land belonging to a third party, and which is not within the control of the developer, and that third party is not willing to cooperate with its placement, then the Court cannot enforce the remedy because of this local circumstance.

As to the technology available to the developer, the Court will expect to hear some evidence that the best available technology is being deployed, subject to a consideration of the third factor identified, a cost-benefit analysis. The limits to the use of the cost-benefit analysis within a defence of best practicable means will vary from case to case, and no firm lessons can be derived from past cases. This is partly because each case will be decided on its facts, but also because cases within the Magistrates Courts are not regularly reported and therefore the findings of the Justices are not readily accessible. Even if such were the case it must be noted that the Magistrates Courts are not courts of record, and that the findings of the Magistrates do not form a body of legal precedent.

Against this background certain extremes can be identified. Provided that the developer was able to show that at the time of deployment of the machines the best available technology was used in the design, manufacture and erection of the turbines then the Magistrates Court would be most unlikely to find that the replacement of those turbines would be a reasonable option open to the developer. In any event, planning permission would be required. However, extensive sound-proofing measures might well be felt to be reasonable even though at considerable cost. The equation to resolve in all cases will be the benefit to be extracted from a particular step when set against the cost of that step.

Summary

In summary a variety of measures are open to local planning authorities and to citizens who perceive detriment to the amenities of neighbouring occupiers because of noise emissions. Because each case will differ in its facts no firm conclusions, particularly in relation to any rating levels, can be derived from case studies. However, it is very clear that well drafted and fair planning conditions will tell a developer what must be achieved, will provide local authorities with an objective initial yardstick if a complaint is received, and will provide the starting point for any evaluation of a defence of best practicable means.

Regulating noise emissions in the public interest

It was noted in the introduction to this chapter that reactions to noise emissions from man-made sources vary widely, depending in part on the physical ability of the receptor to hear the noise and his perceptions of the source. Such factors do not admit readily to objective analysis. A noise which is to one person unbearable can be almost inaudible to another.

The Courts have historically adopted the standpoint of the reasonable man or, as in the cliche, the man on the Clapham omnibus. The Courts have not been prepared to make decisions to accommodate extreme perceptions in controlling noise from legitimate sources. They have adopted, so far as is possible, a reasonable approach.

Planning law follows the Courts. Planning Policy Guidance Note 1 advises that the basis of planning law and practice is that the use and development of land should be regulated in the public interest: the purpose of the planning system is not to protect private rights. It follows from this that extreme private perceptions will not be protected by the planning system. The objective is to promote the current concept, from time to time, of the public good.

With the factors that have been identified in this chapter in mind, it can be seen that to attempt to devise an assessment and rating standard for noise emissions from wind energy development is a difficult exercise. Wind energy remains a new form of development: its symbolic content remains a matter of debate. Opinions of wind energy fluctuate widely between people and over time. Nevertheless, as with minerals, there is an urgent need to assist local planning authorities by suggesting rating standards which would seem to be reasonable. Reasonableness in this case derives from: established standards and advisory notes relating to noise emissions; the need of society for clean energy in pursuance of Government energy policy; what can be achieved by the manufacturers of wind turbines; the researches of the Working Party in the UK, Denmark, Holland and Germany; the professional and career experience of members of the Working Group; and discussions between the members and various others with appropriate experience.

The purpose of this chapter has been to define and analyse the complicated background against which members of the Noise Working Group set out to suggest rating standards for noise emissions from wind turbines, standards which may themselves change with time. Such changes may arise as a result of technical improvements in noise suppression by the manufacturers, because of developing perceptions of clean energy development, because of changing patterns of settlement in the countryside, and due to a host of other factors which cannot be anticipated at present. This acknowledgement of continuing dynamics does not undermine the production of rating standards. It is hoped that, at the same time, they represent well researched assistance to developers, manufacturers and planning authorities as well as a firm basis for further research and guidance.

3. DESCRIPTION OF NOISE EMISSIONS FROM WIND TURBINES

Noise emitted by wind turbines can be associated with two types of noise source. These are aerodynamic sources due to the passage of air over the wind turbine blades and mechanical sources which are associated with components of the power train within the turbine, such as the gearbox and generator and control equipment for yaw, blade pitch, etc. These sources normally have different characteristics and can be considered separately.

Aerodynamic sources

Aerodynamic noise is emitted by a wind turbine blade through a number of sources which have been identified and studied by Lowson [9] and Lowson and Fiddes [10]. The key sources have been categorised as:

1. Self noise due to the interaction of the turbulent boundary layer with the blade trailing edge.

2. Noise due to inflow turbulence (turbulence in the wind interacting with the blades).

3. Discrete frequency noise due to trailing edge thickness.

4. Discrete frequency noise due to laminar boundary layer instabilities (unstable flow close to the surface of the blade).

5. Noise generated by the rotor tips.

Noise due to aerodynamic instabilities, mechanisms 3 and 4, can be reduced to insignificant levels by careful design. The other mechanisms are an inescapable consequence of the aerodynamics of the turbine which produce the power and between them they will make up most if not all of the aerodynamic noise radiated by the wind turbine. The relative contribution of each source will depend upon the detailed design of the turbine and the wind speed and turbulence at the time. The mechanisms responsible for tip noise are currently under investigation but it appears that methods for its control through design of the tip shape may be available. Self noise, mechanism 1 above, is most significant at low wind speeds whereas noise due to inflow turbulence becomes the dominant source at the higher wind speeds. Both mechanisms increase in strength as the wind speed increases, particularly inflow turbulence. The overall result is that at low to moderate wind speeds the noise from a fixed speed wind turbine increases at a rate of 0.5-1.5 dB(A)/m/s.

The experience of some residents who neighbour wind farms in the UK would indicate that the assumption that aerodynamic blade noise sounds like the wind in the trees is perhaps an over-simplification, although the frequency content of this source can be similar to that of wind turbines. It is the regular variation of the noise with time that, in some circumstances, enables the listener to distinguish the noise of the turbines from the surrounding noise. Onomatopoeic descriptions of these noises include swishing, whooshing, chomping and thumping.

Blade swish is an amplitude modulation of noise in the frequency range which is associated with trailing edge noise radiated from the outer portion of the turbine blade and discrete frequencies associated with trailing edge thickness. This rhythmic swishing sound, dependent upon tip speed and blade profile, is normally centred around the 800-1000Hz region of the frequency band for trailing edge noise and at higher frequencies for trailing edge discrete frequencies depending on edge thickness. Measurements of the emitted sound power level of a wind turbine are normally performed using the A-weighting network and a time-averaging period of a minimum of 2 minutes, [11] [12]. This modulation might be expected to be clearly apparent when performing noise measurements close to wind turbines. However, the modulation of the A-weighted noise level is of the order of 2-3dB(A) for typical wind turbine configurations. Measurements performed in Denmark [13] and at some locations in the UK indicate that this level of amplitude modulation may be greater if analysis is performed using third octave or narrow band analysis of the radiated noise from a wind turbine. This modulation may be caused by directivity effects associated with the generation of the noise at the blade and is most apparent when standing close to a wind turbine, less than 50 metres from the base of a supporting tower.

As observer distance increases from the turbine, the rhythmic swishing becomes less pronounced. This may be due to a number of single effects or a combination. As distance increases, the modulation caused by the directivity of the radiated sound wave emitted by a turbine blade will become less significant. Therefore, it would be expected that any directivity effects which may be audible close to the turbine will be reduced in audibility. Atmospheric attenuation will cause a reduction of high frequency blade noise relative to lower frequency blade noise. This removes the high frequency "swish" spectral content which increases its distinguishing character. As the observer distance increases, the level of sound from the turbine incident at the observer position will decrease. However, in exposed locations, it should be expected that the background noise level will remain, in general, the same. Therefore, increased masking by the background noise will reduce the subjective impact of the turbine noise. This rhythmic swishing has been noted to vary between turbine types and between sites where similar turbines have been installed.

Current research projects aimed at more fully characterising the aerodynamic noise emissions from wind turbines are described in Chapter 9 on Further Work. These projects include measurements of blade swish and low frequency noise and vibration emissions.

Mechanical sources

Mechanical noise is normally perceived within the emitted noise from wind turbines as an audible tone(s) which is subjectively more intrusive than a broad band noise of the same sound pressure level. Sources for this noise are normally associated with: the gearbox and the tooth mesh frequencies of the step up stages; generator noise caused by coil flexure of the generator windings which is associated with power regulation and control; generator noise caused by cooling fans; and control equipment noise caused by hydraulic compressors for pitch regulation and yaw control.

Where complaints have been received due to the operation of wind farms, tonal noise from the installed wind turbines appears to have increased the annoyance perceived by the complainants and indeed has been the primary cause for complaint.

Mechanical noise may be radiated by the containing structure of the source, ie the gearbox casing, or by parts of the turbine structure which have a direct mechanical linkage to the source. Where gearbox noise has been perceived as a tonal noise problem, the acoustic energy has normally been found to be radiated by the supporting tower structure upon which the turbine nacelle containing the gearbox is mounted and/or by the wind turbine blades themselves. Vibrational energy is transmitted from the drive train within the gearbox and the drive shafts and enters the gearbox supporting structure. This then travels through the supporting structure and may be re-radiated as sound at any position where the structure is exposed to atmosphere. Supporting towers are normally large, between 25 and 45 metres in height, from which acoustic energy may be radiated. These large radiating surfaces can result in the efficient transmission of the vibrational energy into the external environment surrounding a wind turbine.

Most turbine manufacturers have started to ensure that sufficient forethought is given to the design of quieter gearboxes and the means by which these vibrational transmission paths may be broken. Through the use of careful gearbox design and/or the use of anti-vibration techniques, it is possible to minimise the transmission of vibrational energy into the turbine supporting structure. The benefits of these design improvements have started to filter through into wind farm developments which are using these modified wind turbines. It is possible to obtain turbines which do not emit any clearly distinguishable tones.

Vibrational energy that enters the wind turbine blade may be reduced by the placing of a resilient coupling on the low-speed shaft and/or by treating the blade itself. Foam filling of the blade would provide significant additional damping to the blade skin, thereby reducing the transmitted vibrational energy within the blade.

4. REVIEW OF CURRENT PRACTICE AND GUIDANCE

Introduction

Much work has been carried out and is still current in relation to the measurement of noise from wind generators. However, there is as yet no primary or secondary legislation in the UK relating specifically to the rating of noise from wind generators. This corresponds with the position in all European Community member states which have seen wind energy development, except Denmark where a statutory instrument of 1991 [12] specifically regulates maximum levels of noise emissions from wind generators. There are statutory noise controls in Holland and Germany but these are not specifically related to wind generators.

The only current advice in the UK specifically relevant to wind energy development is contained within the wind energy annex to Planning Policy Guidance Note 22 (PPG 22) [1] which advises on renewable energy development. However, there are numerous elements of advice more or less pertinent to the subject and these are recorded in this section of the report. Advice continues to emerge, and in particular it is noted that Planning Policy Guidance Note 24: Planning and Noise [5], which superseded DOE Circular 10/73 [4] in England (Welsh Office 16/73 is still in effect at time of writing), was issued in September 1994 and a revision to BS 4142: 1990 [2] relating to industrial noise in mixed residential and industrial areas is currently being prepared.

This chapter of the report records and discusses legislation and advice which is current, and either potentially or directly pertinent to noise emissions from wind generators. Chapter 6 of this report discusses the difficulties in theory and in practice of applying the advisory documents described in this chapter to wind energy development and proceeds to recommend a framework for the measurement and assessment of noise from wind farms.

The use of planning conditions

As a result of this lack of direct guidance for the assessment of wind turbine noise, several methods have evolved to limit the noise levels which are incident from a wind turbine or farm. These methods can be summarised as follows:

- The setting of noise limits (maximum limit not to be exceeded or limit at a specified wind speed, typically 5m/s at hub height, the cut-in wind speed for a wind turbine) which are independent of the existing background noise levels. This is like the planning condition for Rhyd-y-Groes on Ynys Mon/Anglesey and some sites in Dyfed.

- The setting of a limit based on measurements of the background noise before the construction of the wind farm. The planning conditions agreed for Four Burrows in Cornwall are of this type.

- The setting of a limit permitting the noise level of the wind farm to the exceed the prevailing background noise level when the wind farm is not operating by a specified amount. This is like the planning condition agreed for Carland Cross in Cornwall.

Furthermore, the methods by which these conditions or obligations are to be tested are different. Some propose the measurement of the L_{Aeq} of the background and incident turbine noise at a property, some propose the measurement of the LA9O of the background and incident noise from the wind turbines and some consider the noise in terms of the LASO. The reasons for this can be summarised as follows:

- The use of L_{Aeq} follows the guidance that is contained within BS 4142: 1990 (Method for rating industrial noise affecting mixed residential and industrial areas) which was updated to align itself with ISO 1996: Parts 1 to 3. This proposes that measurements and an assessment of a new noise source be performed using the L_{Aeq} index.

- The use of LA9O was proposed by some local district councils in Cornwall because transitory, high-energy effects such as aircraft fly-overs and wind upon the microphone could increase the measured L_{Aeq} such that the measured noise levels from the turbines would be masked. As a wind turbine is a fairly constant noise source it was considered that the L^o would be a reasonable approximation to the L_{Aeq} of a wind turbine. However, at a receiver position, where short-term, high-energy events may result in a higher L_{Aeq} than would be expected from just the operation of wind turbines, the L^o was considered to be less affected by these transitory, high-energy events.

- The use of L_{A5}o was adopted during early work by the CEGB at the demonstration test facility at Carmarthen Bay. The reasoning for the use of the L_{A}so follows that described in the previous paragraph.

Therefore, there currently exist several methods by which conditions and obligations have been written and by which developers have considered the effects of their developments upon neighbouring dwellings and noise-sensitive buildings. The purpose of this Working Group is to consider the merits of these and other methods with respect to existing primary and secondary legislation, Planning Policy Guidance Notes, Mineral Planning Guidance and British Standards. This investigation has also taken into account recommendations made by the World Health Organisation (WHO), the European Community (EC) and the Organisation of Economic Co-operation and Development (OECD). Reference has also been made to the experiences of other countries where the development of wind energy has already been underway for a number of years.

Primary and secondary legislation in the UK

The emergence of noise emissions as a core environmental concern is relatively recent. While quite separate law relating to statutory nuisances derives from the Public Health Act 1936, the first relevant advice in a planning context can be seen in the DOE Circular 10/73 (Welsh Office Circular 16/73), now replaced in England by Planning Policy Guidance Note 24. At a statutory level the Control of Pollution Act 1974 contained detailed provisions concerning statutory nuisances. EC Directives of the mid-1980s, and rapidly increasing concerns about a wide variety of environmental issues, culminated in the Environmental Protection Act 1990. A brief summary of relevant provisions in primary legislation of relevance to noise emission control is given below.

Planning juridictions

Section 70 Town and Country Planning Act 1990:

"Where an application is made to a local planning authority for planning permission

a) Subject to (other sections) they may grant planning permission, either unconditionally or subject to such conditions as they think fit; or

b) They may refuse permission. "

Section 106 Town and Country Planning Act 1990:

"Any person interested in land in the area of a local planning authority may, by agreement or otherwise, enter into an Obligation (... "a Planning Obligation"):

a) restricting the development or use of the land in any specified way;

b) requiring specified operations or activities to be carried out in, on, under or over the land;

c) requiring the land to be used in any specific way; or

d) requiring a sum or sums to be paid to the authority on a specified date or dates or periodically

Statutory nuisance

Section 80 Environmental Protection Act 1990:

"Where a local authority is satisfied that a statutory nuisance exists, or is likely to occur or to recur, in the area of the authority, the local authority shall serve a notice ("an abatement notice ") imposing all or any of the following requirements -

a) Requiring the abatement of the nuisance or prohibiting or restricting its occurrence or reoccurrence;

b) Requiring the execution of such works, and the taking of such other steps, as may be necessary for any of those purposes, and the notice shall specify the time or times within which the requirements of the notice are to be complied with. "

Section 82 Environmental Protection Act 1990:

"A magistrates court may act under this section on a complaint made by any person on the ground that he is aggrieved by the existence of a statutory nuisance. If the

magistrates court is satisfied that the alleged nuisance exists, or that although abated it is likely to recur on the same premises, the Court shall make an order for either or both of the following purposes -

a) Requiring the Defendant to abate the nuisance within a time specified in the order, and to execute any works necessary for that purpose;

b) Prohibiting a reoccurrence of the nuisance, and requiring the Defendant, within a time specified in the order, to execute any works necessary to prevent the reoccurrence,

and may also impose on the Defendant a fine not exceeding. . . . .on the standard scale"

Town and Country Planning (Assessment of Environmental Effects) Regulations 1988

By virtue of the Town and Country Planning (Assessment of Environmental Effects) (Amendment) Regulations 1994, which came into force on 6 April 1994, the provisions of the 1988 Regulations now apply to wind energy development. Wind generators are listed within Schedule 2 to the 1988 Regulations as a form of development for which environmental assessment may be appropriate, depending on such factors as the nature, size and location of proposal.

Planning Policy Guidance Notes

PPG 22 Renewable Energy

PPG 22 sets out Government planning policy advice concerned with developing renewable energy sources, against the background of the Government's policies for the environment, and for developing these renewable energy sources. For ease of reference the Government's policy on new and renewable energy as stated in Energy Paper No 62 is:

"To stimulate the development of renewable energy sources wherever they have prospects of being economically attractive and environmentally acceptable in order to contribute to:

- *diverse, secure and sustainable energy supplies*
- *reduction in the emission of pollutants*
- *encouragement of internationally competitive industries.*

In doing this it will take account of those factors which influence business competitiveness and work towards 1500MW DNC of new electricity generating capacity from renewable sources for the UK by 2000. "

The main principle running through PPG 22 is the requirement to balance the local environmental impact of renewable energy generation against global environmental benefits.

This is best illustrated by reference to extracts from paragraphs 21 and 26, the first considering land use planning matters and the second advising on development plans.

> *"Sites proposedfor the development of renewable energy sources will often be in rural areas or on the coast\ and such development will almost always have some local environmental effects. The Government's policies for developing renewable energy sources must be weighed carefidly with its continuing commitment to policies for protecting the environment."*

> *"Authorities will need to consider both the immediate impact of renewable energy projects on the local environment and their wider contribution to reducing emissions of greenhouse gases."*

The PPG specifically considers noise issues within paragraphs 39-51 of its wind annex. The document provides an overview of the issues to be addressed but as it admits, there was insufficient information available at the time of writing for more quantitative general guidance to be given.

PPG 24: Planning and Noise

PPG 24 Planning and Noise, issued in September 1994, gives guidance to local authorities in England and replaces Circular 10/73. This document too highlights the potential conflicts of interest which have to be considered as part of the planning process. The aim of the guidance contained within PPG 24, as stated in the opening paragraph, is:

> *to provide advice on how the planning system can be used to minimise the adverse impact of noise without placing unreasonable restrictions on development or adding undidy to the costs and administrative burdens of business. "*

Paragraph 10 continues:

> *"Much of the development which is necessary for the creation ofjobs and the construction and improvement of essential infrastructure will generate noise. The planning system shoidd not place unjustifiable obstacles in the way of such development. Nevertheless, local planning authorities must ensure that development does not cause an unacceptable degree of disturbance. They shoidd also bear in mind that a subsequent intensification or change of use may result in greater intrusion and they may wish to consider the use of appropriate conditions. "*

Within Annex 1 of PPG 24 the concept of noise exposure categories (NECs) is developed. These categories are to help identify whether noise is an important issue in the development of residential dwellings within an existing noise environment. However, it identifies that when a new noise source is brought to sensitive properties this guidance is not to be used:

> *"The NEC procedure is only applicable where consideration is being given to introducing residential development into an area with an existing noise source, rather*

than the reverse situation where new noise sources are to be introduced into an existing residential area."

This is because:

"... the planning system can be used to impose conditions to protect incoming residential developme?it from an existing noise source but, in general, developers are under no statutory obligation to offer noise protection measures to existing dwellings which will be affected by a proposed new noise source. "

It is also stated that where industrial noise is the dominant noise source rather than transportation noise sources, the NEC noise levels should not be used because:

"... there is insufficient information on people's response to industrial noise to allow detailed guidance to be given. "

However, if industrial noise is present but not dominant in a noise environment, then its contribution should be included when establishing the NEC category. The discussion on the setting of noise limits for the various NECs makes reference to sleep disturbance criteria and attenuation of noise through open and closed windows. The approach of PPG 24 is discussed in Chapter 6 for the purposes ofconsidering the setting of noise limits for wind farms.

However, the derivation of the night-time noise limits contained within the NEC table is based upon the concept of sleep disturbance and the protection of the restorative process of sleep. The setting of these criteria has assumed a reduction of the noise from outside the building through to the inside within bedrooms such that the internal noise level is at or below 35dB L_{Aeq}. (Reference is made to the WHO document Environmental Health Criteria 12 - WHO, 1980 [14]. It should be noted that there is currently a review of the criteria contained within this report. The new draft is discussed later in this chapter.) The reduction through a window that has been assumed for the calculation of acceptable external noise levels is 13dB(A) from internal noise level to facade noise level. (It is stated within PPG 24 that this figure is usually taken to be 10-15dB(A) and that for the purpose of deriving the NEC table it has been assumed to be 13dB(A).)

When advising on the assessment of noise from industrial and commercial developments the PPG comments that the likelihood of complaints about noise from industrial development can be assessed, where the Standard is appropriate, using guidance in BS 4142: 1990. It goes on to say that the "rating level" shall be used when stipulating the level of noise that can be permitted.

Planning and Noise Circular (W.O. 16/73)

Welsh Office Circular 16/73 contains guidance for planning authorities concerning new noise sources. This is equivalent to DOE Circular 10/73 recently cancelled by PPG 24 in England. Although the circular does not directly deal with wind turbine-generated noise it provides some guidance as to what might be considered as acceptable noise levels for the incident noise levels from such development.

Noise from fixed installations and industrial premises is considered within paragraphs 24-36 of the Circular. Within paragraph 24 it is recommended that local planning authorities consult their Environmental Heath Departments at an early stage to minimise the noise effects of developments.

Paragraph 27 proposes a method by which noise from a new noise source introduced into an existing residential environment may be assessed. It states:

> *"Where, by the standards established in BS 4142, the noise from the proposed development "is likely to give rise to complaints' even if reasonable sound insulation is required and provided\ it will hardly ever be right to give permission. In predicting noise levels from new developments it will be necessary to take account of those which can be expected when the plant is operating at maximum capacity, even if this presupposes a higher level of activity than that initially proposed by the developer. "*

Paragraph 28 considers that, where possible, the authorities should operate their development control powers in such a way as to avoid an increase in the ambient noise affecting residential and other noise-sensitive development. It also recognises within this paragraph that this will not always be possible for certain types of development.

Where industrial noise is incident upon a residence, the Circular proposes that the CNL (Corrected Noise Level) for a stationary source to provide a "good standard" of noise within a dwelling with windows closed is 45dB(A) during the day-time and 35dB(A) during the night-time. These are internal noise levels, with windows closed.

MPG11 The Control of Noise at Surface Mineral Workings

The aim of Mineral Planning Guidance Note 11 is to provide advice on how the planning system may be used to keep noise emissions from surface mineral workings within environmentally acceptable limits without imposing unreasonable burdens upon minerals operators.

Paragraphs 31-35 consider the setting of absolute noise limits for such developments, which are linked to day-time and night-time working periods. MPG 11 states:

> *"The Government takes the view, except in the circumstances outlined below, the day-time nominal limit at properties used as dwellings shoidd normally be 55dB $L_{Aeq\,1h}$ (free field)...."*

MPG 11 goes on to say that this level is generally found to be a tolerable noise level and that above this noise level continuous noise starts to cause annoyance.

The suggested night-time noise limit is 42dB $L_{Aeq,1h}$ at a noise-sensitive dwelling. It also recognises that lower nominal noise limits may be appropriate in quiet rural areas if the mineral working threatens to disturb exceptionally low background noise levels.

Paragraphs 37 and 38 discuss the setting of noise limits relative to the existing background noise level. However, MPG 11 recognises the difficulties of this approach when applied to sites where quiet background noise levels exist:

> *"In exceptionally quiet rural areas where the day-time background noise level is below 35dB(A), a condition limiting mineral operators to a 10 decibel excess over the existing background noise level is likely to be both difficult to achieve and unduly restrictive. It would not normally be appropriate to require a day-time limit below 45dB $L_{Ae}q,ih$> as such a limit shoiddprove tolerable to most people in rural areas. The exercise of care and some flexibility are important in addressing these issues. "*

Paragraph 39 states:

> *"In the case of night-time working, MP As and operators should have particular regard to the needs of local people, and discussion with local Environment Health Officers may well be appropriate as to whether the night-time limit stated at paragraph 34 is reasonable. This may be a particular issue in quieter rural areas. "*

These comments indicate that for very quiet background noise environments, the operation of mineral extraction plant should not be allowed to exceed 42dB $L_{Aeq,ih}$ during the course of a night, but that a lower limit may be appropriate after discussions with the local Environmental Health Officer.

British Standards

BS 4142:1990: Method for rating industrial noise affecting mixed residential and industrial areas

It is stated within the foreword of this British Standard that:

> *"The standard is intended to meet the need for rating various noises of an industrial nature affecting persons living in the vicinity. It gives a method of determining a noise level together with procedures for assessing whether the noise in question is likely to give rise to complaints. Although, in general, there will be a relationship between incidence of complaints and the level of general community annoyance, quantitative assessment of the latter is beyond the scope of this standard as is the assessment of nuisance."*

This indicates that although the standard may be used for the rating of a noise incident upon a receiver position, it is not appropriate for either the quantitative assessment of general community annoyance or the assessment of nuisance.

The foreword continues:

> *"In general, a noise is liable to provoke complaints whenever its level exceeds the background noise by a certain margin; or when it attains a certain absolute level. "*

This indicates that complaints may occur if the incident noise level exceeds the background noise level by a margin or if the incident noise exceeds an absolute level that may not be related to the background noise level.

The foreword to BS 4142 also states:

> *"This standard is intended to be used for assessing the measured noise from existing premises or the calculated (or measured) noise levels from new or modified premises. It may be found helpful in certain aspects of environmental planning and may be used in conjunction with recommendations on noise levels and methods of measurement published elsewhere."*

The scope explains that the standard provides a method for assessing whether noise measured at the outside of a building is likely to give rise to complaints from people residing inside the building.

BS 4142 itself acknowledges that it is not suitable for assessing noise in situations where the background noise level is very low, ie below an A-weighted sound pressure level of 30dB.

The rating method described within BS 4142 compares the incident noise from an industrial source, be it calculated or measured, with the measured background noise at the position where the new noise source is incident. The noise levels of the source are measured in terms of $L_{Aeq,T}$ but for background noise level, $L_{A90,T}$ is used. When performing an assessment using BS 4142, not only is the level of incident noise from the new noise source of concern but also the character of the source. BS 4142 proposes that a penalty be applied if the noise has the following characteristics:

> *"7.2 If the noise contains a distinguishable, discrete, continuous note (whine, hiss, screech, hum, etc), or if there are distinct impulses in the noise (bangs, clicks, clatters, or thumps), or if the noise is irregidar enough in character to attract attention, add 5dB to the specific noise level to obtain the rating level. Make only a single 5dB correction if one or more of the above characteristics is present."*

The method of assessment then subtracts the measured background noise level from the rated noise level. A difference of 10dB(A) or greater is considered to indicate that complaints are likely. A difference of around 5dB is of marginal significance. The lower the value the less likelihood there is of complaints.

The issues associated with the application of BS 4142 to noise from wind farms in rural areas are discussed in Chapter 6.

BS 5228: Part 1:1984 Noise Control on construction and open sites. Part 1: Code of Practice for basic information and procedures for noise control

The scope of BS 5228 Part 1 [15] covers recommendations for basic methods of noise control relating to construction sites and other open sites where noisy work activities and operations are carried out. It describes the legislative background to noise control and provides guidance concerning methods of predicting and measuring noise. It also contains recommendations on how the impact of noise on people living nearby and on-site workers can be minimised.

Section 11 within the British Standard discusses the setting of noise criteria. When setting target noise levels at sensitive dwellings adjacent to a site, it is recognised that the period of falling asleep and just before awakening are the most sensitive. It is suggested that site noise will be required to be limited to $L_{Aeq\,1h}$ of 40-45dB at the facade to avoid sleep disturbance; this is equivalent to a free field sound pressure level of 37-42dB. The free field sound pressure level is that which is measured when the measurement position is situated further than 3.5 metres from a reflecting surface.

BS 7445: Parts 1-3:1991 Description and measurement of environmental noise

Part 1. Guide to quantities and procedures
Part 2. Guide to the acquisition of data pertinent to land use
Part 3. Guide to application to noise limits

BS 7445: Parts 1-3: 1991 [16] is the equivalent British Standard to ISO 1996/1-3: 1982 and is identical to this ISO standard. This International Standard does not specify limits for environmental noise. The stated aim of these standards is to:

"...provide authorities with material for the description of noise in community environments. Based on the principles described in this International Standard\ acceptable limits of noise can be specified and compliance with these limits can be controlled."

Part 1 of the standard describes the preferred measurement units which should be used, the type of equipment that should be used for determining the noise level and measurement positions. The standard introduces the concept of measurements performed within a building when assessing the impact upon a nearby receiver. Section 5.2.3 of the standard states that the preferred measurement position within a building is:

"at least 1 metre from the walls or other major reflecting surfaces, 1.2 to 1.5 metres above floor level and about 1.5 metres from windows. "

Section 5.3 of the standard discusses the possible meteorological effects upon the measurements that may be undertaken. It does not specify that there are weather conditions during which measurements are unacceptable. However, it recommends that measurements be made when conditions will be those that will allow the most stable propagation of the noise from the source to the receiver, with a significant wind component from the source to the receiver.

The purpose of Part 2 of the British Standard is:

"To provide methods for the acquisition of data describing environmental noise. Using these data as a basis, authorities may establish a system for selecting the appropriate

land use, as far as levels of noise - existing or planned - which are acceptable with respect to land use, existing or planned."

This part of the British Standard gives some guidance as to the method by which a rating may be made of the noise source, taking into account whether it has an impulsive character or whether it contains any tonal components. The control of such acoustic emissions from a wind turbine are normally addressed through the warranty provided by the manufacturer of the wind turbines and the planning permission for the development.

The tonal adjustment as described below is proposed within BS 7445 in order to take into . account the effects of tonal noise:

"A prominent tonal component may be detected in 1/3 octave spectra if the level of a 1/3 octave band exceeds the level of adjacent bands by 5dB or more, but a narrow band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal. If tonal components are clearly audible and their presence can be detected by a 1/3 octave analysis, the adjustment may be 5 or 6dB. If the components are only just detectable by the observer and demonstrated by narrow band analysis, an adjustment of 2 to 3dB may be appropriate."

Part 2 also states that the measurement of the noise source should be undertaken when the propagation conditions are stable and when the meteorological conditions will enhance propagation towards the receiver position. BS 7445 states that wind conditions should be from the source to the receiver and within an angle of ± 45° of a line connecting the centre of the source with the centre of the receiver position. It also states the wind speeds for this assessment should not exceed an average wind speed of 5m/s between the heights of 3 and 11 metres. This typically equates to average wind speeds of 7.8m/s and 5.9m/s respectively, when measured at a height of 30 metres, which are low to moderate wind speeds for turbine operation (see "wind shear" entry in Glossary). It is also stated within BS 7445 Part 2, Paragraph 5.4.3.3, Note 1, that it should always be ascertained that the wind noise at the microphone does not interfere with the measurements.

Part 3 of BS 7445 describes the application of noise limits and the elements which are necessary in any setting of noise limits. These include:

- the noise descriptor to be used
- the relevant time intervals
- the sources and their conditions of operation, where appropriate
- the locations where the noise limits have to be verified
- meteorological conditions, where appropriate
- criteria for assessment of compliance with the set limits.

Guidance is given within this section of the standard as to how to set the conditions for any noise limits and for checking compliance with any of the noise limits that might have been agreed or imposed by the local authority.

BS 7135: Part 1:1989: Noise emitted by computer and business equipment Part 1. Method of measurement of airborne noise

BS 7135: Part 1 [17] is a measurement method for noise emitted by computer and business equipment. The methods described within the standard are only relevant to the measurement of these noise sources. However, within Annex D (Measurement of impulsive sound pressure levels and discrete tones at the operator position) are methods for the determination of the impulsiveness of the noise and the tonality of the noise.

Measurement of the impulsive sound is performed by aural examination of the noise source at the operator positions. If the noise emitted is perceived to include short-duration high-amplitude sound, then the following test shall be performed:

> *"The A-weighted impulse sound pressure level, $L_{pA}u$ shall be measuredfor the same modes of operation and measurement conditions usedfor the measurement of the* ***A-****weighted sound pressure level\ L_pA, according to 7.7. The difference in decibels between the A-weighted impidse sound pressure level, $L_{pA}j$, and the A-weighted sound pressure level L_{pA}, shall be obtained. The difference (L_{pA1} - L_{pA}) is the impulse parameter ALi, which may be considered a measure of the impulsive content of the noise; if ALj >3dB, the noise is considered to be impulsive."*

The impulsive response of a sound level meter is defined by the time constant for the input signal. An impulse sound level meter has a time constant of 35ms compared with a fast time weighting network of 125ms. The measurement method described within BS 7135 (Section 7.7 of the Standard) to determine the L_{pA} sound pressure level requires that a measurement be performed for a period of at least 8 seconds. Although it is not clearly identified within the standard as to whether the measurement is an L_{Aeq} level or a mean level, it is assumed that the L_{Aeq} level should be recorded.

Section D.4 of the annex describes a method for the detection of a tone within a broad band noise. Section D.4.1 states the following:

> *"A discrete tone which occurs in a broad-band noise is partially masked by the noise contained in a relatively narrow frequency band\ called the critical band\ that is centred at the frequency of the tone. Noise at frequencies outside the critical band does not contribute significantly to the masking effect. The width of the critical band is a function of the frequency. In general, a tone is just audible when the sound pressure level of a tone is about 4dB below the sound pressure level of the masking noise contained in the critical band centred around the tone. For the purpose of this annex, a discrete tone is defined as being prominent if the sound pressure level of the tone exceeds the sound pressure level of the masking noise in the critical band by 6dB. This corresponds, in general, to a tone being prominent when it is more than lOdB above the threshold of audibility. "*

The standard then proceeds to describe a method of assessment to determine the existence of discrete tones within the emitted noise from a computer. This method employs the concept of Zwicker critical bands. When considering critical band theory for the masking of discrete tones within broad band noise, it is clear that the detection of a tone is related to the frequency and level of the tone compared to the critical band masking level. The defined criteria for the threshold of audibility and prominence is a simplification of these criteria as the detection threshold is frequency-dependent.

The British Standard is designed for the assessment of tones that are emitted from computer equipment. Most tones that are emitted by computers are related to the cooling fans and the scanning frequency of the CRT (cathode ray tube). These frequencies are normally found above 1kHz and for a CRT 15-25kHz. At these frequencies the likelihood of a tone being detected is high when the audibility threshold level is 4dB below the critical masking level. However, at lower frequencies, especially below 500Hz, the audibility threshold for a tone is measured as being 2dB below the critical masking band noise level. Therefore, the criterion that is described within the British Standard is a simplification of the detection thresholds of a normal ear due to the assumptions made with respect to the normal range of discrete frequencies that are emitted by computer equipment.

The critical bandwidths are defined within the British Standard as follows:

The width of the critical band, Af_c, centred at any frequency, f, is given by the following equation:

$$Af_c = 25 + 75\ [\ 1 + 1.4\ (f/1000)^2]^{069}$$

(e.g. Af_c = 162.2Hz at f = 1000Hz)

For the purposes of determining the value of L_n, the critical band is modelled as a rectangular filter with centre frequency, f_0, the lower band edge frequency f_b and the upper band edge frequency, f_2, where

$$fi = fo \sim Af</2$$

and

$$f_2 = f_0 + MJ2$$

The British Standard also states that the measurements should be performed using the A-weighting network. However, if measurements are performed using linear quantities then the threshold of audibility should be defined as when a tone is 6dB below the masking band level.

The measurement period that should be used for determining the tone levels is defined as a minimum of 8 seconds, following the measurement methodology used for the impulsive noise assessment. However, performing a narrow band analysis on a signal using an FFT (Fast Fourier Transform) Analyser results in blocks of data, between 125 ms and 1 second in length, being analysed, rather than a continuous stream. To derive the sound pressure level for each narrow band over a longer time period, such as 8 seconds, requires that the average level is obtained from a number of shorter measurements.

The determination of the masking band level within the critical band is dependent upon this averaging of the measured noise. However, for a single spectrum using a Hanning window it is expected that the broad band level calculated would have a 68.3 % chance of being within 4.34dB of the true level, a 95.5 % chance of being within 8.68dB and a 99.7 % chance of being within 13.02dB. However, as the number of averages increases, the standard error will become less due to the greater number of samples. Table 1 details the expected error with increase in the number of samples used to determine the average level of each narrow band.

Table 1 Expected error bands using FFT analysis

Number of Samples	Standard Deviation	2 x Standard Deviation	3 x Standard Deviation
1	4.34	8.68	13.02
2	3.07	6.14	9.21
4	2.17	4.34	6.51
8	1.53	3.07	4.60
16	1.09	2.17	3.26
32	0.77	1.53	2.30
64	0.54	1.09	1.63
128	0.38	0.77	1.15
256	0.27	0.54	0.81
512	0.19	0.38	0.58
1024	0.14	0.27	0.41

Therefore, to undertake measurements that have a high degree of accuracy requires that a significant number of measurements are averaged before the level can be confidently predicted to be within 1dB of the level recorded by the analyser. This compares with the advised minimum measurement period of 8 seconds proposed within the standard. As an example, if the highest frequency of interest is 2kHz and the narrow band bandwidth is 2.5Hz, equivalent to 800 lines, then the sampling frequency will require to be 2.56 times the frequency of highest interest, ie 5120Hz. To obtain sufficient data to perform the FFT analysis will require 2048 data points. Therefore, the time that is required to obtain sufficient data for a single spectrum is 2048 x (1/5120Hz) = 0.4 seconds. If it is assumed that the data is collected as a continuous stream, then in the space of 8 seconds it would be expected that 20 spectra are available for averaging. From Table 1 it may be seen that this would lead to an expected accuracy of the measurement of about 1dB for a single standard deviation. For an accuracy of ± 0.2dB, 470 measurements would be required, resulting in an overall measurement period of 188 seconds, approximately 3 minutes.

International Guidance

European Community Directives

Council Directive 85/337 of the European Community requires the assessment of the environmental impact of certain projects in the public and private domain. The terms of this Directive must be implemented by member states. In the UK most of the Directive's terms have been implemented through the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, reference to which has already been made.

CEC Report EUR 5398 e: 1975

The Commission of the European Communities report EUR 5398 e: Environment and Quality of Life: Damage and Annoyance Caused by Noise [18], contains a number of recommendations for the setting of external and internal noise criteria which will not affect sleep or relaxation in external environments.

The report states within its conclusions that internal L_{Aeq} noise levels within a bedroom of 30-35dB would not affect sleep at all, while a maximum sound level should not exceed the L_{Aeq} level by more than lOdB. The setting of a maximum noise level above the average L_{Aeq} level is due to the human startle response function which results in a sleeper awakening as a result of a short period, high level noise. The report states that a certain safety margin has been taken into account for more susceptible elderly persons when stating this figure. It is proposed within the report that as these levels will result in no sleep disturbance, achieving these noise levels for other rooms within a dwelling will result in no interference in relaxation. Again, the limit for a maximum level lOdB above the continuous L_{Aeq} level applies. However, the report does note that public authorities may be led to decide that such protection should be restricted to specific and particularly sensitive groups, such as invalids, convalescents and residents of old peoples' homes, thereby indicating that this may also be a very safe criterion for most members of the population.

Noise criteria for relaxation in areas external to the dwelling are not so clearly defined. The recommended noise levels contained within Report EUR 5398 e state that L_{Aeq} levels of 50-55dB will result in slight annoyance. However, reference is made within the report that acceptable guide levels for external areas based upon average L_{Aeq} levels are as follows: 45dB during day-time and 35-40dB during the night time. It is stated that:

> *"This would seem to provide an adequate safeguard for night-time and day-time sleep, relaxation and also for the use for relaxation of open-air facilities such as balconies, terraces and gardens."*

OECD Report: Reducing Noise in OECD Countries: 1978

The OECD report Reducing Noise in OECD Countries [19] provides guidance and decision criteria for noise abatement policies. Within this document three criteria are quoted, which are used in some countries not identified within the report, to set internal noise levels. These are as follows:

The extension of time to fall asleep	L_{Aeq} = 35dB
The shortening of light sleep	L_{Aeq} = 45dB
The shortening of deep sleep	L_{Aeq} = 50dB

The three categories of sleep noise criteria reflect the sensitivity which has been found in the average person to noise at various stages of the sleep cycle. It is considered that the most sensitive period for sleep being affected by noise is when a person is falling asleep. Therefore, it is during this period that the lowest noise levels should be achieved within a dwelling and thereby any criteria set. Light sleep or REM (rapid eye movement) sleep is less affected by noise. This sleep period is when most dreaming occurs. Deep sleep is the least sensitive sleep category in the nightly sleep cycle. As such, a level 15dB(A) higher than the falling asleep level may exist without any adverse affect upon a sleeping subject.

It is also stated within this document that maximum peak levels should not exceed the background noise level by 10-15dB(A) to ensure that no sleep disturbance occurs. All the noise levels stated above are internal noise levels.

WHO Environmental Health Criteria 12 - Noise: 1980

The World Health Organisation Environmental Health Criteria [14] recommends an internal noise level of about 35dB(A) L_{eq} during the night in order to prevent sleep disturbance. Some effects of noise level on sleep are described within the main body of the report:

> *"The effects of noise on sleep appear to increase as the ambient noise levels exceed 35dB(A) L_{eq} (Berland et al, 1972). In one study, the probability of subjects being awakened by a peak sound level of 40dB(A) was 5%, increasing to 30% at 70dB(A). When changes in sleep changes were taken as an indication of disturbance, the proportion of subjects affected was 10% at 40dB(A) and 60% at 70dB(A) (Thiessen, 1969)."*

It is to this document that PPG 24 refers when establishing noise exposure categories for the night-time.

WHO Environmental Health Criteria Document on Community Noise, External Review Draft, 1993

There is currently a review of existing research of environmental health noise criteria being undertaken by the World Health Organisation [20]. The final report of the temporary advisors was submitted to the WHO in 1995 but at the time of writing has yet to be published as a replacement of the 1980 document. The external review draft includes a review of current work being performed with respect to sleep disturbance and noise. Section 11.1.1.3 dealing with sleep disturbance effects states:

"Sleep disturbance due to continuous, as well as intermittent noise, has been demonstrated by electrophysical and behavioural methods. The more intense the background noise is, the more disturbing is its effect on sleep. Measurable effects start from about 30dB(A) L_{eq}. Physiological sleep effects include changes in the pattern of sleep stages, especially a reduction in proportion of REM-sleep. Subjective effects have also been identified such as difficulties in falling asleep, subjective sleep quality and adverse after-effects like headaches and tiredness. The sensitive groups will mainly include elderly persons, shift workers, persons who are especially vulnerable due to physical or mental disorders and other individuals who have sleeping difficulties.

Sleep disturbance increases with increased maximum noise level Even if the total equivalent noise is fairly low, a small number of noise events with a high maximum sound pressure level will affect sleep. Therefore, guidelines for community noise to avoid sleep disturbance should be expressed in terms of equivalent noise level as well as maximum levels and number of noise events. It should be noted that low frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low intensity.

Where noise is continuous, the equivalent noise level shoidd not exceed 30dB(A) indoors, if negative effects on sleep are to be avoided. In the presence of a large proportion of low frequency noise a still lower guideline value is recommended. It should be noted that adverse effect of noise partly depends on the nature of the source."

The comments with respect to low frequency noise reflect the effect of using an A-weighted sound pressure level. If most of the acoustic energy was concentrated at a very low frequency, then high levels of acoustic energy might exist but an A-weighted level may still only be 30dB(A). As an example, the A-weighting network applies a correction of 50dB at a frequency of 20Hz. Therefore, a level of 80dB at 20Hz would meet this 30dB(A) requirement.

Section 11.1.1.6 dealing with annoyance responses states that:

"Community annoyance varies with activity (speech communication, relaxation to radio and TV, etc). The threshold of annoyance for steady continuous noise is around 50dB(A)L_{eq} outdoors. Few people are seriously annoyed daring the day time at noise levels below around 55dB(A)L_{eq} outdoors. Noise levels during the evening and night should be 5 to lOdB lower than during the day. "

Section 11.1.2.1 deals with internal noise criteria for dwellings. It states:

"For dwellings, the critical effects are sleep disturbance, annoyance and speech interference. Specifically, for bedrooms the critical effect is sleep disturbance. Recommended guideline values inside bedrooms are 30dB(A)$L_{eq}$for steady-state continuous noise andfor a noise event 45dB(A)LMAX- Lower levels may be annoying depending on the nature of the noise source. The maximum level shoidd be measured with the instrument set at fast

To protect the majority of the peoplefrom being seriously annoyed during the day time, the sound pressure levelfrom steady, continuous noise on balconies, terraces and in outdoor living areas shoidd not exceed 55dB(A)L_{eq}. To protect the majority of people from being moderately annoyed during the day time, the noise level should not exceed 50dB(A) L_{eq}. Where it is practical andfeasible the lower sound pressure level should be considered the maximum desirable sound pressure levelfor decisions in relation to new development.

At night-time outdoors, sound pressure levels should not exceed 45dB(A)L_{eq}, so that people may sleep with bedroom windows open. This value has been obtained by assuming that the reduction from outside to inside with the window open is 15dB. "

It should be noted that an assumption of 15dB(A) level reduction between external and internal noise levels has been assumed. This is quite a high level of attenuation through a building envelope if large glazed areas exist within the building facade of a neighbouring residence. The actual level difference between external and internal noise levels (free field to internal) is typically 10-5dB(A) for a face with 25 - 40 % glazed facade area, respectively. Large glazed areas are not uncommon when patio doors or large picture windows exist in a dwelling but are less common for bedrooms.

Summary of noise limits and criteria in published guidance

Table 2 Summary of sleep disturbance criteria and internal noise levels

Source of Proposed Criteria	**Falling Asleep**	**Light Sleep**	**Deep Sleep**	**Max. Level**
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise		L_{Aeq} = 30 to 35		L_{Aeq}+10
OECD Report: Reducing Noise in OECD Countries: 1978	I-'Aeq = 3 5	LAeq = 45	L_{Aeq} = 50	L_{Aeq}+10to 15
WHO Environmental Health Criteria 12-Noise: 1980	I^Aeq = 35	LAEQ = 35	I^Aeq = 3 5	
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	L_{Aeq} = 30	L_{Aeq} = 30	L_{Aeq} = 30	LAMAX< 45**dB**
PPG 24 Planning and Noise	L_{Aeq} = 35 (Based on WHO Environmental Health Criteria 12)			
Planning and Noise Circular W.O. 16/73	Good Standard Internal Noise Level CNL (Corrected Noise Level) Day = 45dB(A) Night = 35dB(A)			

Table 3 Summary of external noise criteria

Source of Criterion	External Noise Limit dB
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise	L_{Aeq} = 50-55
British Standard BS 5228: Part 1: 1984 Noise Control on Construction and Open Sites. Part 1. Code of practice for basic information and procedures for noise control	$L_{Aeq,1\,Hour}$ at facade = 40-45
PPG 24 Planning and Noise	BS 4142 where appropriate
MPG 11 Control of Noise at Surface Mineral Workings	Day $L_{Aeq\,1h}$= 55, (No less than 45 in quiet area) Night $L_{Aeq\,1h}$ = 42 Gardens/open spaces $L_{Aeq\,1h}$= 55-65
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	Day-time L_{Aeq}= 50 Moderate Annoyance Night-time L_{Aeq}= 45

Experience in other countries

USA

The largest concentration of wind turbines in the world is situated in California, USA. Three main groups of turbines exist at Altamont, Palm Springs and Mojave Desert. Some work has been performed to provide noise criteria for these sites such that a minimum of disturbance is caused to neighbouring properties.

The most recent revisions have been performed under the title "*Tri-County Wind Energy: Mitigation Compliance Monitoring Program*" which has been performed for the Alameda, Contra Costa & Solano Counties and the California Energy Commission. Within this document is a section dealing specifically with noise which contains a brief description of the sources of noise from wind turbines. It also provides a summary of existing policies and regulations for wind turbines and makes a recommendation for adoption by the counties sponsoring the report. Extracts from this and other guidance from the USA are contained in Appendix B.

Denmark

The development of wind turbines and wind farms in Denmark has been under way for at least 15 years. During this time, work has been performed to assess the potential for noise emissions from wind turbines and also the level of ambient noise due to wind in trees and grasses. This work was used, to a degree, to formulate policy for wind turbines with respect to noise. This has been issued by the Ministry of the Environment, Denmark, National Agency of Environmental Protection, and is called *Statutory Order from the Ministry of the Environment No. 304 of May 14_t 1991 on Noise from Windmills.*

Part 2 of this document states the following:

> *"Establishment and Operation of Windmills*
>
> *Section 2. The noise load from windmills shall not exceed 45dB(A) at outdoor open spaces in the immediate vicinity of neighbouring properties in open country.*
>
> *Subsection 2. For the purposes of this order neighbouring properties means all residential buildings other than the private house of the windmill owner.*
>
> *Subsection 3. The noise load from windmills shall not exceed 40dB(A) in the most noise-inflicted spot at outdoor open spaces in residential areas and other noise-sensitive land uses.*
>
> *Subsection 4. For the purposes of this Order noise-sensitive land uses means areas used or reserved for the purposes of institutions, week-end houses, allotment gardens or recreation.*
>
> *Section 3. The noise load shall be determined according to the guidelines laid down in the Annex to this order as the equivalent corrected A-weighted noise level at a height of 1.5 metres at a wind speed of 8m/s at 10 metres above ground height. "*

This statutory order defines the measurement position, the wind conditions and the level which should not be exceeded. The determination of the sound power level (SWL) from the wind turbines has also be defined within the Annex and is the method reported by most Danish manufacturers of wind turbines. The quoted SWL is that which is emitted by the turbine when operating at 8m/s wind speed measured at a height of 10 metres above ground level.

In the UK the level which must be achieved by a wind farm site has sometimes been set at the cut-in wind speeds of the wind turbines, the expectation being that wind-induced noise at the receiver position will increase at a greater rate than the emitted noise from the turbine. Therefore, for a comparison of agreements and conditions which have already been undertaken by some developers in the UK it is better to compare directly these levels at cut-in.

The emitted noise from a wind turbine increases with wind speed. This increase is typically about ldB(A)/m/s. Different wind turbines have different rates of increase but this figure is fairly average for most commercially available wind turbines. Allowing for the height difference between the hub height (sometimes used for specifying the wind conditions when undertaking a noise test for compliance to any agreed noise level in the UK) and the wind speed and height used for the Danish Statutory Order of 8m/s at 10 metres height, Table 4 details the equivalent L_{Aeq} level which might be expected to meet the Danish Statutory Order at the cut-in wind speed of the wind turbines. A range is indicated to reflect the effects of varying ground roughness (0.01-0.05m) and rate of increase of noise with wind speed (0.75-l.OdB/m/s).

Table 4 Comparison of Danish limits to noise levels at cut-in

L_{Aeq} @ 8m/s @ 10m height dB(A)	Equivalent L_{Aeq} @ 5m/s @ 30m height dB(A)
45	40-42
40	35-37

The determination of the character of the noise emitted by wind turbines is performed by both a subjective and an objective test. This takes the form of listening to the emitted noise at the affected property and/or performing objective measurements of the incident noise at the property. The method by which tones are evaluated is the Joint Nordic Method for the Evaluation of Tone in Broadband Noise [21]. This method applies a 5dB(A) penalty to the incident noise from the wind turbine when the tone is deemed "prominent" using the objective test method.

The determination of when a tone is "prominent" is the result of laboratory tests of different tone and masking levels and different tone frequencies. (There is current work being performed for the DOE by NPL & IS VR to determine a more appropriate correction method for tonal noise. It is expected that this will not be included within a revision to BS 4142 for a number of years.)

The audibility criterion that is defined within the Joint Nordic Method is based upon Zwicker critical bands. The audibility criterion is frequency-dependent unlike the criterion defined within BS 7135 which is not frequency-dependent. The audibility threshold is defined as:

AL_t Audibility Criterion = $- 2 - \text{Log} (1 + (f_t / 502)^{2.5})$

where f_t = tone frequency.

The Joint Nordic Method also defines a method for the analysis of tones in non-stationary conditions, ie if the level or frequency of the tone is varying.

The details of the Joint Nordic Method are discussed further in Chapter 6.

Netherlands

The Netherlands has no specific legislation concerning noise from wind turbines but has noise regulations for industrial noise which state the following:

$L_{Aeq24hr}$ = 40dB(A) for rural areas without traffic
L_{Aeq} = 45dB(A) for quiet residential neighbourhoods in the city
L_{Aeq} = 50dB(A) for residential neighbourhoods in the city

The 45dB(A) and 50dB(A) limits are day-time values and should be reduced by 5dB(A) for evening periods and by 10dB(A) during the night. It should be noted that this implies that quiet residential neighbourhoods will, at night, have stricter noise limits than rural areas without traffic. It is understood that these are only recommendations and municipalities may use other standards when they issue a Nuisance Act permit.

Where a noise zone has not been proposed, the quality of the environment around the proposed wind farm will be considered. For example, if a wind farm were to be developed and dwellings were located nearby, background noise measurements would be undertaken to assess the prevailing background noise levels at the dwellings, the background noise level being defined as the La95 level. Turbine noise would then not be allowed to exceed this level, ie the wind farm would be designed to not exceed the existing background noise levels.

Germany

German recommendations for acceptable noise levels are given in documents covering "The law for the protection against any emissions" and detailed under Technical Instructions for Noise.

The sound pressure levels, measured as $L_{Aeq\,x}$, which must not be exceeded, are as follows:

	Day-Time	Night-Time
Commercial Areas	65dB(A)	50dB(A)
Mixed Areas	60dB(A)	45dB(A)
General Residential	55dB(A)	40dB(A)
Pure Residential	50dB(A)	35dB(A)

There currently exists a method for the determination of the audibility of tones , Draft DIN 45 681 [22]. This method is in draft form and is based upon ISO 7779 which forms the basis of BS 7135 Part 1 Annex D. This Draft DIN standard proposes a penalty rating method that follows the guidance contained within ISO 1996 (BS 7445) which gives a tonal penalty to the noise, that is related to the audibility of the tone. The penalty varies from 0-6dB depending upon the exceedence of the tone above the tone detection threshold. However, the penalty system is based upon the tone detection thresholds that are described in ISO 7779, and like BS 7135, the detection thresholds do not follow classic critical band theory. The audibility threshold described in DIN 45 861 is 6dB below the critical band masking level. Classic theory would indicate that this is 4dB over-sensitive at frequencies below 500Hz. Experience through the application of the tonal assessment method described in DIN 45 681 would indicate that a tonal penalty would be, and is, applied even when a tone is not audible but the assessment method indicates that one exists.

DIN 45 681 usefully defines which lines in the spectrum should be counted as contributing to the tone energy. Section 4.3.2 explains:

> *"It is not always obvious whether sidebands contribute to tone energy. A sideband should be included in the sum if the difference with respect to the maximum narrowband level is less than lOdB, and the difference with respect to the average narrowband of the masking noise in the critical band about the tone is larger than 6dB.*

5. SURVEY OF PUBLIC REACTION TO NOISE FROM WIND FARMS

Introduction

One element of the work of the Working Group was to assess the circumstances which have or have not resulted in complaints by the public over noise from wind farms. A survey of public reaction to noise from wind turbines as reported to Environmental Health Departments was therefore conducted, based upon the operational wind farms in England and Wales as of February 1994. A list and brief description of the wind farms used in the survey is given in Table 5 and Fig 1 shows their location.

Table 5 Operational wind farms in England and Wales (Feb 1994)

Wind Farm	Turbine Manufacturer	No.	Rated Power kW	Total Capacity kW
Cemmaes, Powys	WEG	24	300	7200
Kirkby Moor, Cumbria	Vestas	12	400	4800
Chelker, Yorkshire	WEG	4	300	1200
Ovenden Moor, Yorkshire	Vestas	23	400	9200
Delabole, Cornwall	Vestas	10	400	4000
Penrhyddlan and Llidiartywaun, Powys	Mitsubishi	103	300	30900
Rhyd-y-groes, Anglesey	Bonus	24	300	7200
Blyth Harbour, Northumberland	HMZ	9	300	2700
Orton Airport, Cumbria	Carters	10	300	3000
Goonhilly Downs, Cornwall	Vestas	14	400	5600
Cold Northcott, Cornwall	WEG	22	300*	6700
Blood Hill, Norfolk	Vestas	10	225	2250
Taff-Ely, Mid Glamorgan	Nordtank	20	450	9000
Carland Cross, Cornwall	Vestas	15	400	6000
Coal Clough, W Yorkshire	Vestas	24	400	9600
Llangwyryfon, Dyfed	WEG	20	300	6000
Haverigg, Cumbria	Vestas	5	225	1125
Royd Moor, S Yorkshire	Bonus	13	450	5850

* Includes 1x400 kW Turbine

A questionnaire was sent to local authorities having wind farms in their areas. A summary of the results of this survey appears in Table 6 and a more detailed discussion follows.

Figure 1 Wind farms constructed under NFFO-1 and -2

Table 6 Summary of complaints from wind farms
(figures in italics are from conversations on phone rather than from the questionnaire)

Wind Farm	**Distance from residences to wind farm (m)**	**Number of complaints**			**Aspects of noise leading to complaints**			
		Verbal	**Written**	**Distant**	**Overall**	**Tones**	**Swish**	**Other**
Cemmaes		*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
KirkbyMoor	*700*	*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
Chelker	350-500	0	0	0	n/a	n/a	*nidi*	n/a
Ovenden Moor	320-630	0	0	0	n/a	n/a	n/a	n/a
Delabole	350-1380	15	7	5	No	Yes	No	Yes
Penrhyddlan and Llidiartywaun	700-1200		5	2	Yes	Yes	Yes	No
Rhyd-y-Groes	400-600	1	1	0	Yes	No	No	**Yes**
Blyth Harbour		*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
Orton Airport								
Goonhilly Downs								
Cold Northcott	380-500	10+	5	1	Yes	Yes	Yes	No
Blood Hill	400-450	0	0	0	n/a	n/a	n/a	n/a
Taff-Efy		*1*	*1*	*0*				
Carland Cross	370-410	2	2	2	Yes	Yes	**Yes**	**Yes**
Coal Clough	420	0	0	0	n/a	n/a	n/a	n/a
Llangwyryfon								
Haverigg	600, 1000	0	0	0	n/a	n/a	n/a	*nidi*
Royd Moor								

Effects of topography

Following experience from mainland Europe, initial expectations had been that the noise from wind turbines would be most intrusive at wind speeds at and just above cut-in. It had been expected that as the wind speed increased, the background noise generated by the passage of wind through trees and around buildings would increase at a faster rate than the noise generated by the turbines. The margin of the turbine noise above background noise would then have been greatest at relatively low wind speeds with the turbine noise progressively drowned out as the wind speed increased. This has not always been the case, however, particularly at many of the sites at which complaints over wind farm noise have arisen. At Cold Northcott, Penrhyddlan and Llidiartywaun, Rhyd-y-Groes and Delabole the noise was felt to be more intrusive at hub height wind speeds of 8m/s and above. In some cases this is influenced by the switching to a higher turbine rotational speed in higher winds but is primarily because properties are frequently sited in sheltered areas. It is not unusual for turbines to be operating in relatively strong winds on an exposed hill top location while some of the nearest properties in relatively sheltered valleys remain out of the wind and hence background noise levels can remain low in the absence of significant wind-generated background noise.

Change in attitude with time

There was no firm evidence of complainants becoming accustomed to the noise and their **level** of concern diminishing as a result. Decreasing annoyance was seen at some wind farm sites but this was usually due to remedial action being taken to reduce the noise from the wind turbines. An example of this occurred at Delabole where the turbines on commissioning could under certain conditions produce a noise described as a "squawk". This was also observed at Carland Cross using the same model of turbines and was believed to be caused by an instability in the flow over the turbine rotor blades. The effect was remedied by making adjustments to the pitch control settings and application of tapes, or boundary layer trips, to the trailing edges of the blades. These boundary layer trips disturbed the boundary layer or air flow close to the surface of the blade, causing it to become turbulent rather than laminar. As a laminar boundary layer is a prerequisite for the excitation process to occur this eliminated the noise source.

At sites which have not been able to reduce noise levels to the satisfaction of residents, complainants have become impatient and shown increasing annoyance.

Characteristics of the noise

At all sites at which complaints have been made reference has also been made to particular characteristics of the noise. Mechanical noise of a tonal nature, usually from the gearbox, has been frequently cited as being an aspect of the noise leading to complaints. In cases where mechanical noise is present it is not surprising that this should lead to increased annoyance, as is reflected in the penalties for tonal content added to rating levels of noise in standards such as BS 4142.

Blade swish is a phenomenon more peculiar to wind turbines which has emerged as another characteristic which can under certain circumstances add to the likelihood of complaints. Swish was identified as being one aspect of the noise leading to complaints at Penrhyddlan and Llidiartywaun, Cold Northcott and Carland Cross. Recorded time trace data from a property near to Carland Cross showed peak to trough differences of the A-weighted noise up to 3dB in an open situation and up to 6dB in a location where multiple reflections from nearby buildings affected noise levels. A noticeable level of swish was also observed by the Environmental Health Officer at Coal Clough although no complaint has been made at this

Intermittent blade thump was cited as being a contributing factor leading to complaints at Carland Cross.

Noise levels

As illustrated later in Chapter 6 background noise and turbine noise levels can be quite variable and show a fair degree of scatter even when plotted against wind speed. From the often limited data available it has therefore not been possible to reach any firm conclusions on noise levels which are likely to lead to complaints, particularly as in many cases the character of the noise has been as influential as the actual noise level in leading to complaints.

Time of day

Indications of periods during which the noise was found to be most audible or most intrusive were generally the same irrespective of whether weekdays or the weekend were being considered. At Cold Northcott, Rhyd-y-Groes and Delabole night-time (22.00-06.00) was reported to be the period at which nearby residents found the noise most intrusive, along with the evening (18.00-22.00) at Cold Northcott and Delabole and early morning (06.00-09.00) at Rhyd-y-Groes.

Relative impact, indoors compared to outdoors

The level of intrusion was in general a degree less indoors than out of doors. If the level of intrusion was considered high outdoors it was low indoors; if the noise could only be heard faintly outdoors it was inaudible indoors. On some sites (Blood Hill and Chelker) the turbines were considered largely inaudible both indoors and outdoors. The finding that outdoor levels were found to be more intrusive than indoor levels is somewhat at odds with the previous finding that the intrusion was in some cases greater at night when you would expect people to be indoors.

Reasons for absence of complaints

Although this section has concentrated on the factors affecting the likelihood of complaints it should be noted that at eight of the thirteen wind farms for which we have data no complaints have been received. The most frequently given reason is (not surprisingly) the low noise levels or inaudibility of the wind farm. Perceived low noise levels are usually the result of one or more factors including:

- background noise levels being sufficiently high at all wind speeds to substantially mask the turbine noise
- relatively quiet turbines with little or no tonal content in the noise emissions
- relatively large separation distances between turbines and nearest residences
- public acceptability of the wind farm in general.

Conclusions from the survey

- The framework for assessing wind turbines needs to relate noise at residences to turbine noise, taking into account the possibility of nearest residences remaining sheltered from the wind when turbines are operating in moderate-to-high wind speeds.

- Once nearby residents are sensitised to noise they are unlikely to get used to it over a relatively short period of time (approximately 12-18 months at the time of writing).

- The assessment method should impose penalties for distinctive characteristics of the noise.

- The assessment method should take account of the lower background noise levels at night.

- By using best practice it is possible to develop wind farms which are unlikely to lead to complaints over noise levels from the nearby residents.

6. NOISE LIMITS

Introduction

The background against which members of the Noise Working Group have set out to define a procedure for the measurement and rating of noise from wind turbines has been explored in Chapter 2. This chapter describes a framework for measurements with indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. The suggested noise limits and their reasonableness have been evaluated with regard to regulating the development of wind energy in the public interest. They have been presented in a manner that makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.

The noise limits suggested have been derived with reference to:

- existing standards and guidance relating to noise emissions
- the need of society for renewable energy sources to reduce the emission of pollutants in pursuance of Government energy policy
- the ability of manufacturers and developers to meet these noise limits
- the researches of the Noise Working Group in the UK, Denmark, Holland and Germany
- the professional experience of members of the Working Group in regulating noise emissions from wind turbines and other noise sources
- the discussion of the issues at meetings of the Noise Working Group and with others with appropriate experience.

The Noise Working Group has sought to protect both the internal and external amenity of the wind farm neighbour. Wind farms are usually sited in the more rural areas of the UK where enjoyment of the external environment can be as important as the environment within the home.

The noise limits have been devised with regard for the human environment without specific consideration of the effect of noise on farm livestock. Members of the Noise Working Group are however unaware of any problems in this area to date. Indeed, at many windswept locations the turbine towers and transformers appear to offer a welcome degree of protection from the elements.

The guidance contained in this chapter refers to the operation of the wind farm, and is not appropriate to the construction phase which should be considered separately according to existing guidance such as BS 5228: 1984, Noise Control on Construction and Open Sites.

Locations for setting noise limits

At the wind farm, at the site boundary or at noise-sensitive properties?

There are broadly four options to consider when deciding upon the most appropriate location(s) to set noise limits:

1) In the wind farm.

2) At the boundary of the site occupied by the wind farm.

3) At the surrounding noise-sensitive properties.

4) At any position over a given distance from the nearest turbine.

The advantages of options (1) and (2) are that at these positions the noise will be easier to monitor as access to the site is controlled by the operator and the noise levels will be higher and therefore probably more easy to distinguish from the background noise. The disadvantage with this approach is that in its simplest form it does not take account of the proximity of the noise-sensitive properties, and even if noise levels at nearest properties are theoretically derived from limits and measurements close to the wind farm, this type of limit offers little protection to residents if the inferred levels prove inaccurate.

Option (3) has been the preferred method on all planning conditions on wind farms in the UK to date and is described as the normal approach in Annex 5 of PPG 24. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment. In some circumstances access to nearest properties may prove problematical but it is the Noise Working Group's experience that in general residents are happy to allow access to monitor noise levels, particularly if monitoring is required in response to complaints.

The fourth option, setting limits at a standard distance from the development in addition to those limits set at nearest properties, was one of the recommendations of the Welsh Affairs Committee's Report on Wind Energy [23]. This approach has some merits in that it avoids large areas of land becoming unsuitable for future development because of noise and conversely provides the wind farm operator with some protection from claims of nuisance from future development. In practice, because of the population distribution in the UK, limits on wind farm noise will be dictated by consideration of nearest properties. This has been the case with wind farm developments built to date in England and Wales. If limits were related to background noise levels then a knowledge of the variation in background noise levels with wind speed at all positions around a wind farm would be required. Determining these levels would be prohibitively expensive unless some crude assumptions were made.

For the reasons given above the Noise Working Group recommends that the current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment, for the reasons given above.

Internal or external noise limits?

Given that one of the aims of imposing noise limits is to protect the internal environment one might consider it appropriate to set these limits and hence monitoring locations at positions within the building. There are, however, some practicalities to take into consideration which lead us to believe that the current practice of setting external limits on noise is the more sensible approach:

- Monitoring of noise to demonstrate compliance with planning conditions may require data to be logged over a period of days in order to capture enough data at the required conditions. It may not always be feasible or reasonable to expect to leave equipment set up in someone's bedroom or living room for this period of time.

- Noise levels inside a dwelling would be extremely difficult to predict as they would depend upon the noise insulation properties of the windows, doors, roof and walls and the acoustic properties of the rooms. Each room in each property would have to be considered separately. It is simpler and as safe to predict free-field noise levels outside of the property and then make a conservative assumption on the attenuation properties of the building envelope.

- Noise limits, and therefore measurements, are in any event required outside the property to protect the external amenity. If internal noise levels can be inferred from these external limits then a requirement for internal measurements would place an unreasonable burden on the operator.

The noise limits applied to protect the external amenity should only apply to those areas of the property which are frequently used for relaxation or activities for which a quiet environment is highly desirable. For example, if a farm house is one of the noise-sensitive properties it would probably not be appropriate to apply limits to all the land belonging to the farm.

Types of noise limit

Options available

There are three types of constraints that can be placed on noise-producing developments. Ranked in order of complexity these are:

1) A minimum separation distance between the development and the nearest properties.

2) An absolute limit based on the average level of noise which should not be exceeded in a specified time period.

3) A relative limit based upon the permitted increase in noise level with respect to the background noise level. This is the approach used in BS 4142: 1990.

The descriptions of (2) and (3) are taken from PPG 24 which indicates either may be appropriate depending upon circumstances. The merits of each approach are considered in turn below.

Minimum separation distance

Paragraph 47 of the annex to PPG 22 refers to experience from mainland Europe which has shown that there is unlikely to be a significant noise problem for a residential property situated further than distances of 350-400 metres from a wind turbine. The PPG also suggests that:

> *"Lesser separation distances may be acceptable depending on the turbines used and the specific conditions at a site."*

This was true for the flat, open sites typical of Northern Europe and for the size and number of turbines used in wind farms at the time of writing PPG 22. We believe the guidance in PPG 22 was intended to give the reader an appreciation of the magnitude of the separation distances that would be required to protect local amenity. Indeed, wind farms have been constructed with this order of separation distance which have not resulted in complaints over noise. There are however a number of further considerations relevant today.

The emitted sound power level (SWL) from different wind turbines may vary by several dB for the same wind speed condition at hub height depending upon the size and design features of the turbine. Assuming hemi-spherical propagation with atmospheric absorption of 0.005dB/m this means that a quiet wind turbine with a SWL = 95dB(A) positioned at 245m from a dwelling would have the same acoustic impact as a turbine with a SWL = 101dB(A) positioned at 437m from a dwelling. (Note: this would result in an incident noise level at a dwelling of « 38dB(A) from a single wind turbine.)

For small and medium-sized wind farms, say less than 10 to 20 turbines, incident noise levels at a residence are usually only influenced by those turbines closest to the residence. However, the advent of the larger wind farms being proposed and built today means that the cumulative effect of many turbines at some distance from the residence may also increase the noise levels around a property. Greater separation distances will therefore be required to achieve the same noise levels as a smaller wind farm using the same type of turbines.

The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms.

Absolute limits

There are a number of ways in which absolute noise limits for wind farms can and have been

- A maximum level not to be exceeded at any wind speed at any property.

- A maximum level not to be exceeded at a specific wind speed or over a range of wind speeds set irrespective of the prevailing background noise level.

- A maximum level not to be exceeded at a specific wind speed or over range of wind speeds based on measurements of the prevailing background noise level taken prior to the construction of the wind farm.

The second option is of the type used in Denmark where noise from wind turbines is commonly limited to 40dB(A) in residential areas when measured at a wind speed of 8m/s at 10m height. This approach has its attractions in that it is relatively simple to use. Manufacturers need only state sound power levels for their machines at one wind speed, developers do not have to concern themselves with background noise surveys and actual levels need only be monitored at one, frequently occurring wind speed. The flat open countryside of Denmark enables one to be reasonably confident that if the noise limits at 8m/s are attained then the noise from the wind farm at other wind speeds is unlikely to be unduly disturbing. As demonstrated in Chapter 4, at cut-in the noise level will be less than 36-37dB(A) whereas at higher wind speeds the background will increase at a faster rate with wind speed than the turbine noise, such that the background noise soon approaches that of the turbine.

PPG 22 also advises at paragraph 42 that wind-generated background noise increases with wind speed and at a rate greater than that of wind turbines. It is also stated that the greatest level difference between turbine noise and background noise is liable to occur when wind speeds are low. PPG 22 does however note that for some sheltered locations the background noise levels may remain low even when wind speeds are well above the cut-in wind speed for the wind turbines.

In general, the assumption that the greatest difference in level might be at low wind speeds is true for flat sites which do not offer any shelter from the wind. These types of sites may be found in the Netherlands and Denmark where the topography of the landscape is such that little shelter exists. However, within the UK landscape, the positioning of a majority of wind farms to the West of the country has resulted in sites being developed within landscapes that are not flat. The effect of deep valleys (like those found in Wales, the Pennines and Scotland) and sheltered positions (like those that are found in Cornwall), is to protect dwellings from the effects of the wind and thereby from an increase in the background noise level due to the wind. Figs 2, 3 and 4 show the differences that can be experienced by dwellings when positioned in exposed or sheltered positions.

Fig 2 details measurements made within a deep valley positioned 150 metres below a mountain top plateau. Fig 3 details measurements made in a location which was partially protected from the prevailing wind by existing buildings and a tree wind break whereas Fig 4 details measurements performed at an exposed position on the top of a mountain. Wind speed measurements were performed on the top of a mountain at positions where wind turbines would be expected to be erected. It should be noted that the anemometer measurement height is different in Fig 3. The actual wind speed at the hub height of a wind turbine might be expected to be higher than that shown in Figs 2 & 4 by as much as a factor of 1.21, ie a wind speed of lOm/s measured at a height of 10 metres may be expected to be a wind speed of 12.1m/s measured at a hub height of 30 metres.

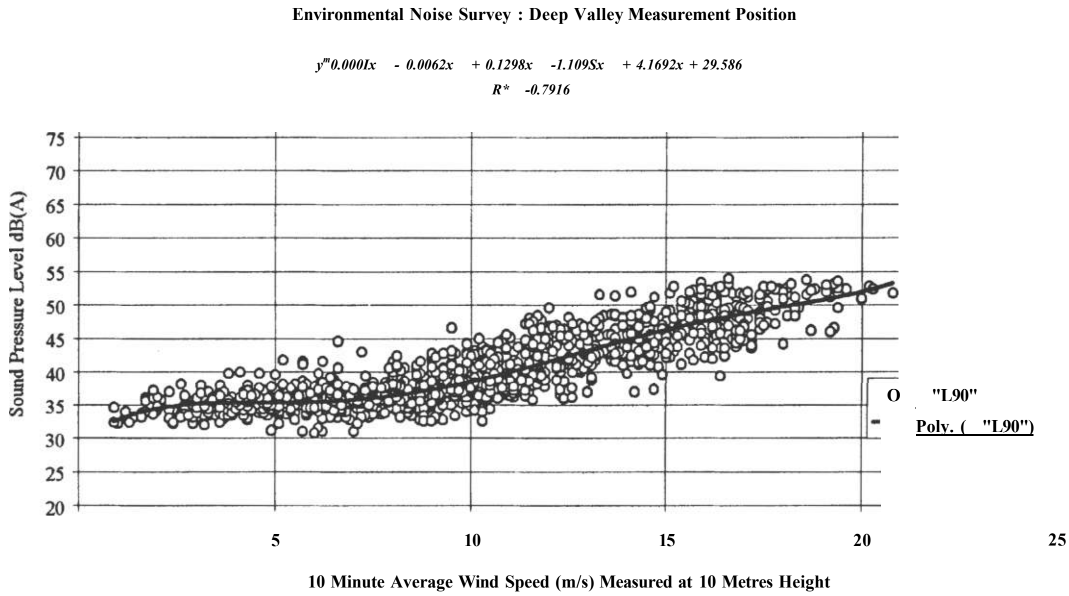


Figure 2 Background noise measurements in a deep valley position

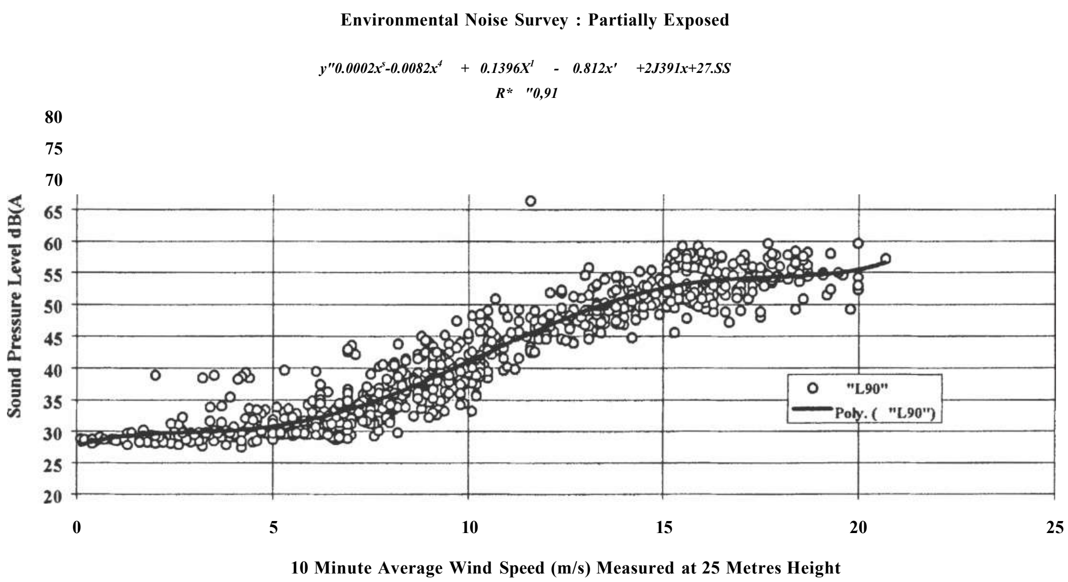


Figure 3 Background noise measurements in a partially exposed position

The variation of the rate of increase of the background noise level with wind speed has resulted in some sites experiencing complaints at high wind speeds but no complaints at low wind speeds. This is because, although turbine noise continues to rise with an increase in wind speed, the background noise levels have remained unchanged. Therefore, the level difference between the incident noise from a wind farm and the prevailing background noise level when the wind farm is not operating has been greatest at these higher wind speeds.

It may be seen that this sheltering effect results in each site having its own background noise environment with respect to wind-generated noise. Therefore, each position adjacent to a site should be considered for sheltering effects from the wind. The assumption that background noise levels will increase at a greater rate than the emitted turbine noise does not always hold true for the hillier sites which are found within the UK.

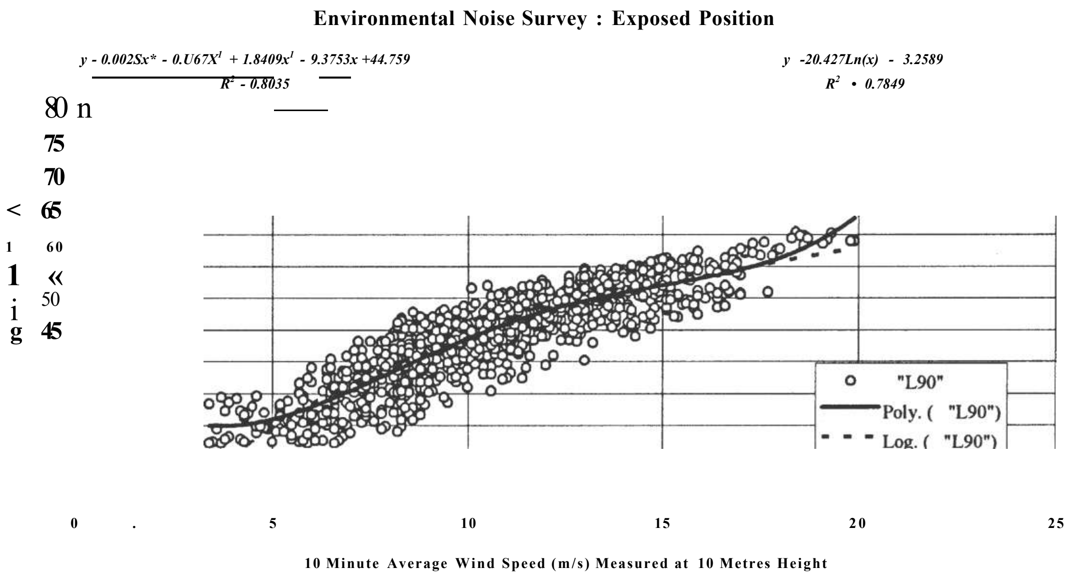


Figure 4 Background noise measurements in an exposed position

Even in Denmark the assumption that background noise increases with wind speed at a faster rate than the turbine noise may not be true for variable speed machines which, although usually quieter than fixed speed machines at low wind speeds, are characterised by a steeper rate of increase in noise emission with wind speed.

For the reasons given above the Noise Working Group considers that absolute noise limits applied at all wind speeds are not suited to wind farms in typical UK locations and that limits set relative to the background noise are more appropriate in the majority of cases. Later in this chapter consideration is given to the use of absolute levels in circumstances when background noise levels are low and in cases where low turbine noise levels can be achieved over a range of wind speeds.

Relative limits

PPG 24 introduces the concept of using BS 4142, a standard designed to predict the likelihood of complaints, as a tool for setting noise limits on industrial development. Paragraph 19 within Annex 3 of PPG 24 considers noise from industrial and commercial developments. It is stated that:

> *"The likelihood of complaints about noise from industrial development can be assessed\ where the Standard is appropriate, using guidance in BS 4142: 1990. Tonal*

or impulsive characteristics of the noise are likely to increase the scope for complaints and this is taken into account by the "rating level" defined within BS 4142. This "rating level" should be used when stipulating the level of noise that can be permitted."

It should be noted that the guidance proposes the use of BS 4142 where the standard is appropriate. For the reasons described in the next section a literal interpretation of BS 4142 is difficult to apply to an assessment of wind farm noise and it may therefore not be appropriate. The Noise Working Group does however consider the principle of setting noise limits relative to the existing background noise level is appropriate, subject to the discussion on low noise levels later in this chapter.

Problems with interpretation and the literal application of BS 4142.

Paragraphs 43-44 of PPG 22 consider the use of BS 4142: 1990 and reports that this standard has been advocated as the standard which comes nearest to dealing with the issues encountered in wind farm developments.

Paragraph 44 states three reasons why using BS 4142: 1990 may be inappropriate for assessing wind turbine noise. These are:

"a) Wind farms are likely to be developed in largely rural areas and not in the areas to which the standard is principally addressed\ namely mixed residential and industrial areas;

b) the scope of BS 4142 specifically precludes situations where background noise levels are below 30dB(A);

c) BS 4142 recommends that noise measurements should not be taken in extreme weather conditions such as high wind speeds greater than 5 metres per second average ".

Paragraph 45 of the annex to PPG 22 states that:

" Where any of these factors gives rise to concern about whether BS 4142 is appropriate as a means of determining potential or actual perceived noise nuisance, the combined effect of the wind turbines should be determined by reference to the particular character and sensitivity of the area. "

It is therefore worth exploring the reasons behind these qualifications on the use of BS 4142 and what measures are necessary to overcome these limitations.

Although the standard is intended for use in mixed residential and industrial areas as suggested by its title, there are no obvious reasons which prevent its application in more rural areas and indeed Members of the Noise Working Group have used it in such areas. There is no evidence to suggest that the average rural dweller is more or less sensitive to noise than their suburban or urban counterparts. On the one hand some people may be attracted to the countryside for its peace and quiet whereas for others the countryside is their workplace and noisy activities are a part of working life.

The scope of BS 4142 precludes its use where background noise levels are below 30dB(A). Background noise levels in rural areas, particularly during the quiet periods of the day and night, may frequently fall below this level. Two reasons have been suggested for this limitation in scope [24]:

- Measurements of background noise giving results below 30dB(A) may not be reliable due to the limitations of the instrumentation (although one could be fairly certain that the actual levels were no more than those measured!).

- The standard is designed to assess the likelihood of complaints from people residing inside a building based on measurements outside of the building. It is considered that when noise levels are less than 30dB(A) when measured externally the masking level inside the property will be dominated by internal noise sources.

This exclusion of the rating method contained within BS 4142 for these situations might be considered to leave rural environments, which can be very quiet, open to developments which could result in a significant change in the noise environment.

The current standard might be precluded if a background noise level was measured of 29dB(A) and the rated incident noise level were 40dB(A). Using the assessment method proposed within BS 4142, a level difference of 1 ldB(A) would otherwise be considered likely to give rise to complaints. However, if the background noise level were 3 ldB(A) and the rated noise level again 40dB(A), BS 4142 would no longer be precluded from use and a level difference of 9dB(A) would still be considered likely to give rise to complaints. The only difference is an increase in the measured background noise level of 2dB(A).

This apparent inconsistency has been considered by the committee for BS 4142 and has led to a proposed change within the scope of BS 4142, in the form of a revision. It is proposed that it will now read:

"The method is not applicable for assessing the noise inside buildings or when the background and specific noise levels are low.

Note: For the purposes of this Standard, background noise levels below SOdB and rating levels below 35dB are considered to be very low. "

The question that arises is: if one intends to apply the principles of BS 4142 to the protection of external amenity, and the instrumentation is available to accurately measure noise levels below 30dB(A), should a margin above background approach be pursued in low noise environments or can an absolute level be justified in such circumstances? This question is addressed in the following section.

BS 4142 also suggests that:

"Noise level measurements should not generally be made under extreme weather conditions such as high winds (greater than 5m/s average).... "

The reason given for this limitation is:

" Weather conditions may affect measurements either by generating extraneous noise or by influencing sound propagation. "

PPG 22 warns that:

"Wind farms are likely to be sited in windy conditions where the BS 4142 conditions may not be satisfied. "

At the nearest residences to wind farms, even though the wind speed will usually be less than at the wind farm site, the local wind speed may still rise above 5m/s during periods when measurements are required. One should therefore exercise caution to ensure that measurements are not contaminated by wind noise on the microphone and consider the use of secondary windshields.

Propagation effects in high winds could result in unrepresentative results being obtained, particularly for ground-based sources located some distance upwind or downwind of the receiver. The warning contained in BS 4142 about taking measurements in winds greater than 5m/s guards against these effects on sound propagation. In the case of wind farms the turbines will often be in winds greater than 5m/s when at the same time the nearest residences are in relatively calm conditions. As wind speeds at both locations and all points in between will affect propagation and because most, if not all, turbine operation will occur at hub-height wind speeds greater than 5m/s one could argue that measurements taken in such conditions would strictly be outside the scope of BS 4142. It should be noted however that the effect of wind strength and direction on propagation may be less for elevated sources such as wind turbines. It is of course essential to be able to take measurements during windy conditions when assessing wind turbine noise and so it is suggested here that measurements are taken over a variety of wind directions to ensure that typical results are obtained.

Setting noise limits relative to the background noise level is relatively straightforward when the prevailing background noise level and source level are constant. However, wind turbines emit noise that is related to wind speed, and the environment within which they are heard will probably also be dependent upon the strength of the wind and the noise associated with its effects. It is therefore necessary to derive a background noise level that is indicative of the noise environment at the receiving property for different wind speeds so that the turbine noise level at any particular wind speed can be compared with the background noise level in the same wind conditions. This is consistent with the approach of BS 4142: 1990 which offers the following guidance on the measurement of background noise levels:

"'Make measurements during periods when the background noise is typical of the background noise when the specific noise source is or will be operating. "

"Measure the background noise during periods when weather conditions are similar to

those which prevail when the specific noise level is measured or are likely to be typical during the operation of a new or modified specific noise source. "

In the case of wind turbines the specific noise level varies with wind speed, as does the background noise level. Measurements of the turbine noise level at a given wind speed should therefore only be compared to background noise measurements taken when weather conditions are similar ie the same wind speed. Only by measuring the background noise over a range of wind speeds will it be possible to evaluate the impact of the turbine noise, which also varies with wind speed, on the local environment.

Structure of limits

When assessing the overall noise levels emitted by a wind farm it is necessary to consider the full range of operating wind speeds of the wind turbines. This covers the wind speed range from around 3-5m/s (the cut-in wind speed) up to a wind speed range of 25-35m/s measured at the hub height of a wind turbine. The Noise Working Group is, however, of the opinion that one should only seek to place limits on noise over a range of wind speeds up to 12m/s at 10m height on the site of the wind farm. There are four reasons for restricting the noise limits to this range of wind speed:

1) Wind speeds are not often measured at wind speeds greater than 12m/s at 10m height. For example, measurements over a one year period from May 1993 to April 1994 at the Delabole Wind Farm indicated that the wind speed measured over a 10-minute period exceeded 12m/s at 10m height (which was shown by measurement to be equivalent to 15m/s at the hub-height of 32m) for only 5% of the time. The annual mean wind speed for this year was 8.0m/s.

2) Reliable measurements of background noise levels and turbine noise will be difficult to make in high winds due to the effects of wind noise on the microphone and the fact that one could have to wait several months before such winds were experienced.

3) Turbine manufacturers are unlikely to be able to provide information on sound power levels at such high wind speeds for similar reasons. 12m/s wind speeds are even rarer in other parts of Europe.

4) If a wind farm meets noise limits at wind speeds lower than 12m/s it is most unlikely to cause any greater loss of amenity at higher wind speeds. Whilst turbine noise levels will still be reasonably constant, even in sheltered areas the background is likely to contain much banging and rattling due to the force of the wind.

At the low wind speed range of turbine operation it is expected that some quiet rural locations will experience background noise levels that are very low. At medium wind speeds, it would be expected that background noise levels would increase with increasing wind speed and noise levels above 30dB(A) would be experienced, although possibly at levels still less than the predicted or actual levels from the wind farm. At high wind speeds it may be expected that, unless tones are present, the wind noise will mask turbine noise levels unless significant shelter is afforded to a dwelling. These different environmental factors require the development of an assessment procedure that will take into account individual dwellings, the noise environment and shelter from the wind that each dwelling experiences.

The recommendation of the Noise Working Group is that generally the noise limits should be set relative to the existing background noise at nearest noise-sensitive properties and that the limits should reflect the variation in both turbine source noise and background noise with wind speed. The Noise Working Group has also considered whether the low noise limits which this could imply in particularly quiet areas are appropriate and has concluded that it is not necessary to use a margin above background approach in such low noise environments. This would be unduly restrictive on developments which are recognised as having wider national and global benefits. Such low limits are, in any event, not necessary in order to offer a reasonable degree of protection to the wind farm neighbour. It is instead proposed to control noise through absolute limits up until wind speeds where the background noise has increased to a level such that relative limits are again appropriate. The proposed values for an absolute limit and their justification are discussed in the next section.

Separate noise limits should apply for day-time and for night-time. The reason for this is that during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. Day-time noise limits will be derived from background noise data taken during quiet periods of the day and similarly the night-time limits will be derived from background noise data collected during the night. Background noise data collected during the night may be lower than those collected during the quiet periods of the day and would lead to unnecessarily tight restrictions on wind farm noise. The absolute limit for night-time operation can be higher than that in place during the day because of the extra attenuation afforded by the propagation of sound through even an open window.

Quiet daytime periods are defined as:
All evenings from 6pm to 11pm,
plus Saturday afternoon from 1pm to 6pm,
plus all day Sunday, 7am to 6pm.

Night time is defined as 11pm to 7am.

Consideration has also be given to circumstances where a more simplified approach, based on a fixed limit, may be appropriate.

Setting values for noise limits

Selection of units

The 1990 revision of BS 4142 was to bring the British Standard into line with ISO 1996 which has subsequently been adopted as British Standard BS 7445. The change that occurred was the proposal that the rating level of a new noise source be based upon a measured L_{Aeq} rather than a visual averaging of the meter. Also, sound power level data for wind turbines are based upon the measured L_{Aeq} at a predetermined distance from a wind turbine. Therefore, it might be expected to be appropriate to use the L_{Aeq} index to perform an assessment of wind turbine noise at dwellings.

However, experience in the field when performing such measurements indicates that short, transitory noise events can significantly change the L_{Aeq}. These events are not related to the noise emitted by the wind farm. These transitory noise events can be sources such as low flying aircraft, bird song, animal noises, cars, wind effects on the microphone, etc. The rating and assessment method contained within BS 4142 compares the existing L_{A90} background noise level with the L_{Aeq} of the rated noise level from the new source. A level difference of 10dB(A) between these two levels indicates that complaints are likely from neighbouring residents to the new noise source.

Measurements performed in rural areas indicate that the ambient L_{Aeq} noise levels may be 5-25dB(A) above the L_{90} background noise level due to these transitory events. Therefore, when performing noise measurements for the assessment of compliance with planning conditions or obligations, confusion can occur due to the L_{Aeq} being significantly higher than the L_{90} background noise level due to noise sources not associated with the wind farm. This might unfairly indicate that the condition is being failed if the condition is related to an L_{Aeq} exceedence above the background L^o.

Fig 5 details environmental noise measurements that indicate the high background L_{Aeq} levels when compared with the background L^o noise levels. These measurements were performed in the absence of any other noise source except those found in a typical rural environment. The figure plots the noise measurements performed over a 24-hour period. It may be seen that there are many occasions when the L_{Aeq} exceeds the L^o by over 10dB(A) and at times by over 20dB(A).

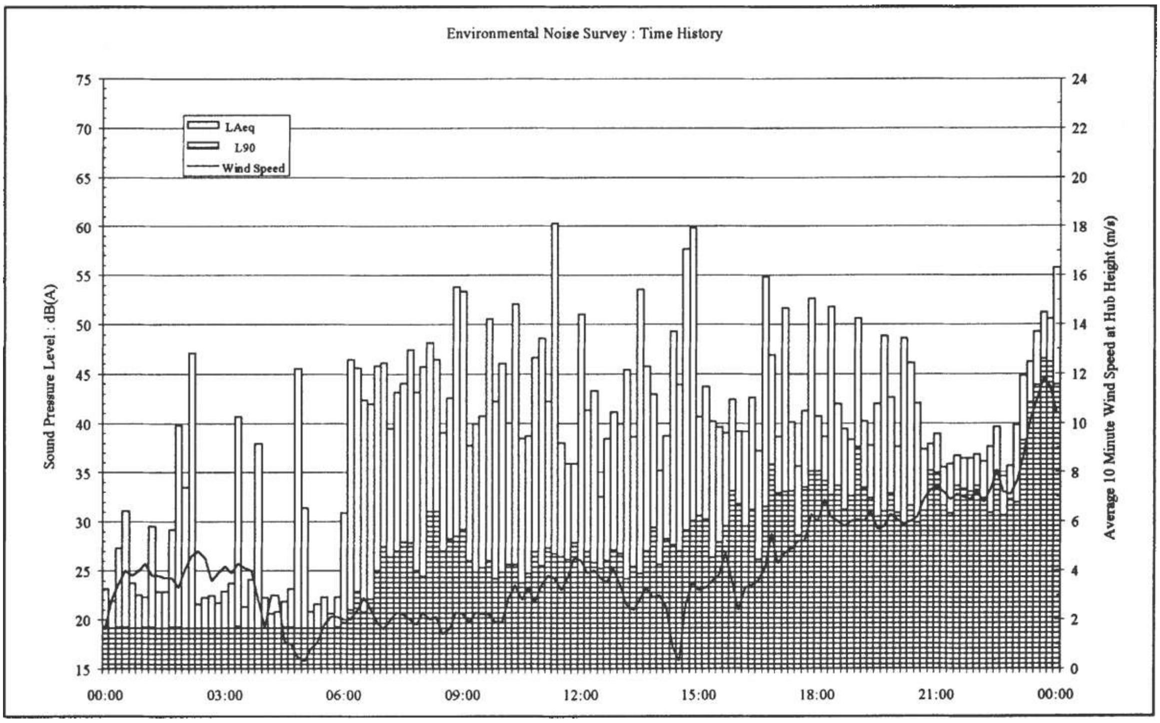


Figure 5 Comparison of L_{Aeq} and L_{A90} background noise levels

Note: The electrical noise floor of the sound level meter used to obtain this data was 18dB(A).

This problem has been encountered when using the L_{Aeq} index and has led to the use of other noise descriptors. Measurements of the L_{A90} and the L_{A90} have been proposed for the testing and application of noise conditions for wind farms. In South West England, conditions have been agreed with local authorities that relate the L_{A90} noise levels of the wind farm to either the existing background noise level during the test or to an agreed level at a specified wind speed, as measured on the wind farm site. The selection of an L_{A90} level does not follow the guidance contained within BS 4142 or BS 7445 but it does attempt to address the problems that may be experienced in the field. Early work performed at the Carmarthen Bay demonstration site used the L_{A90} index to assess turbine noise. Again, this was to minimise the errors that may occur due to transient noise events.

Another related drawback of using two noise indices as suggested by BS 4142 (although outside of its scope in rural locations) becomes apparent when one considers the effect of correcting the noise source measurements for background noise. BS 4142 proposes that a correction should be applied when the new noise source does not exceed the background noise level by more than 10dB (see section 5.4.4 of BS 4142). It advises that to obtain the correct level for the specific noise source, the L_{A90} background noise level when the source is not operating should be subtracted from the measured L_{Aeq} when the source is on. However, as has been identified above, in quiet noise environments the L_{Aeq} level may be 10-20dB(A) above the background noise level even when the source is not operating. Therefore, measurements performed and corrected using the method described within BS 4142 will underestimate the contribution of the existing noise sources to the measured L_{Aeq} noise level when a wind farm is operating. This effect may result in a wind farm being deemed to fail any noise conditions that have been imposed. It is considered very important that, when applying corrections to the measured incident noise source, like indices are used to obtain the necessary corrections, ie L_{A90} levels obtained when the wind farm is not operating are compared with L_{A90} noise levels when the wind farm is operating.

The steady nature of the emitted noise from wind turbines is such that the level difference between the L_{Aeq} and L_{A90} noise levels close to the turbines, and in the absence of other noise sources, is typically less than 2dB(A) as shown in Fig 6. It should be noted that these data are taken using a 1-minute measurement period.

The data in Fig 7 are taken at a residential location a few hundred metres from the nearest turbine. The difference between L_{Aeq} and L_{A90} ranges from 2-4dB(A) although some measurements will be influenced by background noise at these low levels. Data from other operational wind farms indicate that the difference between L_{Aeq} and L_{A90} measurements of wind turbine noise taken at residence-type locations is of the order of 2dB(A).

The use of a 10-minute measurement period has evolved as common practice for wind farm noise assessments. This is because wind speed measurements performed on-site in order to estimate the annual mean wind speed and subsequent energy production are normally performed over 10-minute intervals. As the noise data are usually plotted against wind speed it makes sense to use the same measurement period for the noise measurements.

Experience indicates that a measurement period of 10 minutes is more likely to provide a good correlation of background noise level with site wind speed than a 5-minute period. In simplistic terms, a gust of wind progressing across the ground at 5m/s will cover a distance of

300 metres in a minute. Therefore, separation distances between a wind farm and a dwelling of 1200 metres, a not uncommon distance for large-scale developments, will create a time lag of 4 minutes.

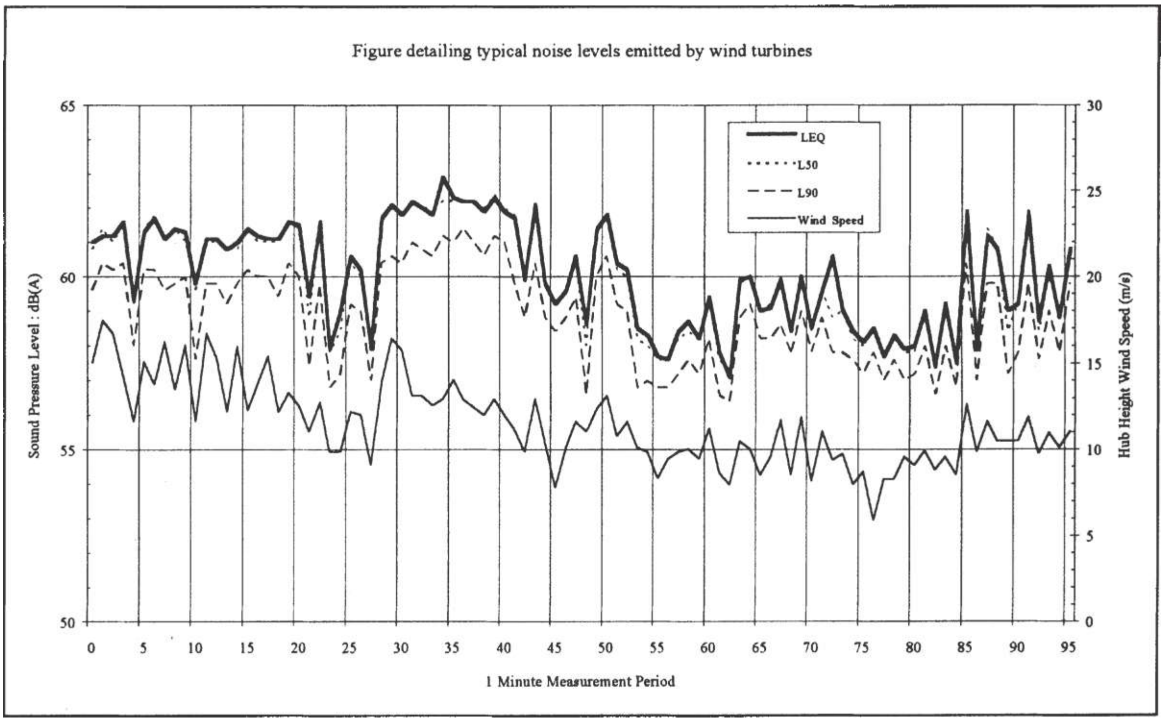


Figure 6 Comparison of measurements with different noise indices

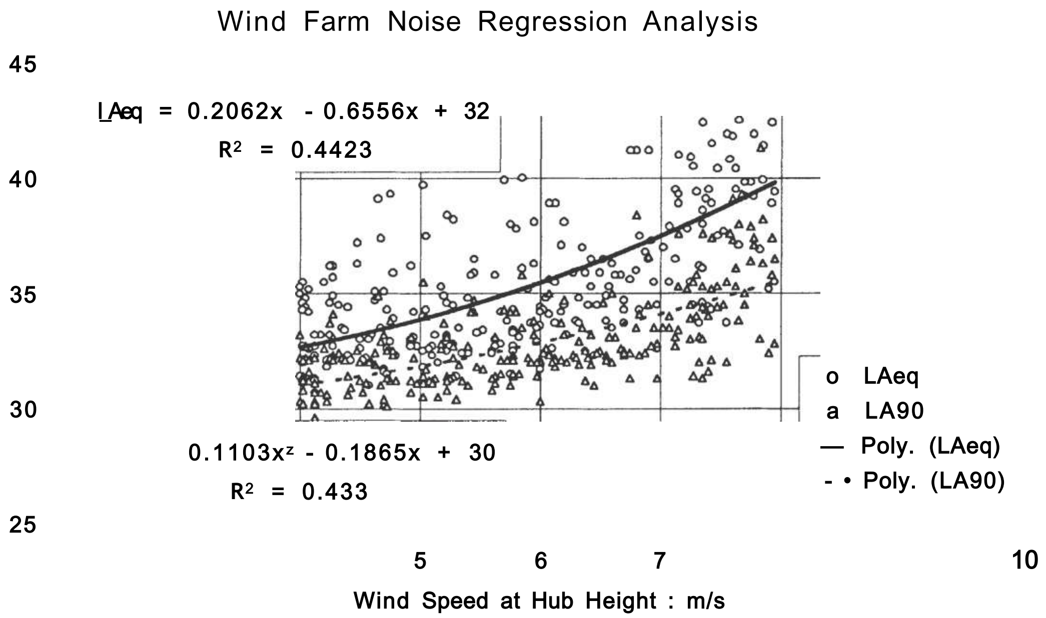


Figure 7 Comparison of L_{Aeq} and L_A9o turbine measurements at a nearby residence

The effect of extending the measurement period to more than 10 minutes would be to lose some resolution in the variation of noise level with time. As the measurement period is increased the results tend towards those of the most typical conditions and it becomes more difficult to establish the variation of either turbine noise or background noise with wind speed.

In summary, the Noise Working Group is agreed that the $L_{A90,10min}$ descriptor should be used for both the background noise and the wind farm noise and that when setting limits it should be borne in mind that the $L_{A90,10min}$ of the wind farm is likely to be about 1.5-2.5dB(A) less than the L_{Aeq} measured over the same period.

Free-field measurements

The limits to be proposed relate to free field (except for ground reflections) measurements in the vicinity of noise-sensitive properties. Measurements performed near or at a building facade will exhibit higher noise levels due to the reflection of the sound from the facade. As this effect is dependent upon the measurement position, it is difficult to allow for in noise predictions and therefore free-field noise levels which are unaffected by the facade of a building are preferred. The potential for "hot-spots" due to particular building configurations should be discussed with the EHO during the initial site assessment. For example, courtyards with an open side facing the site of the proposed wind farm will require special consideration. Further advice on the positioning of microphones is to be found in Chapter 7.

Cumulative impact

The Noise Working Group is of the opinion that absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area which contribute to the noise received at the properties in question. It is clearly unreasonable to suggest that, because a wind farm was constructed in the vicinity in the past which resulted in increased noise levels at some properties, the residents of those properties are now able to tolerate still higher noise levels. The existing wind farm should not be considered as part of the prevailing background noise.

The assessment of typical background noise levels

Wind turbines operate day and night dependent upon wind speeds. It will be necessary to acquire background noise data for both day- and night-time periods because:

- the absolute lower limit is likely to be different for day- and night-time operation
- the noise limits are to be related to the background noise levels
- background noise levels may be different in the day than during the night

The impact from the wind turbines during waking hours will be greatest during otherwise quiet periods, usually Saturday afternoon, all day Sunday and weekday evenings. It is therefore proposed that the background noise measurements upon which the day-time noise limits are based are taken during these quiet periods. This is consistent with the approach of PPG 24 which advises in Annex 3, paragraph 19, that:

> *"Since background noise levels vary throughout a 24-hour period it will usually be necessary to assess for separate periods (eg day and night) chosen to suit the hours of operation of the proposed development Similar considerations apply to developments that will emit significant noise at the weekend as well as during the week. "*

In principle this implies, and quite rightly, that one could justify the setting of higher limits during the working day when background noise levels will be higher due to increased human activity. The developers represented in the Noise Working Group thought that this approach would however be unworkable since the wind farm would have to be designed to meet the stricter conditions applicable during quiet periods and the economics of wind farms would not allow one to consider switching off certain turbines at given times of day at the most critical wind speeds. We therefore propose that the day-time limits should be set in relation to the background noise measured during the quiet period of the day and that these should apply over all waking hours.

Should developers wish to investigate the cost effectiveness of switching off turbines at certain times of day over a given range of wind speeds in order to allow more turbines to be placed on a site, then an additional set of background noise data should be obtained for periods when all turbines would be operating.

Data acquired during all hours of the night are considered relevant to setting of night-time noise levels.

It is proposed that the background noise levels upon which limits are based, and the noise limits themselves, are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels, but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions.

The variation in background noise level with wind speed will be determined by correlating $L_{A90,10min}$ noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data. The mechanics of undertaking the background noise survey and the significance of seasonal effects on background noise are discussed in Chapter 7.

The aim of the background noise survey is to provide an indication of the noise environment existing at each noise-sensitive property in the vicinity of the wind farm. If there are several properties within ear-shot of the proposed wind farm then to conduct noise surveys at each and every property would be time consuming, costly, unnecessary and would therefore impose an unreasonable burden on developers. In such situations it is suggested that the developer and the local authority identify groups of properties that through their exposure and proximity to other noise sources would be expected to have similar background noise levels. In this manner it is expected that the number of noise surveys could be limited to a reasonable amount.

Rating method

The wind farm noise limits proposed below refer to rating levels in a similar manner to that proposed in BS 4142. That is, additions are made to the measured noise to reflect the character of the noise. The procedure for applying penalties for the character of the noise is presented later in this chapter.

Margin above background

It is proposed to limit the noise from a wind farm relative to the existing background noise but with special consideration given to the very low noise limits this would imply in particularly quiet areas. Noise from the wind farm will be limited to 5dB(A) above background for both day- and night-time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different. It should be noted that this limit applies to the noise from the wind farm only and not to the total ambient noise with the wind farm operating. Noise limits would apply up to 12m/s (10m height) on the assumption that, even in the most sheltered areas, if the wind farm can meet the conditions at lower wind speeds, it is unlikely to be a problem in higher winds. In high winds bangs and clatters from existing sources and gusts of wind are likely to be more disturbing than the wind farm noise.

When comparing the proposed margin with the complaints criteria suggested by BS 4142 it is important to bear in mind that the L_{A90} descriptor is also being proposed for the turbine noise. The L_{Aeq} levels can be expected to be about 1.5-2.5dB greater. An addition of 1.5-2.5dB places the margin at the upper end of the range which can be considered to be of marginal significance ie around 5dB.

On balance it is considered that a margin of 5dB(A) will offer a reasonable degree of protection to both the internal and external environment without unduly restricting the development of wind energy which itself has other environmental benefits.

Although not a factor to influence the specification of the allowable margin above background, it is worth noting that limits less than 5dB(A) would be difficult to monitor. One would have to resort to approximate methods such as extrapolating noise levels measured nearer to the turbines than the neighbouring properties, back to the locations of the properties, using an agreed propagation model.

Lower limit

Applying the margin above background approach to some of the very quiet areas in the UK would imply setting noise limits down to say 25-30dB(A) based upon background levels perhaps as low as 20-25dB(A). Limits of this level would prove very restrictive on the development of wind energy. As demonstrated below, it is not necessary to restrict wind turbine noise below certain lower fixed limits in order to provide a reasonable degree of protection to the amenity.

Recommendation of night-time lower limit

During the night one can reasonably expect most people to be indoors and it will not be necessary to control noise to levels below those required to ensure that the restorative process of sleep is not disturbed. A night-time absolute lower limit is therefore appropriate based upon sleep disturbance criteria.

The existing guidance relating to sleep disturbance criteria was reviewed in Chapter 4. The results were summarised, as in Table 7.

Table 7 Summary of sleep disturbance criteria and internal noise levels

Source of Proposed Criteria	Falling Asleep	Light Sleep	Deep Sleep	Max. Level
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise		L_{Aeq} = 30-35		L_{Aeq}+10
OECD Report: Reducing Noise in OECD Countries: 1978	L_{Aeq} = 35	L_{Aeq} = 45	L_{Aeq}= 50	L_{Aeq}+10 to 15
WHO Environmental Health Criteria 12-Noise: 1980	L_{Aeq} = 35	L_{Aeq} = 35	L_{Aeq} = 35	
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	L_{Aeq} = 30	L_{Aeq} = 30	L_{Aeq} = 30	L_{Amax}< 45dB
PPG 24 Planning and Noise, 1994	L_{Aeq} = 35 (Based on WHO Environmental Health Criteria 12)			
Planning and Noise Circular W.O. 16/73	Good Standard Internal Noise Level CNL (Corrected Noise Level) Day = 45dB(A) Night = 35dB(A)			

The Noise Working Group recommends that an appropriate fixed limit for the night-time is 43dB(A). This limit is derived from the 35dB(A) sleep disturbance criteria referred to in PPG 24. An allowance of 10dB(A) has been made for attenuation through an open window (free-field to internal) and 2dB subtracted to account for the use of L_{A90}s rather than L_{Aeq}s (assuming the L_{A90} of turbine noise is 1.5-2.5dB below the L_{Aeq}).

Recommendation of day-time lower limit

Guidance relating to the control of external noise levels was also summarised in table form in Chapter 4 and this too is reproduced below.

Table 8 Summary of external noise criteria

Source of Criterion	**External Noise Limit dB**
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise.	L_{Aeq} = 50-55
British Standard BS 5228: Part 1: 1984 Noise Control on Construction and Open Sites. Part 1. Code of practice for basic information and procedures for noise control	$L_{Aeq,1 Hour}$ at facade = 40-45
PPG 24 Planning and Noise	BS 4142 where appropriate
MPG 11 Control of Noise at Surface Mineral Workings	Day $L_{Aeq 1h}$= 55 (No less than 45 in quiet area) Night $L_{Aeq 1h}$ = 42 Gardens/open spaces $L_{Aeq 1h}$= 55-65
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	Daytime L_{Aeq}= 50 Moderate Annoyance Night-time L_{Aeq}= 45

The Noise Working Group believes that the external levels around 50dB(A) suggested by some of these documents for the protection of external amenity would be entirely inappropriate in the quiet rural locations of the UK. Furthermore, even the 43dB(A) limit ($L_{A90,10min}$) derived above to protect sleep disturbance inside the property does not offer sufficient protection to the external amenity in quiet areas of the UK during the day.

It is also the opinion of the Noise Working Group that there is no need to restrict noise levels below a lower absolute limit of $L_{A90,10min}$ = 33dB(A); if an environment is quiet enough so as not to disturb the process of falling asleep or sleep itself then it ought to be quiet enough for the peaceful enjoyment of one's patio or garden. This level would however be a damaging constraint on the development of wind power in the UK as the large separation distances required to achieve such low noise levels would rule out most potential wind farm sites. There are however the following justifications for relaxing this limit:

- Wind farms have global environmental benefits which have to be weighed carefully against the local environmental impact.

- Wind farms do not operate on still days when the more inactive pastimes (eg sunbathing) are likely to take place. For example, wind speed measurements at Delabole Wind Farm over the period May 1993 to April 1994 show that over the Summer months (June, July, August) the wind speed was below the 5m/s cut-in wind speed of the turbines for 34% of the time [25]. If the cut-in wind speed had been reduced to 4m/s the proportion of time would have been reduced to 20%. The figures for the whole year are 22% and 13% of the time for wind speeds below 5m/s and 4m/s respectively. So that residents benefit from periods of low wind speeds it is important to ensure that the turbine controllers do not allow for excessive idling. When a turbine is idling it is rotating, probably at a speed less than its normal operating speed, but without producing any power. The turbines can however generate a degree of noise in this condition, although usually at lower levels than when the turbines synchronise with the grid and start producing power.

- The absolute lower limits will only come into force when the turbine noise is more than 5dB above the background noise level and when this level of 5dB above background is below a figure in the range discussed below. The period of greater exposure to noise will therefore be limited and on some sites will not occur at all.

- There is no evidence for or against the assertion that wind farm noise with no audible tones is acceptable up to and including $L_{A90,10min}$ levels of 40dB(A) even when background noise levels are 30dB or less.

- Noise levels inside the property will be approximately 10dB less than those outside assuming an open window. Noise levels could therefore be increased before sleep and relaxation inside the property begin to be affected.

For periods during the day the Noise Working Group has adopted the approach that external noise limits should lie somewhere between that required to avoid sleep disturbance even if the occupant is outside of the property and the higher level that would still prevent sleep disturbance inside the property.

The Noise Working Group has therefore concluded that in low noise environments the day-time level of the $L_{A90,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). We believe that limits within this range offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development. The levels are low compared to some of the advisory documents reviewed and this is because of our concern to properly protect the external environment.

As the night-time lower fixed limit is greater than the day-time limit, the night-time limit could become superfluous unless background noise levels are less during the night than during the quiet day-time periods. Where the local authority and the developer are in agreement that the background noise levels do not vary significantly between the quiet day-time periods and the night-time, then a single lower fixed limit of 35-40dB(A) can be imposed based upon background noise levels taken during quiet day-time periods and the night analysed together.

There are two aspects to consider when assessing the impact of the absolute lower limit:

- Although the range of limit proposed is 5dB, the actual difference in wind farm noise levels between the two cases, at any given wind speed, is usually less than 5dB.

- Imposing an absolute lower limit of 40dB(A) on a property with background noise levels at turbine cut-in of, say, 30dB(A) will not result in the turbine noise being 10dB greater than the background.

These two initially somewhat surprising results arise because of the variation in turbine noise with wind speed and can be illustrated by reference to Fig 8. Noise limits with an absolute lower limit of 35dB(A) and 40dB(A), both giving way to a 5dB margin above background criterion at higher wind speeds, have been constructed for a typical background noise curve in a quiet and reasonably sheltered rural location. Two lines were then drawn to represent the maximum level of turbine noise which could be experienced for each of the two cases. The slope of the increase in turbine noise with wind speed has been chosen to be 1.0dB(A) per m/s, a typical rate of increase for modern turbines.

It can be seen that the gap between the two lines representing the turbine noise is somewhat less than 5dB (3.5dB for the example given) and that the turbine noise limited to an absolute lower limit of 40dB(A) is only 37dB(A) at a typical cut-in wind speed of 4m/s. The extent to which these two effects are seen increases with the rate of increase in turbine noise with wind speed and the degree of shelter of the property from the wind.

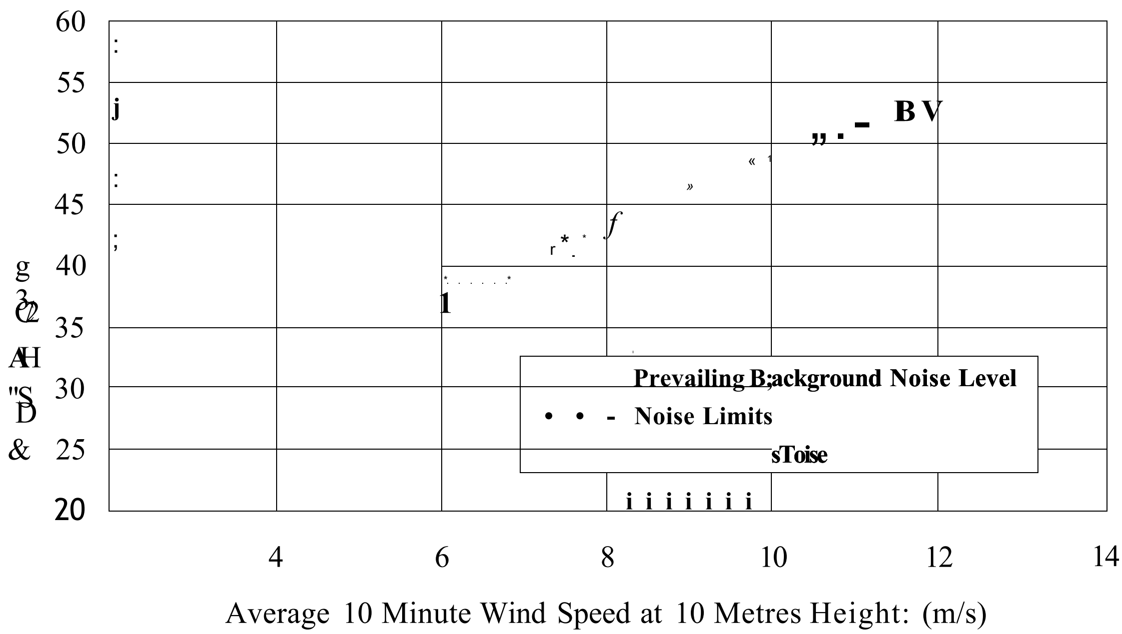


Figure 8 Comparison of day-time noise criteria

It is of interest to note that the Danish Statutory Order for Noise from Wind Mills [12] proposes noise limits of 45 and 40dB L_{Aeq} at dwellings and noise-sensitive locations when measured at external positions. These noise levels must be shown by calculation to be achievable before construction of the wind farm. However, the source sound power level used to perform this calculation is set at a wind speed of 8m/s at a height of 10 metres above ground level. This is equivalent to a wind speed of about 9.5m/s at the hub height of the wind turbine (see "wind shear" in Glossary). Table 4 in Chapter 4 indicates the predicted noise levels that may be experienced at the cut-in wind speed for wind turbines of 30m hub height, based upon the Danish Statutory Order criteria levels. It may be seen that at the cut-in wind speed, it would be expected that these levels would be 35-42dB L_{Aeq}. Thus, the levels proposed here for absolute lower limits are similar to those in use in Denmark at cut-in. The difference is that the lower absolute limits proposed for use in the UK will extend to higher wind speeds until the background noise increases sufficiently to be within 5dB of the turbine noise.

The actual value chosen for the day-time lower limit, within the range of 35-40dB(A), should depend upon a number of factors:

- Number of dwellings in the neighbourhood of the wind farm.

  The planning process is trying to balance the benefits arising out of the development of renewable energy sources against the local environmental impact. The more dwellings that are in the vicinity of a wind farm the tighter the limits should be as the total environmental impact will be greater. Conversely if only a few dwellings are affected, then the environmental impact is less and noise limits towards the upper end of the range may be appropriate. Developers still have to consider the interests of individuals as protected under the Environmental Protection Act 1990. It is our belief however, in accordance with the report of the Welsh Affairs Committee [23], that there have been no cases of complaints of noise at levels similar to those caused by wind farms leading to a successful prosecution as a statutory nuisance. It should be noted however that the Welsh Affairs Committee also reports that although the noise may not be a statutory nuisance it can clearly be a cause for distress and disturbance, particularly if residents have been promised inaudibility and the noise has a particular quality leading to complaints.

- The effect of noise limits on the number of kWh generated.

  Similar arguments can be made when considering the effect of noise limits on uptake of wind energy. A single wind turbine causing noise levels of 40dB(A) at several nearby residences would have less planning merit (noise considerations only) than 30 wind turbines also causing the same amount of noise at several nearby residences.

- Duration and level of exposure.

  The proportion of the time at which background noise levels are low and how low the background noise level gets are both recognised as factors which could affect the setting of an appropriate lower limit. For example, a property which experienced background noise levels below 30dB(A) for a substantial proportion of the time in which the turbines would be operating could be expected to receive tighter noise limits than a property at which the background noise levels soon increased to levels above 35dB(A). This approach is difficult to formulate precisely and a degree of judgement should be exercised.

Increased lower fixed limit with financial involvement

It is widely accepted that the level of disturbance or annoyance caused by a noise source is not only dependent upon the level and character of the noise but also on the receiver's attitude towards the noise source in general. If the residents at the noise-sensitive properties were financially involved in the project then higher noise limits will be appropriate, particularly if a tie could be made between the wind farm and the property, such as giving the developer first option to buy the property if it came up for sale. We recommend that both day- and night-time lower fixed limits can be increased to 45dB(A) and that consideration should be given to increasing the permissible margin above background where the occupier of the property has some financial involvement in the wind farm.

Simplified assessment method

Much of the complexity of the proposed method is necessary because of the variety of background noise environments present in the UK. However, if the developer can demonstrate that noise conditions would be met even if there was no increase in background noise with wind speed until quite high wind speeds, then a simplified approach can be adopted. We are of the opinion that if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height then this condition alone would offer sufficient protection of amenity, and background noise surveys would be unnecessary. We feel that, even in sheltered areas when the wind speed exceeds 10m/s on the wind farm site, some additional background noise will be generated which will increase background levels at the property. This type of condition may be suitable for single turbines or wind farms with very large separation distances between the turbines and the nearest properties.

Summary of noise limits

A graphical representation of the recommended limits appears in Figs 9 and 10 based upon a fairly typical background noise curve for a quiet rural area. Both background levels and turbine noise are determined by best fit curves through representative data. Further guidance appears in Chapter 7.

At low wind speeds noise is controlled through the application of the lower absolute limit in the range of $L_{A90,10min}$ = 35-40dB (day-time) and 43dB (night-time). In the example shown, during the day, between wind speeds of 5.5m/s and 7.0m/s depending on the lower limit agreed, a limit of 5dB above the existing background noise limit then comes into force.

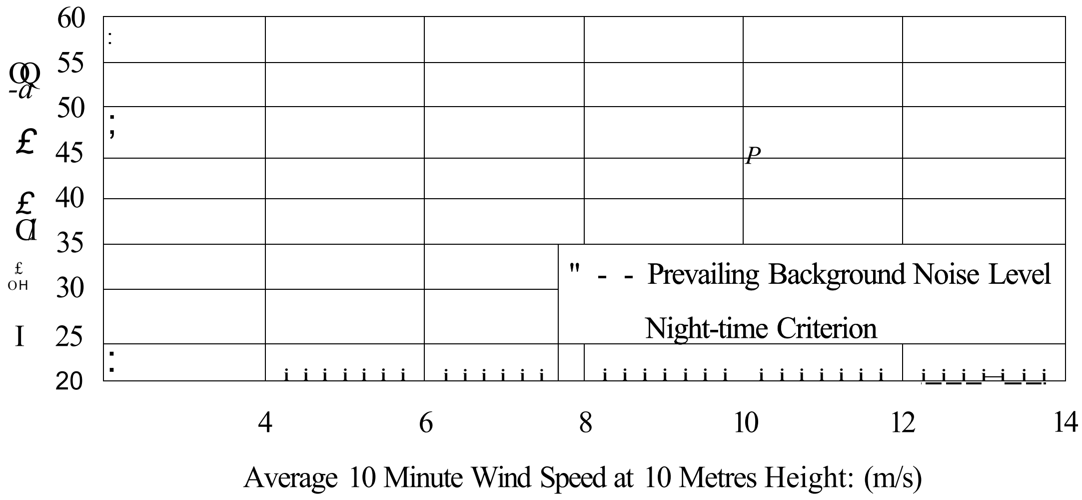


Figure 9 Example of night-time noise criterion

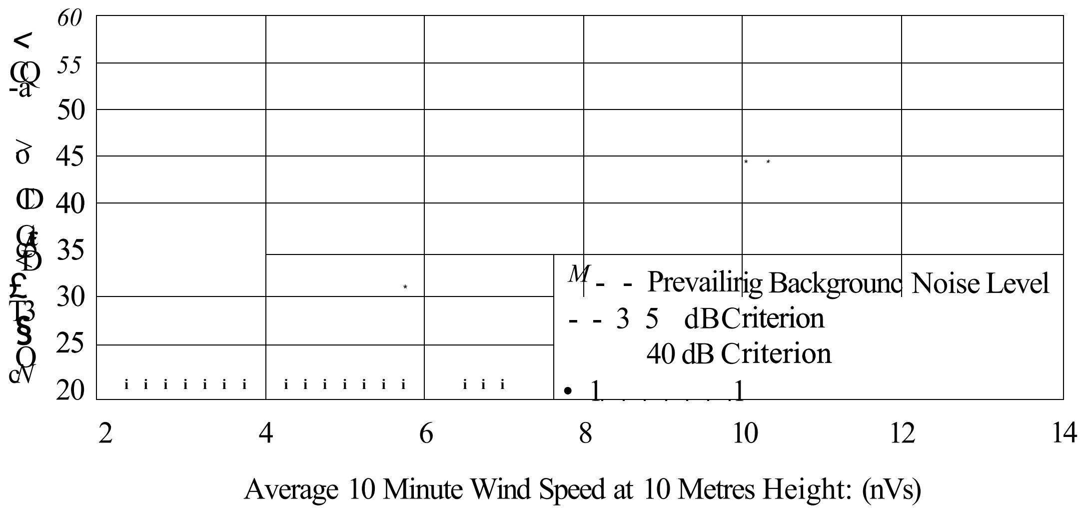


Figure 10 Examples of day-time noise criteria

Penalties for the character of the noise

We have decided that, as far as possible, the limits suggested here for wind turbine noise should account for the particular character of the noise received. This is the approach adopted by BS 4142 in which the rating level of the noise source includes the addition of any adjustment necessary for the character of the noise [2]. We have considered the two main elements that can add to the character of wind turbine noise: blade swish and tones.

Blade swish

Blade swish, the amplitude modulation at blade passing frequency of the aerodynamic noise caused by the passage of the blades through the air, has been fully described in Chapter 3.

The modulation or rhythmic swish emitted by wind turbines has been considered by some to have a characteristic that is irregular enough to attract attention. The level and depth of modulation of the blade noise is, to a degree, turbine-dependent and is dependent upon the position of the observer. Some wind turbines emit a greater level of modulation of the blade noise than others. Therefore, although some wind turbines might be considered to have a character that may attract one's attention, others have noise characteristics which are considerably less intrusive and unlikely to attract one's attention and be subject to any penalty.

This modulation of blade noise may result in a variation of the overall A-weighted noise level by as much as 3dB(A) (peak to trough) when measured close to a wind turbine. As distance from the wind turbine/wind farm increases, this depth of modulation would be expected to decrease as atmospheric absorption attenuates the high frequency energy radiated by the blade. However, it has been found that positions close to reflective surfaces may result in an increase in the modulation depth perceived at a receiver position remote from a site. If there are more than two hard, reflective surfaces, then the increase in modulation depth may be as much as ± 6dB(A) (peak to trough).

The selection of the measurement position can also result in particular frequencies exhibiting a greater depth of modulation due to standing wave effects from reflected waves off the surrounding structures. These effects are very specific to the positions at which measurements are undertaken and are more the result of building layouts at the receiver position than a change in the character of the emitted wind turbine noise.

It is the opinion of the Noise Working Group that there is insufficient data available at this time to formulate an accurate measurement methodology for blade swish where it occurs. It is envisaged that further research will be required to enable proper measurement and assessment to be devised, if in the future this is felt to be necessary. Work is already under way aimed at establishing the causes of blade swish, the frequency and magnitude of its occurrence and developing an appropriate metric for its measurement.

The noise levels recommended in this report take into account the character of noise described in Chapter 3 as blade swish. Given that all wind turbines exhibit blade swish to a certain extent we feel this is a more common-sense approach given the current level of knowledge. Debates at public inquiries on whether a literal interpretation of clause 7.2 of BS 4142:1990 would include blade swish have in general been unhelpful.

Method of tonal assessment

Introduction

It has been our experience, confirmed by the survey reported in Chapter 5, that where complaints have been made over noise from existing wind farms the tonal character of the noise has been the feature that has caused greatest annoyance. This finding corresponds with the results of a survey of EHOs and noise consultants undertaken by NPL on complaints about industrial noise sources [26] which indicated that a significant number of noise complaints are caused by the tonal character of the noise. In order to reflect the increased potential for annoyance caused by noise containing a tonal component we therefore feel it appropriate that tonal noise should be penalised. This penalty should be imposed in a similar manner to that described in BS 4142 ie the noise level of the source is described as a rated level, that is the sum of the overall level and any penalty due to a tonal content.

Review of options

Broadly speaking, there are three methods by which a noise can be assessed as to whether a tonal penalty is appropriate: subjective methods, 1/3 octave methods and narrow band methods. The relative merits of each are reviewed below.

Subjective methods

The method for rating a noise source that is contained within BS 4142 requires that the noise is assessed by the subjective judgement of a listener. The perceived level of the tonal noise will however be dependent upon the attitude of the listener towards the noise source and the sensitivity of the individual to tonal noise. What may therefore be acceptable to one person may not be acceptable to another. Another drawback with this method is that in order to obtain a warranty for a wind turbine from a manufacturer that includes a criterion for tonal emission, an objective measurement procedure must be agreed. This warranty will provide little comfort unless tonal emissions from the wind farm are assessed in a similar manner. The absence of any standard method within the UK has caused problems when agreeing noise conditions. To reduce these potential areas of conflict it is proposed that an objective test be undertaken of the incident noise that assesses the audibility of any tonal noise emissions and provides a rating for the noise.

Methods based on 1/3 octave bands

BS 7445 [16] (ISO 1996, DIN 45 465) indicates that a prominent tone may be identified when the level difference between contiguous third octaves is greater than 5dB. This definition of prominent tone is satisfactory when the frequency of interest is above 500Hz. However, at frequencies below 500Hz the criterion is too severe. It is possible that at low frequencies, this assessment method may result in a tone being measured objectively when none is audible. This effect has been allowed for within the third octave criteria that have been developed by Kern County in the USA, see Appendix B. Furthermore the method is unsuited to the detection of tones that are only just detectable by the observer and would prove difficult to implement for the sometimes complex spectrum shapes associated with wind turbine noise.

Narrow band analysis

The principles of three, narrow band, tonal assessment methods, BS 7135 [17], the Joint Nordic Method [21]and the draft DIN 45 681 [22], have been described in Chapter 4. This Section reviews the strengths and weaknesses of the methods available so that recommendations leading to a reliable method of assessment can be made.

All three methods are based upon the concept of Zwicker critical bands. The methods compare the sound pressure level of the tone to the sound pressure level of the broadband masking noise with a range of frequency either side of the tone, the critical band width. The audibility of a tone is determined according to the difference between the tone level and the masking level, often referred to as the tone level difference. The main differences between the methods are in the precise specification of the critical band width, audibility criteria and the measures taken, if any, for non-stationary tones (tones whose amplitude varies with time).

The Joint Nordic Method simplifies the derivation of the critical band bandwidths, ie the critical bandwidth for a tone below 500Hz is 100Hz and above 500Hz is 0.2 x the tone frequency. BS 7135 and DIN 45 681 use the mathematical formula obtained by Zwicker. The width of the critical band, Afc, centred at any frequency, f, is given by the following equation:

$$Afc = 25 + 75 \times [\, 1 + 1.4 \times (\, f / 1000\,)^{2}\,]^{069}$$

(eg Afc = 162.2Hz at f = 1000Hz)

This results in a small, frequency-dependent difference between the Joint Nordic Method and the other two methods in the calculated critical band masking level. Fig 11 details the level difference between each critical band assuming a flat spectrum. It may be seen that predicted difference will be less than 1dB until a frequency of over 1.0kHz is reached, although a peak of 0.69dB occurs at a frequency of 500Hz. The graph shows that the Joint Nordic Method would underestimate the masking level around a tone of 500Hz by 0.69dB.

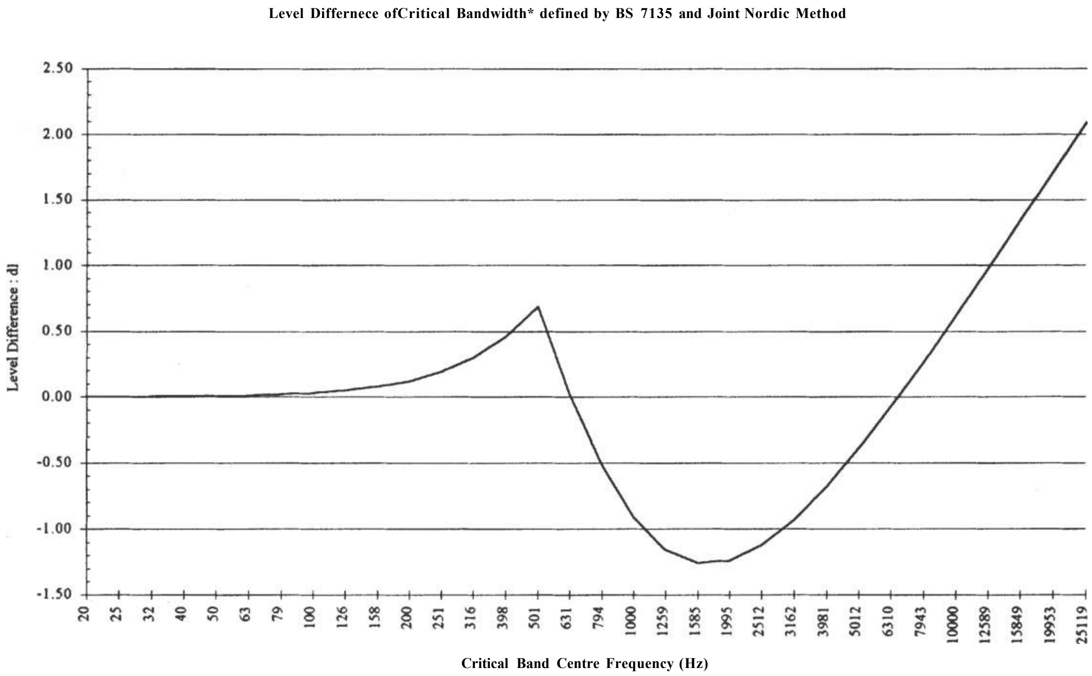


Figure 11 Level difference of critical bandwidths defined by BS 7135 and the Joint Nordic Method

Differences also exist in audibility criteria. Fig 12 details the difference between the audibility criteria defined within the Joint Nordic Method, BS 7135 and DIN 45 681. It can be seen that at relatively low frequencies, commonly of interest when assessing tonal noise from wind turbines, the audibility threshold for DIN 45 681 is up to 4dB lower than the Joint Nordic Method. The Joint Nordic Method uses the frequency-dependent audibility curve suggested by Zwicker whereas the other two methods adopt a simplified approach, assuming the tone level difference necessary for audibility is constant across the frequency range. The following extract from the draft DIN 45 681 illustrates the thinking behind this approach.

"At low frequencies the level difference LQ - LR (LQ = masking level, LT = tone level) *at the audibility threshold is 2dB. This rises continuously to 6dB at high frequencies. On average then, a sinusoidal tone in a masking noise is just perceptible (midrange audibility threshold) when L_g-L_t = 4dB. This is the value set by the tone content criterion ISO 7779: 1988, section D.4.1* (and BS 7135).

The mid-range hearing threshold is defined such that in repeated hearing tests a group of people with normal hearing will perceive the tone in 50% of cases. The tone content criterion introduced by this standard (a noise has tone content when L_G-L_T = 6dB, see section 2.) is more stringent at midrange and low frequencies in that about 20 to 30% of people will hear the tone. "

At low frequencies the differences between the two approaches to audibility is reduced because the Joint Nordic Method applies a "Hanning correction" to the measured level of the masking noise. This is designed to correct for the effective analysis bandwidth of the frequency analyser being wider than the frequency resolution. With the commonly applied

Hanning window, the analysis bandwidth is 1.5 times the resolution resulting in a correction or reduction in the measured level of 10log1.5dB or 1.8dB. This means that a tone of given magnitude would appear to have a level difference 1.8dB greater when analysed using the Joint Nordic Method than it would have if assessed using BS 7135 or DIN 45 681.

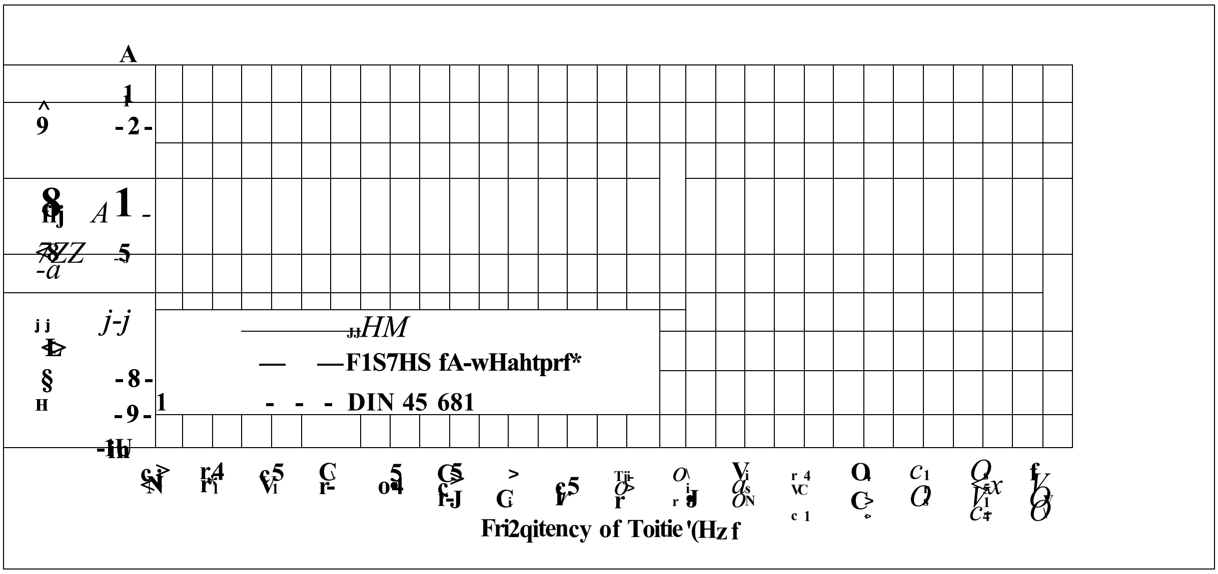


Figure 12 Difference in audibility criteria as defined by the Joint Nordic Method, BS 7135 and DIN 45 681.

The situation is further complicated by the recommendation within BS 7135 that if the measurements are performed using a linear weighting instead of an A-weighting the threshold of audibility should be reduced so that a tone is deemed audible when it is 6dB below the masking level in the critical band, the same level as in the DIN standard. This suggestion for change in audibility criteria with frequency weighting is difficult to understand as the tone is compared to masking noise of similar frequency to itself and differences will be second order, resulting from the slope in the A-weighting curve. It has been demonstrated [27] that, for wind turbine noise, choice of frequency weighting has no systematic effect on the magnitude of the tone level difference.

Tones from wind turbines can be classed as non-stationary; that is, the level of a tone, and hence its audibility, can fluctuate by several dB over the course of a few seconds [28]. These fluctuations arise from variations in source level and short-term propagation effects over distances of a few hundred metres. The Joint Nordic Method is the only one of the three which attempts to deal with non-stationary tones by suggesting that the highest level of the tone is found by averaging the five highest tone levels from a number of individual spectra. It has been shown [28] that, for wind turbine noise measured at near-residence type locations, averaging the 10% highest tone levels will result in the measured tone level being typically 3-4dB higher than if it had been derived from the rms level of the tone in accordance with DIN 45 681 or BS 7135.

It can be seen from the above discussion that even the use of objective, narrow band methods of tonal analysis can lead to widely differing assessments of audibility because of differences in the specification of critical band widths and audibility curves and in the treatment of Hanning correction, frequency weighting and non-stationary tones. The Noise Working Group has decided that the method proposed here will be based upon the Joint Nordic Method because of the more accurate, frequency-dependent audibility curve and in the interests of maintaining consistency, where possible, with other recommended practices.

The Joint Nordic Method is the tonal assessment method that is proposed for the assessment of the character of the noise within Nordic countries and has been adopted by the IEA as the basis for tonal assessment in their series of Recommended Practices [11]. It has also been adopted by Danish wind turbine manufacturers as a standard against which they will test and warrant their wind turbines. The tonal assessment method within the current draft of IEC/TC 88 Part 10 [29], dealing with acoustic measurement techniques of wind turbines, is also based upon the Joint Nordic Method. This method, therefore, currently seems to be the method by which most wind turbine manufacturers within the world market will be assessing the tonality of their wind turbines.

Description of Recommended Method

The recommended method is based upon the Joint Nordic Method for non-stationary tones with some embellishments in areas where it is not entirely prescriptive such as tone identification and averaging periods. The method aims to assess the audibility of a tone as perceived by the average listener. There are three main steps in the procedure:

A) Frequency analysis of the noise at receiver locations.

B) Determination of the sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band.

C) Evaluation of the difference between the tone and the masking noise sound pressure levels (ALtm) by comparison with a criterion curve to determine the audibility of a tone.

A. Frequency analysis

The analysis of non-stationary tones is quite intensive; it will therefore be convenient to record the signal to be analysed on to tape. For each tonal assessment 2-minutes of uninterrupted clean A-weighted recording is required.

A 2-minute, rms-averaged FFT is performed on the sampled data using a Hanning window, a frequency resolution of 3.0 + 0.5Hz and an analysis bandwidth of 2kHz. It may be necessary to inspect a similar spectrum with greater bandwidth to ensure that there are no tones present at higher frequencies.

The short term, individual rms-averaged FFTs within the sampled data are also calculated using the same parameters as described above. This results in an averaging time of 0.29 to 0.4 seconds.

B. Determination of sound pressure levels

The bandwidth of a critical bands is:

Centre Frequency f_r Hz	20-500	Above 500
Bandwidth	100Hz	20% of f_c

If a single tone is present the critical band is centred upon the tone. If two or more, closely spaced tones are present, the critical band is placed so that it contains the maximum possible amount of tonal energy. In order to do this it is first necessary to identify the tones within the spectrum. To do this each line in the 2-minute spectrum must be classified according to the following criteria based upon the draft DIN 45 681. A peak is classed as a tone if its level is more than 6dB above the logarithmic average of the sound pressure levels of the rest of the lines in the critical band centred on the peak, but excluding the one line each side of the peak. If the peak qualifies as tone the adjacent lines are also classified as a tone if their level is within lOdB of the peak and greater than 6dB above the average level previously calculated. If a spectral line is more than 6dB above the average masking level and more than lOdB below the peak level it is classified as neither tone nor masking. Having identified the tones the critical band can be placed to maximise the sound pressure level of the tones within the critical band.

Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. This is described by reference to the worked example below.

Fig 13 shows the stages in the tone identification and classification process. These are:

- Find peaks in the spectrum, in this case line 23.
- Calculate the average energy in the critical band centred on each peak, not including the two lines adjacent to the peak (9. lOdB).
- If the peak is more than 6dB above the average masking level then it is a tone, therefore line 23 is a tone.
- Classify adjacent spectral lines:

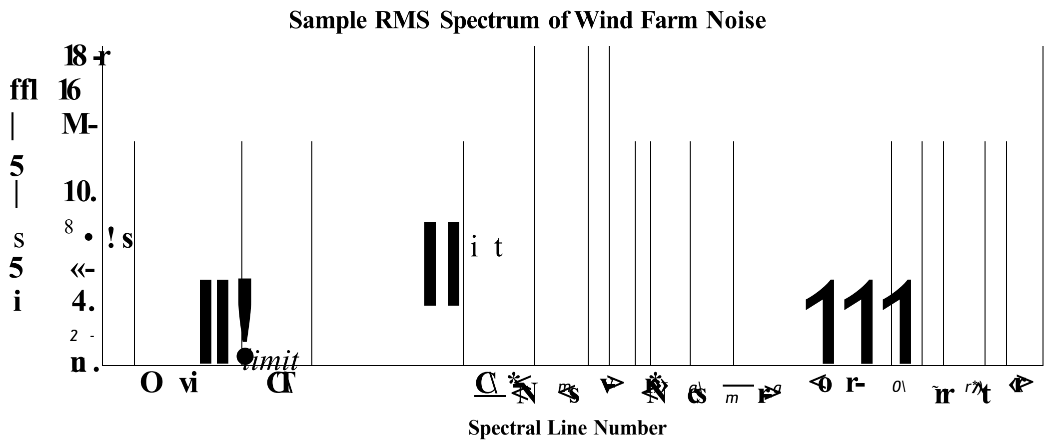
  Pass 1
  - Compare spectral lines above and below the peak to the average level.
  - If a line is more than 6dB above the average and less than lOdB below the peak then it is a tone, therefore lines 22, 24 and 25 are tones.

  Pass 2
  - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.75dB).
  - Compare spectral lines above and below the peak to the average level.

- If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 21, 22, 24 and 25 are tones.

Pass 3

- Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.39dB).
- Compare spectral lines above and below the peak to the average level.
- If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone. Therefore lines 21, 22, 24 and 25 are tones, but no spectral lines have been reclassified in this pass so the iterative process is complete.



Tone Identification and Classification						
Peak line = 23	**Peak Level = 17.71dB**					
	Pass 1		**Pass 2**		**Pass 3**	
Average about peak	**9.10**		**8.75**		**8.39**	
Adjacent line assessment	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**
Line number						
19	**-0.49**	**masking**	**-0.14**	**masking**	**0.22**	**masking**
20	**0.20**	**masking**	**0.55**	**masking**	**0.91**	**masking**
21	**5.83**	**masking**	**6.18**	**tone**	**6.54**	**tone**
22	**6.34**	**tone**	**6.69**	**tone**	**7.05**	**tone**
24	**7.64**	**tone**	**7.99**	**tone**	**8.35**	**tone**
25	**6.26**	**tone**	**6.61**	**tone**	**6.97**	**tone**
26	**1.40**	**masking**	**1.75**	**masking**	**2.11**	**masking**
27	**-0.01**	**masking**	**0.34**	**masking**	**0.70**	**masking**

Figure 13 Tone identification and classification process

If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level then it is classified as neither tone nor masking, and not included in the calculation for either level.

The process described above is repeated for every critical band centred around tonal peaks in the spectrum. The result is that within each critical band every spectral line is classified as tone energy, masking energy or neither.

Having identified the lines in each spectrum contributing to tonal levels, masking levels or neither, the tonal analysis can continue as follows:

- The masking energy within the critical band is calculated from the 2-minute rms spectrum. Calculate the masking level in the critical band, L_{pm}, correcting for a reduction in the number of lines due to the exclusion of tones and for the Hanning window.

  L_{pm} = IQ1og11oW1O + lQlog(<u>critical band width</u>) + 101og(l/1.5)
  (N$_m$ x Af)

  where L_m = sound pressure level of each line containing masking noise
  N_m = number of lines within the critical band containing masking noise.

  2 = sum of

- For each of the short term spectra of 0.29 to 0.4 seconds duration, calculate the tone energy within each critical band, L_{pt}', using the lines identified as tones from the 2-minute spectrum.

  Lpt' = loiogEioWio

  where Lt is the sound pressure level of each line containing tonal noise.

  The Joint Nordic Method for non-stationary tones calculates tone level as the mean of the top 5 levels from a "number of analysis" (at least 50 short term spectra as interpreted by the IEA Recommended Practice). As the result obtained using 5 out of 50 would obviously be different to that using 5 out of 500, the method proposed here is more specific. The tone level used in the assessment, L_{pt}, is the arithmetic mean of the top 10% of tone levels, L_{pt}', from all the short-term spectra constituting the 2 minutes of data.

C. *Evaluation of the audibility of the tone(s)*

The audibility of a tone is dependent upon the tone level difference, ALtm, and the frequency of the tone:

AL^ = Lpt

The audibility criterion is defined as follows:

ALtm,crit = - 2 -Log(1+(f/502)2.5)

where f= frequency at the centre of the critical band.

This is the level at which the average listener will be just able to hear the tone. Fig 14 details the audibility criterion based upon the above equation. It can be seen from the figure that the audibility criterion is related to the frequency of the tone.

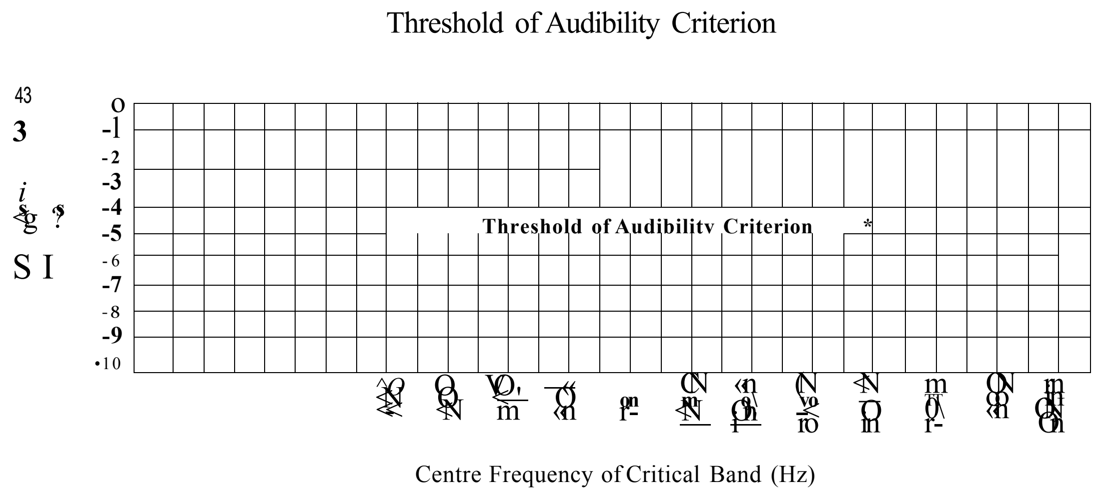


Figure 14 The audibility criterion for tonal noise assessment

It is recognised that this method for assessing the audibility of a tone is somewhat complex and may prove difficult for some to perform. It is nevertheless a rigorous implementation of the widely accepted Joint Nordic Method. It would be helpful to be able to simplify the method without undue loss of reliability so it can be more easily applied. One possibility is to replace the assessment of the tonal pressure from the top 10% of the short term spectra with a level derived from the 2-minute rms spectra. This would however require the adjustment of the audibility criterion to account for the reduced tonal levels which would result from such a change. Further work would be required to calibrate a new audibility criterion with the average listener's response.

Penalties for tonal noise

No standard, objective method is currently available within the UK for the assignment of penalties to noise containing tonal components. BS 4142 allows for a subjective assessment to determine whether a 5dB penalty should be added (see Chapter 4). The DOE has initiated studies on tonal penalties and rating systems but this work is not expected to be included within any revised version of BS 4142 for a number of years. Therefore, the penalty system proposed derives from existing standards and guidance, recent research on the subjective response to tones from wind farms and the experiences of members of the Noise Working Group.

Comparison of existing standards

The tonal penalties imposed by the Joint Nordic Method (JNM), draft Din 45 681 and BS 7445 are considered below.

The Joint Nordic Method proposes that a 5dB penalty be applied when the tone is considered prominent; prominence is defined as being 6.5dB above audibility. The method proposed by the Noise Working Group is based upon the Joint Nordic Method for variable tones.

Draft DIN 45 681 proposes that a sliding scale of penalties ranging from 0-6dB be used which is related to the level of a tone above the audibility criterion. When applying these penalties to the method proposed by the Noise Working Group three differences between the Noise Working Group method and the DIN standard have to be borne in mind:

1. The audibility criterion is different for the two methods (see Fig 12). For tones of less than 800Hz, ie those most commonly identified in wind turbine spectra, the tone level difference required for audibility is 3-4dB lower for the DIN standard than for the JNM. This implies that tones will be identified as audible at lower levels using the DIN standard.

2. Conversely, the method proposed here is based upon an average of the highest 10% of short-term spectra rather than on rms spectra which results in higher tone levels being identified using this method. Studies have shown this difference to be on average 3.6dB, with a range of 2.2-4.4dB [28].

3. The method proposed here, being based upon the JNM, applies a Hanning correction (reduction) of 1.8dB to the broadband masking noise thus increasing the tone level difference by 1.8dB when compared to the DIN standard.

The net result of these differences is that a tone measured using this method and equal in level difference to the audibility criterion of the JNM would be ranked between zero and 3.2dB below audibility using the draft DIN standard, typically -2dB below audibility. Or put the other way round, a tone identified as being on the threshold of audibility using the DIN standard would be ranked as 2dB above audibility using this method. The penalties specified in the draft DIN 45 681 and how they transpose to the audibility criterion of the Noise Working Group's implementation of the JNM are shown in Table 9.

BS 7445 also describes a progressive approach to tonal penalties differentiating between tones that are "just detectable" and "clearly audible".

> *"In some practical cases, a prominent tonal component may be detected in 1/3 octave spectra if the level of a 1/3 octave band exceeds the level of adjacent bands by 5dB or more, but a narrow band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal If tonal components are clearly audible and their presence can be detected by a 1/3 octave analysis, the adjustment may be 5 or 6dB. If the components are only just detectable by the observer and demonstrated by narrow band analysis, an adjustment of 2 to 3dB may be appropriate."*

Table 9 Comparison of DIN 45 681 with the Joint Nordic Method

Tone Level above Audibility, AL (dB), using DIN 45681	Equivalent Tone Level above Audibility, AL (dB), using this Implementation of the JNM for Variable Tones	Tone Penalty, dB, from DIN 45681
0> AL	2> AL	0
0 < AL < 2	2 < AL < 4	1
2 < AL < 4	4 < AL < 6	2
4 < AL < 6	6 < AL < 8	3
6 < AL < 8	8< AL< 10	4
8<AL< 10	10 < AL < 12	5
L> 10	L> 12	6

Pedersen [30] has computed the equivalent narrow band tone level difference for a tone responsible for a 5dB increase in a 1/3 octave band level. The tone level differences are calculated using the critical band widths of the JNM but do not include any correction for use of the Hanning window. In order to enable a comparison with the JNM for variable tones to be made, a further adjustment of 3.6dB is required because of the difference in peak and rms levels as for the DIN standard above. The results are frequency-dependent and summarised in Table 10.

Table 10 Comparison of a 1/3 octave based criterion to the JNM audibility criterion

Tone Frequency Hz	Equivalent Tone Level Difference of 5dB 1/3 Octave Tone	Tone Level Difference after Correction (+ 1.8 + 3.6)	JNM Audibility Criterion	Equivalent Margin above Audibility for 5dB Penalty.
50	-6	-0.6	-2.0	1.4
100	-3	2.4	-2.0	4.4
200	0	5.4	-2.0	7.4
400	3	8.4	-2.2	10.6
500	4	9.4	-2.3	11.7
800	4	9.4	-2.6	12.0
1000	4	9.4	-2.8	12.2
2000	4	9.4	-3.5	12.9

It can be seen that the results are strongly frequency-dependent, but for the frequency range of interest (100-800Hz) the application of the 5-6dB penalty for a clearly audible tone would be incurred at levels above audibility of 4.4-12dB when using the JNM for variable tones. Given the above it is unclear at what levels the 2-3 dB penalty would be incurred but one could interpret "just detectable by the observer" as any audible tone.

A graphical comparison of the three penalty systems is shown in Fig 15. The BS7445 penalties for "just detectable" and "clearly audible" have been set in the middle of the range suggested, ie 2.5dB and 5.5dB respectively, and have been plotted for 100Hz and 800Hz tones to represent the frequency range most commonly encountered.

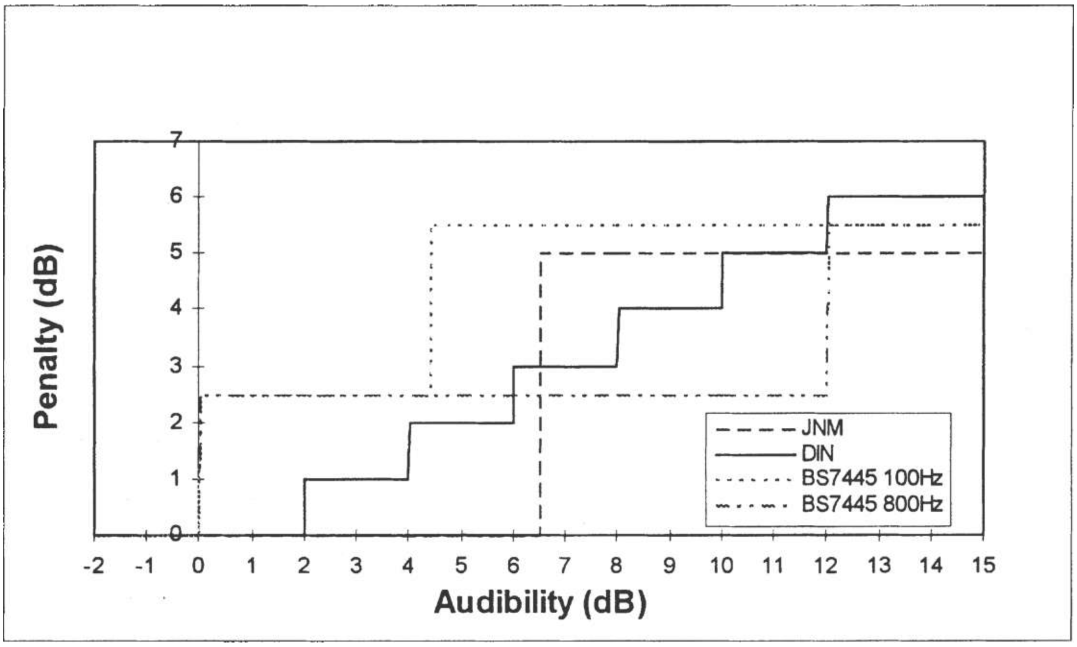


Figure 15 Comparison of tonal penalties from various standards

Recommended levels of tonal penalties

The members of the Noise Working Group agreed on the penalty system depicted in Fig 16 based upon their review of existing standards and guidance, recent research on the subjective response to tones from wind farms from listening tests [27] and their experiences in the field.

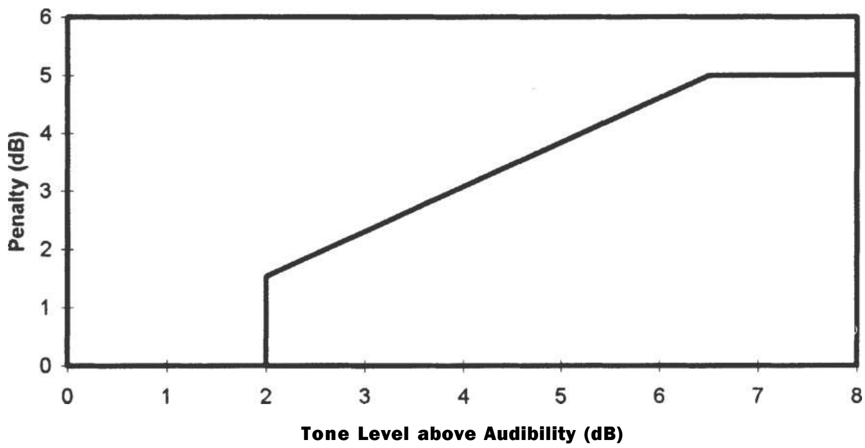


Figure 16 Penalties for tonal noise

At levels of audibility above 6.5dB a 5dB penalty is incurred. Between audibility levels of 2dB and 6.5dB a sliding scale of penalties is introduced varying linearly from 1.54dB to 5dB. Extrapolation of this linear relationship passes through the origin. No penalties are incurred at audibility levels below 2dB.

A penalty of 5dB at 6.5dB above audibility is suggested because:

- it is consistent with the Joint Nordic Method upon which the Noise Working Group method is based and is broadly in line with the advice for prominent tones in BS 7445

- the results from the listening tests demonstrated that at audibility levels at and above 6dB more than 95% of listeners describe the tone as audible and around 50% find the tone to be prominent

A sliding scale of penalties is preferred for audibilities between 2dB and 6.5dB because:

- intuition suggests that annoyance gradually increases with margin above audibility

- it prevents large differences in tonal penalty being affected by small differences in the measured level of audibility

- it enables local authorities to exert downward pressure on tonal levels from turbines which do not represent best practice

- it penalises tones which the subjective tests indicate a large proportion of the population will be able to hear

- below levels of audibility of 2-4dB the results from the listening tests indicate that the measured level of audibility does not correlate well with the subjective response, be it percentage of subjects describing the tone as audible or equal annoyance level; the Noise Working Group was agreed that a significant penalty should be introduced at 2dB above audibility; a convenient method for constructing such a penalty system which increases progressively up to 5dB at 6.5dB above audibility was a straight line passing through the origin but with no penalties incurred below 2dB of audibility.

- it is the view of the Noise Working Group, based upon a comparison of their experiences of tonal levels from a variety of wind farms against measured levels for those wind farms, that tonal penalties are not appropriate at levels measured below 2dB.

It is important to note that although this assessment procedure and associated penalties have been derived and tested [27, 28] using the best information currently available they have not yet been proven in the field For example, little is known about the medium to long term variation in tonal levels from wind turbines and, if such variations do occur, which levels are most appropriate for assessment purposes. It is the belief of the Noise Working Group that the best of the turbines currently available are without tonal noise problems and would not warrant any penalty; it is intended that this assessment procedure reflects that evaluation.

Complex tones containing harmonic components

A wind turbine may emit a complex tone comprising a series of harmonics (partials) at integral multiples of some fundamental frequency. Although several peaks may occur in a narrow band spectrum of such noise, the tone complex is usually perceived as having a single pitch. For the purposes of this specification, when an audible discrete tone comprises two or more harmonic components, only that component with the greatest audibility need be evaluated unless two or more harmonics lie within the same critical band.

Variable speed machines

If a variable speed wind turbine were to be assessed using this technique and the wind turbine were to emit tonal noise, the variation in rotation speed would result in a variation of the tone frequency. Over a two-minute period it would be expected that the tone would affect the masking band level centred around the tone such that the masking band level would be considered higher than the actual level when measured instantaneously.

Additional problems will also occur with variable frequency tones, as the tone frequency during the analysis will not be the same throughout the assessment period. Therefore, the average maximum level for an individual tone will not necessarily be easily determined.

It is possible these difficulties could be overcome if tonal measurements were performed close to one machine and the measurements were of short duration. Further experience in this area is needed before more precise advice can be given.

7. NOISE MONITORING

Introduction

During the planning stage of a wind farm, discussions are likely to have been held with the local Environmental Health Officer with respect to agreeing acceptable levels of noise from the proposed site. The performance of a background noise survey around the site will help identify the dwellings that are the most sensitive with respect to noise and the wind speeds at which the greatest noise impact from the development will occur.

The prevailing background noise level at sensitive dwellings will need to be agreed with the local EHO so that noise limits at different turbine operating wind speeds can be set. Predictions are then undertaken and changes made to the proposed wind turbine layout, where necessary, to ensure that the noise limits that have been set can be achieved.

These noise limits may then form the basis of any conditions that are imposed by the local district council and agreed by the developer. Testing of these conditions is required to ensure compliance in the event of any complaints arising over noise from the wind turbines. Therefore, a method for undertaking this compliance test is required that eliminates errors due to noise not associated with the wind farm and which relates the operating condition of the wind farm to the noise levels incident at a dwelling.

Monitoring will be complaint-driven as developer access to properties cannot be guaranteed. A condition requiring periodic monitoring at residences in the absence of complaints would be unenforceable and therefore fail the test of a planning condition.

Monitoring locations

Nearest properties

Monitoring should be undertaken at the locations to which the noise limits apply, ie the noise-sensitive properties around the wind farm from which complaints have been received.

Microphone height and position

The microphone should be tripod mounted at a height of 1.2-1.5 m above ground level in accordance with the requirements of BS 4142. A height of 1.2m is most commonly used as the microphone is then that little more out of the wind, less likely to be shaken or blown over and 1.2m is generally a more convenient working height.

The measurement position should be selected to minimise the effects of reflections from buildings because the noise limits recommended refer to free-field measurements for the reasons given in Chapter 6. Measurements performed in the field around existing wind farms indicate that reflection effects from buildings are minimised when measurement positions are at least 10 metres from a building facade. This compares with the guidance given in the USA where measurements are performed at a distance of 50' (15.24m) from the sensitive property. However, it should be borne in mind that areas within gardens such as patios may be used by an occupier more often that other areas of their garden. Such seating areas may be positioned close to buildings for protection from the wind. Dwellings may also have small gardens. In this event, it may not be possible to undertake measurements that are free of reflections from buildings. This should be considered during any initial assessment of the wind farm site by the developer.

In order to ensure that measurements of wind turbine noise are not influenced by reflections off buildings the microphone should be positioned at least 10m away from the facade. It may be appropriate to undertake background noise measurements closer than this if sheltered locations close to the property are most often used for rest and relaxation. Background noise measurements should not be taken closer than 3.5m from the facade. In circumstances where these conditions cannot be fulfilled an alternative location should be identified at which the measurements of free-field turbine noise can be expected to be the same as at the property in question, or can be readily corrected by an agreed method, and with some confidence, to levels at the property.

Equipment

Wind shields

Even using the $L_{A90,10min}$ noise descriptor there is a risk that measured noise levels can become contaminated by the effect of wind noise on the microphone when using the wind shields available commercially. Studies are currently being undertaken to evaluate the constraints on existing measurement systems with a view to offering suggestions for improved windshield design [31].

Certification and calibration

As specified in Sections 3 and 4 of BS 4142: 1990.

Background noise survey

The limits proposed are set in relation to the existing background noise level at wind speeds up to 12m/s measured on the wind farm site at 10m elevation. It is therefore necessary that background noise measurements should be correlated with wind speed measurements performed at the proposed site, such that the actual operating noise levels from the turbines may be compared with the noise levels that would otherwise be experienced at a dwelling.

Survey Period

Background noise measurements should be undertaken over a sufficient period of time to allow a reliable assessment of the prevailing background noise levels to be performed. Variations in the background noise levels due to wind effects may result in changes of ± 5dB(A) during a period of 1 minute, a medium term variation in level. Long-term variation of the background level may be caused by a change in wind direction. Background noise levels will also change according to the amount of rain that may have fallen during the preceding days; levels in deep valleys in Mid-Wales have been found to vary by as much as 25dB L_{A90}. The time of year that measurements are performed may also have an effect. Summer months may be expected to give higher ambient noise levels due to leaves on trees but lower levels due to reduced rainfall. Winter months may result in lower ambient noise levels due to no leaves on trees but higher level due to more rain. Conversely, the increased wind resistance of trees and shrubs in Summer can increase the level of shelter at the property such that lower wind speeds and hence noise levels are experienced for a given wind speed at the wind farm. Periods of external amenity vary in time of year from site to site and this should be considered when planning background noise surveys.

It is expected that to avoid the results being weighted by unrepresentative conditions at least 1 week's worth of measurements will be required. The actual duration will depend upon the weather conditions, in particular the strength and direction of the wind that has blown during the survey period and the amount of rain.

Measurements should not be used from periods of heavy rainfall when noise levels will be high due to the noise of the rain itself, and more important, due to the increased water flow in nearby streams and rivers.

When sheltered dwellings are positioned close to a site within a deep valley, it is recommended that special consideration is given to noise data that are collected for the wind condition that affords maximum shelter to the property.

Measurement of wind speed

Wind speed measurements are likely to be performed on-site as part of the wind resource study prior to development and if they are to be used for the noise assessment, measurements of the 10-minute average should be recorded. Measurements are performed using anemometers placed at known heights above ground level. Wind speed varies with height above ground level, increasing with increased height (see "wind shear" in Glossary). Therefore, the height at which wind speed measurements are performed and the height of the proposed wind turbines will affect the derived prevailing background noise level. We propose that measurements should be corrected to a standard height of 10m using the procedure described under "wind shear" in the Glossary. The recommendations for noise limits have been made assuming wind speed measurements corrected to 10m. Measurements at 10m will be easier to perform due to the availability of portable masts of this height.

Wind speed measurements performed at two different heights on the same mast will allow an assessment of the wind shear that exists at the wind measurement position. Derivation of the wind shear allows an assessment of the wind speed at 1 Om height to be performed if the anemometers are not positioned at 10m.

Analysis and derivation of background noise levels

The derivation of the prevailing background noise level at a dwelling is performed using the noise data that have been collected at the dwelling and the measured on-site wind speed at the anemometer height.

When deriving the prevailing background noise level, the height at which the wind speed is measured should be clearly stated and converted to 10m height.

It should be expected that measurements performed over an extended survey period will be affected by weather conditions that are not associated with wind speed. Rainfall will lead to increased noise levels at a measurement position due to a number of factors. These may include the increased flow of water within streams and brooks, the sound of rain drops falling on the wind shield and any associated equipment that may contain the sound level meter. Other noise sources may also increase measured noise levels. Work in fields, milking equipment and milk chillers, traffic and aircraft noise all increase the measured noise levels especially during the day-time periods.

The increased levels due to sources not associated with the wind will reduce the correlation between the wind speed and the measured background noise level. However, measurements undertaken during evening and night-time periods are less affected by these extraneous sources as human and animal activity is reduced, thereby minimising any effects. Rainfall, however, is harder to detect. Rain gauges provide an indication when rain fell during survey periods. Increased noise levels during night-time periods that are not associated with respective increases in wind speed are also an indication that rain may have fallen.

It is considered appropriate to remove the noise data that may be affected by rainfall during a survey. Measurements that are affected by human or animal activity during the night, ie traffic passing along nearby roads or owls in nearby trees, should be considered as the noise environment at the dwelling.

Background noise curves are required for both the day-time quiet periods and for the night-time. The periods are defined in Chapter 6.

Appendix C provides a fuller discussion on the measurement of background noise levels.

Measurement of wind farm noise

Wind speed measurement

To assess wind farm noise levels, measurements are correlated with the operating condition of the wind turbines. This is because the emitted noise from a wind turbine is related to the wind speed that a turbine experiences.

A possible method for determining the wind speed during a compliance test is to use an anemometer mast that has a height that is below the lowest point described by the wind turbine rotor, the suggested height being 10 metres. At this height it has been suggested that the true wind speed will be measured, ie which has not been affected by the rotor wakes of wind turbines upwind of the anemometer mast. This mast could then be placed at the original mast position used to determine the prevailing background noise level.

It should be noted that data collection of the wind speed resource at a proposed wind farm site may also have measured the wind shear at the mast position. If measurements have been gathered of the wind speed at 10 metres height, the background noise level measurements may be correlated with this measurement height data and any noise conditions set based upon this wind speed measurement height. A potential additional benefit of using a wind speed measurement height of 10 metres is that the IEA Recommended Practice for the measurement of noise emissions from wind turbines [11] proposes that the standardised sound pressure level and sound power level of a wind turbine be quoted for a wind speed reference condition of 8m/s at a height of 10 metres above ground level. Therefore, the use of a lOm-high anemometer mast may provide additional consistency through the measurement and assessment procedure.

Identification of critical periods for monitoring

It will not normally be necessary to demonstrate compliance with planning conditions at ail wind speeds. If monitoring is required in response to complaints then a log of times at which the turbine noise is most intrusive, taken by the complainant, will enable the developer to establish the conditions which require further investigation.

Having established the critical wind speed conditions over which measurements are to be carried out one needs to consider the amount of data that will be required to give a reliable estimate of the typical turbine noise levels in these conditions. It is the opinion of the Noise Working Group that at least 20 to 30 measurements of the $L_{A90,10min}$ should be taken within ± 2m/s of the critical wind speed. At least ten measurements should lie either side of the critical wind speed. Measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

To minimise the effects of extraneous noise sources it may be necessary to perform these measurements during night-time periods when other human and animal activity noise sources are likely to be at a minimum.

Analyses

Filtering of data

As with the background noise data it will again be necessary to filter data for effects such as periods of rainfall to ensure reliable results are obtained. Also, if the measurement of wind speed is from an anemometer which may be in the wake of a turbine in certain wind directions these data should also be removed.

Calculation of windfarm noise level

A best fit curve can be fitted to the data obtained for a particular critical wind speed. A straight line will usually be sufficient given the small range in wind speed. The noise level at the critical wind speed can be read from this curve. If this level is below that set in the noise limits and the EHO considers that there are no audible tones then no further action is necessary. If, however, either the noise is above the limit or the application of a tonal penalty may take the noise over the limit then a correction for the influence of the existing background noise should be performed or the measurements repeated at times of lower background noise.

The background noise at the critical wind speed should be assessed using the procedure described for turbine noise above. A correction shall then be made as follows:

$$L_{pw} = 10 \log (\mathrm{io} V^{10} - \mathbf{io} V^{\mathbf{10}})$$

where L_{pw} = wind farm noise, dB(A)
L_{pc} = combined wind farm and background noise as measured, dB(A)
$L_{p}b$ = background noise only, dB(A).

It is recognised that the correction method above only strictly applies to the correction of one L_{eq} by another. Readers are referred to the paper by Nelson [32] for more discussion on correcting percentile measurements.

Measuring tonal levels

A review of options and a description of a recommended method for tonal assessment were given in Chapter 6. This Section describes the application of that method in the field so that reliable results can be obtained.

Instruments

The information contained in this assessment method is sufficiently complete to allow the identification of audible discrete tones to be made using a variety of measuring instruments; therefore no specific type of instrument is specified. The procedure requires, however, the measurements of the sound pressure level of the tone, L_{pt}, and the sound pressure level of the noise in the critical band centred at the frequency of the tone, L_{pm}. The instruments used should be capable of determining the difference between these levels to within ± ldB.

Commercially available or specially designed analogue or digital instruments may be used to measure the levels directly or, more conveniently, raw data may be acquired and then processed by a digital computer. An A-weighted network shall be used when performing this assessment as this may be more convenient given a requirement to simultaneously measure the overall A-weighted sound pressure level.

Measurements

Tonal assessment should be carried out at times of typical background noise levels so that the effect of the existing background noise on the masking of tones is not over- or under-emphasised. It has been shown [27] that the audibility of a tone from wind turbines evaluated by the method described in Chapter 6 fluctuates by several dB without any appreciable change in wind speed. It is therefore necessary to introduce some averaging into the assessment procedure to increase the repeatability and reliability of the derived results. As for overall levels, 20 to 30 measurements should be taken within ± 2m/s of the critical wind speed. These measurements should be taken during the same periods as the measurements of overall noise level. At least ten measurements should lie either side of the critical wind speed. The measurements should be taken over a period of 2 minutes and regularly spaced at 10-minute intervals so that each measurement corresponds to a measurement of the $L_{A90,10min}$ used in the assessment of the overall noise level. As with overall levels, measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

Analysis

Tonal analysis of each 2-minute sample is performed according to the recommended procedure described in Chapter 6:

- For each of the 2-minute samples calculate the margin above or below the audibility criterion of the tone level difference, ΔL_{tm}, by comparison with the audibility criterion given in Chapter 6.

- Plot the margin above audibility against wind speed for each of the 2-minute samples. For samples for which the tones are inaudible or no tone is identified substitute a value of zero audibility.

- Perform a linear regression to establish the margin above audibility at the critical wind speed. If there is no apparent trend with wind speed then a simple arithmetic average will suffice.

- The tonal penalty, Kj, is derived from the margin above audibility of the tone according to Fig 16 in Chapter 6.

The rating level

The rating level is the arithmetic sum of the wind farm noise level, L_{pw}, and the tonal penalty, K_T. It is this level which determines whether the wind farm has complied with the limits set in the planning condition.

8. THE PLANNING OBLIGATION

The Noise Working Group thought that it would be beneficial to present its recommendations in a form which might be useful to developers and planners. We therefore considered drafting planning conditions, but came to the conclusion that the necessary definitions of terms which would be required would make planning conditions too complicated. Therefore it was decided to produce covenants for inclusion within an Agreement between a developer and a local authority. Alternatively, the developer may be required, through a planning condition, to agree a noise rating and monitoring scheme with the local planning authority prior to operation of the development. The scheme may then incorporate the definitions and provisions which we have included within the Planning Obligation. This may be particularly helpful where a developer does not own the proposed wind farm site.

It is appreciated that on first reading the Planning Obligation can appear somewhat complicated. It is anticipated that when there has been more experience of drafting such obligations it may be possible for some simplifications to be made.

The Planning Obligation is supplemented by some Guidance Notes to which it refers. These Guidance Notes also serve as a useful summary of the proposed measurement procedure.

DATED 1996

THE WIND FARM LIMITED

and

THE COUNCIL

PLANNING OBLIGATION BY AGREEMENT

Relating to Land at

Assumptions within this document:

The Developer owns the freehold of the Site
There are no other interests in the Site and
in particular there is no charge over the Site

Bond Pearce
Plymouth

THIS PLANNING OBLIGATION BY AGREEMENT is made the day of 199 BETWEEN:

(1) **THE WIND FARM LIMITED** a company registered in with number and whose registered office is at

(2) **THE COUNCIL** of the Council Offices at

WHEREAS:

(1) The Council is the local planning authority for the purposes of the 1990 Act for the area which includes the Site

(2) The Developer owns the legal estate in the Site

(3) The Developer intends to construct and operate the Development

(4) The Developer has by the Application applied to the Council for planning permission for the Development

(5) The Council in exercise of its powers under the 1990 Act has decided to grant planning permission for the Development

(6) The Developer has agreed to enter into this Obligation

NOW THIS OBLIGATION WITNESSES as follows:

1. In this Obligation unless the context otherwise requires:-

1.1 **"the Developer"** means The Wind Farm Limited and its successors in title

1.2 **"the Council"** means The [ ] Council and any successor authority

1.3 **"the Site"** means the land edged red on the plan numbered x attached to this Obligation being land at

1.4 **"the Application"** means an application for the Permission for the Development submitted to the Council under the 1990 Act on registered under number

1.5 **"the Development"** means the erection on the Site of x wind turbine generators, a grid connection building and ancillary development as specified in the Application

1.6 **"the Permission"** means any planning permission issued pursuant to the Application (together with any modifications thereto made with the consent of the Developer) by the Council on the determination of the Application

1.7 **"the 1990 Act"** means the Town and Country Planning Act 1990 (as amended by the Planning and Compensation Act 1991 and any subsequent legislation)

1.8 **"the Wind Turbines"** means the wind turbine generators proposed to be erected **as** part of the Development.

2. It is the intention of the parties that:

2.1 This Obligation is made pursuant to the provisions of Section 106 of the 1990 Act

2.2 This Obligation shall be enforceable by the Council

2.3 This Obligation shall not take effect until the Permission has been granted and implemented by the carrying out of a specified operation as defined in Section 56 (4) of the 1990 Act

2.4 No person or company shall be liable for any breach of this Obligation unless he or it holds an interest in the part of the Site in respect of which such breach occurs or held such an interest at the date of the breach

2.5 Nothing in this Obligation shall be construed as prohibiting or limiting the development of the whole or any part of the Site in accordance with any planning permission granted by the Council after the date of this Obligation (save and except the Permission)

2.6 Where the context so requires the singular includes the plural and terms using the masculine gender include the feminine

2.7 References to Schedules and Appendices mean Schedules and Appendices to this Obligation

3. The Developer hereby covenants with the Council to observe and perform the obligations contained in the Schedule all of which relate to the Development

4. Any dispute arising from the terms of this Obligation will be referred to the decision of a single arbitrator (acting as an expert and not an arbitrator) under the terms of the Arbitration Act 1979, such arbitrator to be appointed by agreement between the parties or in default of agreement by the President for the time being of the Institute of Acoustics (or provision for determination of disputes by the County Court)

IN WITNESS whereof the parties hereto have executed these presents the day and year first before written

THE SCHEDULE

1. In this Schedule unless the context otherwise requires:

1.1 **"Audibility"** means the audibility of Tonal Noise as defined in (and to be measured in accordance with) the recommended method in Section 2.1 of the Guidance Note

1.2 **"Background Noise Level"** means the ambient noise level already present within the environment (in the absence of noise generated by the Development) as measured **prior** to the date of this Obligation and correlated with Wind Speeds

1.3 **"Best Fit Curve"** means **a** best fit linear regression curve expressing noise levels **as a** function of wind speed derived from measured noise levels for data points extracted in accordance with the recommendations in Section 1.2 of the Guidance Note

1.4 **"Critical Band Width"** means a band with a prescribed frequency range determined in accordance with the recommendations in Section 2.1 of the Guidance Note Appendix 3

1.5 **^{M}dB(A)$_{L90>10min}$"** means the dB(A) level exceeded 90% of the time and measured over a period of 10 minutes

1.6 **"Free-field Conditions"** means an environment in which there are no reflective surfaces (except the ground) affecting measurements within the frequency range being measured

1.7 **"Guidance Note"** means the 'Supplementary Guidance Notes to the Planning Obligation" presented in Chapter 8 of the report 'The Assessment and Rating of Noise from Wind Farms", September 1996, report number ETSU-R-97.

1.8 **"Night Hours"** means 2300-0700 hours on all days

1.9 **"Quiet Waking Hours"** means 1800-2300 hours on all days plus 0700-1800 hours on Sundays and 1300-1800 hours on Saturdays

1.10 **"Tonal Noise"** means noise containing a discrete frequency component

1.11 **"Wind** Speeds" means (unless the context otherwise demands) wind speeds measured at a height of 10 metres above ground level on the Site at Ordnance Survey grid reference aaaaaa.

1.12 **"Wind Turbine Noise Level"** means the rated noise level due to the combined effect of all the Wind Turbines including any penalty incurred under clause 7 or 8 of this Schedule but excluding the existing background noise level

2. At the reasonable request of the Council following a complaint to the Council relating to noise emissions from Wind Turbines the Developer shall measure at its expense the level of noise emissions from the Wind Turbines (inclusive of existing background noise) using an L_{A90} index over a minimum of 20 periods each of 10 minutes duration. At least 10 of the periods of measurement shall be made at Wind Speeds between a wind speed specified by the Council and a wind speed of not more than 2 metres per second above that specified by the Council. At least 10 measurements shall be made at Wind Speeds between the wind speed specified by the Council and a wind speed not less than 2 metres per second below that specified by the Council. Measurements of noise emissions shall be made in consecutive 10-minute periods provided that they fall within the wind speed range defined in this clause

3. The measurements under clause 2 shall be made using a sound level meter of at least type 1 quality (as defined in International Electrotechnical Commission standard 651 (1979)) incorporating a windshield with a Vi inch diameter microphone in free-field conditions between 1.2 and 1.5 metres above ground level and at least 10 metres from any wall, hedge or reflective surface (using a fast time weighted response)

Alternative 1

(a) In this clause the values of X Y and Z are specified in the Tables within Appendix A of this Agreement in relation to the dwellings referred to or named as described in Section 1.3 of the Guidance Note.

(b) The Wind Turbine Noise Level as measured in accordance with clauses 2, 3 and 5 shall not exceed:

(i) During Night Hours the greater of the Night Hours L_{A90} Background Noise Level plus XdB or $YdB(A)_{L9010min}$ at Wind Speeds not exceeding 12 metres per second;

and at all other times

(ii) The greater of the Quiet Waking Hours L_{A90} Background Noise Level plus XdB or $ZdB(A)_{L9010min}$ at Wind Speeds not exceeding 12 metres per second

Provided that this covenant shall only apply to dwellings existing at the date of this Obligation.

Alternative 2

The Wind Turbine Noise Levels as measured in accordance with clause 2, 3 and 5 shall not exceed $35dB(A)_{L9010min}$ at Wind Speeds not exceeding 10 metres per second provided that this can only apply to dwellings existing at the date of this Obligation.

5. (a) Measurements made in accordance with the provisions of this Schedule in order to demonstrate compliance with the requirements of clause 4 shall be correlated with Wind Speeds

(b) The $L_{A90,10min}$ noise level from the combined effect of the Wind Turbines (inclusive of existing background noise) shall be derived using a Best Fit Curve.

6. Tonal Noise shall be measured for Audibility in accordance with the recommended method described in Section 2.1 of the Guidance Note.

7. If Tonal Noise from the combined effect of the Wind Turbines (when measured in accordance with clause 6) exceeds the threshold of Audibility by more than 6.5dB a penalty of 5dB shall be added to the noise level derived in accordance with clause 5(b)

8. If Tonal Noise from the combined effect of the Wind Turbines (when measured in accordance with clause 6) exceeds the threshold of Audibility by more than 2.0dB but less than 6.5dB a penalty of ((5/6.5)xAudibility)dB shall be added to the noise level derived in accordance with clause 5(b)

9. If measurements made in accordance with clauses 2, 3 and 5 exceed the levels of noise emissions provided in clause 4 then in order to investigate compliance with such levels by an assessment of the contribution of background noise to the measured levels the measurements shall be repeated by the Developer at a time when the contribution of the Background Noise Level to measured noise levels can be expected to be less than at the time of the first set of measurements.

10. If measurements made in accordance with clause 9 exceed the levels of noise emissions provided in clause 4, or noise levels measured in accordance with clauses 2, 3, 5, 6, 7 and 8 exceed the levels provided in clause 4, then in order to investigate compliance with such levels by an assessment of the contribution of background noise to the measured levels, measurement shall be made in accordance with the requirements of clause 2, 3 and 5(b) (with the Wind Turbines stationary). A correction shall be applied in accordance with the recommended method in Section 2.0 of the Guidance Note to the measured noise levels in order to determine the contribution of background noise to the overall levels of noise measured when the Wind Turbines are in operation.

11. The Developer shall supply Wind Speeds and wind direction data to the Council at its request to enable the Council to check compliance by the Developer with the provisions of this Schedule.

EXECUTED AS A DEED AND DELIVERED
BY authorised to
sign for and on behalf of

in the presence of:

THE COMMON SEAL OF THE)
COUNCIL)
was hereunto affixed)
in the presence of:)

Authorised Person

Authorised Person

Bond Pearce
1996 (ref GMT)

SUPPLEMENTARY GUIDANCE NOTES TO THE PLANNING OBLIGATION

1.0 Prior to construction of the wind farm

1.1 Identification of properties where background noise surveys are required

Before the wind farm is constructed, the developer/operator should identify the nearest noise-sensitive properties to the wind turbines.

If there is a small number of such properties, a background noise survey will be required at each one.

If there are rather more properties, it may be appropriate to identify a smaller number of properties, in agreement with the local authority/EHO, that have similar background noise levels to a group of properties in their immediate vicinity. A background noise survey will be required at each one of these indicative properties as the noise limits relate to the existing background noise levels.

The precise locations at which the background noise surveys should be made at each property should be agreed in consultation with the local authority/EHO.

In addition, the developer/operator of the wind farm should agree, in consultation with the local authority/EHO, the lower limit on wind farm noise that will apply at each property, or group of properties under consideration. This limit should normally lie in the range 35-40dB(A), except where the occupants of a property receive a financial benefit from the wind farm, where a higher limit of 45dB(A) may be appropriate. It may be desirable to agree these lower limits after the background noise surveys have been completed, rather than beforehand.

Note that where it can be demonstrated that the expected levels of wind farm noise would not exceed 35dB(A) at a property for wind speeds of up to 10m/s at 10m height, then no background noise survey is required for that property.

Note also that where a new wind farm is planned for an area where another wind farm is already operating, the contribution to noise levels from the existing wind farm should not be included in any assessment of prevailing background noise levels.

1.2 The background noise survey

The background noise survey should be taken over a sufficient period of time to enable a reliable assessment of the prevailing background noise levels at each property to be made. As a guideline, an appropriate survey period might be 1 week, although the actual duration will depend upon the weather conditions, in particular the wind speed and direction during the survey period. It must be ensured that, during the survey period, wind speeds over the range zero to at least 12m/s (10min average at 10m height), and a range of wind directions that are typical of the site, are experienced.

The aim of the survey, at each location, is to characterise the variation in prevailing background noise level with wind speed. This is achieved by correlating background noise measurements with wind speed measurements made over identical time periods. The following sections identify the measurements required to enable this.

1.2.1 Acoustic measurements

Background noise levels should be measured using the A-weighted L_{90} statistic over consecutive 10-minute intervals, ie L^o™,. A sound level meter of at least IEC 651 type 1 quality should be used, and this should be fitted with a *Vi"* diameter microphone and calibrated in accordance with the procedure specified in BS 4142: 1990.

The microphone should be mounted on a tripod at 1.2-1.5 m above ground level, fitted with a wind shield, and placed in the vicinity of, and external to, the property, at least 3.5m away from any reflecting surfaces. The intention is that the acoustic measurements should be made in "free-field" conditions.

1.2.2 Wind speed and direction measurements

Wind speed and direction data should be recorded as average values over 10-minute intervals, v_{10min} & ©10™, these intervals to be synchronised with the measurement period for the L_{A9U}omin acoustic data.

The measurements should preferably be made using instruments mounted at 10m height. Where this is not possible, wind speeds measured at one height can be "corrected" to the value that would have been measured at another height using the expression:-

V1/V2 = In (hj/zo) / In (h_2/z_0)

where = wind speed (m/s) at a height of hj metres above ground level.
V2 = wind speed (m/s) at a height of I12 metres above ground level.
$^z0$ = ground roughness length (m).

The ground roughness length can be calculated from wind speed measurements at two or more heights. Alternatively it can be estimated from Table 11.

The instruments should be mounted on a mast positioned on the site so that they give a reasonable description of meteorological conditions at the noise-sensitive properties. Where there are several masts on a site, data from the instruments mounted on the mast closest to each property should be used.

Table 11 Roughness lengths for various types of terrain

Type of Terrain	Roughness Length ZQ
Water areas, snow or sand surfaces	0.001m
Open, flat land, mown grass, bare soil	0.01m
Farmland with some vegetation	0.05m
Suburbs, towns, forests, many trees and bushes	0.30m

1.2.3 Data reduction

At the end of the survey period, data recorded during periods of rainfall, or afterwards, where rainfall may have affected flow in nearby rivers or streams, should be discarded.

Two sub-sets of the data should be created, for the following periods:

- quiet waking hours (18:00-23:00 every day, 13:00-18:00 on Saturday, 07:00-18:00 on Sunday)
- night hours (23:00-07:00, every day).

These two sub-sets are identified as the "day-time" data, and the "night-time" data. For each sub-set, a "best fit" curve should be fitted to the data using a least squares approach, usually a polynomial model (of no more than 4^{th} order).
Where there is considerable scatter in the data, it may be appropriate to bin the acoustic data into 1m/s bins, before identifying a best fit model.

These two curves, referred to as the "day-time curve" and the "night-time curve", provide a characterisation of the prevailing background noise levels, for the day-and night-time respectively, as functions of wind speed from zero to 12m/s at 10m height.

Note that whatever model is used to describe the measured data, this should not be extrapolated outside of the range of measured wind speed data.

1.3 Identification of noise criteria

1.3.1 Day-time noise criterion

The criterion curve for acceptable levels of wind farm noise during day-time, ie 07:00-23:00 each day, is usually equal to the day-time curve plus 5dB(A) at every wind speed.

Where this criterion curve falls below the lower limit (35-40dB(A), or 45dB(A) - see Section 1.1), the criterion curve should be amended so that it equals the lower limit. This results in a piece-wise, continuous curve, equal to the lower limit from zero to the wind speed at which the day-time curve plus 5dB(A) equals the lower limit, and the day-time curve plus 5dB(A) thereafter, to an upper wind speed of 12m/s at 10m height.

1.3.2 Night-time noise criterion

The criterion curve for acceptable levels of wind farm noise during night-time, ie 23:00-07:00 each day, is equal to the night-time curve plus 5dB(A) at every wind speed.

Where this criterion curve falls below 43dB(A), the criterion curve is amended so that it equals 43dB(A). As before, this results in a piece-wise, continuous curve, equal to 43dB(A) from Om/s up to the wind speed at which the night-time curve plus 5dB(A) equals 43dB(A), and the night-time curve plus 5dB(A) thereafter, to an upper wind speed of 12m/s at 10m height.

Note that where the occupants of a noise-sensitive property are financial beneficiaries of the wind farm, the 43dB(A) figure may be replaced with 45dB(A) - see section 1.1.

1.3.3 Table of noise limits

The limits agreed for each property or group of properties can be summarised in tabular form in an Appendix to the Planning Obligation, see Section 4 of the Schedule. Properties not mentioned specifically by name or address should be included by applying limits to "any other property". In Section 4 X refers to the margin above background (usually 5dB), Y refers to the night-time lower fixed limit (usually 43 dB) and Z refers to the day-time lower fixed limit (usually in the range 35-40dB).

2.0 Procedure to be followed in the event of a complaint

Where the local authority/EHO receive a complaint about noise levels following the construction of the wind farm, the following steps should be taken:

1 The complainant should log the times when the noise is most intrusive. This will enable the meteorological conditions in which the complaint occurs to be determined and, in particular, the critical wind speed.

2 At least 20 values of the LA^IO^ noise statistic should be measured at the affected property using a sound level meter of at least IEC 651 Type 1 quality. This should be fitted with a *V2"* diameter microphone and calibrated in accordance with the procedure specified in BS 4142: 1990. The microphone should be mounted on a tripod at 1.2-1.5 m above ground level, fitted with a wind shield, and placed in the vicinity of, and external to, the property. The

intention is that, as far as possible, the measurements should be made in "free-field" conditions. To achieve this, the microphone should be placed at least 10m away from the building facade or any reflecting surface, where possible, and no less than 3.5m away where this is not possible with appropriate adjustment made to measured levels to account for facade effects.

The 20 $L_{A90,10min}$ measurements should be synchronised with measurements of the 10-minute average wind speed, and be made in wind speeds within ± 2m/s of the critical wind speed. Further, at least 10 of these should lie either side of it. The measurements should be made during conditions that are generally typical for the site and not, for example, during periods with a rarely encountered wind direction.

To minimise the effects of extraneous noise sources, it may be necessary to perform these measurements during night-time periods.

Any data recorded during periods of rainfall, or immediately afterwards, where rainfall may have affected flow in nearby rivers or streams, should be discarded. Where this is necessary it shall be ensured that the conditions relating to the number of data points, and their distribution, are still adhered to.

3 A least squares, "best fit" curve should be fitted to the data points - generally a straight line fit will be sufficient.

4 The noise level at the critical wind speed, L_c, shall be determined from this best fit curve. If this level lies below the value indicated from the two noise criteria curves at the critical wind speed, and the local authority/EHO consider there to be no audible tones, then no further action is necessary.

5 If the noise level is above the limit, or if the application of a tonal penalty - see later - takes it above the limit, a correction for the influence of background noise should be made. This may be achieved by repeating steps 2-4, with the wind farm switched off, and determining the background noise at the critical wind speed, L_b. The wind farm noise at this speed, L_w, is then calculated as follows:

$$L_w = 10\log\left(10^{\frac{L_c}{10}} - 10^{\frac{L_b}{10}}\right)$$

If the wind farm noise level lies below the value indicated from the two noise criteria curves at the critical wind speed, and the local authority/EHO consider there to be no audible tones, then no further action is necessary.

Where, in the opinion of the local authority/EHO, the noise immission contains a tonal component, the following rating procedure should be used. This is based on the repeated application of a tonal assessment methodology - see below.

For each 10-minute interval for which $L_{A90]0min}$ data have been obtained, a tonal assessment - see Section 2.1 - is performed on noise immission during 2-minutes of the 10-minute period. The 2-minute periods should be regularly spaced at 10-minute intervals provided that uninterrupted clean data are obtained.

For each of the 2-minute samples the margin above or below the audibility criterion of the tone level difference, ALtm, is calculated by comparison with the audibility criterion given in Section 2.1 below.

The margin above audibility is plotted against wind speed for each of the 2-minute samples. For samples for which the tones were inaudible or no tone was identified, substitute a value of zero audibility.

A linear regression is then performed to establish the margin above audibility at the critical wind speed. If there is no apparent trend with wind speed then a simple arithmetic average will suffice.

The tonal penalty, K_T, is derived from the margin above audibility of the tone according to Fig 17.

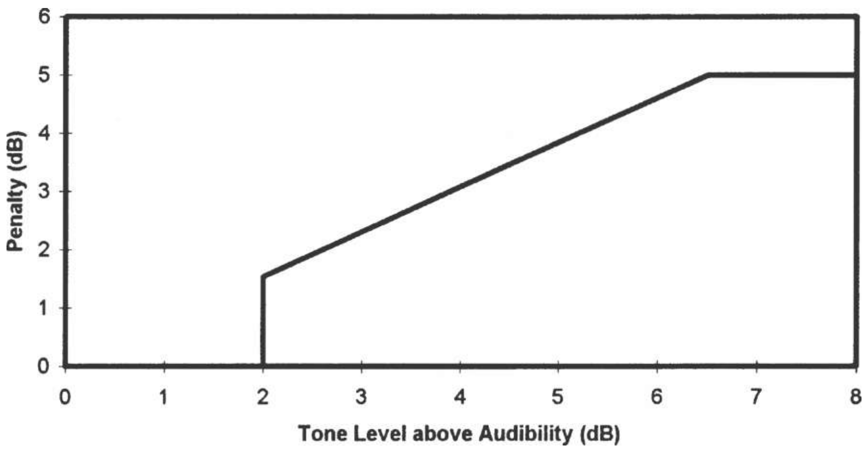


Figure 17 Penalties for tonal noise

The rating level is the arithmetic sum of the wind farm noise level, L_{pw} and the tonal penalty, K_T. It is this level which determines whether the wind farm has complied with the limits set in the planning condition.

2.1 Tonal assessment methodology

The recommended method is based upon the Joint Nordic Method for non-stationary tones with some embellishments in areas where it is not entirely prescriptive such as tone identification and averaging periods. The method aims to assess the audibility of a tone as perceived by the average listener. There are three main steps in the procedure:

A) Frequency analysis of the noise at receiver locations.

B) Determination of the sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band.

C) Evaluation of the difference between the tone and the masking noise sound pressure levels (ΔL_{tm}) by comparison with a criterion curve to determine the audibility of a tone.

A. Frequency analysis

The analysis of non-stationary tones is quite intensive; it will therefore be convenient to record the signal to be analysed onto tape. For each tonal assessment 2-minutes of uninterrupted clean A-weighted recording is required.

A 2-minute, rms-averaged FFT is performed on the sampled data using a Hanning window, a frequency resolution of 3.0 ± 0.5Hz and an analysis bandwidth of 2kHz. It may be necessary to inspect a similar spectrum with greater bandwidth to ensure that there are no tones present at higher frequencies.

The short term, individual rms-averaged FFTs within the sampled data are also calculated using the same parameters as described above. This results in an averaging time of 0.29 to 0.4 seconds.

B. Determination of sound pressure levels

The bandwidth of a critical band is:

Centre Frequency f_p. Hz	20-500	Above 500
Bandwidth	100Hz	20% of f_c

If a single tone is present the critical band is centred upon the tone. If two or more, closely spaced tones are present, the critical band is placed so that it contains the maximum possible amount of tonal energy. In order to do this it is first necessary to identify the tones within the spectrum. To do this each line in the 2-minute spectrum must be classified according to the following criteria based upon the draft DIN 45 681. A peak is classed as a tone if its level is more than 6dB above the logarithmic average of the sound pressure levels of the rest of the lines in the critical band centred on the peak, but excluding the one line each side of the peak. If the peak qualifies as tone the adjacent lines are also classified as a tone if their level is within 10dB of the peak and greater than 6dB above the average level previously calculated. If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level it is classified as neither tone nor masking. Having identified the tones the critical band can be placed to maximise the sound pressure level of the tones within the critical band.

Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. This is described by reference to the worked example below.

Fig 18 shows the stages in the tone identification and classification process. These are:

- Find peaks in the spectrum, in this case line 23.

- Calculate the average energy in the critical band centred on each peak, not including the two lines adjacent to the peak (9.10dB).

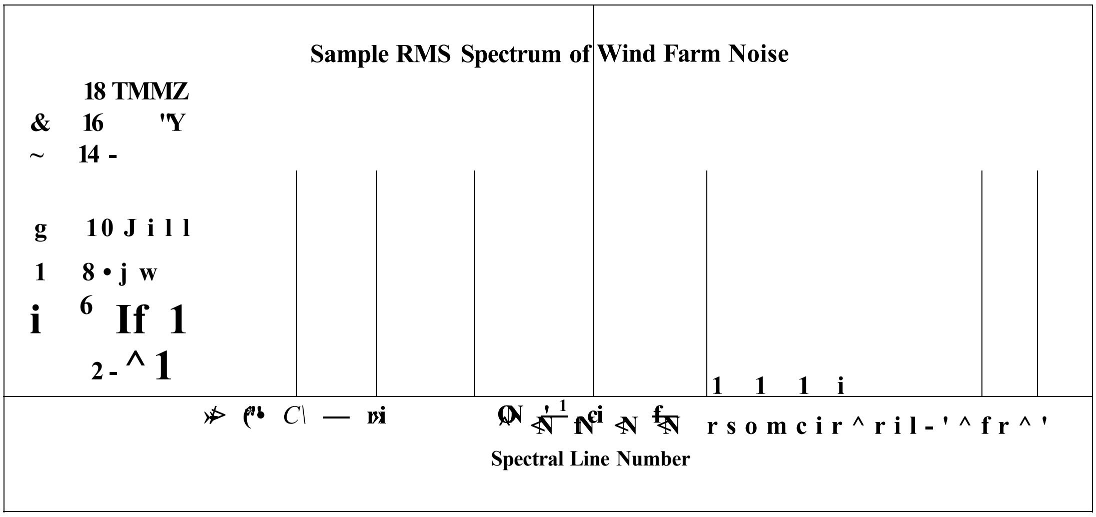
- If the peak is more than 6dB above the average masking level then it is a tone, therefore line 23 is a tone.

- Classify adjacent spectral lines :

  Pass 1
  - Compare spectral lines above and below the peak to the average level.
  - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 22, 24 and 25 are tones.

  Pass 2
  - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.75dB).
  - Compare spectral lines above and below the peak to the average level.
  - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 21, 22, 24 and 25 are tones.

  Pass 3
  - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.39dB).
  - Compare spectral lines above and below the peak to the average level.
  - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone. Therefore lines 21, 22, 24 and 25 are tones, but no spectral lines have been reclassified in this pass so the iterative process is complete.



Tone Identification and Classification Peak line = 23	Peak Level = 17.71dB					
	Pass 1		Pass 2		Pass 3	
Average about peak	9.10		8.75		8.39	
Adjacent line assessment	Level above average	Classif-ication	Level above average	Classif-ication	Level above average	Classif-ication
Line number						
19	-0.49	masking	-0.14	masking	0.22	masking
20	0.20	masking	0.55	masking	0.91	masking
21	5.83	masking	6.18	tone	6.54	tone
22	6.34	tone	6.69	tone	7.05	tone
24	7.64	tone	7.99	tone	8.35	tone
25	6.26	tone	6.61	tone	6.97	tone
26	1.40	masking	1.75	masking	2.11	masking
27	-0.01	masking	0.34	masking	0.70	masking

Figure 18 Tone identification and classification process

If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level then it is classified as neither tone nor masking, and not included in the calculation for either level.

The process described above is repeated for every critical band centred around tonal peaks in the spectrum. The result is that within each critical band every spectral line is classified as tone energy, masking energy or neither.

Having identified the lines in each spectrum contributing to tonal levels, masking levels or neither, the tonal analysis can continue as follows:

- The masking energy within the critical band is calculated from the 2-minute rms spectrum. Calculate the masking level in the critical band, L_{pm}, correcting for a reduction in the number of lines due to the exclusion of tones and for the Hanning window:

Lpm = lOlogXioWlO + lQlogf<u>critical band width</u>) + 10log(l/1.5)

(N_m x Af)

where L_m = sound pressure level of each line containing masking noise
N_m = number of lines within the critical band containing masking noise.

- For each of the short term spectra of 0.29 to 0.4 seconds duration, calculate the tone energy within each critical band, L_{pt}', using the lines identified as tones from the 2-minute spectrum.

L_{pt}' = lOlogZloWlO

where Lt is the sound pressure level of each line containing tonal noise.

The tone level used in the assessment, L_{pt}, is the arithmetic mean of the top 10% of tone levels, L_pt', from all the short-term spectra constituting the 2-minutes of data.

C. Evaluation of the audibility of the tone(s).

The audibility of a tone is dependent upon the tone level difference, ALtm, and the frequency of the tone:

ALtm= L pf-^pm-

The audibility criterion is defined as follows:

ALtm,crit = - 2 - Log (1 + (f / 502)$^{2.5}$)

where f = frequency at the centre of the critical band.

This is the level at which the average listener will be just able to hear the tone. Fig 19 details the audibility criterion based upon the above equation. It can be seen from the figure that the audibility criterion is related to the frequency of the tone.

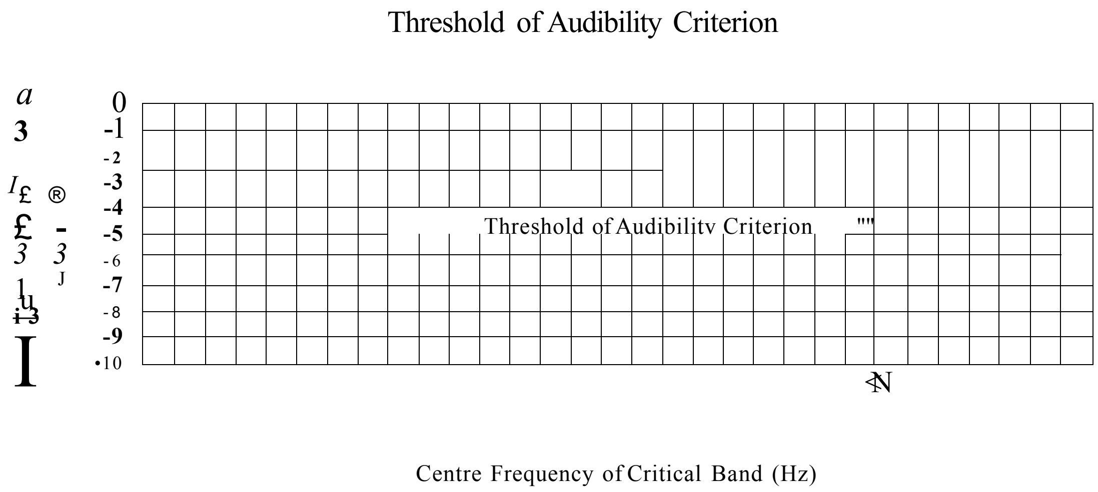


Figure 19 The audibility criterion for tonal noise assessment

Tonal assessment should be carried out at times of typical background noise levels so that the effect of the existing background noise on the masking of tones is not over- or under-emphasised.

It has been shown [27] that the audibility of a tone from wind turbines evaluated by the method described in these guidance notes fluctuates by several dB without any appreciable change in wind speed. It is therefore necessary to introduce some averaging into the assessment procedure to increase the repeatability and reliability of the derived results. As for overall levels, 20 to 30 measurements should be taken within + 2m/s of the critical wind speed. These measurements should be taken during the same periods as the measurements of overall noise level. At least 10 measurements should lie either side of the critical wind speed. The measurements should be taken over a period of 2 minutes and regularly spaced at 10-minute intervals so that each measurement corresponds to a measurement of the $L_{A90,10min}$ used in the assessment of the overall noise level. As with overall levels, measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

9. FURTHER WORK

This chapter makes some observations that may form the basis of a review of the contents of this report. It also outlines current research within the DTI New and Renewable Energy Programme of relevance to those working in the environmental assessment of noise from wind turbines.

Review of the report and its recommendations

This report was drafted in the light of the best information available at the time and in the circumstances prevailing at the time. However it is acknowledged that as more experience and information become available and as circumstances develop it may become necessary to revise and improve the contents of this report

The Noise Working Group therefore suggests this report and its recommendations are reviewed in 2 years time. We anticipate that the wind industry will itself take the initiative for such a review and that this review will be undertaken by a cross-section of users of the report. This review should establish:

- To what extent have the recommendations been followed?
- Have the recommendations been interpreted as originally intended?
- Do the suggested noise limits provide the right balance between protecting the local amenity and providing for the development of renewable energy sources?
- Do the measurement procedures strike the right balance between repeatability and reliability on the one hand and ease of use on the other?
- Are there any circumstances which the recommendations do not properly address but which could be covered by general advice?

More specific issues which could warrant further attention are:

- The simplification of the tonal assessment method.
  An IEA Recommended Practice on "The Measurement of Noise Immission Levels from Wind Turbines at Noise Receptor Locations" is currently under preparation. This may contain a simpler method for the measurement of the difference between the tone level and the masking noise based upon rms-averaged spectra. It is unlikely however that this tone level difference will be able to be transformed into a measure of the audibility of a tone without validation by further work.

- Tonal assessment of variable speed machines.
  In 2 years time there is likely to be more information and experience available on the tonal emissions from variable speed machines which could then be incorporated in to the tonal

assessment method.

- The correction of turbine noise for the influence of background noise.
  The report acknowledges that the expression used for correction of turbine noise for background noise is only strictly applicable to L_{eq} measurements and may slightly underestimate the correction required. If user experience shows that greater accuracy is required then further investigation of how to correct one average L_{90} measurement by another will be necessary.

Current research projects

This section briefly reviews current research projects being undertaken as part of the DTFs New and Renewable Energy Programme which may be of interest to readers. The reports from these projects will be available on loan from the Enquiries Bureau at ETSU following publication.

Low Frequency Wind Turbine Noise and Vibration

Contractor: Powergen.
Objectives: 1. To measure the low frequency noise and vibration levels in the frequency range 0.1 Hz to 60Hz in the immediate vicinity of a modern wind farm and at distances up to 1km.
2. To assess the measured noise and vibration levels in relation to existing noise and vibration criteria and in relation to existing published data on low frequency noise and vibration.
Publication: November 1996.
Report No: ETSU W/13/00392/REP.

Wind Turbine Measurements for Noise Source Identification

Contractor: Hoare Lea and Partners.
Objectives: 1. To acquire high quality data on noise and vibration from two types of wind turbine.
2. To relate the noise to vibration and turbulence measurement.
3. To provide full information on the trends of principal noise features with wind speed, wind turbine power, direction of observation, and other relevant parameters.
4. To compare the data with recently developed theory for aerodynamic noise.
5. To establish the mechanisms that result in blade "swish", to determine its temporal and spectral character, to devise an objective metric for blade swish prominence and to identify conditions under which blade swish is likely to occur.
Publication: December 1996.
Report No: ETSU W/13/00391/REP.

Wind Farm Noise Control Strategy

Contractor: Wind Prospect Ltd.

Objectives: 1. To develop and implement a tuned dynamic wind farm noise control strategy based upon varying cut-in wind speeds with wind direction to achieve specified noise constraints at specified locations close to a wind farm.

2. To evaluate the effectiveness and financial implications of such a method.

Publication: June 1997.

Report No: ETSU W/13/00499/REP.

Propagation of Noise from Wind Turbines over Variable Terrain

Contractor: The Hayes McKenzie Partnership.

Objectives: 1. To use an impulsive noise source to establish the influence of secondary propagation paths and other terrain effects on received noise levels in complex terrain.

2. To establish improved (empirical) modelling techniques for noise propagation over various types of terrain under different wind conditions.

Publication: March 1997.

Report No: ETSU W/13/00354/045/REP.

A Critical Appraisal of Wind Farm Noise Propagation

Contractor: Renewable Energy Systems Ltd

Objectives: 1. To obtain high quality noise immission ("far" field) data at locations surrounding a controlled loudspeaker noise source.

2. To obtain high quality noise emission ("near" field) and noise immission ("far" field) data from a number of UK wind farms.

3. To review existing long-term noise immission data previously collected by the participants from UK wind farms.

4. To use these data to critically appraise the performance of a wide range of popular sound propagation models and, based on this, to estimate the prediction uncertainties associated with the different propagation models.

5. To recommend either the "best" sound propagation model to use, or the "best" given certain circumstances, eg flat, open terrain.

6. To develop a new, empirical noise propagation model for predicting wind farm noise immission levels under practically encountered conditions, and to place confidence limits on these predictions by defining an envelope in which sound pressure levels are likely to lie.

Publication: May 1998.

Report No: ETSU W/13/00385/REP.

Noise Immission from Wind Turbines

Contractor:	National Engineering Laboratory.
Objectives:	1. To reduce the effects of wind-induced self noise on noise measurements made with outdoor microphones. 2. To measure noise levels around a number of wind farms for comparison with noise propagation models. 3. To develop, validate and generate a PC version of a noise propagation model developed under a previous JOULE II contract. 4. To quantify the uncertainty of reported sound power measurements due to different measurement practices and differing interpretation of existing standards. 5. To quantify the uncertainty of reported tone levels from wind turbines. 6. To quantify the "nuisance value" of noise from wind turbines in comparison with a common reference.
Publication:	May 1998.
Report No:	ETSU W/13/00503/REP.

10. REFERENCES

1. Department of the Environment, Planning Policy Guidance Note PPG 22: Renewable Energy. 1993, HMSO.

2. British Standards Institution 1990. Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas. BS 4142.

3. Noise: Report of the Committee on the Problem of Noise. A Wilson (Chairman) HMSO 1963/4.

4. DOE Circular 10/73 (WO 16/73), Planning and Noise, HMSO.

5. Department of the Environment, Planning Policy Guidance, PPG 24: Planning and Noise. 1994, HMSO.

6. Department of the Environment. Mineral Planning Guidance Note, MPG 11: The Control of Noise at Surface Mineral Workings. 1993, HMSO.

7. Department of Trade and Industry Energy Paper 62. New and Renewable Energy: Future Prospects in the UK. March 1994, HMSO.

8. DOE Circular 11/95, The Use of Conditions in Planning Permissions, HMSO.

9. Lowson, M. V., Assessment and Prediction of Wind Turbine Noise, 1993, ETSU W/13/00284/REP.

10. Lowson, M.V. and Fiddes, S.P., Design Prediction Model for Wind Turbine Noise, 1994, ETSU W/13/00317/REP.

11. IEA Expert Group Study on Recommended Practices for Wind Turbine Testing and Evaluation. 4. Acoustics Measurement of Noise Emission from Wind Turbines. 3rd Edition 1994.

12. Statutory Order from the Ministry of the Environment No:304 of May 14, 1991 on Noise from Windmills, Ministry of the Environment, Denmark, National Agency of Environmental Protection.

13. Antoniou, I., Madsen, H.A., Paulsen, U.S. A Theoretical and Experimental Investigation of New Tip Shapes, European Community Wind Energy Conference, 8-12 March, 1993.

14. The World Health Organisation Environmental Health Criteria 12 - Noise: 1980

15. British Standards Institution 1984. Noise Control on Construction and Open Sites. Part 1 : Code of Practice for Basic Information and Procedures for Noise Control. BS 5228: Part 1.

16 British Standards Institution 1991. Description and Measurement of Environmental Noise. BS 7445: Parts 1-3.

17 British Standards Institution 1989. Noise Emitted by Computer and Business Equipment Part 1. Method of Measurement of Airborne Noise, BS 7135: Part 1.

18 The Commission of the European Communities Report EUR 5398 e: Environment and Quality of Life: Damage and Annoyance caused by Noise, 1975.

19 OECD Report: Reducing Noise in OECD Countries: 1978.

20 WHO Environmental Health Criteria Document on Community Noise, External Review Draft, 1993.

21 Danish National Agency of Environmental Protection, Guideline No 6, Measurement of Environmental Noise from Industry, The Joint Nordic Method for the Evaluation of Tones in Broadband Noise. 1984.

22, DIN 45 681. Detection of Tonal Components and Determination of Tone Adjustment for the Noise Assessment. Draft 1995.

23, The Welsh Affairs Committee, Second Report, Wind Energy. 1994, HMSO.

24. Porter, N.D., Acoustics Bulletin, Jan/Feb 1992, pp.11.

25, CSM Assiciates Ltd, Delabole Wind Farm Technical Performance Analysis, May 1993 - April 1994, ETSU W/32/00302/REP, 1995.

26, Porter, N.D., Final Results of the NPL Data Sheet Study on BS 4142: 1990, Proc. I.O.A. Vol 15, Part 8, pp.149-158, 1993.

27. Hoare Lea and Partners, Objective and Subjective Rating of Tonal Noise Radiated from UK Wind Farms (Part II), ETSU W/32/00228/55/REP, 1996 (in preparation).

28. Hoare Lea and Partners, Objective and Subjective Rating of Tonal Noise Radiated from UK Wind Farms (Part I), ETSU W/13/003 54/44/REP, 1996 (in preparation).

29. IEC. Wind Turbine Generator Systems - Part 10: Acoustic Noise Measurement Techniques. Committee Draft, 1995.

30. Pedersen, T.H., Methods for Evaluating the Prominence of Audible Tones in Noise. Lydteknisk Institut, 1988.

31. ISVR Consultancy Services, Noise Measurements in Windy Conditions, ETSU W/13/003 86/REP 1996.

32. Nelson. P.M., The Combination of Noise from Separate Time Varying Sources, Applied Acoustics (6), pp. 1-21, 1973.

11. GLOSSARY

Aerodynamic Noise

Noise emitted by **a** wind turbine due to the passage of air over the blades.

Background Noise

The ambient noise level already present within the environment in the absence of wind farm operation.

Blade Passing Frequency

The frequency at which the blades pass the tower ie three times rotational speed for three-bladed machine.

Blade Swish

The modulation of broadband noise at blade passing frequency.

CNEL (Community Noise Equivalent Level)

An Leq noise level with the 5dB penalty added to noise emitted between 1900 and 2200 hours and lOdB added to noise emitted at night between 2200 and 0700 hours.

Critical Bandwidth

A band with a prescribed frequency range centred around a tone.

Cut-in Wind Speed

The wind speed at which a turbine produces a net power output. This is usually at hub height wind speeds of 4-5 metres per second.

Downwind Rotor

Rotor which is positioned downwind of the turbine tower.

Free Field

An environment in which there are no reflective surfaces affecting measurements within the frequency region of interest.

Hertz (Hz)

The unit of frequency measurement representing cycles per second.

Hub

The centre of the rotor.

Hub Height Wind Speed

The wind speed at the hub height of the turbine or the centre of the rotor. Measurements made during turbine operation are corrected for the slowing down effect that an operational wind turbine has on the air.

Infrasound

Sound frequencies below the audible range ie below about 20 Hertz.

The dB(A) level exceeded N% of the time, eg L_{A90}, the dB(A) level exceeded 90% of the time, is commonly used to estimate background noise level.

Masking

The process by which threshold of audibility of one sound is raised by the presence of another (masking) sound.

Masking Level

A measure of the sound energy contained within a critical band.

Mechanical Noise

Noise emitted by a wind turbine from machinery usually within the nacelle.

Modulation

Periodic variation in phase, frequency or amplitude but most commonly in amplitude when associated with wind turbine noise.

Nacelle

Enclosure at the top of the tower usually housing gearbox and generator.

Pitch Regulation

The control of turbine output power by altering the angle of the turbine blades to the oncoming wind.

Rated Output

The maximum steady output power of the wind turbine.

Rating Level

The noise level, as measured by a defined method, after corrections have been made for any tonal content.

Rotor

Wind turbine blade assembly.

Sound

Energy that is transmitted by pressure waves in air or other materials and is the objective cause of the sensation of hearing. Commonly called noise if it is unwanted.

Sound Intensity

The rate of sound energy transmission per unit area in a specified direction.

Sound Level Meter

An electronic instrument for measuring the rms level of sound in accordance with an accepted national or international standard.

Sound Power

The total sound energy radiated by a source per unit time.

Sound Power Level

The fundamental measure of sound power. Defined as:

$$L_W = 10 \log \frac{P}{P_0} dB$$

where P is the rms value of sound power in watts, and P_0 is 1pW. (1×10^{-12}W).

Sound Pressure

A dynamic variation in atmospheric pressure. The pressure at a point in space minus the static pressure at that point.

Sound Pressure Level

The fundamental measure of sound pressure. Defined as:

$$L_p = 20 \log \frac{p}{P_0} dB$$

where p is the rms value (unless otherwise stated) of sound pressure in pascals and P_0 is $2 \times 10^{-5} N/m^2$ (20μPa) for measurements in air. When A-weighting is used, the sound level is given in dB(A).

Stall Regulation

The control of turbine output power by stalling the air flow over the turbine blade.

Standard Deviation

A quantitative measure of the spread of readings.

Tones/Tonal Noise

Noise containing a discrete frequency component most often of mechanical origin.

Audible Tone

A tone whose level is sufficiently above the broad band masking level such that it can just be heard by 50% of the population.

Upwind Rotor

Rotor which is positioned upwind of the turbine tower.

Wavelength

The distance measured perpendicular to the wave front in the direction of propagation between two successive points in the wave, which are separated by one period. Equals the ratio of the speed of sound in the medium to the fundamental frequency.

Wind Shear

A description of the increase in wind speed with height above ground level. Wind speeds measured at one height can be "corrected" to the value that would have been measured at another height using the expression:

$$V \wedge - 1 n \ (hi/z_0)/ln \ (h_2/z_0)$$

where V\ = wind speed (m/s) at a height of hj metres above ground level.
V2 = wind speed (m/s) at a height of h_2 metres above ground level.
$^{z}0$ $^{=}$ ground roughness length (m).

The ground roughness length can be calculated from wind speed measurements at two or more heights. Alternatively it can be estimated from Table 12.

Table 12 Roughness length for various types of terrain

Type of Terrain	**Roughness length zo**
Water areas, snow or sand surfaces	0.001m
Open, flat land, mown grass, bare soil	0.01m
Farmland with some vegetation	0.05m
Suburbs, towns, forests, many trees and bushes	0.30m

Table 13 Examples of wind shear calculations

zo (m)	VWVin	V_4n/V in	**Vm (m/s)**	**V™ (m/s)**	V40 **(m/s)**
0.01	1.16	1.20	4.17	4.83	5
0.01	1.16	1.20	8	9.28	9.6
0.05	1.21	1.26	3.96	4.80	5
0.05	1.21	1.26	8	9.68	10.08
0.30	1.31	1.40	3.57	4.68	5
0.30	1.31	1.40	8	10.48	11.2

10-Minute Average Wind Speed (m/s)

The wind speed measured by a calibrated cup anemometer at a specified height above ground level, averaged over a 10-minute period.

APPENDIX A

PRACTICE TO DATE IN CONTROLLING NOISE EMISSIONS FROM WIND GENERATORS BY REFERENCE TO PLANNING CONDITIONS AND COVENANTS IN PLANNING AGREEMENTS

Deli Farm, Delabole
(North Cornwall District Council)

A.l (a) The following conditions to regulate noise emissions were attached to a planning permission for the erection of ten wind turbine generators, issued by the Council on 1 August 1991:

1. Wind generators shall not commence productive operation at a wind speed of less than 5 metres per second at a hub height of 25 metres above ground level unless otherwise agreed by the Local Planning Authority.

2. Subject to the provisions of Condition 6 hereof the noise level expressed on a 10-minute L50 basis from the combined effect of the wind turbine generators as measured at any dwelling beyond a distance of 350 metres from any of the turbines shall not exceed 39dBA during low speed operation or 45dBA during high speed operation when measured over a ten minute period with a precision grade sound level meter of at least a type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface using a slow time weighted response, or if after the turbines commence operation variations to these limits are agreed in writing by the Planning and Development Officer (on the grounds that it would appear that no noise nuisance would be created at the varied levels) then such agreed variations shall be complied with.

3. The change over speed from low (32rpm) to high (48rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second at hub height (25 metres above ground).

4. The noise emitted from the wind turbine generators as heard at any dwelling shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses, such as to cause a nuisance to the occupiers of any dwelling beyond a distance of 350 metres from any of the wind turbine generators.

5. All practicable means shall be employed to the satisfaction of the Local Planning Authority in order to prevent and minimise the creation of any nuisance by noise emission during the erection, operation and use of the

wind turbine generators. "Practicable" shall have the meaning given to it by the Environmental Protection Act 1990.

6. Noise emitted from the turbines as measured on any point of the boundary of the permitted camp site Lower Pendavey which is shown hatched black on the approved location plan (and when measured over a ten minute period with a precision grade sound level meter of at least a Type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface using a slow time weighted response) shall not exceed the ambient L50 plus 5dBA.

All the above conditions were imposed for the following reason:

To ensure that noise emitted by the operation of the turbines does not have a detrimental effect on the amenities of a locality and, in particular, on the local residents living in the vicinity of the site.

In addition to the planning conditions the following covenants and agreements were made in a Planning Obligation (the clause numbering has been altered for this Report):

Covenants

1. Upon receiving notification from the Planning and Development Officer for the time being of the Council ("the Planning and Development Officer") that a nuisance or annoyance is in his reasonable opinion being caused to occupiers of dwellings beyond a distance of 300 metres from any of the turbines the Owners will as soon as reasonably practicable take all necessary steps to abate such nuisance or annoyance to the reasonable satisfaction of the Planning and Development Officer.

2. No turbines shall be erected on the site unless they are of the MS-3 (Refined) type at present manufactured and supplied by the Wind Energy Group Limited and strictly in accordance with the specification of the same annexed hereto or such other type as may be approved in writing by the Planning and Development Officer (such approval not to be unreasonably withheld).

3. No wind turbine generator shall be erected in a position which is closer than 350 metres from any dwelling existing at the date of this Agreement.

4. Before any of the turbines are brought into use the First Owner shall submit and obtain the written approval of the Planning and Development Officer (such approval not to be unreasonably withheld) for a scheme for the monitoring of noise emissions and background noise levels and for the keeping of records of such noise emissions and

background noise levels and thereafter the said records shall be kept in accordance with the said scheme and shall be made available at all reasonable times for inspection by the Planning and Development Officer and it is hereby agreed that in the event that a scheme is not approved in writing by the Planning and Development Officer within 28 days of such submission the question of whether the scheme is reasonable can be referred to arbitration in accordance with clause X hereof

They will comply with the following requirements relating to noise:

(i) except as provided by Clause 5 (iv) and subject to the provisions of Clause 7 (iv) hereof the L50 noise level resulting from the combined effect of the wind turbine generators as measured at any dwelling beyond the distance of 350 metres from any of the turbines shall not exceed 39dBA during low speed operation or 45dBA during high speed operation when measured in accordance with the method described in Clause 7 (i).

(ii) the noise emitted from the turbines as heard at any dwelling shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses such as to cause (in the reasonable opinion of the Planning and Development Officer) a nuisance to the occupiers of any such dwelling beyond a distance of 350 metres from any of the turbines within the area defined in Clause 5 (i).

(iii) all practicable means shall be employed to the reasonable satisfaction of the Planning and Development Officer in order to minimise the creation of any nuisance by noise emission during the erection, operation and use of the turbines. "Practicable" shall have the meaning given to it by section 79 of the Environmental Protection Act 1990.

(iv) noise emitted from the turbines and measured at any point on the boundary of the site with the property known as Lower Pendavey (for the purposes of identification only hatched black on the plan marked "B" annexed hereto) and when measured in accordance with the method described in Clause 7 (i) (during such time as the camping site on the said property may be operated under any planning permission or site licence which may at any time be implemented) shall not exceed the ambient L50 level plus 5dBA.

The owners will allow the Planning and Development Officer and his authorised representatives (being only employees or suitably qualified agents of the Council) to have such access as he or they require to the

Site at all reasonable times for the purposes of monitoring compliance by the Owners with their obligations herein.

Agreements

(i) The level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of a least a Type 1 quality) using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres away from any wall hedge or reflective surface (using a slow time weighted response).

(ii) If the turbines in operation on the Site shall be of the type referred to in Clause 2 measurements under this Agreement of noise levels at the slower speed of operation and the higher speed of operation of the turbines shall be made with average hub height wind speeds of 6 metres and 9 metres per second respectively.

(iii) If the turbines in operation on the Site shall be of a type other than that referred to in Clause 2 the scheme to be submitted under Clause 4 shall include proposals for an alternative basis of measurement to that described in Clause 7 (ii).

(iv) Following a reasonable period of operation of the turbines if upon representations by the First Owner the Planning and Development Officer is of the opinion that other levels of noise emission ("the Alternative Levels") than specified in Clause 5(i) and Clause 5(iv) would give rise to no nuisance to dwellings beyond a distance of 350 metres from any of the turbines the parties hereto shall conclude a Supplemental Agreement whereby the First Owner the Second Owner the Third Owner and the Fourth Owner shall jointly and severally covenant to comply with the Alternative Levels in place of the levels specified in the said Clauses.

(v) Clause X of this Agreement *{an arbitration provision)* shall apply to any disagreement between the First Owner and the Council arising under Clause 7 (iv) hereof.

(vi) For the purposes of this Agreement the change over speed from low (32rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second at hub height (25 metres above ground).

8. For the avoidance of doubt it is hereby agreed that this Agreement does not prevent the Council or the Owners or any of them from exercising any other powers or taking any legal proceedings under any other legislation including the Environment Protection Act 1990 in respect of any noise nuisance.

Cold Northcott
(North Cornwall District Council)

A.2 **(a)** The following conditions were attached to a planning permission issued by the Council on 12 February 1992 for the erection of 23 horizontal axis wind turbines:

1. The cut in wind speed for wind turbine generator operations shall not be less than 5 metres per second measured at hub height of 25 metres above ground level unless otherwise agreed with the Local Planning Authority.

2. The noise level expressed on a ten minute L50 basis from the cumulative site of the wind turbine generators as measured at any dwelling beyond a distance of 380 metres from any of the turbines shall not exceed levels of 40dB(A) during low speed operation or 45dBA during high speed operation when the ambient noise level at the location is not greater than 35dB(A) when measured in accordance with the following method: the level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of at least a Type 1 quality) using a half-inch diameter microphone in free field conditions 1.2 metres above ground level and at least 4 metres from any wall or other reflective surface (using a slow time weighted response). If after the Turbines commence operation variations to these limits are agreed in writing by the Planning and Development Officer (on the grounds that it would appear that no noise nuisance would be created at the varied levels) then such agreed variations shall be complied with.

3. Subject to the provisions of Condition 2 noise emitted from the Turbines as measured at any dwelling beyond 380 metres and when measured over a ten minute period with a precision grade sound level meter of at least a Type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 4 metres from any wall or other reflective surface using a slow time weighted response shall not exceed the ambient L50 plus 5dBA.

4. The change-over speed from low (32 rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second measured at hub height 25 metres above ground.

5. There shall be no audible tonal component to the noise emitted by the turbines so as to cause a nuisance to the occupiers of any dwelling

beyond a distance of 380 metres from any of the wind turbine generators.

6. The Best Practicable Means shall be employed to the satisfaction of the Local Planning Authority in order to prevent and minimise the creation of any nuisance by noise emission during the erection operation and use of the wind turbine generators "Best Practicable Means" shall have the meaning given to it by Section 79(9) of the Environmental Protection Act 1990.

All the above planning conditions were imposed for the following reason:

To ensure that noise emitted by the operation of the turbines does not have a detrimental effect on the amenities of the locality and in particular on the local residents living in the vicinity of the site.

In addition to the planning conditions the following covenants and agreements were made in a Section 106 TCPA 1990 Obligation (the clause numbering has been altered for this Report):

1. No turbines shall be erected on the Site until details and engineering specifications of the precise type of turbine have been agreed in writing by the Planning and Development Officer for the time being of the Council and thereafter no other type of turbines shall be erected unless it has been subsequently approved in writing by the Planning and Development Officer (such approval not to be unreasonably withheld).

2. No wind turbine generator shall be erected in a position which is closer than 380 metres from any dwelling existing at the date of this Agreement.

3. Before any of the Turbines are brought into use the Leaseholder shall submit and obtain the written approval of the Planning and Development Officer (such approval not to be unreasonably withheld) for a scheme for the measurement of machine noise emissions and for the keeping of records of such noise emissions and thereafter the said records shall be kept in accordance with the said scheme and shall be made available at all reasonable times for inspection by the Planning and Development Officer and it is hereby agreed that in the event that the scheme is not approved in writing by the Planning and Development Officer within 28 days of such submission the question of whether the scheme is reasonable can be referred to arbitration in accordance with Clause X hereof

4. To comply with the following requirements relating to noise:

   (i) Subject to the provisions of Clause 5(iv) hereof the L50 noise level resulting from the combined effect of the wind turbine generators as measured at any dwelling beyond a distance of 380 metres from any of the Turbines shall not exceed 40dB(A) during low speed operations or 45dB(A) during high speed operation when measured in accordance with the method described in Clause 5(i).

(ii) The noise emitted from the Turbines as heard at any such dwelling within the area defined in Clause 4(i) shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses such as to cause (in the reasonable opinion of the Planning and Development Officer) a nuisance to the occupiers of any such dwelling beyond a distance of 380 metres from any of the Turbines within the area defined in Clause 4(i).

(iii) The best practical means shall be employed to the reasonable satisfaction of the Planning and Development Officer in order to minimise the creation of any nuisance by noise emission during the erection operation and use of the turbines. "Best Practicable Means" shall have the meaning given to it by Section 79 (9) of the Environmental Protection Act 1990.

Agreement

5(i) The level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of at least a Type 1 quality) using a half inch diameter microphone in free field conditions 1.2 metres above ground and at least four metres from any wall, hedge or reflective surface (using a slow time weighted response).

5(ii) If the Turbines in operation on the Site shall be of a 2-speed type measurements under this Agreement of noise levels at the slowest speed of operation and the higher speed of operation of the Turbines shall be made with average hub height wind speeds of 6 metres and 9 metres per second respectively.

5(iii) If the Turbines in operation on the Site shall be of a type other than the 2-speed type the scheme to be submitted under Clause 3 shall include proposals for an alternative basis of measurement to that described in Clause 5(ii) to the satisfaction of the Planning and Development Officer.

5(iv) Following a reasonable period of operation of the Turbines if upon representations by the Owner and Leaseholder the Planning and Development Officer is of the opinion that other levels of noise emission ("the Alternative Levels") than specified in Clause 4(i) would give rise to no nuisance to dwellings beyond a distance of 380 metres from any of the Turbines the parties hereto shall conclude a Supplemental Agreement whereby the Owner covenants to comply with the Alternative Levels in place of the levels specified in the said Clauses.

5(v) Clause X of this Agreement *(an arbitration provision)* shall apply to any disagreement between the Owner and/or the Leaseholder and the Council arising under Clause 5(iv) hereof.

5(vi) For the purposes of this Agreement the changeover speed from low (32 rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second measured at hub height of 25 metres above ground.

Rhyd-y-Groes, Ynys Mon/Anglesey
(Cyngor Bwrdeistref Ynys Mon)

A.3 The following conditions relating to noise were attached to a planning permission issued by the Council on 2 November 1992 for the erection of 24 wind turbines:

1. No wind generator shall be erected in a position which is closer than 400 metres from any dwelling existing at the date of this permission.

2. The level of noise emissions referred to in condition 5 shall be measured over six periods of ten minutes within a total of one hour with a precision grade sound level meter (incorporating best current practice) using a half inch diameter microphone in free field conditions, 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a slow time weighted response).

3. In order to evaluate compliance with the level of noise emissions referred to in condition 5 background sound pressure level measurements shall be made:

   (a) during the hour before or the hour after the measurements referred to in condition 2 and

   (b) such background sound pressure level measurements shall be expressed on an L(a)eq index.

4. The measurements made in accordance with conditions 2 and 3 shall both be correlated with wind speeds measured at hub height over the same periods as described in condition 3.

5. When measured in accordance with the method described in condition 2 the level of noise emissions resulting from the combined effect of the wind generators as measured at any dwelling existing at the date of this permission beyond a distance of 400 metres from any of the turbines shall not exceed 40dBL(a)eq measured at 5 metres per second at hub height.

6. The level noise emitted by the combined effect of the wind generators (when measured and correlated in accordance with condition 2, 3 and 4) shall be demonstrated at the request of the Local Planning Authority on commissioning and thereafter every twelve months.

The reason given for the position of the above planning conditions is:

> To ensure that the development will be satisfactory from an amenity and architectural point of view

Penrhys, Rhondda
(Rhondda Borough Council)

A.4 The following condition was attached to a planning permission dated 2 April 1993 granted on appeal against the refusal of the Council to grant planning permission for the erection of 12 turbines:

"The level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling (in existence at the date of this letter) beyond a distance of 400 metres from any of the wind turbine generators shall not exceed 7.5dBL(A)90 above the background sound pressure levels measured in accordance with a method to be agreed by the planning authority."

Four Burrows, Cornwall
(Carrick District Council)

A.5 The following conditions relating to noise were imposed on the grant of planning permission dated 6 August 1993 on appeal against the refusal of the Council to grant planning permission for the erection of 15 wind turbine generators:

1. The level of noise emissions referred to in condition 4 shall be measured using the LA90 10 minutes level over a minimum of 6 consecutive periods of 10 minute with a precision grade sound level meter of at least type 1 quality, (incorporating best current practice), using a half inch diameter microphone in free field conditions, 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a slow time weighted response). The LA90 ten minute

level at a hub height wind speed of 5m/sec shall be derived using a linear regression of the measured noise levels.

2. In order to evaluate compliance with the level of noise emissions referred to in condition 4 background sound pressure level measurements shall be made: (a) during the hour before or the hour after the measurements referred to in condition 1; and (b) such background sound pressure measurements shall be made on an LA90 10 minute index.

3. The measurements made in accordance with conditions 1 and 2 shall both be correlated with wind speeds measured at hub height over the same periods as described in condition 1. The background noise level shall be derived for a hub height wind speed of 5m/sec by use of a linear regression undertaken upon the measured noise levels.

4. When measured in accordance with the method described in condition 1 the level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling existing at the date of this permission shall not exceed the following LA90 10 minute noise levels with the on-site measured wind speed of 5m/sec at hub height:

Four Burrows	42dB(A)
Four Burrows Farm	40dB(A)
Silver Valley	37dB(A)
Chybucca	37dB(A)
Causilgey	37dB(A)
Carvinack Brake	40dB(A)
Carvinack	37dB(A)
Creegmeor Farm	40dB(A)

5. The level of noise emitted by the combined effect of wind generators (when measured and correlated in accordance with conditions 1 to 3), shall be demonstrated at the request of the local planning authority on commissioning and thereafter every 12 months.

6. If the noise emissions resulting from the wind farm as measured at any residential property referred to in condition 4 contain a distinguishable tonal character as defined in "The Assessment of Audible Tones Second Draft, Carrick District Council", the noise limits specified in condition 4 shall be reduced by 5dB.

Bryn Titli, Powys
(Radnorshire District Council)

A.6 The following conditions relating to noise were imposed on the planning permission granted by the Council on 9 August 1993 to erect 22 wind turbines:

1. When measurements are made in accordance with the method described in condition 2 the level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling existing at the date of this permission beyond a distance of 400 metres from any of the turbines shall not exceed 40dB(A)Leq (5 minutes) at an on-site measured wind speed of 6 metres per second at hub height, or 5dB A above the Laeq (5 minutes) background as measured in accordance with condition 3 whichever is the greater.

2. The level of noise emissions, referred to in condition 1 shall be measured over 5 periods of five minutes within a total of one hour with a precision grade sound level meter of at least type one quality (incorporating best current practice) using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a fast time weighted response). The wind farm sound pressure measurements shall be recorded as LAeq 5 minute values.

3. In order to evaluate compliance with the level of noise emissions referred to in condition 1 background sound pressure level measurements shall be made:

   (a) Over 5 x 5 minute periods during the hour before or the hour after the measurements referred to in condition 2.

   (b) Such background sound pressure measurements shall be recorded as LAeq, 5 minute values.

   (c) Measurements of the LA90, 5 minute noise levels shall also be monitored throughout the measurement period to assist in the validation of the LAeq, 5 minute measurements.

4. The measurements made in accordance with conditions 2 and 3 shall both be correlated with wind speeds measured at hub height over the same periods as described in conditions 2 and 3. The target wind speed for the measurements shall be 6 metres per second. The data pairs shall be used to determine a best fit relationship between LAeq and hub height wind speed.

5. The level of noise emitted by the combined effect of the wind generators shall be demonstrated at the request of the Local Planning

Authority on commissioning. The tests shall be carried out in the vicinity of Dolhelfa Ganol or other relevant dwelling as may be agreed.

6. Tonal noise shall be measured for audibility using the methodology described in BS 7135: Part I Annex D (or equivalent) and shall be measured at a distance of not less than 550 metres from the nearest wind turbine.

7. The tonal (narrow band) spectrum shall be measured in accordance with condition 6 over a period 2 minutes between the frequencies of **0Hz** (Hertz) and 2kHz (Kilohertz) and with a maximum measurement bandwidth of 6.25Hz (Hertz).

8. If tonal noise from any of the wind turbines (when measured in accordance with conditions 6 and 7) exceeds the threshold of audibility by more than 8dB then the level of permissible noise emission referred to in condition 1 shall be reduced by 5dB.

The reason given for the imposition of the above planning conditions is:

In order to secure a satisfactory means of noise measurement to safeguard the residential amenity of local residents.

St Breock Downs, Wadebridge
(North Cornwall District Council)

A.7 The following conditions were imposed on the planning permission granted on 1 September 1993 on an appeal against the failure of the Council to determine a planning application for the erection of 11 wind turbines:

1. No wind turbine generators shall be erected in a position closer than 550m from any dwelling existing at the date of this permission.

2. No wind turbine generator shall start producing electricity at a wind speed of less than 5 metres per second measured at a hub height of 35 metres above ground level without the prior written approval of the local planning authority.

Trysglwyn Fawr, Amlwch, Ynys Mon/Anglesey
(Cyngor Bwrdeistref Ynys Mon)

A.8 The following conditions relating to noise were imposed on the grant of planning permission on appeal dated 10 December 1993 against the refusal of the Council to grant planning permission for the erection of 15 wind turbines:

1. No wind turbines shall be erected in a position which is less than 400 metres from any occupied dwelling existing at the date of this permission, except the participating properties of Trysglwyn Fawr and Taldrwst Mawr unless otherwise agreed in writing with the local planning authority.

2. The level of noise emissions resulting from the combined effect of the wind turbines hereby approved as measured at any dwelling existing at the date of this permission, except the participating properties Trysglwyn Fawr and Taldrwst Mawr, shall not exceed 40dB(A) L(A)eq 5 minutes at an on-site measured wind speed of 5 metres per second at hub height.

3. The level of noise emissions, referred to in condition 2, shall be measured in accordance with a noise monitoring scheme to be agreed in writing with the local planning authority.

4. If tonal noise from any of the turbines hereby permitted, when measured in accordance with condition 3, exceeds the threshold of audibility by more than 8dB then the level of permissable noise emission referred to in condition 2 shall be reduced by 5dB.

5. The level of noise emitted by the combined effect of the turbines hereby permitted shall be demonstrated at the request of the local planning authority on commissioning and annually thereafter in accordance with the noise monitoring scheme referred to in condition 3.

Carland Cross, Mitchell, Cornwall
(Carrick District Council)

A.9 No conditions relating to noise were imposed on the planning permission issued by the Council on 29 April 1992. Control over noise emissions is exercised through a Planning Obligation dated 29 April 1992 and the following covenants were given to the developer (the clause numbering has been altered for this Report):

1. No Turbines shall be erected on the site until the details and engineering specifications of the precise type of Turbine have been approved in writing (such approval not to be unreasonably withheld) by the Chief Planning Officer for the time being of the Council ("the Chief Planning

Officer") and thereafter no other type of Turbine shall be erected unless it has been approved in writing by the Chief Planning Officer (such approval not to be unreasonably withheld or delayed).

No Turbines shall be erected in a position which is closer than 350 metres from any dwelling existing at the date of this Agreement.

None of the Turbines shall be brought into use until:

(i) a scheme for the measurement of machine noise emissions and hub height wind speeds to operate for a period of two years from the date of the Turbines coming into use and for the keeping of records of such noise emissions and wind speeds ("the Scheme") is submitted for the approval of the Chief Planning Officer and

(ii) written approval to the Scheme is provided by the Chief Planning Officer (such approval not to be unreasonably withheld or delayed) and upon the Turbines being brought into use the Scheme as approved shall be implemented and the said records shall be kept in accordance with the Scheme and shall be made available at all reasonable times for inspection by the Chief Planning Officer.

(i) Subject to the provisions contained in clause 5(c) hereof the L90dB(A) noise level resulting from combined effect of the Turbines as measured within 10 metres of the facade at any dwelling at or beyond a distance of 350 metres from any of the Turbines shall not cause the prevailing background noise level to be increased by more than 7.5dB(A) when measured in accordance with the method described in clause 5 hereof; and

(ii) notwithstanding clause 4(i) above if the noise emitted from the Turbines as heard and measured at any such dwelling at or beyond a distance of 350 metres from any of the Turbines contains distinguishable discreet continuance (sic) notes or distinct impulses as specified in paragraph 7.2 of BS 4142 1990, then the noise from any of the turbines shall not cause the prevailing background noise level (L90dB(A)) to be increased by more than 2.5dB(A) when measured in accordance with the method described in clause 5 hereof.

(iii) (a) In the event that the noise levels specified in the sub-clauses 4(i) or 4(ii) above or both whichever apply are exceeded when measured in accordance with the method described in clause 5 the best practical means shall be employed to the reasonable satisfaction of the Chief Planning Officer in order to reduce within 14 days of the date of the completion of the said measurement or within such longer period as may be allowed by the Chief Planning Officer the noise emission to the levels specified in sub-clauses 4(i) or 4(ii) hereof or both whichever apply during the operation and use of the Turbines. "Best Practicable Means" shall have the meaning given to it by Section 79(9) of the Environmental Protection Act 1990.

(b) If at the expiry of the period specified in sub-clauses 4iii(a) above the noise levels specified in sub-clause 4(i) or 4(ii) or both whichever apply continue to be exceeded then the Owners and Leaseholder shall forthwith use whatever means are necessary to comply with sub clauses 4(i) or 4(ii) or both whichever apply.

5. (a) The L90dB(A) noise level emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter of at least Type 1 quality using a half inch diameter microphone calibrated in accordance with paragraph 4.1 and 4.2 of BS4142 1990 positioned in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall hedge or reflective surface using a fast time weighted response.

(b) The standard of measurement applied in this Agreement shall be as specified in paragraph 5.4.1 of BS4142 1990 with regard to prevailing weather conditions over the measurement period.

(c) The increase in the L90dB(A) background noise level referred to in this Agreement shall be determined as the difference of the noise levels measured in accordance with the method described in Clause 5(a) and 5(b) with the Turbines in operation and the Turbines stopped. The measurement period shall be consecutive where practicably possible and the average of 4 such measurements shall constitute a result.

Gonnhilly, Cornwall
(Kerrier District Council)

A.10 (a) The following condition relating to noise was attached to a planning permission issued by the Council on 7 December 1992 for the erection of 14 wind turbine generators:

"All practicable means shall be employed by the developer for preventing and minimising the emission of dust or smell or the creation of noise during the tipping of excavated material derived from carrying out the development hereby permitted".

In addition to the planning conditions the following covenants were given in a Planning Obligation (the clause numbering has been altered for this Report):

All practicable means shall be employed by the owner and/or the operator of the wind turbine generators for preventing and minimising the emission of dust, smoke and fumes and the creation of noise during the approved use of site. The word "practicable" and the phrase "practical means" in this Agreement shall have the meanings assigned to them in Section 79(9) of the Environmental Protection Act, 1990, as defined hereafter. The provisions of this paragraph include the installation of and maintenance of effective silencers on all plant and machinery.

Definition

Section 79(9) of the Environmental Protection Act, 1990:

"Practicable" means reasonably practicable having regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications; the means to be employed include the design, installation, maintenance and manner and periods of operation of plant and machinery, and the design, construction and maintenance of buildings and structures.

Each of the wind turbine generators the subject of this Agreement shall be erected within 10 metres of the positions shown on the submitted drawings and shall not be relocated from such positions without the prior written approval of the Council, such approval being within the absolute discretion of the Council.

Notwithstanding the provisions of Paragraph 2 of this Schedule no wind turbine generators shall be sited closer than 370 metres to any residential premises existing at the date of this Agreement, which the Owner shall identify on a 1:2500 scale plan to be submitted to the Council for approval within two months of the date of this Agreement.

No wind turbine generator shall commence productive operation at a wind speed of less than 5 metres per second at a hub height of 32 metres above existing ground level without the prior written approval of the Council.

If the noise emitted by the wind farm at any distance greater than 370 metres from an individual wind turbine generator contains:

(i) any distinguishable, discrete, continuous notes (whine, hiss, screech, hum or similar noise);

(ii) distinct impulses (bangs, clicks, clutters, thumps or similar noises);

(iii) a characteristic noise sufficiently irregular to attract attention;

an arbitrary reduction of 5dB(A) shall be applied to the noise limit defined in Paragraph 8 of this Schedule.

6. The Sound Power Level of any wind turbine generator during the approved use of the site calculated from measurements at 50 metres from that wind turbine generator by the method in the attached IEA booklet 4 "Acoustics Measurement of Noise Emission from Wind Turbines" shall not exceed a value of 99dBA for a hub height wind speed of 8.8 metres per second. Alternatively, if wind speed is available at a height of 10 metres then the corresponding wind speed is 8 metres per second. The calculation shall be made using at least 5 measurements over individual time periods of not more than 10 minutes, to be agreed in advance by the Council within a wind speed range of plus or minus 2 metres per second of the reference wind speed noted of either 8.8 or 8 metres per seconds respectively.

7. When measured in accordance with the method described in Paragraph 8 hereof the combined level of noise from all the wind turbine generators at any time shall not exceed 36dBA as measured at any dwelling existing at the date of the grant of the Planning Permission beyond a distance of 370 metres from any wind turbine generator.

8. The noise level shall be measured 1.2 metres above the ground at least 3.6 metres from any wall, hedge or reflective surface using a Precision grade sound level meter of Type 2 or better equipped with a **V2**" microphone. The measurement shall be made as LA90 for a time period of not more than 10 minutes, to be agreed in advance by the Council.

At least five measurement periods in the hub height wind speed range of 5 to 8 metres per second shall be used to provide a regression line for predicting the noise level at 5 metres per second.

The noise measurement may be carried out only when all wind turbine generators are operating and the wind speed in any measurement period is averaged over all the wind turbine generators if agreed in advance by the Council.

Llangwyryfon, Dyfed
(Cyngor Dosbarth Ceredigion)

A. **11** The following conditions relating to noise were attached to a planning permission issued by the Council in 1992 for the erection of 20 wind turbine generators:

1. At the critical wind speed (ie the speed at which the noise radiated by the total complement of wind turbines and blades is most substantially in excess of ambient noise) the noise from the wind park, as measured externally at any dwelling house, shall not exceed 45dB(A).

2. In the event of any noise complaint, investigated and judged by the authority to be justified, the developer will demonstrate that the best practical means are being, or will be, employed to limit and/or reduce noise emissions.

3. Notwithstanding conditions 1 and 2 above the basis for the reasonableness of a noise complaint shall be L50 plus 5dB(A) at the external wall of any dwelling house.

4. The developer will undertake measurements of noise levels during the first year of the operation of the wind turbines in a scheme to be agreed by the local planning authority to determine the characteristics of noise radiation. The data produced in accordance with the scheme shall be forwarded to the local planning authority on request.

The reason given for the imposition of the above planning conditions is:

To ensure a minimum level of noise disturbance.

APPENDIX B

PRACTICE TO DATE IN CONTROLLING NOISE EMISSIONS FROM WIND GENERATORS IN THE USA

Alameda County (Resolution Z-7500, February 1992)

- *No electric wind generator shall be located closer than 1000feet (304.8 metres) in an upwind (generally south-westerly to west-south-westerly) direction or closer than 300feet in any other direction from any existing dwelling or building site. These setbacks may be reduced by a maximum of 50% with the written, notarised and recorded concurrence of the affected property owner.*

- *The following procedures should be adhered to in the event of a reasonable complaint that noise levels from an operating wind turbine or windfarm exceed the levels described in the application, or that noise levels from a rebuilt wind turbine or windfarm exceed either 55dB(A)* ***(Ldn)*** *or 70dB**(C) (Ldn)** at the exterior of any dwelling unit within a minimum distance of 1000feet:*

  1. *A hearing shall be schedided between the Permittee and the Zoning Administrator*

  2. *A qualified firm shall be engaged to make a site-specific study and furnish a report and recommendation as to the Permittee's conformance with all applicable noise regulations.*

  3. *The permittee shall attempt in good faith to negotiate a resolution of this matter with the party making the allegation.*

  4. *Until the conclusion of the complaint proceedings, one fourth of the wind turbines authorised to be constructed and maintained in closest proximity to the dwelling or building site of the party making the allegation shall not be operated.*

- *Acoustic measurement and reporting procedures shall attain or exceed the minimum standards for precision described in AWEA First Tier standard. The Zoning Administrator, in consultation with the County Environmental Health Services, shall establish criteria for noise samples and measurement parameters (e.g., the duration of the data collection, time of day, wind speed, atmospheric conditions and direction) following the guidelines established by Wyle Research.*

Contra Costa County

In 1985, Contra Costa County adopted a WECS (Wind Energy Conversion System) ordinance as Chapter 88-3 of the County code. This ordinance can be summarised as follows:

- *According to Section 88-3.404, a WECS located on residential property may operate only between the hours of 08:00 Hrs and 1800 Hrs.*

- *According to Section 88-3.602, a minimum WECS setback of three times overall machine height (measured from grade to the top of the structure, including the uppermost extension of any blades) or 500feet, which ever is the greater, shall be maintained from exterior project boundaries. A minimum WECS setback of 1000feet shall be maintained from any existing legal off-site residence or General Plan designated residential areas.*

- *According to Section **88-3.**612, no WECS shall create noise which exceeds 65dB(A) **Leq** (over any averaging time), as measured at the lot line.*

Solano County

The *Wind Turbine Siting Plan & Environmental Impact Report,* prepared in 1987, found that:

- *Although the majority of the county was already at 50dB(A) CNEL or greater, a 50dB(A) CNEL standard for noise generated at neighbouring residencies was adopted as a standard for WECS to preserve compatibility with other General Plan criteria for stationary noise sources.*

- *A 47dB(A) Leq standard was established under the assumption that, under typical WECS operating conditions, it would be equivalent to a 50dB(A) CNEL (i.e. a wind turbine operating 50 % of the time, as is typical during the productive season in the Altamont area, would produce a CNEL about 3dB(A) higher than the 24-Hour average **Leq).***

- *Typical noise impact areas adjacent to WECS extend from 1000 {305 m} to 1800 {550 m} feet from the nearest wind turbines based upon standards described above. Actual setbacks are determined on a case-by-case basis, based on computer noise modelling for the specific turbine models and array patterns proposed.*

- *WECS developers must develop a noise monitoring program in co-operation with the County Division of Environmental Management and, if necessary, impose noise mitigations (eg revised spacing patterns of turbine).*

The final recommendations contained within the report are a compromise between all of the standards which have been adopted by the Tri-Counties.

The recommendations on noise are as follows:

Establish a consistent noise level standard for WECS near residencies. A noise level standard of 55dB(A) CNEL should be established, measured at existing residencies or potential residential development sites.

*This standard would be a compromise between Solano County's 50dB(A) CNEL (47dB(A) **Leq)** and Contra Costa County's 65dB(A) **Leq.***

The use of a 55dB(A) noise level standard would provide for a slight increase above ambient noise levels in many cases, but would not exceed state exposure standards for residential areas or significantly deteriorate the rural atmosphere of the wind resource areas, given the natural noise of the wind and other activity in the area. Wyle Research WR 88-19 provides that 60dB(A) may be appropriate, but a 55dB(A) standard should be considered in areas that were especially quiet prior to installation of wind turbines.

The **Ldn,** day-night average noise level, is a 24-hour average **Leq** with a 10dB(A) weighting added to noise which is emitted during the hours of 22:00-07:00 to account for the greater nocturnal sensitivity of people.

The CNEL (Community Noise Equivalent Level) allows a correction to be applied for increased sensitivity during the evening as well as the night. A 5dB penalty is applied for noise emitted during the 19:00-22:00 period.

If we compare these criteria levels in terms of 24-hour **Leq** then the table below details the relative levels:

Leq dB(A)	**Ldn** dB(A)	**CNEL** dB(A)
25	31.40	31.66
35	41.40	41.66
45	51.40	51.66

Riverside County

Resolution No. 93-378
Amending and Superseding Resolution No. 86-180
Adopting Technical Specifications and Criteria for the Measurement and Projection of Noise from Commercial WECS Projects.

The County of Riverside is within the state of California. On the 5th October 1993 the above resolution was passed concerning the development of wind turbines and the assessment of noise that they radiate. This resolution covers the testing and assessment of the noise that is emitted by wind turbines, and proposes a method for the determination of the noise levels that may be expected from the development of a wind farm.

Included within the resolution are the following definitions:

a) *Observed representative noise level: the measured noise level excluding pseudo-noise, wind noise, vegetation noise and transient noise events from sources other than the subject noise source.*

b) *Pseudo-noise: the noise perceived by the microphone and originating from the air flow turbulence around the diaphragm of the microphone.*

c) *Vegetation noise: the noise resulting from the rattling of leaves and other vegetation excited by the wind.*

d) *Wind noise: the noise of the wind itself originating from turbulence in the air.*

Recommendations are made for the measurement of the emitted noise from the wind turbines. However, these follow neither the guidance that is given within the IEA method of turbine evaluation nor the Danish Statutory Order, measurements being performed at a height above ground level of 5'. This compares with the ground board measurement method that is used for the determination of the sound power level of a wind turbine within the IEA and Danish Statutory Order.

Measurements are required of the L_{A90}, L_{A50} and L_{Aeq} noise levels using a slow time weighting. The procedure for determining the A-weighted noise level from the turbine considers the measured L_{A90} noise levels to determine the signal to noise ratio of the measured noise. This allows any corrections to be assessed and applied to the measured noise if the background noise level at the measurement position is near that of the wind turbine when it is operating. It is proposed within the resolution that if the turbine noise level is greater than 10dB above the background noise level then no correction need be applied. If the noise level is between 3dB and 10dB above the background noise level when the wind turbine is not operating then the intensity subtraction should be used. This method is outlined within BS 4142 for the correction of measured noise levels when performing an assessment. When the measured noise level from the turbine is not more than 3dB above the background noise level then cross-correlation techniques should be used. However, it is also stressed that this procedure is not preferred and will not be accepted if other procedures are feasible.

Measurements are also required to determine the directivity of the emitted noise from the wind turbines. This requires that measurements are made at the four positions around the wind turbine and are correlated with the downwind measurement position.

To assess the tonal characteristics of the wind turbines, one-third octave noise measurements are also required. These measurements are required to cover the frequency bands from 20 Hz up to at least 8000 Hz. These measurements are to be performed for an operating condition of an average power output of 30 % ± 15 % of the maximum rated power of the wind turbine.

Noise measurements of the wind turbine are required to cover three operating conditions. These are defined as low (20 % ± 5 % of maximum rated power {MRP}), medium (50 % ± 10 % MRP) and high (90 % ± 10 % MRP) wind speed conditions. However, although a minimum measurement period of 30 minutes is proposed there is no attempt to correlate the measured wind speed with the measured noise level. Therefore, the measurements would appear to be an attempt to obtain an indicative noise level rather than a precise measurement of the emitted noise from the wind turbine.

Measurements are also proposed to determine the reference level of the wind turbine noise at a distance of 400' downwind of the wind turbine. These measurements are to be made when the low wind speed conditions are prevailing. It is then proposed to use the near-turbine noise measurements to predict the noise level from the wind turbine at the high wind speed condition. It is this level that is then used to determine the maximum noise level from the wind farm. These noise levels are determined by the use of the LAPO noise level that has been measured.

The County proposes to use this data to determine the noise level from the proposed wind farm development at the high wind speed condition. This is because the noise limits that are proposed for Riverside County are set as not to be exceeded noise levels. The prediction of the noise levels by the County will be used for the granting of permits to build. However, a measurement methodology is proposed for the assessment of a working wind farm where measurements of the LA90 noise level should be performed for a minimum of 30 minutes. The noise criteria are set out as follows:

TECHNICAL SPECIFICATIONS AND CRITERIA FOR SUBSTANTIAL CONFORMANCE

For windfarms with an original residential noise limit of 50 or more dB(A), the replacement WECS shall resxdt in substantially fewer potential cumulative noise impacts as projected at the nearest residence on land designated residential in December, 1985 version of the Western Coachella Valley Plan (WCVP).

For wind farms with an original residential noise limit of 45 or less dB(A), the replacement WECS shall result in the same or substantially fewer potential cumulative noise impacts as projected to the nearest residence regardless of the underlying WCVP designation. "Same or substantially fewer potential cumulative noise impacts" shall be defined as follows:

A NON-MEASUREMENT METHOD

To elect this method the project shall comply with the following criteria:

a) The foundation of each replacement WECS including tower shall be topographically elevated above the nearest appropriate residence less than the height specified in Table A.

b) More than half of the permitted turbines shall be removed.

c) The permitted noise level for the original WECS permit shall not be less than 60dB(A)

d) The replacement WECS shall not exceed a maximum power output of500kW. The maximum rated power output of each replacement WECS shall be provided along with tower height, total height, hub height and rotor diameter.

e) Minimum distance (as measured from the nearest WECS to nearest appropriate residence), associated maximum number of turbines and associated maximum height of WECS above the nearest appropriate residence shall conform to Table A

Table A		
Minimum Distance in feet	*Maximum Number of Turbines*	*Maximum Height (topographical) in feet*
2,000	*10**	*100*
3,000	*25**	*125*
4,000	*50**	*150*
5,000	*110**	*175*
6,000	*200**	*200*

** Can be increased (based upon the reference noise value of 70dB(A)$_t$ includes 5dB(A) pure tone penalty at a slant distance of 150 feet per turbine), if noise level of the array of turbines projected (use model specified in Section 2.C. hereof with atmospheric absorption loss of ldB(A) per 1,000feet) to nearest appropriate residence does not exceed 55dB(A).*

B MEASUREMENT METHOD

The measurement for each replacement and remaining WECS shall be made in accordance with Section 2. hereof in terms of L_A9o at 90% of rated power, or in accordance with the latest committee's approved version of AWEA - "Standard Procedure for Measurement of Acoustic Emissions from Wind Energy Conversion Systems" reporting the reference noise in terms of LAeq (-2dB for ground reflection) at wind velocity of 10 metres per second.

a) A-Weighted Criteria

Using the replacement and remaining WECS noise reference data for single wind turbines the modelling for projected noise levels from commercial WECS shall be done in accordance with Section 2. hereof with reference noise levels adjusted to 100 metres slant distance. Pure tone shall be defined as specified in Ordnance No. 348, Subsection d(12) of Section 18.41, **a.2.**

The new noise limit shall be the greater of one of the following:

a. No more than that allowed by present County ordinance (45dB(A) and pure tone criteria), or

b. 5dB(A) below original noise limit or latest substantial conformance noise limit, and

if WECS exhibit pure tone , a 5dB(A) penalty shall apply, and

if replacement WECS are at a greater height (topographically) above the nearest appropriate residence than specified in Table A, a 5dB(A) penalty shall apply, and

if less than four WECS are available for field verification, a 5dB(A) penalty shall apply.

b) Low Frequency Noise Criteria

The projected cumulative low frequency noise to the nearest appropriate residence shall not exceed the following criteria using the model specified in B deleting those sections on atmospheric attenuation loss.

The PC weighted level (as designated in "A Proposed Metric for Assessing Potential of Community Annoyance from Wind Turbine, Low Frequency Noise Emissions" SERI November 1987) of 75dB for non-impulsive and 67dB for impulsive sources representing annoyance thresholds shall be the criteria.

To determine the "PC Weighted" level at the interior of the building, steps 1 through 4 shall be adhered to as outlined in the above test under the heading of "Suggested procedure for estimating the interior LF annoyance potential of a given turbine design " and in addition, a 5dB penalty shall be added to the results of step 4.

Kern County, California

Kern County has a number of wind farms within its district. Noise has been addressed within Section 16.64.140 of the County Ordinance. It reads as follows:

J Where a residence , school, church, public library or other sensitive or highly sensitive land use, as identified in the noise element of the county general plan, is located within one (1) mile in a prevailing downwind direction or within one-half (½) mile in any other direction of a project's exterior boundary, an acoustical analysis shall be prepared by a qualified acoustical consultant prior to the issuance of any building permit. The consultant and the resulting report shall be subject to review and approval by the county health department. The report shall address any potential impacts on sensitive or highly sensitive land uses.

In addition, the acoustical report shall demonstrate that the proposed development shall comply with the following criteria:

1. *Audible noise due to wind turbine operation shall not be created which causes the exterior noise level to exceed forty-five (45) dB(A) for more than five (5) minutes out of any one (1) hour time period (LSJ) or to exceed fifty (50) dB(A) for any period of time when measured within fifty (50) feet of any existing residence, school, hospital, church or public library.*

2. *Low frequency noise or infrasound from wind turbine operations shall not be created which causes the exterior noise level to exceed the following limits when measured within fifty (50) feet of any existing residence, school, hospital, church or public library.*

One-third Octave Band Centre Frequency (Hz)	*Sound Pressure Level (dB)*
2 to 16	*70 (each band)*
20	*68*
25	*67*
31.5	*65*
40	*62*
50	*60*
63	*57*
80	*55*
100	*52*
125	*50*

3. *In the event audible noise due to wind turbine operations contains a steady pure tone, such as a whine, screech or hum, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by five (5) dB(A). A pure tone is defined to exist if the one-third octave band sound pressure level in the band\ including the tone, exceeds the arithmetic average of the sound pressure levels of the two (2) contiguous one-third octave bands by five (5) dB(A) for centre frequencies offive hundred (500) Hz and above, by eight (8) dB(A) for centre frequencies between one hundred sixty (160) Hz andfour hundred (400) Hz, or by fifteen (15) dB(A) for centre frequencies less than or equal to one hundred twenty-five (125) Hz.*

4. *In the event the audible noise due to wind turbine operations contains repetitive impulsive sounds, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by five (5) dB(A).*

5. *In the event the audible noise due to wind turbine operations contains both pure tone and repetitive impulsive sounds, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by a total of five (5) dB(A).*

6. *In the event the ambient noise level (exclusive of the development in question) exceeds one (1) of the standards given above, the applicable standard shall be adjusted so as to equal the ambient noise level For audible noise, the ambient noise level shall be expressed in terms of the highest whole number sound pressure level in dB(A) which is exceeded for no more than five (5) minutes per hour (.Ls.3). For low-frequency noise or infrasound, the ambient noise level shall be expressed in terms of the equivalent level* ***(Leq)*** *for the one-third octave band in question, rounded to the nearest whole decibel. Ambient noise levels shall be measured within fifty (50) feet ofpotentially affected existing residences, schools, hospitals, churches or public libraries. Ambient noise level measurement techniques shall employ all practical means of reducing the effects of wind-generated noise at the microphone. Ambient noise level measurements may be performed when wind velocities at the proposed project site are sufficient to allow wind turbine operation, provided that the wind velocity does not exceed thirty (30) mph at the ambient noise measurement location.*

7. *Any noise level falling between two (2) whole decibels shall be the lower of the two.*

APPENDIX C

BACKGROUND NOISE

This appendix presents results from a background noise survey and discusses the issues involved in obtaining reliable data.

Fig A1 details a time history of measurements performed at a dwelling neighbouring a proposed wind farm site, these measurements undertaken using a 5-minute time period. Wind speed measurements were also measured in 5-minute periods at an anemometer position approximately 400 metres from the dwelling. Measurements were performed over 10 days. During this time the wind blew from the south, west and north.

Fig A2 details the wind speed and direction data that were collected. The dwelling was situated to the north and east of the proposed wind turbines. Therefore, during the survey period the wind direction was such that the worst-case propagation conditions would be expected from the turbines towards the dwelling.

Fig A3 details the regression analysis performed upon all the measured data, with rainfall removed, to derive the prevailing background noise level at the measurement position. The wind speed data have been corrected to provide the expected hub height wind speed for the proposed wind turbines that were to be installed. It will be noted that a high order polynomial has been used to derive the prevailing background noise level. Care must be used when deriving the prevailing background noise level at the extremes of the data, ie at the low and high speed ends of the curve. It may be seen from Figure 3 that at very low wind speeds the derived line is increasing with decreasing wind speed. An alternative to a polynomial is a log curve of the form

$$L_{pb} = 10 \log (10^{A/10} + 10^{(B+C \log V)/10})$$

where L_{pb} = background noise level as a function of wind speed, dB(A)
A = constant equal to the background noise present with no wind, dB(A)
B and C = constants describing the contribution to the background noise from wind induced sources.
V = wind speed at turbine hub-height, m/s.

This curve has been derived by assuming the background noise is made up of a fixed level which does not vary with wind speed plus a contribution from wind-induced sources whose sound power varies with V^x. Curves of this form have the advantage that they tend to predict reliable levels for wind speeds at which no experimental data have been obtained.

Fig A4 details the spread of the measured data around the derived prevailing background noise level. It may be seen that the spread indicates a normal distribution around the line. It may also be seen from this Figure that the derived prevailing background noise level is 5dB higher than the measured background noise level for about 9% of the measurements. If the allowable turbine noise level above the background noise level were 5dB and it is assumed the turbine noise is constant, then it would be expected that for 9% of the operating period of the wind farm, wind turbine noise levels may exceed the prevailing background noise levels by lOdB or more.

Fig A5 details the regression analysis performed for the data collected during the evening and night-time periods. It may be seen that a lower correlation exists for this data than that derived for the all data regression line shown in Fig A3.

Fig A6 details the spread of the measured data around the derived regression line. Again, it may be seen that the derived prevailing background noise level is 5dB higher than the measured background noise level for about 9% of the time.

Fig A7 details the regression analysis performed upon the evening and night-time noise data when the wind was blowing from the development towards the dwelling, a south-westerly wind. This would be the wind direction from which the maximum noise impact from the proposed site may be expected to occur because the dwelling would be downwind of the development, although comparison with the curve for all directions shows the background noise levels to be about 2dB greater when the wind is in this direction than on average. The correlation between the measured background noise levels and the measured wind speed has greatly improved and there is a significant reduction in the scatter of the noise data around the derived line.

Fig A8 details the spread of the measured data around the derived regression line. It may be seen that the spread is greatly reduced. Furthermore, it may be seen that the derived prevailing background noise level is 5dB higher than the measured background noise level for less than 1% of the time. If an allowable turbine noise level is set at 5dB above the derived prevailing background noise level, then it should be expected that the actual background noise level will be exceeded by lOdB or more for less than 1% of the operating time at the most sensitive operating condition, ie approximately 5 minutes in every 8 hours for the critical wind speed.

The example that has been given in Figs A1 to A8 is for a dwelling that does not have any significant noise sources from sources not associated with the wind. (It may be noted that a single high L_{A90} noise level is plotted within Figs A3 and A5. This was most likely due to the running of an engine within the farmyard which was adjacent to the measurement position.) Steady sources like water were not audible at this position. Such sources can significantly change the scatter of the measured data.

Figs A9 and A10 detail the regression analysis for a dwelling positioned close to a water source. It may be seen that a significant proportion of the measurements are centred around 33-35dB L_{A90}. Fig A10 detailing the spread of the measured data around the derived prevailing background noise level indicates that measured data never fall below the derived prevailing background by more than 4dB. However, the figure also indicates that a criterion of + 5dB upon the prevailing background noise level will result in the background noise level being exceeded by 8dB or more for 30% of the operating period.

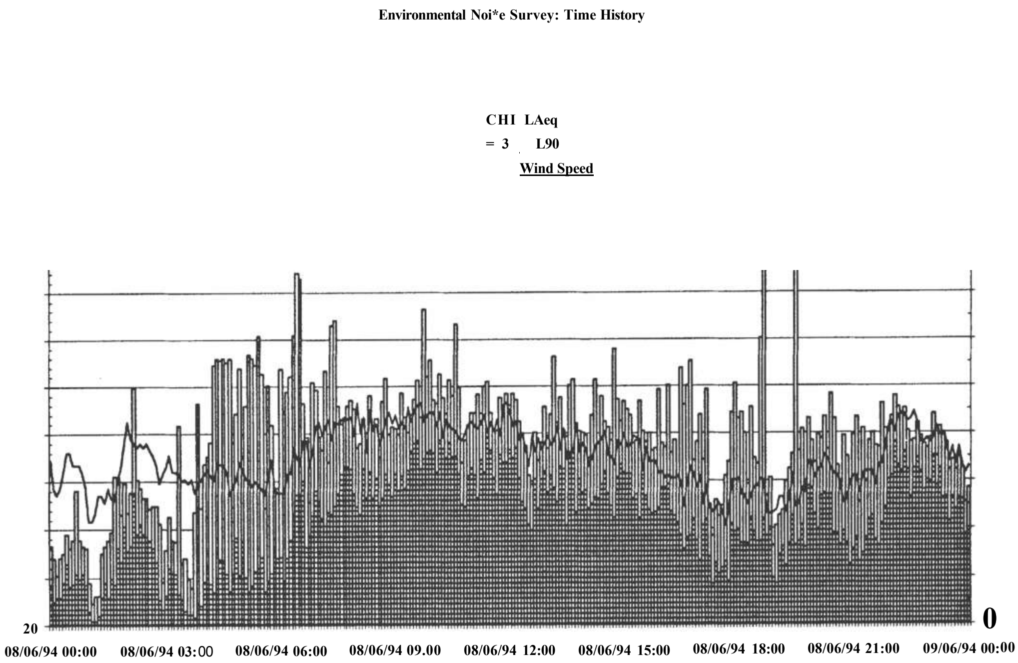


Figure A1 Typical time history measurements: single day shown only

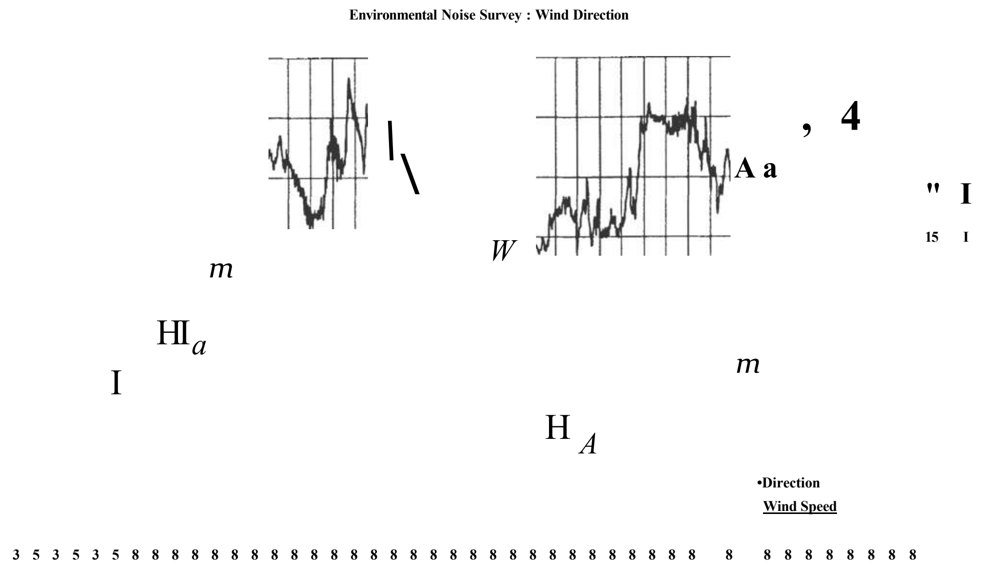


Figure A2 Typical time history of measured wind data from anemometer before site construction

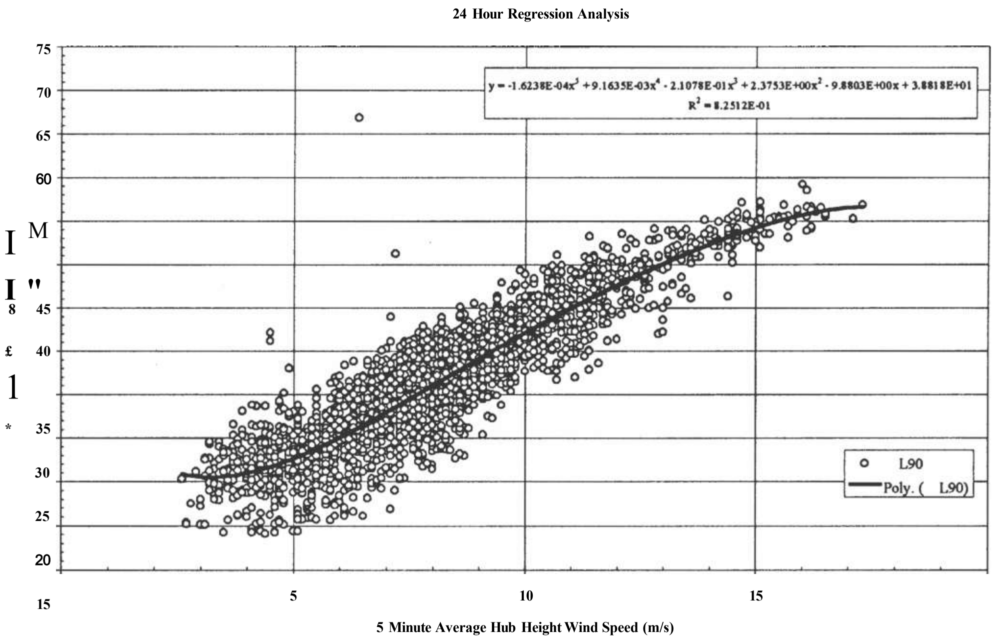


Figure A3 Regression analysis of all measured wind speed and noise data to determine the prevailing background noise level

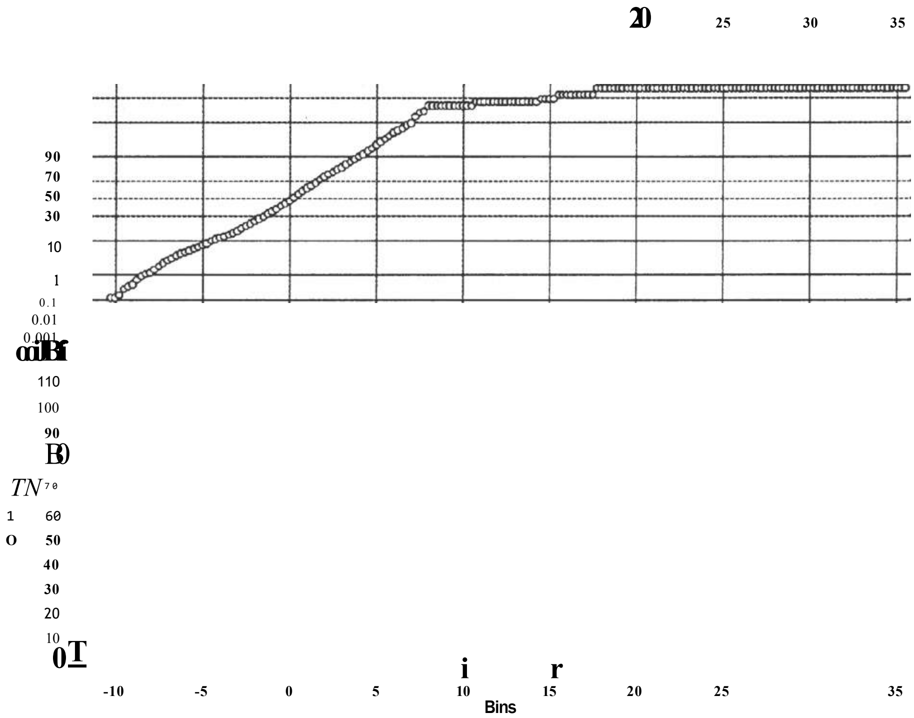


Figure A10 Deviation of measured levels around derived regression line plotted in Figure A9

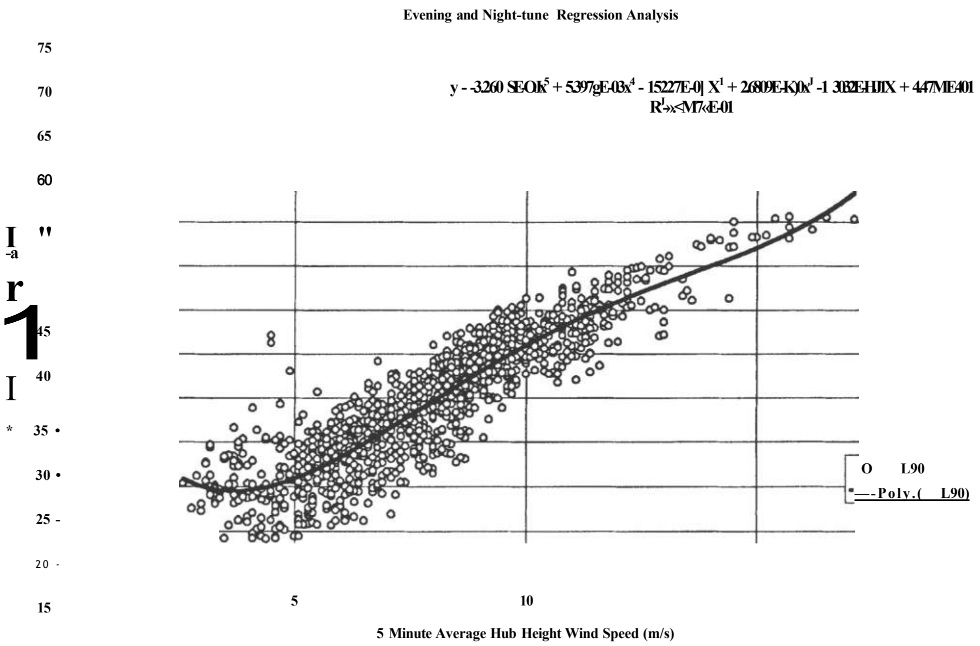


Figure A5 Regression analysis of evening and night-time measured wind speed and noise data to determine the prevailing evening and night-time background noise level

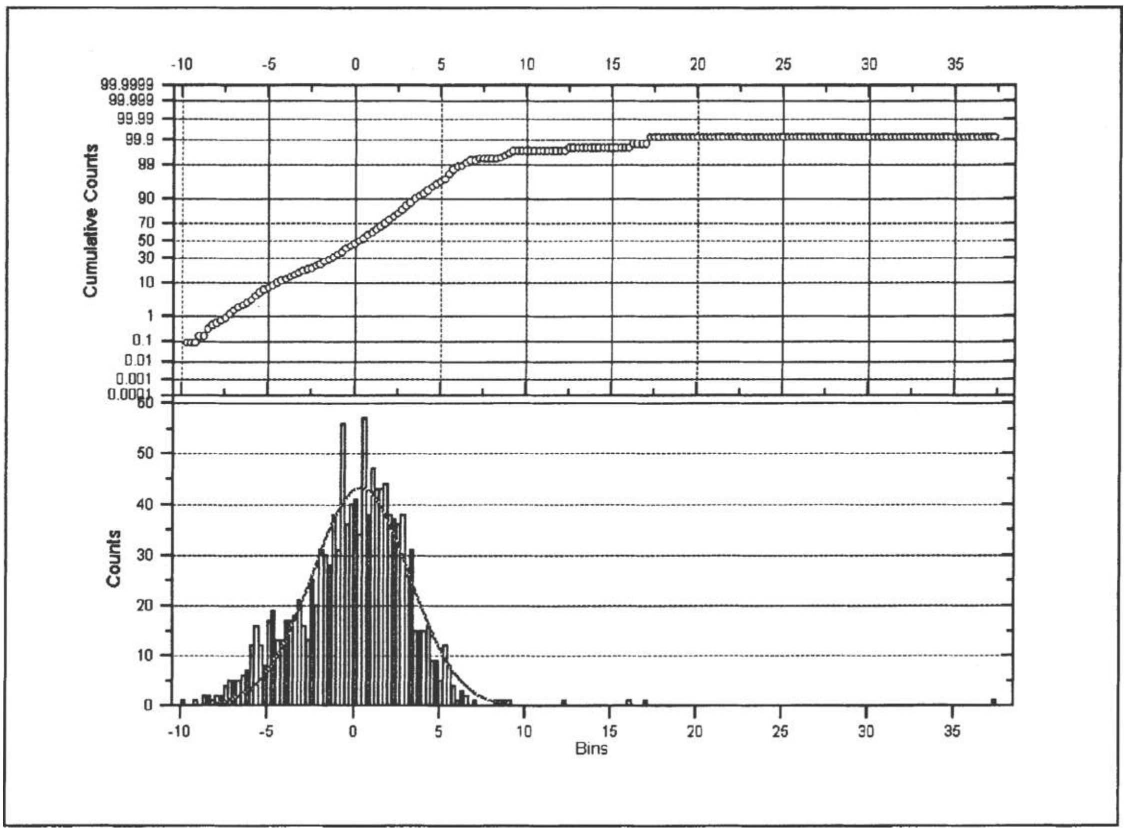


Figure A10 Deviation of measured levels around derived regression line plotted in Figure A9

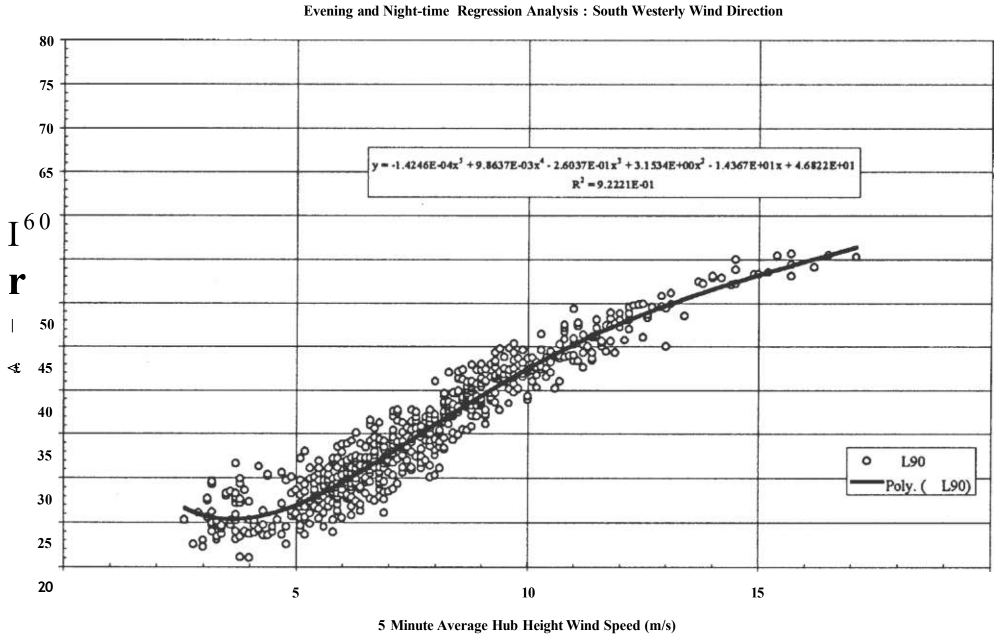


Figure A7 Regression analysis of all measured wind speed and noise data for south-westerly wind direction to determine the prevailing background noise level

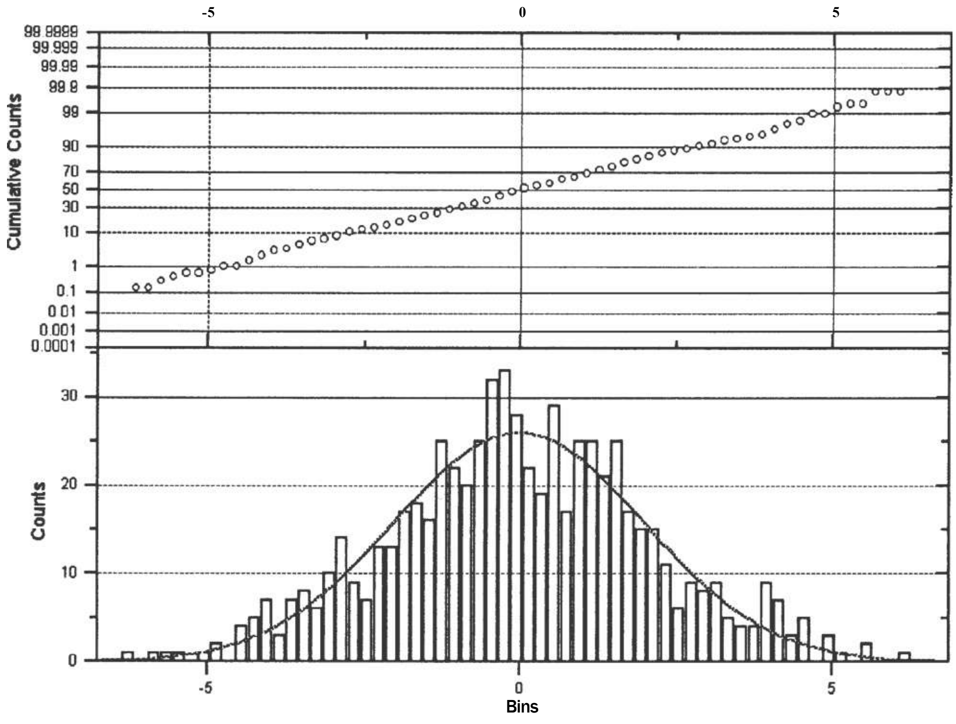


Figure A8 Deviation of measured levels around derived regression line plotted in Figure A7

Figure A9 Regression analysis of evening and night-time wind speed and noise data to determine the prevailing evening and night-time background noise level

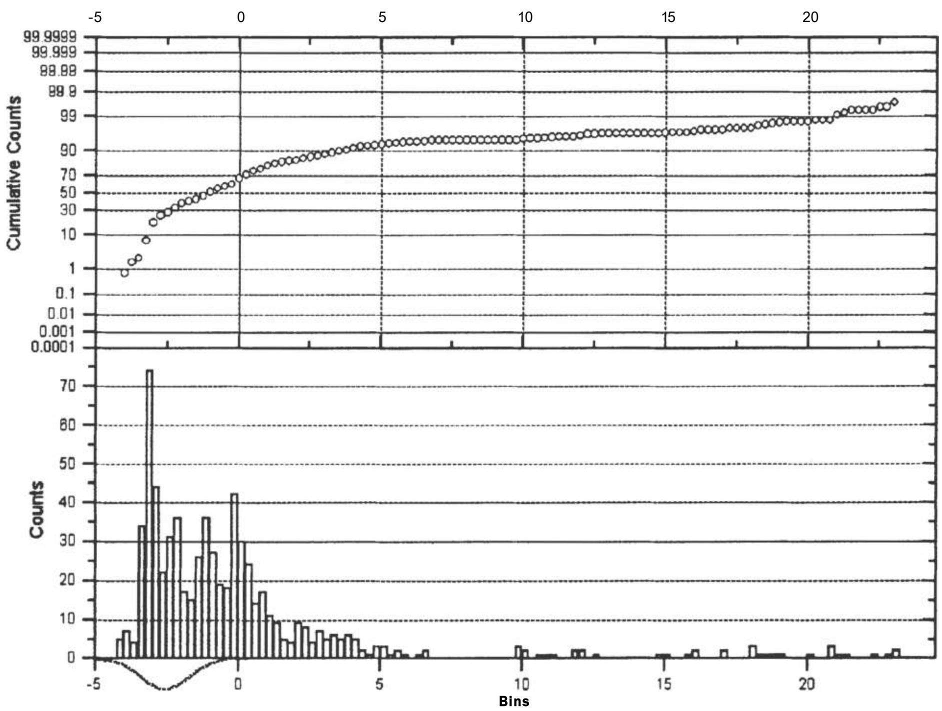


Figure A10 Deviation of measured levels around derived regression line plotted in Figure A9

FURTHER INFORMATION

Information on any area of the New and Renewable Energy Programme is available from:

New and Renewable Energy
Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 ORA

Telephone: 01235 432450/433601
Facsimile: 01235 433066

ITSY

for the

dti

IJepan*>l Þi(k« ami Jndusln