Update of UK Shadow Flicker Evidence Base

Department of Energy and Climate Change

Update of UK Shadow Flicker Evidence Base

Final Report

Prepared for
Department of Energy and Climate Change
Area 4B
3 Whitehall Place
London
SW1A 2HD

Prepared by
Parsons Brinckerhoff
Amber Court
William Armstrong Drive
Newcastle Upon Tyne
NE4 7YQ

CONTENTS

EXECUTIVE SUMMARY

The term 'shadow flicker' refers to the flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties as they turn, through constrained openings such as windows. The magnitude of the shadow flicker varies both spatially and temporally and depends on a number of environmental conditions coinciding at any particular point in time, including, the position and height of the sun, wind speed, direction, cloudiness, and position of the turbine to a sensitive receptor.

Planning guidance in the UK requires developers to investigate the impact of shadow flicker, but does not specify methodologies.

To enable the Department of Energy and Climate Change to advance current understanding of the shadow flicker effect, this report details the findings of an investigation into the phenomenon of shadow flicker. This report presents an update of the evidence base which has been produced by carrying out a thorough review of international guidance on shadow flicker, an academic literature review and by investigating current assessment methodologies employed by developers and case study evidence. Consultation (by means of a questionnaire) was carried out with stakeholders in the UK onshore wind farm industry including developers, consultants and Local Planning Authorities (LPAs). This exercise was used to gauge their opinion and operational experience with shadow flicker, current guidance and the mitigation strategies that can and have been implemented.

All of the data collated was analysed and a number of conclusions were drawn. The current recommendation in Companion Guide to PPS22 (2004) to assess shadow flicker impacts within 130 degrees either side of north is considered acceptable, as is the 10 rotor diameter distance from the nearest property. It is acknowledged that this is a 'one size fits all' approach that may not be suitable depending on the latitude of the site.

It has become clear that there is no standard methodology that all developers employ when introducing environmental and site specific data into shadow flicker assessments. The three key computer models used by the industry are WindPro, WindFarm and Windfarmer. It has been shown that the outputs of these packages do not have significant differences between them. All computer model assessment methods use a 'worst case scenario' approach and don't consider 'realistic' factors such as wind speed and cloud cover which can reduce the duration of the shadow flicker impact.

On health effects and nuisance of the shadow flicker effect, it is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health. Mitigation measures which have been employed to operational wind farms such as turbine shut down strategies, have proved very successful, to the extent that shadow flicker can not be considered to be a major issue in the UK.

1 INTRODUCTION

The term 'shadow flicker' refers to the flickering effect caused when rotating wind turbine blades periodically cast a shadow over neighbouring properties as they turn, through constrained openings such as windows. The magnitude of the shadow flicker effect varies both spatially and temporally, and depends on a number of environmental conditions coinciding at any particular point in time, including, the position and height of the sun, wind speed and direction, cloudiness, and proximity of the turbine to a sensitive receptor.

Planning guidance in the UK (Companion Guide to PPS22, PAN45, Best Practice Guidance to PPS18 and the Welsh Planning Guidelines) requires developers to investigate the impact of shadow flicker, but does not specify methodologies.

To enable DECC to advance current understanding of the shadow flicker effect; this report details the findings of an investigation into the phenomenon of shadow flicker. In this report, Parsons Brinckerhoff (PB) update the evidence base by providing a review of planning guidance on shadow flicker from across the world, academic literature on the subject of shadow flicker, and has investigated assessment methodologies and case study evidence. Parsons Brinckerhoff has also consulted with stakeholders in the industry – both developers and local planning authorities (LPAs) through a questionnaire to gauge their opinion and operational experience with regard to shadow flicker, current guidance and the mitigation strategies that can be implemented.

Following this introduction (**Section 1**), the report is structured in six key sections:

- **Section 2** provides a review of guidance on shadow flicker from countries across the world.
- **Section 3** is an academic literature review, investigating the current understanding of the phenomenon.
- **Section 4** examines software models which are available to allow the assessment of shadow flicker on proposed developments.
- **Section 5** includes information from the respondents to the questionnaires which were sent to developers and planning authorities.
- **Section 6** collates information from the preceding four sections and provides a discussion of ten key themes and issues that were identified during the study.
- **Section 7** provides conclusions.

This report focuses solely on shadow flicker effect caused by large scale onshore (approximately 500kW upwards) wind turbines and does not consider the distinct shadow flicker conditions and impacts that are related to shadow flicker from small and micro scale (also known as 'domestic' scale, 0.3-10 kW) wind turbines.

Another distinct phenomenon that is often confused with 'shadow flicker effect' is that of 'strobe effect'. Strobe effect refers to the flashing of reflected light which can be visible from some distance. This phenomenon has largely been ameliorated by the development of an industry standard (light grey semi-matt) for the colour and surface finish of turbine blades, as proposed by the ETSU (1999) study and the Companion Guide to PPS22 (2004). As a point of clarity, PB has disregarded the 'strobe effect' phenomenon from this study.

Throughout this report, we have included relevant quotations taken from our questionnaire responses. Whilst these are used in context, these quotations do not necessarily represent the views of Parsons Brinckerhoff or DECC and are the opinions of the questionnaire respondent. Please bear this in mind when reading the report.

2 CURRENT GUIDANCE

2.1 Introduction

This section reviews available guidance and policy literature relating to the shadow flicker phenomenon. This section is split into:

- Section 2.2 – United Kingdom Guidance
- Section 2.3 – International Guidance
- Section 2.4 – Non-governmental Organisation Guidance

For each country, relevant shadow flicker literature is detailed. For each guidance / policy document, the following information is included:

- Publication details – eg. report title, institution / author name, date, etc;
- A short synopsis detailing the salient issues raised and mitigation measures proposed;
- Extracts of the relevant text from the original document.

For the international guidance, the following European countries with an installed onshore wind energy capacity of greater than 100 megawatts (EWEA, 2010) were short listed and each country's national wind energy association was contacted for information on country specific shadow flicker guidance or regulatory policy.

Austria	Finland	Italy
Belgium	France	Netherlands
Bulgaria	Germany	Poland
Czech Republic	Greece	Portugal
Denmark	Hungary	Spain
Estonia	Ireland	Sweden

2.2 United Kingdom Guidance

2.2.1 England

2.2.1.1 Planning for Renewable Energy – A Companion Guide to PPS22 Office of the Deputy Prime Minister (2004)

Synopsis

Companion Guide to PPS22 makes the following statements:

- Shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening;
- Only properties within 130 degrees either side of north of the turbines can be affected at UK latitudes;
- Shadow flicker has been proven to occur only within ten rotor diameters of a turbine position;
- Less than 5% of photo-sensitive epileptics are sensitive to the lowest frequencies of 2.5-3 Hz; the remainder being sensitive to higher frequencies; and
- A fast-moving three-bladed wind turbine will give rise to the highest levels of flicker frequency of well below 2 Hz. The new generation of wind turbines is known to operate at levels below 1 Hz.

Relevant *text*

"It [shadow flicker] only occurs inside buildings where the flicker appears through a narrow window opening. The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the site. Although problems caused by shadow flicker are rare, for sites where existing development may be subject to this problem, applicants for planning permission for wind turbine installations should provide an analysis to quantify the effect. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year. The likelihood of this occurring and the duration of such an effect depends upon:

- *the direction of the residence relative to the turbine(s);*
- *the distance from the turbine(s);*
- *the turbine hub-height and rotor diameter;*
- *the time of year;*
- *the proportion of day-light hours in which the turbines operate;*
- *the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,*
- *the prevailing wind direction."* (Page 176)

"Only properties within 130 degrees either side of north, relative to the turbines can be affected at these latitudes in the UK – turbines do not cast long shadows on their southern side." (Page 177)

"The further the observer is from the turbine the less pronounced the effect will be. There are several reasons for this:

- *there are fewer times when the sun is low enough to cast a long shadow;*
- *when the sun is low it is more likely to be obscured by either cloud on the horizon or intervening buildings and vegetation; and,*
- *the centre of the rotor's shadow passes more quickly over the land reducing the duration of the effect."* (Page 177)

"At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines." (Page 177)

"Shadow flicker can be mitigated by siting wind turbines at sufficient distance from residences likely to be affected. Flicker effects have been proven to occur only within ten rotor diameters of a turbine. Therefore if the turbine has 80 m diameter blades, the potential shadow flicker effect could be felt up to 800 m from a turbine." (Page 177)

"Around 0.5 % of the population is epileptic and of these around 5 % are photo-sensitive. Of photo-sensitive epileptics less than 5 % are sensitive to lowest frequencies of 2.5 – 3 Hz, the remainder are sensitive only to higher frequencies. The flicker caused by wind turbines is equal to the blade passing frequency. A fast-moving three-bladed machine will give rise to the highest levels of flicker frequency. These levels are well below 2 Hz. The new generation of wind turbines is known to operate at levels below 1 Hz." (Page 177)

2.2.1.2 Onshore Wind Energy Planning Conditions Guidance Note, Renewables Advisory Board and BERR (2007)

Synopsis

This document provides guidance to Local Planning Authorities and other stakeholders on preparing planning conditions for onshore wind energy developments.

The document states that only dwellings within 130 degrees either side of north relative to a turbine can be affected and the shadow can be experienced only within 10 rotor diameters of the wind farm.

Shadow flicker is more likely to be relevant when considering potential effects on residential amenity than on health effects.

It is worth noting that this document states that where wind turbines lie within the geographical range which may be affected by shadow flicker, it will not be possible to determine whether or not shadow flicker effects will actually be felt until an assessment has been made of window widths, the uses of the rooms with potentially affected windows and the effects of intervening topography and other vegetation. Therefore, the document proposes that local ameliorating factors are taken into account when preparing a shadow flicker report.

If shadow flicker is determined to have a potentially significant impact, then a Local Planning Authority may wish to impose the following planning condition:

> *"The operation of the turbines shall take place in accordance with the approved shadow flicker mitigation protocol unless the Local Planning Authority gives its prior written consent to any variation."*

Relevant *text*

> *"When blades rotate and the shadow passes a narrow window then a person within that room may perceive that the shadow appears to flick on and off; this effect is known as shadow flicker. It occurs only within buildings where the shadow appears through a narrow window opening. Only dwellings within 130 degrees either side of north relative to a turbine can be affected and the shadow can be experienced only within 10 rotor diameters of the wind farm."* (Page 22)

> *"The operating frequency of a wind turbine will be relevant in determining whether or not shadow flicker can cause health effects in human beings. The National Society for Epilepsy advises that only 3.5 % of the 1 in 200 people in the UK who have epilepsy suffer from photosensitive epilepsy. The frequency at which photosensitive epilepsy may be triggered varies from person to person but generally it is between 2.5 and 30 flashes per second (hertz). Most commercial wind turbines in the UK rotate much more slowly than this, at between 0.3 and 1.0 hertz. Therefore, health effects arising from shadow flicker will not have the potential to occur unless the operating frequency of a particular turbine is between 2.5 and 30 hertz and all other pre-conditions for shadow flicker effects to occur exist."* (Page 22)

> *"Shadow flicker is therefore more likely to be relevant in considering the potential effects on residential amenity. Where wind turbines lie within the geographical range which may be affected by shadow flicker it will not be possible to determine whether or not shadow flicker effects will actually be felt until an assessment has been made of window widths, the uses of the rooms with potentially affected windows and the effects of intervening*

topography and other vegetation. Where it has been predicted that shadow flicker effects may occur in theory, a local planning authority may consider it appropriate to impose a planning condition to provide that wind turbines should operate in accordance with a shadow flicker mitigation scheme which shall be submitted to and approved by the Local Planning Authority prior to the operation of any wind turbine unless a survey carried out on behalf of the developer in accordance with a methodology approved in advance by the local planning authority confirms that shadow flicker effects would not be experienced within habitable rooms within any dwelling." (Page 22)

"Sample Condition: The operation of the turbines shall take place in accordance with the approved shadow flicker mitigation protocol unless the Local Planning Authority gives its prior written consent to any variation." (Page 22)

2.2.2 Northern Ireland

In Northern Ireland, wind farm planning decisions are overseen by the National Planning Service rather than local councils.

2.2.2.1 Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy', Northern Ireland Department of the Environment (2009)

Synopsis

Best Practice Guidance to Planning Policy Statement 18 makes the following statements:

- Shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening;
- Only properties within 130 degrees either side of north of the turbines can be affected at UK latitudes;
- The potential for shadow flicker at distances greater than ten rotor diameters from a turbine position is very low;

The document also recommends that shadow flicker at offices and dwellings within 500 m of a turbine position should not exceed 30 hours per year or 30 minutes per day, quoting a survey undertaken by Predac, a European Union sponsored organisation that promotes best practice in energy use and supply.

In addition, the guidance proposes that developers should quantify the shadow flicker effect, and implement measures to ameliorate the impact, such as by turning off a particular turbine at certain times.

Relevant *text*

"It [shadow flicker] only occurs inside buildings where the flicker appears through a narrow window opening. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year. The likelihood of this occurring and the duration of such an effect depends upon:

- *the direction of the residence relative to the turbine(s);*
- *the distance from the turbine(s);*
- *the turbine hub-height and rotor diameter;*
- *the time of year;*
- *the proportion of day-light hours in which the turbines operate;*
- *the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,*
- *the prevailing wind direction."* (Page 28)

"Shadow flicker generally only occurs in relative proximity to sites and has only been recorded occasionally at one site in the UK. Only properties within 130 degrees either side of north, relative to the turbines can be affected at these latitudes in the UK – turbines do not cast long shadows on their southern side." (Page 28)

"The further the observer is from the turbine the less pronounced the effect will be. There are several reasons for this:

- *there are fewer times when the sun is low enough to cast a long shadow;*
- *when the sun is low it is more likely to be obscured by either cloud on the horizon or intervening buildings and vegetation; and,*
- *the centre of the rotor's shadow passes more quickly over the land reducing the duration of the effect."* (Page 28)

"At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines." (Page 28)

"Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low. The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the site. Where shadow flicker could be a problem, developers should provide calculations to quantify the effect and where appropriate take measures to prevent or ameliorate the potential effect, such as by turning off a particular turbine at certain times." (Page 29)

"Careful site selection, design and planning, and good use of relevant software, can help avoid the possibility of shadow flicker in the first instance. It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day3." (Page 29)

2.2.3 Wales

In Wales, planning policy and guidance is prepared by the Welsh Assembly Government.

2.2.3.1 Practice Guidance – Planning Implications of Renewable and Low Carbon Energy, Planning Division – Welsh Assembly Government (2010)

Synopsis

This Welsh guidance document proposes the following mitigation strategies for shadow flicker: careful site design; turbine shut down; installation of blinds and landscaping (tree / shrub planting) at affected residential properties.

Relevant *text*

"Shadow flicker can occur when the sun passes behind the rotors of a wind turbine, which casts a shadow over neighbouring properties that flicks on and off as the blades rotate. However, this only occurs under particular circumstances and lasts only for a few hours per day. Shadow flicker can cause a disturbance for affected residents of nearby properties and can have potentially harmful impacts on sufferers of photo-sensitive epilepsy. These potential impacts can be mitigated by micrositing turbines as far as practically possible from residential properties and through the use of technological fixes such as the shutting down of turbines during periods of predicted shadow flicker. The use

of blinds at residential properties or tree/shrub planting to screen shadow flicker can also help minimise potential impacts." (Page 25)

Generating Your Own Energy. Wind: A Planning Guide for Householders, Communities and Businesses.
Welsh Assembly Government (2010)

Synopsis

This guidance document proposes two mitigation strategies - careful site design and introducing vegetation screening,

Relevant text

"Site and position the turbine to avoid shadow flicker (where possible)." (Page 6)

"Screen shadow flicker impacts using planting." (Page 6)

2.2.4 Scotland

2.2.4.1 Planning Advice Note (PAN) 45: Renewable Energy Technologies Scottish Executive (2002)

Synopsis

Scottish guidance on shadow flicker is given in PAN45. The following statements are made:

- Shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening;
- A general rule of ten rotor diameters should be used for separation distance from a turbine position to a dwelling.

Relevant text

"It [shadow flicker] occurs only within buildings where the flicker appears through a narrow window opening. The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the potential site. Where this could be a problem, developers should provide calculations to quantify the effect. In most cases however, where separation is provided between wind turbines and nearby dwellings (as a general rule 10 rotor diameters), "shadow flicker" should not be a problem." (Paragraph 64)

2.3 International Guidance

2.3.1 Spain

PB contacted the Spanish Wind Energy Association to obtain information on shadow flicker guidance. A translation of the response received is below:

"In Spain, shadow flicker is not included in the planning requirements at present. As wind farms in Spain tend to be located very far away from any populated settlement, no complaints have been registered and no standard practice has been implemented."

2.3.2 Ireland

2.3.2.1 Planning Guidelines
Department of Environment, Heritage and Local Government (Undated)

Synopsis

The Irish Planning Guidelines document makes the following statements:

- It is recommended that shadow flicker at offices and dwellings within 500 m of a turbine should not exceed 30 hours per year or 30 minutes per day;
- At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low;
- Careful site design and turbine shut down are proposed as mitigation measures.

Relevant text

"*Shadow flicker only occurs in certain specific combined circumstances, such as when:
The sun is shining and is at a low angle (after dawn and before sunset), and
The turbine is directly between the sun and the affected property, and
There is enough wind energy to ensure that the turbine blades are moving." (Page 33)*

"Careful site selection, design and planning, and good use of relevant software can help avoid the possibility of shadow flicker in the first instance. It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day [Predac]" (Page 33)*

"At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low. Where shadow flicker could be a problem, developers should provide calculations to quantify the effect and where appropriate take measures to prevent or ameliorate the potential effect, such as by turning off a particular turbine at certain times." (Page 33)

*The shadow flicker recommendations are based on the survey by Predac, a European Union sponsored organisation promoting best practice at energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany.

2.3.2.2 Best Practice Guidelines for the Irish Wind Energy Industry
Irish Wind Energy Association and Sustainable Energy Ireland (2008)

Synopsis

This document suggests that it is reasonable to take into account ambient environmental conditions (such as wind direction and general climate) to modify the astronomical worst case scenario calculations.

Two mitigation options are recommended – turbine shut down and provision of screening measures.

In addition, the document states that the '10 x rotor diameter' rule is normally sufficient for EIA purposes.

Relevant text

"Calculations for shadow flicker modelling generally assume 100% sunshine conditions. It is reasonable in Ireland's climate to modify these figures. Some attention can also be given to the wind rose. If winds rarely come from the sectors which would give rise to the greatest shadow flicker effects on a dwelling, this can be taken into account." (Page 24)

"Where shadow flicker is anticipated to lead to potential problems, measures can be implemented to mitigate these effects. Wind turbine control software is available, which can turn the relevant turbine off at these times. The developer may wish to consider the economic impact of use of this mechanism. Other mitigation measures could include the provision of screening measures, where this is acceptable to the relevant householder." (Page 24)

"The assessment of potentially sensitive locations or receptors within a distance of ten rotor diameters from proposed turbine locations will normally be suitable for EIA purposes. A guideline of not more than 30 hours of shadow flicker per year is suggested for dwellings." (Page 25)

2.3.3 Germany

2.3.3.1 Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)

Synopsis

This document provides a clear set of criteria for an astronomic worst case scenario. German guidance sets strict limits on the levels of acceptable shadow flicker effect, using two methods:

- An astronomic worst case scenario limited to a maximum of 30 hours per year or 30 minutes on the worst affected day; and
- A realistic scenario including meteorological parameters limited to a maximum of 8 hours per year.

If the above limits are exceeded, then mitigation measures should be implemented. The document makes particular reference to adopting a planning condition for automatic turbine shut-down timers, which use radiation or illumination sensors.

The following strict criteria are provided to define the astronomic worst case and realistic shadow flicker scenarios:

- There is continual sunshine and permanently cloudless skies from sunrise to sunset
- There is sufficient wind for continually rotating turbine blades
- Rotor is perpendicular to the incident direction of the sunlight
- Sun angles less than 3 degrees above the horizon level are disregarded (due to likelihood for vegetation and building screening)
- Distances between the rotor plane and the tower axis are negligible.
- Light refraction in the atmosphere is not considered.

The German guidance does not specifically refer to a distance limit for shadow flicker assessments. However, there is reference to a point where the contrast between shadow and ambient conditions are so low that the impact is excluded from assessment.

The 30 minutes per day rule for shadow flicker at any given receptor is based on a psychology academic survey by the University of Kiel (Pohl et al 2000).

This document also provides an example case study demonstrating how shadow flicker should be calculated. The methodology sets the indoor reference height at the centre of a receptor window, and a reference height of 2m above ground level if measured outside. This case study can be found in Appendix 1.

Relevant text

Please note – this text is a translation and is not quoted verbatim. Some elements of the translation may not reflect the exact wording of the original documents.

> *Scientific research* [no reference given in text] *has demonstrated experience that optical emissions in the form of periodic shadows can result in considerable harassment effects.*
>
> *Technical measurements and limits on the time of operation are based on WEA guidance. Turbine shut down is only considered in cases where the operation is an endangerment to life or health, or will result in significant damage.*
>
> *Astronomically maximum shading time (worst case) is the theoretical time when the sun is during the entire period between sunrise and sunset passing through a cloudless sky and the rotor surface is perpendicular to the solar radiation, and the wind turbine is in operation.*
>
> *Actual shading time is the realistic estimate of accumulated exposure to periodic shadows. If the irradiance of the direct solar radiation in the direction normal to the incident plane is more than 120 W/m^2, then sunshine and shadows are acceptable.*
>
> *Relevant emission figures that could occur are defined by ambient weather conditions. The effect of predicted periodic shadow is not considered a significant nuisance if the cumulative astronomical maximum loading at a reference height of 2m above ground level does not exceed 30 hours per calendar year and is not greater than 30 minutes per calendar day.*
>
> *If the time values for the astronomical maximum shading are exceeded, there are technical measures that can be considered to impose time-limit restrictions on the operation of the wind turbine. An automatic switching unit, with radiation or illumination sensors, which record the specific meteorological situation can allow terms and conditions agreed for shadow flicker time limits to be achieved. Since the value of 30 hours per calendar year was developed using the astronomical maximum loading, automatic switch-off is an appropriate solution to mitigate the actual, real time shadows. The actual real-time shadows are limited to 8 hours per calendar year (Freund 2001).*
>
> *The sun is assumed to be point-like source and appears on all day.*
>
> *There is a cloudless sky, sufficient wind to turn the turbines blades. Wind direction corresponds to the azimuth angle of the sun (ie. rotor is perpendicular to the incident direction of the sunlight). Calculations are based on geographic north. Distances between the rotor plane and the tower axis are negligible. Light refraction in the atmosphere is not considered.*
>
> *Sun angles less than 3 degrees above the horizon are removed from analysis because vegetation and buildings will remove shadow impact.*
>
> ***Annual limits***
> *Wind turbines are only approved if the maximum astronomic shading period of 30 hours per calendar year is not exceeded. A review of complaints relating to shadow flicker at*

existing systems, has informed the setting of this benchmark. When using an automatic cut off system that does not takes account metrological parameters, the maximum astronomic shading is limited to 30 hours per calendar year. For systems that do take into account metrological parameters (ie intensity of the sun), the actual shading is limited to 8 hours.

Daily Limits
Shadow flicker should be limited to a maximum of 30 minutes per day. The laboratory study by the University of Kiel (Pohl et al 2000) noted that even a one-off exposure to 60 minute duration of shadows can cause stress reactions. For precaution, shading duration is therefore limited to 30 minutes per day.

For planned plants, the astronomic maximum shading period should be used, and for existing plants, the actual shadow duration is used. When this benchmark is exceeded for at least three days, appropriate measures need to be implemented to reduce the impact to guarantee a maximum duration of shading of 30 minutes.

When siting wind turbines, there is an obligation to take precautionary measures to reduce the shadow flicker, taking account of proportionality and the requirements of the planning department.

Exceedance of the allowable emission values for a wind turbine is carried out by emission-verified compliance. Reduction of shadow is carried out by an electronic circuit which calculates the time of shadows at relevant receptors. In determining exact times, the type of receptor (eg. window) should be considered. When indoors, the reference height should be set at the centre of the window. When outdoors, the reference height is set at 2m above ground level. Sunshine duration data should cover a period of at least a year, and the data should be available by a competent authority on request.

Evidence of the amount of shadow flicker needs to be calculated in the context of planning projects and monitoring systems. This allows the shut-down timings for wind turbines to be determined.

Shadow forecast is based on an algorithm which calculates the location, day and time dependent solar position. To ensure uniform implementation, widely available computational models are recommended (DIN 5034-2 1985; VI 3789 1994).

Accuracy of geometric parameters should be ±3-10m. The determination of shadow cast times should have an accuracy of 1min per day. Absolute times are in GMT or BST.

The start and end points of shadow at each relevant receptor point needs to be calculated in relation to the receptor. In the case of several wind turbines, the cumulative contributions need to be taken into account.

As part of the calculation, excerpts are required from topographical maps, as are coordinates of plant locations and receiver points. The result from the software is iso-shadow contours (especially the 30 hour contour) for the plant.

Because of the complexities of the calculations, commercial computer programmes should be used to calculate shadow flicker. Forecast times should be presented in appropriate data tables.

2.3.4 United States

2.3.4.1 Wind Turbines and Health, American Wind Energy Association (2010)

Synopsis

The American Wind Energy Association recommends that shadow flicker impacts are mitigated by use of appropriate turbine-dwelling separation distances or screening by vegetation planting. The document also states that shadow flicker issues are less common in the United States than in Europe.

Relevant text

> *"Computer models in wind development software can determine the days and times during the year that specific buildings in close proximity to turbines may experience shadow flicker. Mitigation measures can be taken based on this knowledge and may include setbacks or vegetative buffers. Issues with shadow flicker are less common in the United States than in Europe due to the lower latitudes and the higher sun angles in the United States."*

2.3.4.2 Final Programmatic Environmental Impact Statement on Wind Energy Development on BLM- Administered Lands in the Western United States, US Department of the Interior – Bureau of Land Management (2005)

Synopsis

This document produced by the United States' Department of the Interior states that shadow flicker is not considered as significant an issue in the United States as in Europe.

However, this document does note that flickering effect may be considered an annoyance, but that modern three-bladed wind turbines are unlikely to cause epileptic seizures in the susceptible population due to the low blade passing frequencies.

Relevant text

> "*When the sun is behind the blades and the shadow falls across occupied buildings, the light passing through windows can disturb the occupants (Gipe 1995). Shadow flicker is recognized as an important issue in Europe but is generally not considered as significant in the United States (Gipe 1995). The American Wind Energy Association (AWEA 2004) states that shadow flicker is not a problem during the majority of the year at U.S. latitudes (except in Alaska where the sun's angle is very low in the sky for a large portion of the year). In addition, it is possible to calculate if a flickering shadow will fall on a given location near a wind farm and for how many hours in a year (AWEA 2004). While the flickering effect may be considered an annoyance, there is also concern that the variations in light frequencies may trigger epileptic seizures in the susceptible population (Burton et al. 2001). However, the rate at which modern three-bladed wind turbines rotate generates blade-passing frequencies of less than 1.75 Hz, below the threshold frequency of 2.5 Hz, indicating that seizures should not be an issue (Burton et al. 2001)."*
> (Section 3-20)

Canada

2.3.4.3 Draft HRM Wind Energy Generation Plan, Halifax Regional Municipality (2006)

Synopsis

This document refines the shadow flicker definition to a ‘pulsing change in light intensity’. This document does not propose any particular separation distance between turbines and dwellings, but instead outlines the various approaches adopted in three Environmental Statements, covering a fixed radius of 500-1000 m in Denmark, ’10 x rotor diameter’ rule in Aberdeenshire in Scotland, and 30 hours per year in Germany. A case study from the United States is also included that outlines a turbine shut-down mitigation measure strategy.

This document also states that even within an urban environment, careful site design in the first instance and mitigation measures thereafter may manage any potential shadow flicker impacts.

Relevant text

> *“Shadow flicker is the effect of the sun passing through the blades of the tower and creating a flickering effect or pulsing change in light intensity based on the speed of the turbine (Botha 2005). The impact of the flicker is dependent on the orientation of the tower and location of the sun. For example, if the sun is low on the horizon and the turbine blades directly face the sun the impact will cover a larger area compared to if it is parallel to the sun’s rays. In most cases the effect will fall on open countryside, however, where towers are located closer to residential properties consideration needs to be given to protect the residents from this impact. The impact is basically an annoyance and there are suggestions that it can lead to inducing epilepsy in susceptible individuals, however the study team is not aware of any recorded incidents of this actually occurring.”* (Page 16)
>
> *“A considerable amount of international research has been undertaken on the impacts and management of shadow flicker and the following summary is outlined in a comprehensive environmental impact assessment (Awhitu Wind Farm 2004):*
> *“The Danish Wind Energy Association reports that shadow flicker does not need to be assessed at distances more than 500 – 1000 metres from a wind turbine.*
> *Environmental assessments for other wind farms (e.g., by Renewable Energy Systems for the Meikle Carewe project in Aberdeenshire, Scotland) state that shadow flicker is only a potential problem at closer than 10 rotor diameters to the turbine.*
> *The ministry for the Environment of Schleswig-Holstein, a northern German region with more than 1,000 MW of installed wind power, recommend the use of flicker timer if more than 30 hours of theoretical flicker occurs per year.”* (Page 16)
>
> *“The above provides some guidance on how this impact may be managed. Based on consultations done in Alberta, the Municipality of Pincher Creek advises that operators either shut down the machines between the time the sun is rising and setting for approximately an hour, or that computers manage to control the direction of the turbine so the blades are directly parallel to the sun. Access to information on calculating and modeling the impacts of wind shadow is provided on the Danish Wind Industry Association website.* (page 16)
>
> *In an urban environment, it will be more challenging to create a sufficient clearing around the turbine. Notwithstanding this, one should not prohibit the ability to establish these structures in an urban environment because there may be site circumstances that avoid this impact (e.g., parkland area/industrial premises) or controls and technologies that manage the impact.* (page 16)
>
> *There has also been concern that wind turbines, in particular their shadow flicker, have an impact on certain grazing animals. Studies have been undertaken in a number of countries to assess this potential impact, and all indicate farm animals and horses*

adapt to the new environment within a brief acclimatization period. In relation to horses, evidence indicates that generally horses should not be ridden in these environments if they have not been acclimatized (page 16)

2.3.5 Denmark

No guidance on shadow flicker from Denmark was found during literature searches by the authors, however the following comments were noted on the Danish Wind Industry Associations website (Danish Wind Industry Association, accessed 2010):

> *"The hub height of a wind turbine is of minor importance for the shadow from the rotor. The same shadow will be spread over a larger area, so in the vicinity of the turbine, say, up to 1,000 m, the number of minutes per year with shadows will actually decrease."*

> *"If you are farther away from a wind turbine rotor than about 500-1000 metres, the rotor of a wind turbine will not appear to be chopping the light, but the turbine will be regarded as an object with the sun behind it. Therefore, it is generally not necessary to consider shadow casting at such distances."*

2.3.6 Australia

2.3.6.1 Planning Bulletin – Wind Farms (Draft for Consultation) Government of South Australia (2002)

Synopsis

This document states that shadow flicker is unlikely to be a significant issue if a separation distance of 500 m is maintained between the turbine and any dwelling or urban area.

Relevant text

> *"This occurs when the sun is low on the horizon and the blades pass between the sun and an observer, creating a flickering. This issue needs to be considered as it could cause irritation and visual impairment. This is unlikely to be a significant issue if a separation distance of at least 500 metres is maintained between the turbine and any dwelling or any defined urban area."* (Page 7)

2.3.6.2 Western Australia Planning Bulletin – Guidelines for Wind Farm Development, Western Australian Planning Commission (May 2004)

Synopsis

This document states that shadow flicker can affect local amenity but is uncommon in Australia.

Relevant text

> *"A wind energy facility can affect local amenity due to: Shadow flicker, which occurs when the sun passes behind the blades and the shadow flicks on and off, although in Australia this is uncommon."* (Page 4)

2.4 Non-governmental Organisations Guidance

2.4.1 Spatial Planning of Wind Turbines, PREDAC – European Actions for Renewable Energies

Synopsis

Predac have developed a set of recommendations for the special planning of wind energy developments, based on a survey of guidance from Belgium, Denmark, France and The Netherlands, as well as some information from Germany and Ireland.

From this document, it is clear that the approach to this issue varies across Europe, with Belgium adopting the German quantitative limits (30hrs per year and 30 min per day), and both Denmark and The Netherlands adopting similar quantitative limits (Denmark - 10 hrs per year, The Netherlands 20 minutes per day, 17 days per year – equivalent to 5 hours 40 min per year). France has no set limits on shadow flicker effect.

Additionally, there are differences between the countries in how the calculations should be carried out, with Denmark taking 'average cloud cover' into account and The Netherlands specifying that calculations should be carried out with a clear sky.

This document recommends that at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky).

Relevant text

> *"It is recommended at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30 min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky)."* (Page 21)
>
> *"Belgium*
> *In Wallonie, the government recommends to apply the threshold of tolerance that are fixed on the German pattern, that is 30hrs per year and 30 min per day. In practice, they are always applied as condition to obtain the permit and must be studied in the EIA."* (Page 21)
>
> *"Denmark*
> *Recommendation: max. 10 hours/year allowed at neighbouring dwellings with average cloud cover."* (Page 21)
>
> *"France*
> *No recommendations are fixed, but the calculation of the occurrence of the shadow flicker at the nearest neighbours should be indicated in the EIA."* (Page 21)
>
> *"The Netherlands*
> *When there is more than 20 minutes per day, 17 days per year (5 hours 40 min / year calculated, with clear sky), at neighbours it is regarded as a nuisance, which is unacceptable, and a standstill device is requested."* (Page 21)

3 ACADEMIC LITERATURE

3.1 Introduction

Parsons Brinckerhoff has undertaken an academic literature review on the phenomenon of shadow flicker. Literature has been obtained from various sources, including online, direct from the authors or publishers and from the British Library. In all cases, an attempt has been made to source literature that has been referenced in guidance or other literature to provide a full review. Where necessary, Parsons Brinckerhoff has translated from the original language. Where this has been the case, it has been highlighted in the review below.

3.2 Literature

3.2.1 Shadow Hindrance by Wind Turbines, Verkuijlen E. & Westra C.A. (1984)

Synopsis

This paper is from the Interfaculty Department of Environmental Science at University of Amsterdam, and is part of the original evidence base addressing the amenity issues associated with shadow flicker effect from onshore wind turbines. The paper is set in The Netherlands and the technical drawings adopt criteria (eg. latitude and predominant wind direction) that are comparable with the United Kingdom.

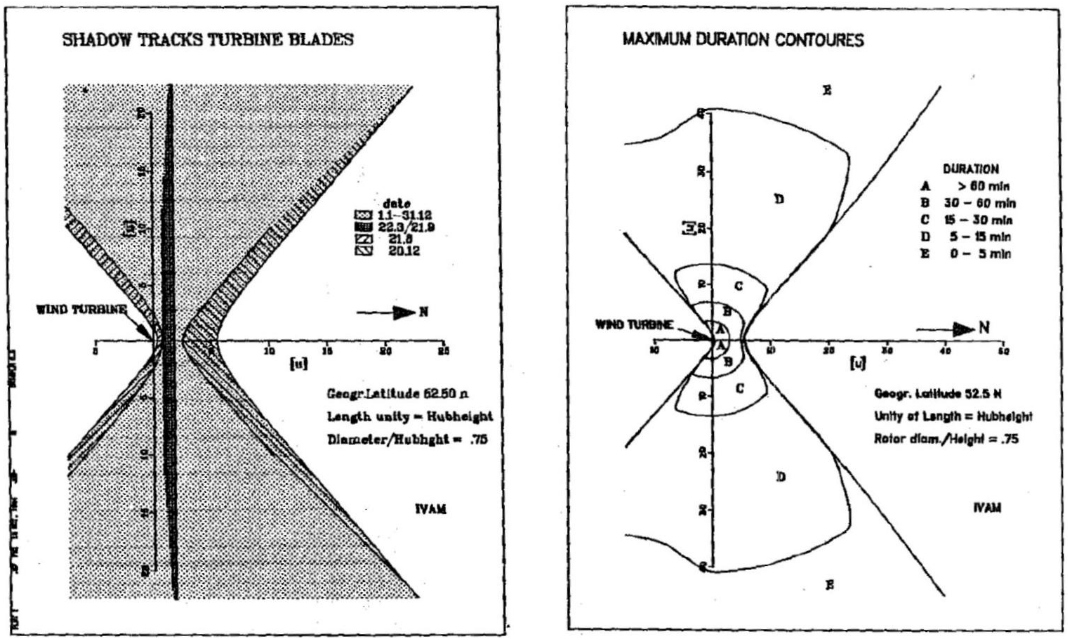
The paper states that the greatest shadow flicker impact can be expected:

- Inside a property where the change in light intensity is most noticeable
- When turbines are rotating at between 5 and 14 Hz (below 2.5 Hz and above 40 Hz will cause “hardly any nuisance”).
- In areas to the east-northeast and west-northwest of a turbine

The paper suggests that three factors are important in determining the impact of shadow flicker:

1. The receptors location relative to the turbine;
2. The time at which the shadow covers a particular place;
3. The duration of exposure to shadow.

Figure 1: Shadow influence of a wind turbine (figure extracted from paper)



The paper also states that during winter, the sun is lower in the sky than in summer, so the daily track of shadow flicker effect will extend farther from the turbine.

Several mitigation measures are proposed including sensitive site design, installation of blinds, and wind turbine shut-down strategies. The paper expands on the sensitive site design aspect, suggesting that hindrance from shadow flicker would occur particularly in east-northeast and west-northwest directions from a wind turbine.

The paper concludes that further research is necessary on the impact of flicker frequencies and duration of exposure.

Relevant text extracts

> *"Indoors the effect will be far greater, because in this case (almost) all the light that reaches the observer is modulated in intensity by the turbine blades."* (Page 356)
>
> *"The effect of light flicker on an observer depends largely on its frequency. In frequencies below 1 Hz every change in light intensity is felt as such. Beyond a certain frequency flickers are no longer perceived separately. This limit is called the flicker fusion frequency and as a rule lies at 50-80 Hz."* (Page 357)
>
> *"Flicker frequencies approaching the fusion frequency may be felt to be a nuisance."* (Page 357)
>
> *"Various experiments for the lighting of traffic tunnels led to the conclusion that most persons (tested) feel flicker frequencies from 5-10 Hz as a nuisance (8-9) [Collins & Hopkinson (1957); Schreuder (1964)]. From other research projects, too, men have found to be maximally sensitive to flickers between 8 and 14 Hz. Below 2.5 Hz and beyond 40 Hz hardly any nuisance is caused."* (Page 357)
>
> *"It is well known that in some people suffering from epilepsy an epileptic seizure may be triggered by light flickers (photosensitive epilepsy). Around 2 % of the population are epileptics. In brain research about 5 % of people with epilepsy have shown*

anomalous EEG (electroencephalogram) reactions to flickers from 2.5 to 3 Hz. Higher frequencies (15-20 Hz) may even cause convulsions in epileptic persons (5) [Ginsburg (1970)]. (page 357)

"Most wind turbines give a flicker frequency between 1 and 6 Hz. The aforesaid limit of 2.5 Hz falls within this frequency range. Some wind turbines, therefore may cause hindrance (when there is wind and sunshine)." (Page 357)

"(rotor diameter/hub height = 0.75; position 52.5^o N *and 4^o E)."* (Page 357)

"When the sun is shining, the rotor shadow describes a track on the earth's surface from west to east as a result of the sun's daily orbit along the sky. Because the sun is lower in winter than in summer, the daily track will be farther from the turbine in winter (see Figure 1). At sunrise and sunset, the shadow shifts very fast. At sunset the shadow first becomes diffuse and then vanishes; at sunrise exactly the opposite occurs. Nevertheless it may cause nuisance during this brief spell of time. The shape of the rotor shadow depends on the relative positions of rotor and sun. The extremes are:

a) Rotor position perpendicular to the sunlight;
b) Rotor position parallel to the sunlight.

In the former case the rotor casts a shadow covering a elongate strip. In the latter case the shadow has an oval shape. When the rotor plane turns from position b. to position a. the oval will become narrower till it is transformed to a narrow strip. In our further calculations of the period during which the shadow covers on particular place, we always start from case a. Three factors are important for the eventual hindrance caused by the shadow:

1) The place covered by the shadow;
2) The time at which the shadow covers a particular place
3) The duration of the shadow covering one particular place." (Page 357)

"It is obvious from these figures that particularly large areas in E-NE and W-NW directions from the wind turbine can be shadowed for long periods of time. In these directions, therefore, most hindrance is to be expected." (Page 358)

"From the above it can be concluded that the revolving blades of present wind turbines may inflict shadow hindrance on a number of people in a large area around the turbine, particularly if the flicker frequency is beyond 2.5 Hz. Largely because of the development of wind turbines running with variable rpm (turbines with a so-called inverter system), the number of turbines whose flicker frequency may rise above this limit of 2.5 Hz is bound to increase. This will greatly add to the change of change [sic – shadow] hindrance. It must be noted, though, that this limit was found in literature which did not refer to the shadow of wind turbine blades. Therefore, further research is necessary. This will have to go into both the impact of the resulting flicker frequency and the duration of the exposure. For the present it seems to be advisable only to install wind turbines whose resulting flicker frequency remains below 2.5 Hz. Shadow hindrance may occur particularly in east-northeast and west-northwest directions from a wind turbine. In order to reduce shadow hindrance in buildings to a minimum, this could be taken into account when siting new wind turbines. With southwest winds predominating in the Netherlands, wind turbines are often sited southwest of built-up areas. These locations, however, are most likely to suffer shadow hindrance. Siting south of buildings would therefore be a fine compromise. For numerous reasons wind turbines may still be so sited that shadow hindrance is caused in buildings. In such cases several solutions could be considered to reduce the shadow hindrance:

a) *Fitting the buildings' windows with sunblinds. This could lessen the difference in intensity between light and shadow.*
b) *Stopping the wind turbine. Whenever the shadow of a wind turbine causes nuisance, it could be stopped. Because one knows at what times shadow hindrance can be expected in a certain situation, the wind turbine could be stopped with a time switch. From exploratory calculations we have found that the annual output of wind turbines in areas of low building intensity would be reduced by a few percent only."* (Page 358)

3.2.2 A Case of Shadow Flicker / Flashing: Assessment and Solution, Clarke A.D. (1991)

Synopsis

This paper makes reference to a complaint submitted to a Local Planning Authority (LPA) relating to disturbance from shadow flicker and reflected sunlight from a wind turbine – the details of the complaint and the LPA that it was submitted to were not included in the paper. However, the rotation rate of the three-bladed turbine in question was recorded as between 33 and 44 revolutions per minute, creating a flicker frequency of between 1.65 and 2.2 Hz.

The paper also states that sunny hours are likely to lower between October and early February when shadow flicker is predicted to occur, although this is likely to be the windiest period of the year. This paper also advocates the use of the '10 x rotor diameter' rule for separation between wind turbines and habitations or occupied buildings.

The paper considers shadows cast from turbines being an issue when cast through windows of buildings, and does not make reference to impacts outside of buildings.

Relevant text extracts

"*A recommendation was made that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East / Southeast or West / Southwest, and the shadow path identified."* (Page 93)

"The effect can be pronounced in rooms in buildings facing the turbine, especially if the window is the sole source of light for a room." (Page 93)

"It has been found that the frequencies of flicker that produce disturbance are between 2.5 Hz and 40 Hz." (Page 93)

"Most medium and large wind turbines have a rotation rate of between 30 r/min [rotations per minute] and 60 r/min, and smaller turbines often have a faster rotation. Most turbines in use today are two or three bladed, constant speed types, producing shadow flicker rates in the range of 1-3 Hz. Variable speed turbines may produce a 2-6 Hz flicker rate. Therefore the shadow flicker from turbines has frequencies that could in the right conditions produce light flicker effects to susceptible persons." (Page 93)

"The shadow will be most pronounced when the blades of the turbine face the building and present the largest shadow area." (Page 94)

"Residents of a neighbouring house claimed that shadow flicker and reflected sunlight from the turbine blades were causing disturbance to them (5). After complaints were made to the local Planning Authority, a study was carried out to investigate the problem." (Page 94)

“The turbine’s dimensions and data were obtained:
turbine rating: 200kW
blade diameter: 25m
tower height: 30m
swept area: 491m square
rotation rate: 44 r/min & 33 r/min in light winds
number of blades: 3
flicker frequency: 2.2 Hz & 1.65 Hz.” (Page 94)

“It was recommended that a timer plus photo cell should be employed to automatically switch off the turbine for the duration of the flicker period, which will not be more than about 20 minutes, if the sun is shining and the wind blowing.” (Page 94).

“In addition, the number of sunny hours is likely to be small in late October, November, December, January and early February when flicker is predicted to occur, although this will be in the windiest period.” (Page 95)

“Other solutions that have been suggested are that the turbine should be stopped at those hours when shadow flicker is likely to occur, or that blinds should be fitted. In one reported case the neighbours have been equipped with a switch to shut down the turbine if they are disturbed by shadow flicker.” (page 95)

“Wind turbines close to habitations, eg. ten diameters distance should not be sited to the East or South East, or West or South West of habitations, unless the shadow path has been identified and does not fall on windows of habitations or occupied buildings.” (Page 95)

“The minimum separation distance for wind turbines from habitations should be approximately 10 blade diameters. This is emerging from experience and research as a standard guideline, in order to reduce problems of visual impact, noise, shadow disturbance, and safety”. (Page 95)

3.2.3 Wind Energy Handbook, Burton et al. (2001)

Synopsis

The Wind Energy Handbook presents a review of shadow flicker understanding at the time of publishing. This handbook states that shadow flicker frequencies between 2.5 and 20 Hertz (Hz) can cause nuisance, and restates the findings of Verkuijlen & Westra (1984) in relation to health effects relating to epilepsy.

Relevant text extracts

“Although considered to be an important issue in Europe, and recognized in the operation of traditional windmills (Verkuijlen and Westra, 1984) shadow flicker has not generally been recognized as significant in the USA (Gipe, 1995). (Page 527)

“The frequencies that can cause disturbance are between 2.5-20 Hz.” (Page 527)

“In the case of shadow flicker the main concern is variations in light at frequencies of 2.5-3 Hz which have been shown to cause anomalous EEG (electroencephalogram) reactions in some sufferers from epilepsy. Higher frequencies (15-20 Hz) may even lead to epileptic convulsions. Of the general population, some 10 percent of all adults

and 15-30 percent of children are disturbed to some extent by light variations at these frequencies (Verkuijlen and Westra, 1984).” (Page 527)

“Large modern three-bladed wind turbines will rotate at under 35 r.p.m. giving blade-passing frequencies of less than 1.75 Hz, which is below the critical frequency of 2.5 Hz. A minimum spacing from the nearest turbines to a dwelling of 10 rotor diameters is recommended to reduce the duration of any nuisance due to light flicker (Taylor and Rand, 1991).” (Page 527)

3.2.4 Planning for Wind Energy in Dyfed, Taylor D. & Rand M. (1991)

Synopsis

Taylor & Rand (1991) presents details of a complaint arising in relation to shadow flicker effect in Cornwall (Cornwall County Council, 1989). Specific details relating to the origin and severity of the complaint, the dimensions of the wind turbines, and the proximity and direction of the affected receptor (etc.) were not included in the paper.

The authors of this study undertook extensive correspondence with Cornwall County Council, however it was not possible to source a copy of the original document ‘Planning Implications of Renewable Energy: Onshore Wind’.

The report concludes that at distances of greater than 10 rotor diameters between turbines and the habitation, shadow flicker effect can be reduced to relatively short periods of the year. In relation to the Cornwall case study, the short period is defined as 30 minutes a day for 10-14 weeks a year.

The paper also proposes two mitigation strategies – ‘blind installation’, and ‘turbine shut down’.

Relevant text extracts

“The effect seems to be confined to people inside buildings exposed to light from a narrow window source. The frequencies of flicker that cause disturbance, dizziness, and disorientation are between 2.5 and 40 Hertz (cycles per second). A frequency of 2.5-3 Hertz can trigger epileptic seizures in some 5% of those who are susceptible. It is estimated that about 2% of the population are susceptible to epileptic seizures.” (Page 91)

“Frequencies of flicker between 2.0 and 40 Hertz can produce disturbance. Most wind turbines produce a flicker frequency of around 1 and 6 Hertz and so are likely to induce flicker disturbance if their shadow falls on a building.” (Page 91)

“One study noted that rotor speeds of below 45 rpm for three bladed turbines and 70 rpm for two-bladed turbines should help ease the effect (Clarke, 1988).” (Page 91)

“One study in Cornwall has illustrated the effect of all these factors on the position and duration of the shadow (Cornwall County Council, 1989):

1) *The area affected forms a narrow zone on the north side of the wind turbine but elongated to the west and the east. The effect would be greater near the machines; further away the effect would be less acute and last for a shorter time.*
2) *In the direction north from the machine, the shadow would affect a building (10 metres wide) at a distance equivalent to one rotor diameter 8.5 hours a day for*

39 weeks per year; at 2 diameters 7.75 hours a day for 13 weeks; & at 3 diameters 6 hours a day for four weeks a year."

3) *At a distance of 2 rotor diameters, in directions form south-west through north, to south-east, the shadow could affect a dwelling 2-7 hours a day for 13-26 weeks a year.*
4) *At a distance of 10 rotor diameters, again in directions from south-west, through north, to south-east, the shadow could affect a dwelling 30-45 minutes a day for 10-14 weeks a year."* (Page 91)

"Wind turbines can cause shadow disturbance over a large area around a turbine, but the duration is likely to be limited. From the data presented above it is possible to deduce that the shadow effect can be reduced to relatively short periods of the year (30 minutes a day for 10-14 weeks a year) when spacings of 10 rotor diameters to the nearest habitation are employed." (Page 91)

"2. The siting of wind turbines less than 10 rotor diameters from habitations should be discouraged due to the increased duration of shadow effects." (Page 92)

"3. Should shadow disturbance generate problems then the following actions can be taken:

a) *The installation of blinds to the windows of the properties affected.*
b) *The shutting down of the wind turbine(s) during the relevant periods."*
(Page 92)

3.2.5 Harrassment by Periodic Shadow of Wind Turbines (English translation of abstract) (Belästigung durch periodischen Schattenwurf von Windenergieanlagen) Pohl et al. (1999).

Synopsis

This paper by the Institute of Psychology at Christian-Albrechts University of Kiel documents a laboratory experiment to record changes in indicators of performance, mental and physical well-being, cognitive processing and stress of the autonomic nervous system (heart rate, blood pressure, skin conductance and finger temperature) as a result of exposure to periodic shadows. The experiment was undertaken on male and female participant of varying ages. Shadows were simulated by using a system which could vary the light source and speed of shadow flicker. This was set up to simulate a shadow impact through a doorway between two laboratories, with the lighting equipment in one room and the participants in the connected room.

The study concludes that under the specific lighting conditions used in the laboratory tests, the shadow flicker effect did not constitute a significant harassment. However, the increased demands on mental and physical energy, indicated that cumulative long-term effects might cause a significant nuisance.

Relevant text extracts

Please note – this text is a translation and is not quoted verbatim. Some elements of the translation may not reflect the exact wording of the original documents.

The focus of the investigation was the question of whether periodic shadows, with a duration of more than 30 minutes from one-off performance would cause stress effects. (Page 1)

Two groups of different ages were studied, namely 32 students (average age 23 years) and 25 professionals (average age 47 years) who were each randomly assigned to two experimental conditions. In each condition was the same number of women. The experimental group (EG) received 60 minutes of periodic shadow with 80% lighting contrast. For the control group (CG) lighting conditions were the same as in the EG, but without periodic shadow. The main part of the investigation consisted of a series of six tests and measurement phases, of which two were before turning on the light, three were for a period of 20 minutes with the addition of lighting, and one phase after switching off the light. Among the variables collected included stress indicators of general performance (computing, visual search tasks), the mental and physical well-being, cognitive processing and stress of the autonomic nervous system (heart rate, blood pressure, skin conductance and finger temperature). (Page 1)

Students and professionals of the EC showed slower performance during the first 20 minutes of lighting. When the professionals were subjected to this phase there was a range of stress and performance effects, the physical condition was impaired and a greater cognitive engagement with the situation occurred. In the next 40 minutes there was compensation or even an increased performance compared to the CG. This compensating or over-compensating required additional energy due to increased physical effort, manifested in the EG students in a reduced finger temperature and in professionals in increased sweat gland activity. Younger subjects (students) compensated with other mental processes than older volunteers (professionals). The former appears to be able to shut out the stimulus and reduce the harassment, and were able to compensate even thought they were aware of the harassment. The older subjects also exhibited a stronger stress cognitive processing. The duration of stress was prolonged and there were after effects even after turning off the lights. The additional after effect that occurred in older subjects, resulted in a deterioration in their overall test performance. (Page 2)

The laboratory study showed that under specific conditions periodic shadow did not constitute a significant harassment. However, the documented increased demands on mental and physical energy, indicated that cumulative long-term effects might meet the criteria of a significant nuisance. (Page 2)

The results of this pilot study indicated that as a whole it would seem reasonable to conduct further studies with modified experimental conditions. These conditions could be various time patterns of the periodic shadow (random, intermittent, unpredictable) and the combination of periodic shadow and noise / noise (in particular, periodic noise) [It is not known whether these further studies have been carried out]. (Page 2)

3.2.6 Influences of the Opaqueness of the Atmosphere, the Extension of the Sun and the Rotor Blade Profile on the Shadow Impact of Wind Turbines (English translation of abstract) (Einflüsse der Lufttrübung, der Sonnenausdehnung und der Flügelform auf den Schattenwurf von Windenergieanlagen), Freund H-D. (2002)

Synopsis

This paper from the University of Applied Sciences at Kiel critically analyses existing geometrically calculated shadow flicker models. The paper concludes that the ambient environmental conditions that exist in reality – the finite extension of the sun; the trapezoidal structure of rotor blades; and the opaqueness of the atmosphere as a medium of radiation – reduce the shadow flicker effect of wind turbines. These inaccuracies in the modelling methodology, result in wind turbine operators facing unnecessary 'turbine shut-down' systems.

Relevant text extracts

Please note – this text is a translation and is not quoted verbatim. Some elements of the translation may not reflect the exact wording of the original documents.

> *"At present, shadow flicker periods are determined by purely geometrical models. This approach is questioned in the research project referred to in this article. The project investigates in detail the ambient conditions existing in reality. These are:*
> 1) *The finite extension of the sun*
> 2) *The trapezoidal structure of the rotor blades*
> 3) *The opaque atmosphere as a medium of radiation*
>
> *These physical parameters have a significant influence on the shadow flicker. One can see that the shadow flicker periods calculated geometrically cannot represent the worst-case periods as a matter of principle. For the distances in question, they are generally too large. For approx. 76% of the maximum range the geometric system error is 100% and gets even larger with increasing distance. Because of this system error, wind turbine operators are sometimes faced with costs for shut-off systems that are not really necessary. By using a new supplementary software in addition to the conventional computer programmes, such extra costs should be avoided."* (Page 43)

3.2.7 Wind Power Environmental Impact – Case Study of Wind Turbines Living Environment, Widing et al. (2005)

Synopsis

This paper prepared by the Centre for Wind Power Information at Gotland University presents case study information from residents living near the wind turbines in När, Klintehamn and Näsudden in Sweden. Operational experience presented suggests that 94% of persons in 69 households were not disturbed by shadow flicker effects.

The paper also indicates that it is more important on which day and in which season shadows occur, than how long the calculated/expected shadow time lasts.

In addition, a report by the Swedish Federal Housing Association (the Boverkets handbook 2003) suggests that shadow flicker duration should be assessed both on the plot of land around a house (the curtilage) as well as the façade (windows) of the property. The report states that there is a statistically significant correlation between shadow minutes per day on the façade of a property and the specified disturbance, whereas shadow minutes per day on the plot of land and disturbance are not related. However, shadow duration on the plot of land is likely, on average to be three times longer than on the façade, therefore the limits on a plot of land would need to be adjusted to make them reasonable.

Relevant text extracts

Please note – this text is a translation and is not quoted verbatim. Some elements of the translation may not reflect the exact wording of the original documents.

> *Three different wind areas on Gotland were selected for case studies: a) När; b) Klintehamn; and c) Näsudden. Only the people who live in close proximity to wind turbines have been interviewed. In När everyone living within 1100 metres from two large wind turbines, in Klintehamn a sample of those who live ESE of wind turbines*

and receiving shadows from the turbines when the sun goes down, and in Näsudden those households that are among the wind turbines on the peninsula. A total of 94 persons in 69 households were interviewed.

Of all respondents, 85 % are not disturbed by noise from wind turbines around them. In the case of shadows, the proportion who are not disrupted is even higher at 94 %.

Although none of the calculations of shadows on the facade for the respondents in Klintehamn yielded, in the worst case, more than 30 shadow hours per year and a maximum of 30 minutes per day, 24 % (of the respondents) stated that they get annoyed quite a lot or a lot by the shadows. The calculations for 17 % of the respondents in Näsudden gave 30 shadow hours per year (facade, worst case) but only 4 % were disturbed quite a lot or a lot of shadows.

In När nobody was bothered by shadows. One possible explanation why so many people are disturbed by the shadows in Klintehamn may be that the majority of the respondents live east-south-east of the power plant which, according to the calculations, results in the majority (approximately 90 % of respondents) having shadows in the evenings from April to September.

In Näsudden about half of the respondents get shadows in the evenings while the other half get the shadows in the morning or at midday. For those respondents who do not get disrupted even though the expected shadow time is long, shadows appear mainly in the morning or in winter. For those respondents who are disturbed despite the short estimated shadow time shadows occurring in the evenings. In När no respondent got shadows during summer evenings. This may indicate that it is more important on which day and in which season shadows occur, than how long the calculated/expected shadow time lasts.

In Näsudden there is no relationship what-so-ever between the estimated shadow time and the specified disturbance. However, there is a moderately-strong correlation between distance from the nearest wind turbine and stated disturbance due to shadows. This may indicate that the geometric calculation model for shadow time is not reliable when there is a large power plant that is situated far away from the current residence, as the shadow time of the power plant is included for long distances, although according to a German study the shade does not extend longer than about 1 km (Freund 2002).

Since according to the Boverkets handbook (the handbook of the "Federal Housing Agency") (Boverket 2003) a new guideline has been introduced, due to which the shadow time is calculated on the plot of land instead of on the windows, the shadow time in Klintehamn was calculated partly on land and partly on the facade. There is a statistically significant moderate correlation between shadow minutes / days on the facade and the specified disturbance. Whereas shadow minutes / days on the plot and disturbance are not related. Calculation of shadow time on the plot instead of on the facade give, on average, approximately three times longer shadow times. To introduce a new guideline that time shall be calculated on the plot/land without having adjusting the limit how long shadow time is acceptable is in this perspective not reasonable.

3.2.8 Wind Power: Renewable Energy for Home, Farm and Business, Gipe P. (2004)

Synopsis

The author of this book provides case study information on measured shadow flicker effect and experiences of local equestrians relating to operational wind farms. The author states that at an operational wind farm in Germany, research has shown that under worst –case conditions, shadow flicker would result in 100 minutes per year, however the effect in real life only equated to 20 minutes per year. Experience by an equestrian in North America, was that shadow flicker from an operational wind turbine startled horses but the shadows simply caused the horse to stop briefly until their riders urged them on.

Relevant text extracts

> *"Near Flensburg in Schleswig-Holstein, German researchers examined the effect and found that flicker, under worst-case conditions, would affect neighbouring residents a total of 100 minutes per year. Under normal circumstances the turbine in question would produce a flickering shadow only 20 minutes per year."* (Page 298)

> *"There are few recorded occurrences of concern about shadow flicker in North America. Ruth Gerath, however, notes that the flickering shadows from the turbines on Cameron Ridge near Tehachapi have startled her horse and those of others in the local equestrian club. Except for the flickering shadows, she says, the turbines seem to have no effect on the horses. The shadows simply cause the horses to stop briefly until their riders urge them on."* (Page 298)

4 COMPUTER MODELS

4.1 Introduction

As part of the development and planning process for a prospective wind farm, computer models are used by the developer in order to predict and quantify the impact shadow flicker may have on receptors within the vicinity of the prospective wind farm. The output of these models can be included in the environmental assessment of the wind farm.

There are three main computer packages which are used in the industry to model the phenomenon:

- WindFarm
- GH WindFarmer
- WindPRO

In addition to these packages, there was found to be two additional modelling tools available (add on packages to CAD and ArcGIS), however it is apparent that these tools have not been widely adopted by the industry.

4.2 Current Computer Models Used

WindFarm

The Shadow Flicker module of WindFarm is one of the most used in the industry. This software predicts the times throughout the year when shadow flicker is likely to occur and predicts a worst case scenario impact at the receptor/aperture where shadow flicker would be observed. A contour map and predicted shadow flicker times can be generated as outputs from this process.

The inputs to and outputs from the WindFarm model are summarised in Table 1 and Table 2 below.

Table 1: Inputs for WindFarm software.

Inputs
Receptor locations
Site Latitude and Longitude
Angle from grid north to true north
Wind farm layout and turbine specification
Time Zone (local regional time i.e. GMT)
Wind farm layout
Size of assessment area (specified in Metres, rotor diameters or tip height)
Maximum sun height
Earth's curvature

Table 2: Outputs from WindFarm software.

Output
Map Spatial Extent of Shadow Flicker
Time at which Shadow Flicker will occur

Garrad Hassan (GH) WindFarmer

The Shadow Flicker module of GH WindFarmer calculates the occurrence of shadow flicker impact time and intervals for receptors at given locations. In addition, a map of the spatial distribution of the impact of the shadow flicker can be generated. GH state (GH Website, accessed 2010) that the module allows the user to:

- Determine the accurate shadow flicker effect for a particular year
- Represent the turbine rotor as a sphere or as a disk
- Consider the offset and orientation between turbine rotor and tower
- Model the sun as a point or a disc
- Use the topography as alternative to the simplified flat terrain assumption
- Create maps of shadow flicker occurrence on an annual or daily basis
- Analyses the shadow flicker at specific receptor points, of given elevation and orientation
- Identify the shadow flicker periods from each turbine onto each receptor

The module can also be used in 'real-time' and in conjunction with a SCADA (Supervisory Control And Data Acquisition) system, where it can be used to switch of the turbine when the shadow impact would cause disturbance.

Inputs to and outputs from the model are summarised in Table 3 and Table 4 below:

Table 3: Inputs for WindFarmer software

Inputs
Site Latitude and Longitude
Time Zone
Maximum minutes per day (constraint)
Maximum hours per year
Calculation option (calculation to a defined distance from the centre of the project or from each turbine)
Minimum Elevation Angle of the Sun
Calculation time interval (temporal resolution of model)
Model sun as a disc (yes/no)
Height above ground for shadow flicker mapping
Terrain and Visibility (options include No calculation of visibility due to terrain, use terrain to calculate turbine visibility and use terrain to calculate turbine and sun visibility)

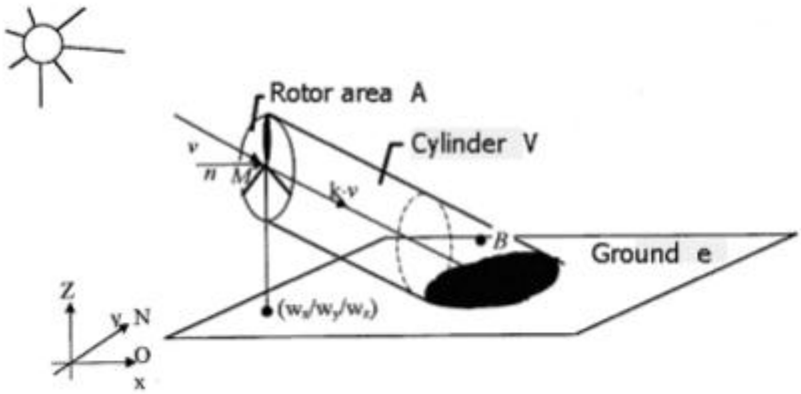
Table 4: Outputs from WindFarmer software

Output
Map of Spatial Extent of Shadow Flicker
Times at which SF is most likely to occur

WindPRO

The Shadow Flicker module (SHADOW) in WindPro calculates how often and in which intervals a specific neighbour or area will be affected by one or more wind turbines. The calculations are again 'worst case scenarios'.

The model calculates outputs using the following principles:



Source: WindPro tutorial, accessed 2010

Inputs to and outputs from the model are summarised in Table 5 and Table 6 below:

Table 5: Inputs for WindPro software

Inputs
The position of the WTGs (xyz coordinates)
Hub Height and rotor diameter
Position of the receptor (x,y,z, coordinates)
The size of the window and it's orientation, both directional(relative to south) and tilt (angle of wind pane to the horizontal)
Site Latitude and Longitude
Time Zone
A simulation model

Table 6: Outputs from WindPro software

Output	
Main Results	
Calendar for each shadow receptor	Timetable of sunrise and sunset for each day of the year in local time
	Table for when Shadow impact may occur for each day of the year, total hours of impact per day
	Number of turbines which may cause shadow impact
	Total hours of impact month by month
	Reductions due to sunshine and statistics of operational hours
Graphic calendar	
Calendar per wind turbine	
Calendar per wind turbine, graphical	

Map	

4.3 Discussion of Models

Inputs

The input parameters needed to run each of the models are essentially identical including Longitude and Latitude, Time Zone, wind turbine specification and topography. However, some differences can be observed in the entry of constraint and receptor inputs.

Defining Criteria

All of the models allow the modelling extent to be defined as either a spatial or temporal extent. These extents are set usually with reference to guidance or local planning authority advice. The spatial extent is usually defined with the wind turbine as the origin, though in WindFarmer it is possible to define the spatial extent from the centre of the project as it appears in the screen window. In addition, GL WindFarmer is the only computer model where the maximum length of time of exposure can be defined as a constraint.

Defining Receptors

The input of receptor parameters (e.g. location of receptor, size of window) slightly varies across the models and is a potential source of subjectivity and error in the output of the model since they are user defined. In addition, the way in which this data is input into the models varies. For example in WindFarm, window size, tilt and orientation are defined in the *Designer*, whereas in GH WindFarmer, location, orientation of the window, the height of the window can be defined, however the size of the window is assumed to be constant. This may lead to variations in the output of the model.

Defining sun angle

Sun angle is manually defined by the user and values are dependent on the terrain and aspect of the turbine. GH WindFarmer describe that for flat terrain a sun angle value of approximately 3° is appropriate, however for more undulating or mountainous terrain then it would be reasonable to increase the sun angle value because the terrain will have a sheltering effect on the receptors. All three models allow the sun angle variable to be defined by the user.

Digital Terrain Model Data

All packages allow the input of terrain data. The data needs to be clean of all anomalies and if possible ground truthed.

Worst Case Scenario

We have evidence to suggest that all of the models predict a 'worst case scenario' impact of the shadow on properties, as discussed already in other Sections of this report. It must be noted that this worst case scenario is not explicitly stated in the GL WindFarmer literature.

Assuming the turbine rotor as a disk

The impact of the shadow is intermittent and variable depending on the wind speed which can not be analysed in any of the software packages. The turbine rotor is assumed to be a disk which can not be penetrated by sunlight. Any shadow generated by this disc onto the receptor is classed as an impact.

Turbine Yaw Direction

It is assumed in all of the models that the rotor is yaw angle is set at 90° to the receptor to model maximum interference. In reality, the yaw of the turbine would vary with the wind direction, therefore the shadow impact would be variable.

Sunlight conditions
The sunlight conditions used in the software models are set up to result in a worst case scenario. The weather is always assumed to be sunny which would cause the greatest shadow effect. In reality sunlight intensity is dependent on factors including cloud cover and time of day.

Obstacles
All of the models allow the user to input terrain data although they do not take into account obstacles between the turbine and the receptor, for example, trees or buildings.

4.4 Applying the Computer Models

To compare these three models, Parsons Brinckerhoff has obtained versions of the software packages and has run the same scenario in each package. The results of this can be seen in Figure 2 to Figure 4 below.

An area in the Scottish Borders was chosen for the model as this area had diverse terrain, with a ridge to the north west of the turbine and undulating terrain elsewhere. A single turbine was placed in this landscape. The turbine model chosen was typical for modern onshore machines, with a 70m hub height and 80m rotor diameter. In each case, shadow flicker was calculated for a 2.5km radius around the turbine, thus far larger than the 10 rotor diameter rule. Shadow flicker receptors were added in a radial manner with an incremental spacing of 500m from the turbine as can be seen in the figures.

It should be noted that the shadow flicker calculation area can be defined in the software – 2.5 km was chosen as an indicative value so that the models could be compared with each other. The shadows are likely to be too diffuse at this distance to have an impact.

The contours used in the outputs from the model are spaced at 20 hrs/year, with the outer most (large blue) contour representing 0 – 20 flicker hrs/year. This was considered the most appropriate ‘bin size’ given the magnitude of flicker. Whilst it was not possible to match the contour colours between the models exactly, similar colours were chosen so that a visual comparison is possible.

It can be seen that the outputs from the three models are very similar, and whilst there are some differences at the edges of the model, the models show very similar results within 1 km from the turbine. Also, the shape of the shadow area is very similar where it interfaces with the terrain, especially to the west of the turbine.

There are differences between how Windfarm and Windpro calculate shadow start and end times. In Windfarm, the mapping data is entered in rectangular grid coordinates (for example bng grid in the UK). To calculate where on the surface of the planet the site is, (to calculate when the sun rises and sets), Latitude and Longitude coordinates need to be entered. In Wind Farm, there is an automatic conversion tool between most coordinate systems used across the world. This is used to calculate shadow times for the project which can be fed into shadow flicker timers for mitigation. In the Windfarmer ‘control panel’ it is also possible to set up the Latitude and Longitude values for this reason.

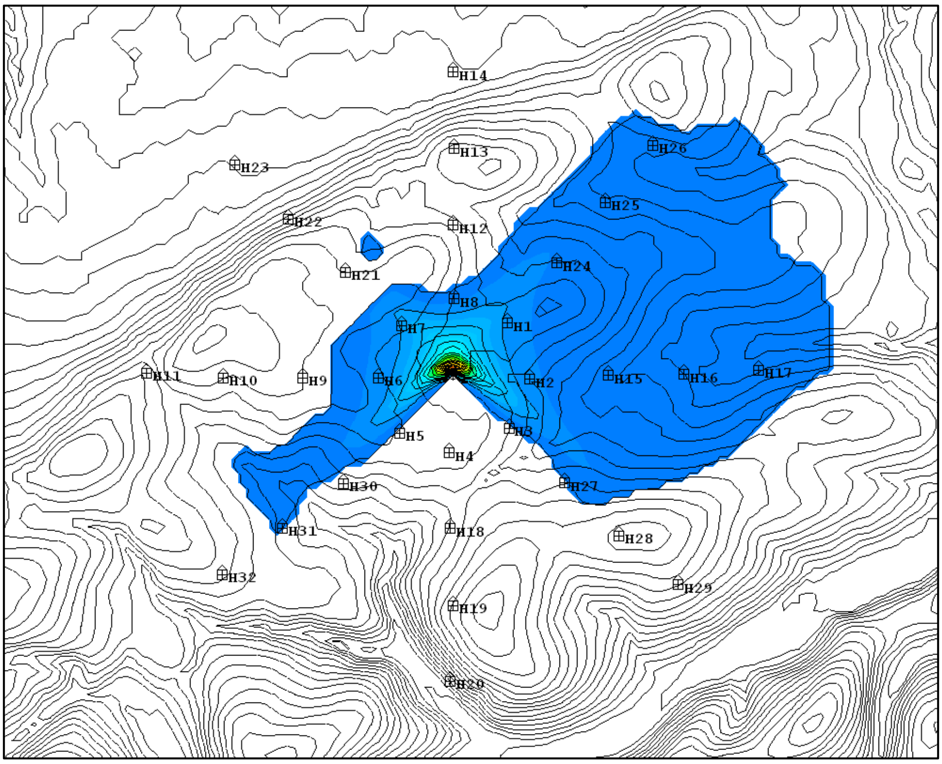


Figure 2: Output from Windfarm software

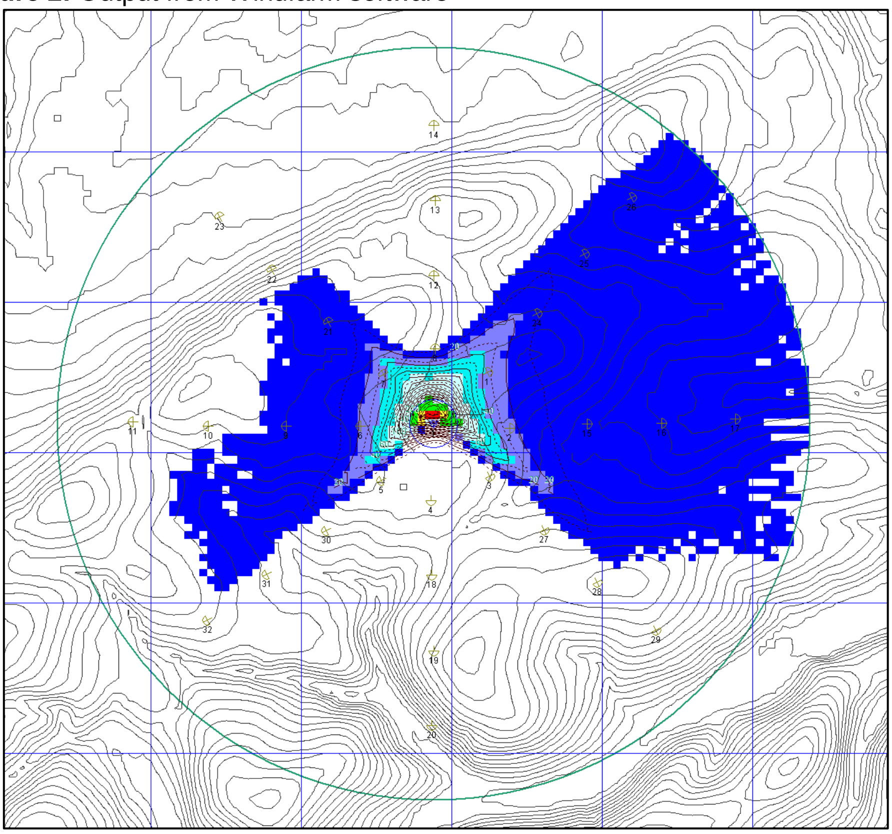


Figure 3: Output from WindFarmer software

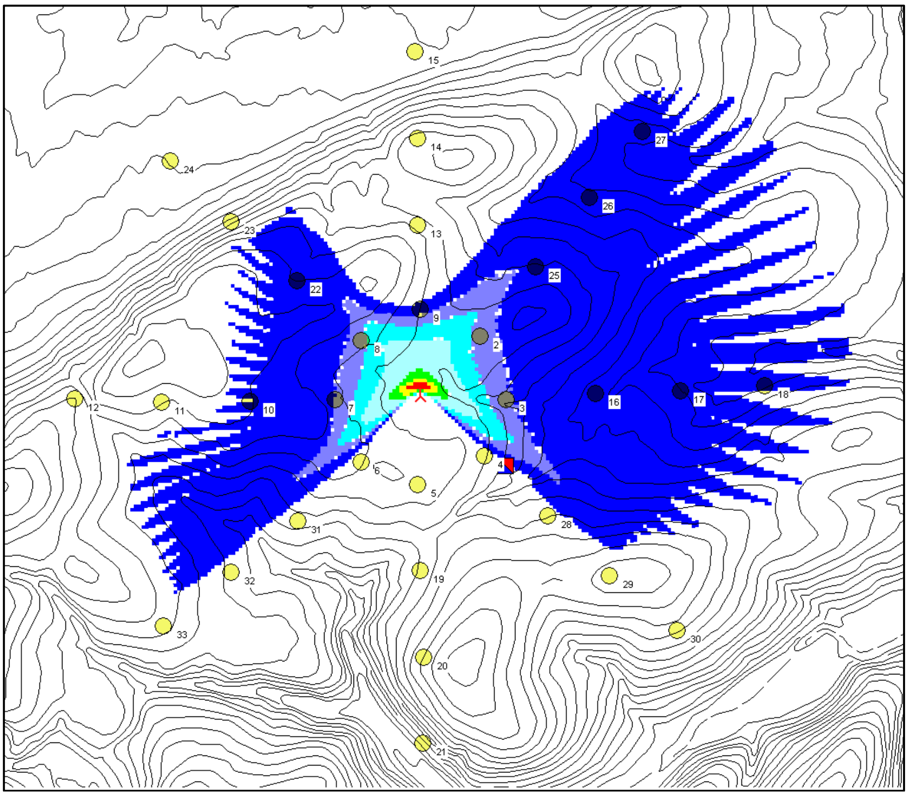


Figure 4: Output from WindPRO software

It appears that there are obvious similarities between each of the three models which have been reviewed, though it is difficult to quantify as the software vendors do not give details of the algorithms which are used to calculate the spatial and temporal extent of the flicker phenomenon.

4.5 Conclusions

This section has investigated the computer models available on the market. The three computer models investigated are similar in their approach to calculating shadow flicker around wind turbines. None of the software packages allow the input of real climatic parameters, and so can only be used to produce 'worst case' shadow flicker assessments.

For the purposes of demonstrating and comparing the outputs, the three computer systems were used to model simple scenario of a single wind turbine in a location in the Scottish Borders. The results from these models are displayed as contour plots which show very similar shadow flicker patterns close to the turbine with minor discrepancies between the models at distances further from the turbines.

5 STAKEHOLDER QUESTIONNAIRE SURVEY.

5.1 Introduction

In an effort to gauge the opinion of the wind energy industry on shadow flicker issues, questionnaires were distributed to industry stakeholders. Different questionnaires were produced, with one aimed at developers and consultants working in the industry and one aimed at local planning authorities (LPAs). There were four variants of this LPA questionnaire specific to planning authorities in England, Scotland Wales and Northern Ireland.

This section outlines the methods that PB employed to obtain data from these parties, and the resulting data which has been analysed to look for trends in data and parameters. This is not intended as original research but as a study into the extent of shadow flicker issues in the UK.

It must be acknowledged that the responses which are reported in this section are the viewpoint of the stakeholders consulted and thus may not be evidential based.

5.2 Methodology

The questionnaires were produced as a 'PDF form', which could be edited directly using standard adobe PDF reader software. The format allowed respondents to email the data back to PB using a dedicated email address. In case of technical issues with this method, PB provided several submission options and additionally provided contact details so that we could assist directly. This approach was developed to speed up the process, helping to ensure a high response rate, and for the environmental reason of reducing paper use.

Industry Questionnaire
The questionnaire can be found in the Appendices.

The specific aims of this questionnaire were:

- To determine the extent to which developers and consultants use the shadow flicker indicators in 'Companion Guide to Planning Policy Statement 22' (or relevant country guidance) to model shadow flicker, and to determine methodologies used to assess the occurrence of the phenomenon;
- To ascertain whether developers thought the planning guidance was sufficient for the assessment of shadow flicker, and their opinion on whether other approaches to setting guidance would be more appropriate; and,
- To improve understanding of shadow flicker impacts at operational wind farms, looking for case studies where shadow flicker was found to be causing an issue and to assess the effectiveness of current mitigation measures.

The industry questionnaire was sent out to 178 company members on the mailing list of the industry association RenewableUK. A reminder email was sent three days before the final submission deadline to help ensure the highest response rate possible. 14 responses were obtained and discussion of the results from this questionnaire can be found in the section below.

Local Planning Authority Questionnaire
The questionnaire was sent to all Local Planning Authorities and England, Wales, Scotland and Northern Ireland. Additionally, the Welsh Planning Division and the Clean Energy & Steel Production Department were invited to participate in the questionnaire. Although not

able to offer a response, staff at the Assembly Government did offer advice on relevant guidance documents and suggested key developers who should be contacted.

The specific aims of this questionnaire were:

- To determine the extent of LPAs knowledge of shadow flicker, and their opinions on 'Companion Guide to Planning Policy Statement 22' (or relevant country guidance) to model shadow flicker;
- To ascertain whether developers thought the planning guidance was sufficient for the assessment of shadow flicker, and their opinion on whether other approaches to setting guidance would be more appropriate; and,
- To improve understanding of shadow flicker impacts at operational wind farms, looking for case studies where shadow flicker was found to be causing an issue and to assess the effectiveness of current mitigation measures.

5.3 Industry Questionnaire - Response Summary

Fourteen questionnaire responses were received from developers and consultants working in the wind industry. Of these respondents, thirteen stated they have been involved in preparing shadow flicker assessments for onshore wind energy developments in the UK, five have presented evidence at public local inquiry and five are involved in 'Operation & Maintenance' of operational onshore wind farms.

Questions were split into the following four sections:

1) General assessment criteria – questions were designed to assess the degree of variance between assessment criteria methodologies for shadow flicker assessments in Environmental Statements.
2) Computer models – questions were designed to gauge the parameters that input into shadow flicker models.
3) Operational experience – collection of case study information on complaints relating to shadow flicker, operational experience in relation to mitigation measures, and anecdotal evidence of observed shadow flicker effects.
4) Current guidance – questions designed to gauge opinion on key elements of Companion Guide to PPS22 or other national guidance documents.

Please note - where a respondent has not provided comment, or stated that the question is not applicable to them, they have been excluded from the summary statistics.

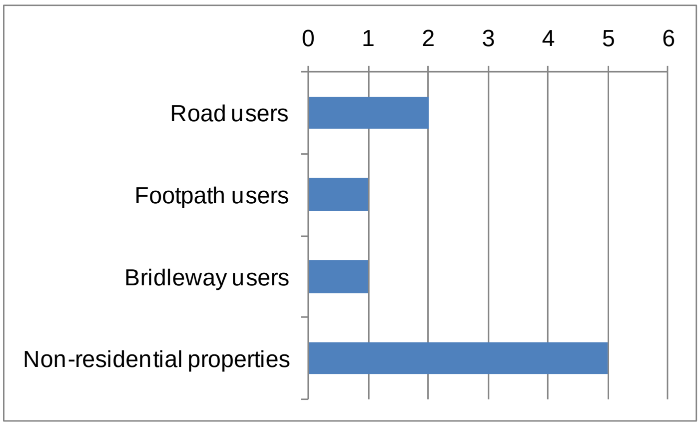
General assessment criteria
When determining the size of the assessment area, 10 out of 13 respondents adopt the 10 rotor diameter' rule. Other approaches that were adopted include:

- Using a combination of '10x rotor diameter' rule with a 2km fixed radius; and
- Assessing properties which lie just outside the '10 x rotor diameter' area.

10 out of 13 respondents only assess shadow flicker impact on users within residential properties, whilst 2 respondents assess the 'shadow flicker' impact on users both within residential properties and in the curtilage of properties. This report has is concerned only with that inside properties and through a constrained opening such as a window, however it is important that this point as part of the stakeholder responses.

Receptors that respondents include in shadow flicker assessments, are shown in Figure 5 below.

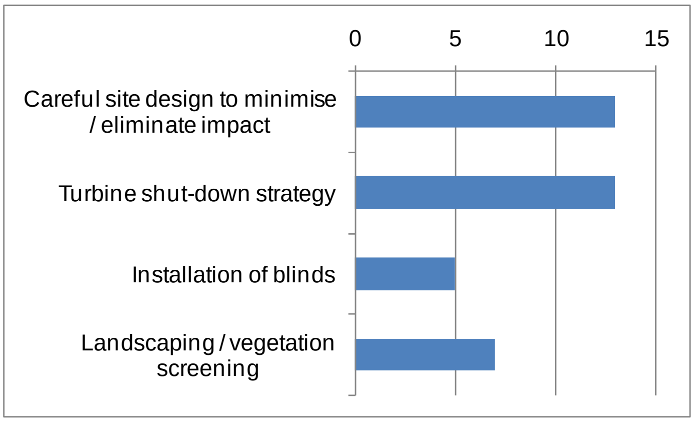
Figure 5: Results from Question 7: What receptors do you assess shadow flicker effects on?



It is clear from the responses that many developers and consultants assess shadow flicker impacts on non-residential properties, but it is not common to assess the impact of passing shadows on road, footpath, and bridleway users. Several respondents adapt their assessment methodology to meet the requirements of the LPA or specific requests from other stakeholders. Two respondents made it clear that shadow flicker is restricted to the interior of buildings.

A summary of questionnaire responses relating to various mitigation measures for shadow flicker impacts can be seen in Figure 6 below:

Figure 6: Results from Question 8: "When preparing a planning application, what mitigation strategies for predicted shadow flicker effects do you propose?"



All four mitigation options have been proposed by different respondents, with 'careful site design' and 'turbine shut down' ranking as the most popular.

Computer models

For the purposes of undertaking shadow flicker assessments, it is clear that three computer modelling software packages are used by all respondents – these programmes are WindFarm, Windfarmer, and WindPro. All three are discussed in greater detail in Section 4. With one exception, all respondents felt the respective software package was satisfactory for preparing shadow flicker assessments that are of an appropriate standard to support a planning application.

When undertaking shadow flicker assessments, 7 out of 13 respondents include field data or site-specific environmental data in their software models, while 6 out of 13 respondents do not include this data. The following comments were included elaborating on the data included in software models:

- Existing screening is taken into account;
- Topographical models (Digital Terrain Models) are included in the model;
- Location of residential properties are considered;
- Initial screening of properties by potential visibility using a Zone of Theoretical Visibility (ZTV) graphic;
- Turbine layout and dimensions;
- Wind rose information to provide idea of predominant wind direction;
- Orientation and size of receptor windows.

It is clear from the above responses that LPA's requirements for information input into software models varies, due to a lack a standard methodology for shadow flicker assessment.

The questions in this section asked respondents about whether their shadow flicker assessments adhere to the 'worst case scenario'. This was defined as:

- Continuous sunshine during daylight hours;
- Continually rotating turbine blades;
- No vegetation or other obstacles are screening the receptor;
- The wind turbine rotor plane is always perpendicular to the receptor and sun.

10 out of 12 respondents felt that their shadow flicker assessments adhered to worst case scenario criteria. Of the respondents that responded that their shadow flicker assessments did not adhere to the worst case scenario, the following comments were provided:

- Proportion of time that turbines were operational was taken into account;
- Both worst case and 'realistic' shadow flicker duration figures were considered;
- Sunshine data was included when preparing a 'realistic' shadow flicker duration figure.

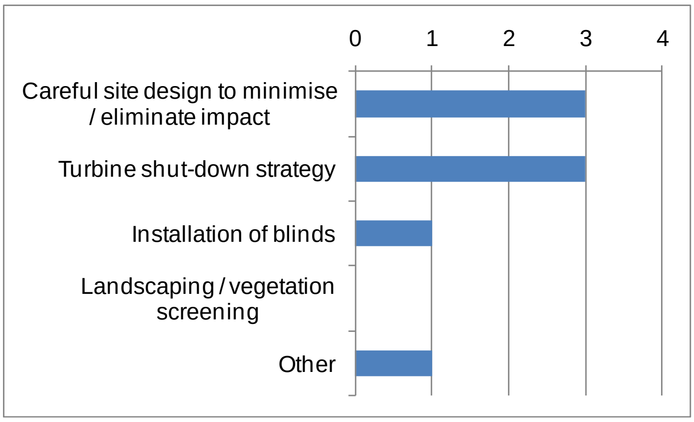
Operational experience
5 out of 12 respondents own or manage operational wind energy developments, of which 2 respondents were owners, four respondents were operators, and one respondent was involved in technical operations.

Three respondents noted complaints in relation to shadow flicker at their operational wind energy developments. Details of their comments are listed below.

- *A member of the landowners family has observed shadow flicker but this has not given rise to a complaint, as such no resolution was required or requested.*
- *Wind farm in flat, lowland location – complaints arose during commissioning and related to dwellings within '10 x rotor diameter' that were identified in the Environmental Statement as being potentially at risk. Sensor-triggered operational management and turbine shut-down has been implemented and is expected to resolve the situation.*
- *Complaint from a office building that was not built at the time of consent.* Please see case study information in section 5.5 below for more information.

Of the respondents who operate or manage wind energy developments, it was noted that careful site design and turbine shut-down strategies were the most popular implemented mitigation strategies, whilst installation of blinds also featured. Landscaping / vegetation screening did not feature. The results are shown in Figure 7 below.

Figure 7: Results from Question 8: What mitigation strategies for shadow flicker effects have been implemented on your operational wind energy developments?



The respondents who stated they had implemented both careful site design and turbine shut-down strategies noted that no complaints had been received and by virtue of this it could be assumed that the mitigation measures had been successful. One additional respondent stated that the turbine shut-down strategy had been ultimately successful – further case study details are provided in Section 5.5.

One respondent noted that contact details for Operation & Maintenance staff were provided to affected properties to implement turbine shut-down.

No respondents stated that they had observed shadow flicker effect occurring outside buildings or in other circumstances different from those set out in current guidance (which states "shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening"). One respondent commented:

> *"Shadow flicker can only occur within properties through a restricted space. The effect through a narrow window opening is totally different to the effect out of doors where the high ambient light and diffuse shadow conditions cannot create the same level of disturbance."*

Current guidance

9 out of 13 respondents consider the '10 x rotor diameter' rule an appropriate area for shadow flicker assessments. Of the remaining respondents, most believed a combination of a fixed radius and the '10 x rotor diameter' rule would provide an appropriate alternative. One respondent provided a justification for adopting a fixed radius approach, commenting:

> *"In general for most of the UK the '10 x rotor diameter' rule is sufficient, however in higher latitudes where the sun is lower in the sky for longer, it might be appropriate to introduce a fixed radius. A study would be required to define this fixed radius as shadows become very diffuse further out and it is important not to define a radius which is too conservative."*

8 out of 12 respondents believed shadow flicker assessments should be limited to the interior of residential buildings. Of the four remaining respondents, one commented that an assessment of the impact on users of adjacent A roads and motorways is sometimes requested by the Highways Agency due to the potential for driver distraction, and three

respondents felt shadow flicker assessments should extend to non-residential properties. One respondent commented:

> *"High-occupancy non-residential buildings such as offices should be afforded similar protection to residential properties, within the context of the likely occupancy of the building at the time when shadow flicker is calculated to occur."*

There was a varied response to the value of adopting quantitative guidance on shadow flicker effects. The majority (8 out of 11 respondents) felt that quantitative guidance was inappropriate for the following reasons:

- Difficulties in quantifying acceptable levels of shadow flicker impact due to local environmental factors (eg. existing screening, cloud cover) and site specific details (eg. number of properties affected, number and nature of rooms affected, duration of effect, strength of shadowing, etc)
- Worst case scenario shadow flicker duration figures can be misinterpreted by the public as definitive impact; and
- Impacts should be assessed on a site by site basis.

The two overarching themes that emerge from this question on quantitative guidance are the difficulties in setting a level on acceptability of shadow flicker impact, and the potential for a development to be rejected where mitigation measures could provide a complete solution.

Further comments were welcomed at the end of the questionnaire. Several respondents took the opportunity to stress that shadow effects outside buildings should not be confused with shadow flicker, as the effect is much less severe. One respondent commented that there is a lack of case study data relating to shadow flicker impacts, and that an evidence base rather than limits and separation distances would be more useful. Other notable responses are included below:

> *"I think it would be a positive step to introduce some form of approach to methodology for assessing shadow flicker effects that would work in a similar way to ETSU and noise, that way it would give clarity to developers, planning authorities and communities alike that a clear and consistent framework was being worked within."*
>
> *"Guidance should be clear that shadow flicker can be accurately predicted. It should state that shadow flicker effects can be successfully mitigated and that mitigation can be successfully secured by way of a planning condition. In this respect shadow flicker issues should not be cited as a reason for refusal in a planning decision."*

5.4 Local Planning Authority (LPA) Questionnaire Responses.

Seventeen responses were received from the questionnaire that was sent to LPAs, of which ten were from councils in England, one from each of Wales and Northern Ireland and five from councils in Scotland. All of those councils who responded offer pre-planning advice to onshore wind energy developers, with the majority (13 out of 17) providing pre-planning advice specifically on shadow flicker. However, only seven of the councils offer guidance on how the shadow flicker impact could be assessed.

Please note - where a respondent has not provided comment, or stated that the question is not applicable to them, they have been excluded from the summary statistics.

Questions were split into the following four sections:

1) Current guidance – questions related to current UK guidance and are designed to gauge opinion on key elements of Companion Guide to PPS22, or relevant country specific guidance.
2) Best Practice Shadow Flicker Assessments – questions designed to assess the LPAs opinion on current shadow flicker assessment methodologies.
3) Proposed Mitigation Measures – questions on mitigation measures and planning conditions related to shadow flicker.
4) Operational experience – this section collected case study information on complaints relating to shadow flicker, operational experience in relation to mitigation measures, and anecdotal evidence of observed shadow flicker effects.

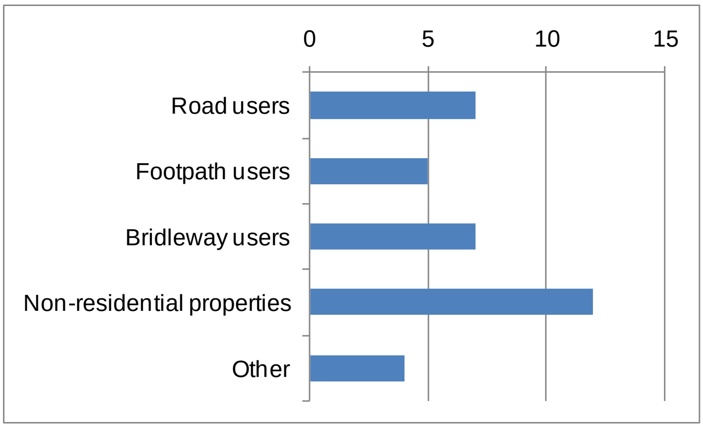
Current Guidance

This section looked at current guidance in the UK. There was general consensus among the respondents (13 out of 17) that the ten rotor diameter rule provided an appropriate area for shadow flicker assessment, with three councils having the opinion that this rule was not appropriate. Three councils had the opinion that using a combination of a fixed radius and the '10 x Rotor Diameter' would be a preferable approach, with four councils specifying alternative approaches.

Some useful comments were made on the subject of alternative approaches, especially that the assessment distance should take into account the height of turbines as well as rotor diameter, and that the 10 rotor diameter approach may not be appropriate with turbines sited on higher ground, as shadows may be thrown further. Additionally, a comment was made that the assessment distance should also be determined by the project latitude, solar elevation, height, rotational rate of turbines and cumulative impact of aligned turbines.

Although blade shadows passing across windows produce a different impact (shadow flicker) to shadows passing across open ground, a question was asked to determine opinion on whether outdoor impacts should be assessed. Four councils responded that assessment should be limited to inside buildings; with thirteen responding that the impact on other receptors should be assessed. Figure 8 shows the receptors that councils would like to see assessed.

Figure 8: Results from Question 7: If you don't think shadow flicker assessments should be limited to the interior of buildings, what receptors should be included?



Some useful comments were made on the reasons LPAs thought other receptors should be taken into account. Several comments were made that road user distraction and safety was important, with several also commenting on safety of horse riders on bridleways. There were several comments that shadow flicker has the ability to affect office / commercial workers and so it is important to assess these buildings in addition to residential buildings.

There was a generally positive attitude towards adopting quantitative guidance in the UK, although various concerns were raised about how this could be implemented in practice. Several respondents commented that having quantitative guidance would be simple to assess against. One respondent suggested that the guidance should not necessarily be carried out based on only the 'number of hours' but that also a secondary 'sensitivity' measure should be used based on the usage of affected buildings. An example of this is that early evening hours may be more valuable as 'family time' than other times of the day.

Best Practice Shadow Flicker Assessments

The four questions in this section asked respondents about whether shadow flicker assessments should adhere to the 'worst case scenario'. This was defined as

- Continuous sunshine during daylight hours;
- Continually rotating turbine blades;
- No vegetation or other obstacles are screening the receptor;
- The wind turbine rotor plane is always perpendicular to the receptor and sun.

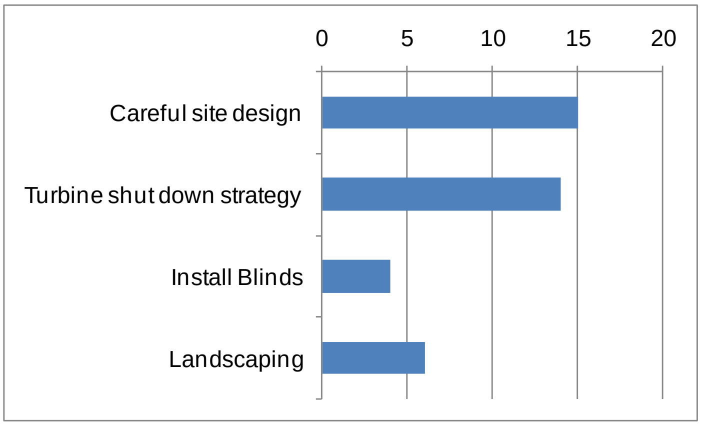
Of the respondents, eleven had the opinion that assessments should adhere to this worst case model, with six not considering this to be suitable. Five comments were made that a likely / realistic shadow flicker assessment needs to be carried out alongside this worst case model. A concern was raised that any method used other than worse case would lead to assumptions being made that could be challenged in the planning process.

Twelve respondents thought that the addition of field data would aid the assessment process, with four not considering field data to be necessary. It was noted that the use of field data can aid an assessment by making it more realistic. It was also noted that site specific data should be included as it can help planners to make an informed decision on a development.

Proposed Mitigation Measures

Three questions were asked about mitigation measures used to limit shadow flicker from wind energy developments. Figure 9 below shows the strategies that councils consider to be appropriate when considering planning applications with potential shadow flicker issues.

Figure 9: Results from Question 15: When considering a planning application, what mitigation strategies for predicted shadow flicker effects do you consider appropriate?



It is clear that designing the development in such a way that shadow flicker does not occur is considered the most preferable option, with the implementation of a 'turbine shut down strategy' considered the next preferred option.

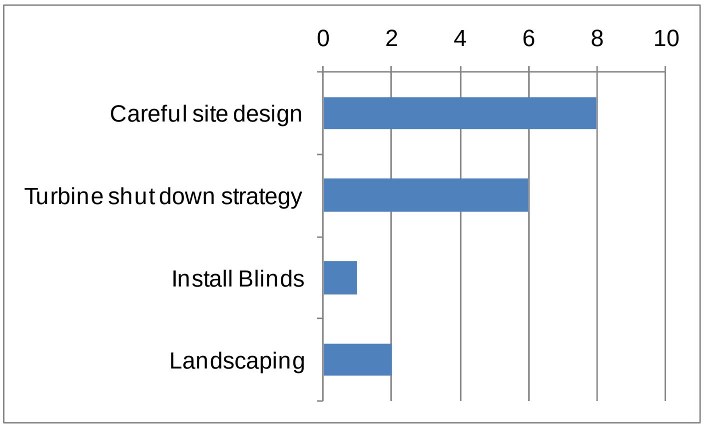
Of the councils questioned, nine have been involved with assigning a planning condition relating to shadow flicker, with eight not having assigned a planning condition related to shadow flicker. There was a range of planning conditions supplied by the councils, from the specific, (outlining the mitigation strategy to be used) to more general conditions (specifying that approved measures should be implemented should complaints be received).

Operational Experience

Of the councils who responded to the questionnaire, only one had received a complaint about a shadow flicker issue from an operational windfarm. In this case, business park workers complained of the shadow flicker effects. The issue was resolved by implementing a 'turbine shut down' protocol that acted when certain conditions of sun/alignment prevailed, or when a complaint was made from the office workers.

The mitigation strategies that have been implemented by the councils that responded are shown in Figure 10 below.

Figure 10: Results from Question 20: What mitigation strategies for shadow flicker effects have been implemented on operational wind energy developments within your planning area?



It can be seen that the most popular operational mitigation approach is to install shadow flicker timers using a turbine shut down strategy. For some of the councils, turbines have yet to be built, so it remains to be seen if the strategy has been a success, however a comment was made that this approach was successful in that no complaints had been received. It was also noted that the use of blinds and planting as mitigation approaches are considered less acceptable as they are harder to enforce, may not necessarily work and planting may not establish.

Additional Comments

A final comments box was provided for respondents to provide any additional information on shadow flicker. Whilst the majority of councils did not use this, two useful comments were raised, which reflect their experiences with the phenomenon.

The first comment was regarding the occurrence of shadow flicker, and that as it is only an issue on bright days, the occasions when it is likely to present a real problem to people in buildings nearby are likely to be few. Members of the public are often poorly informed and will assume shadow flicker to be a problem.

Another comment from one LPA was that shadow flicker has not been a major issue of concern to wind energy objectors. The visually intrusive nature of large scale proposals is the most common concern.

5.5 Operational Wind Farm Case Study

A case study has been taken from the questionnaire responses. For this wind farm, PB received information from both the developer and the Local Planning Authority involved in the development. This wind farm in Scotland has been left unnamed for reasons of confidentiality.

Complaint

Complaints were received from office users in a nearby business park, of flicker effects causing annoyance and triggering headaches. Environmental Health Officers from the local council investigated and concluded that there were adverse impacts as a result of the shadow flicker from the nearby turbines.

The office building was not in place at the time of wind farm consent or turbine installation, and was therefore not included in the shadow flicker assessment for the Environmental Statement. The first two wind turbines in the development were operational when the buildings on the site were developed for business uses. As personnel moved into the buildings, complaints were lodged over the shadow flicker effect, which especially occurred in the afternoon when the sun was from the west/ north west. Flicker became a major issue when a subsequent extension (four turbines) to the wind farm was developed and built. Both phases of development have turbines which are within ten rotor diameters of the office building.

Mitigation measures

Two mitigation measures were implemented – turbine shut-down using control modules on certain turbines that were causing the shadow flicker effect, and installation of blinds in the affected offices.

The turbine shut down strategy was deemed to have been relatively successful, although due to controller errors with the clock timer there were instances where the turbine was not shutting down at the correct times. An additional measure was implemented which allowed the complainant to contact ‘Operation & Maintenance’ staff who could remotely shut-off the turbines.

Result

The complainant was satisfied with the developer’s mitigation actions and stated that their concerns had been alleviated. Both the developer and Local Planning Authority considered that the issue had been resolved by the mitigation measures implemented.

6 RESULTS ANALYSIS

A number of themes have arisen during the course of the guidance and literature review that warrant further discussion. This section separates out individual overarching themes and provides a summary of variations and common understanding between national guidance and academic literature. The key themes that are discussed in greater detail below are as follows:

- Section 6.1 - Assessment area – geometrics of study area
- Section 6.2 - Assessment area – radius of study area
- Section 6.3 - Quantitative guidance
- Section 6.4 - Shadow flicker in offices
- Section 6.5 - Indoor assessment versus outdoor assessment
- Section 6.6 - Proposed mitigation
- Section 6.7 - Health effects - epilepsy
- Section 6.8 - Health effects and nuisance
- Section 6.9 - Environmental and site-specific factors
- Section 6.10 - Planning conditions

The authors also note that during the literature searches, no regulatory policy relating to shadow flicker was found; in all countries where it is a perceived issue, shadow flicker falls under the remit of best-practice guidelines.

It is clear from our literature searches that much of the academic research on the subject of shadow flicker was carried out in the 1980s and 1990s. Since then, turbines have got larger with lower blade rotational frequencies, so some of the results may not be directly applicable to modern turbines found on the market today.

6.1 Assessment area – geometrics of study area

England's Companion Guide to PPS22 (2004) and BERR (2007), and Northern Ireland's Best Practice Guidance to PPS18 (2009) state that only properties within 130 degrees either side of north of a particular turbine can be affected by shadows. Verkuijlen & Westra (1984) confirm this assertion, stating that particularly large areas to the east-northeast and west-northwest of the turbine experience shadows for long periods of time. Both German guidance (2002) and Verkuijlen & Westra (1984) provide figures demonstrating the azimuth extent of the shadow flicker zone.

The concept of limiting the assessment to within 130 degrees either side of north is not contested (nor are any alternative assessment methodologies proposed) in any guidance documents or academic literature.

6.2 Assessment area – radius of study area and 10 x rotor diameter

England's Companion Guide to PPS22 (2004) and BERR (2007) state that shadow flicker only occurs within '10 x rotor diameters' of a turbine. Northern Ireland's Best Practice Guidance to PPS18 (2009) is not as explicit in this regard, stating instead that the potential for shadow flicker at distances greater than ten rotor diameters is very low. Similarly Scotland's PAN 45 (2002) guidance refers to the '10 rotor diameter' as a general rule and infers that outside this area shadow flicker should not be problematic. The Irish Planning Guidelines (undated) state that at distances greater than '10 x rotor diameter', the potential for shadow flicker is very low.

Based on case study evidence from an operational wind farm, Cornwall County Council (1989) concluded that for properties at a distance of 2 rotor diameters, maximum shadow duration is calculated as 2 – 7 hours per day for 13 – 26 weeks per year. For properties at a distance of 10 rotor diameters, maximum shadow duration is calculated as 30 – 45 minutes per day for 10-14 weeks per year. Clarke (1991) and Taylor & Rand (1991) recommend that turbines should be sited at least ten diameters distance from habitation, and Clarke (1991) states that greater separation may be necessary if properties are sited to the east - southeast or west – southwest.

Other international guidance documents adopt a fixed radius. The Danish Wind Industry Association website (2010) suggests that at distances greater than 500-1000 m from a wind turbine, the rotor will not appear to be 'chopping' the light, but the turbine will be regarded as an object with the sun behind it, and it is therefore not necessary to consider shadow casting at such distances. The South Australian Planning Bulletin (2002) notes that shadow flicker is unlikely to be a significant issue at distances greater than 500 m.

The majority of industry respondents who completed the questionnaire as part of this study both used the '10 x rotor diameter' rule when preparing a shadow flicker assessment, and considered it an appropriate survey distance. Of particular note is the potential need for a differentiation between impacts at different latitudes, as the sun is lower in the sky for longer at higher latitudes, an assertion that is supported by an LPA respondent.

Similarly to industry responses, there was general consensus among LPA respondents that the '10 x rotor diameter' rule was an appropriate assessment area.

It is worth noting the Danish Wind Energy Association website comments that the hub height of a wind turbine is of minor importance in determining the shadows cast from the rotor. The same shadow will be spread over a larger area resulting in a reduced intensity of shadow in the vicinity of the turbine.

6.3 Quantitative guidance

England's Companion Guide to PPS22 (2004), Northern Ireland's Best Practice Guidance to PPS18 (2009), and Scotland's PAN45 (2002) (among others) require shadow flicker impacts to be quantified by the assessor, however only Northern Ireland's Best Practice Guidance to PPS18 (2009) and Irish Planning Guidelines (undated) set quantitative limits for acceptable duration at 30 hours per year or 30 minutes per day at neighbouring offices and dwellings. In addition, Predac (2004) recommends that shadow flicker should not exceed an astronomic worst case figure of 30 hours per year or 30 minutes per day at neighbouring offices and dwellings, however there is considerable variation between the limits set in Germany, Denmark, and the Netherlands.

German guidance (2002) adopts two maximum limits:

- An astronomic worst case scenario limit of 30 hours per year or 30 minutes on the worst affect day; and
- A realistic scenario taking account of meteorological parameters limited to 8 hours per year.

Gipe (1995) states that operational experience from the Untied States suggests shadow flicker has generally not been recognised as a significant issue. In addition, a survey by Widing et al. (2005) of residents in Swedish towns near an operational wind farm concludes that respondents who claim not to be impacted by shadow flicker were exposed to the phenomenon mainly in the morning or in winter. Contrastingly, those who do experience shadow flicker are mainly exposed in the evenings (Widing et al., 2005).

The majority of respondents to the industry questionnaire expressed concerns that quantifying acceptable levels of shadow flicker duration would be problematic due to latitudinal variations of impact, and the potential for wind energy developments to be rejected where, in reality, mitigation measures could provide a complete solution. Conversely to the developer's response, LPAs were generally in favour of adopting quantitative guidelines, although concerns were raised about the practicalities of implementation, in particular the need to characterize the sensitivity of receptors in order to determine appropriate levels of shadow flicker. It is thought that LPAs favour a quantitative solution as it is straightforward to assess when developments are taken through the planning process.

6.4 Shadow flicker in offices

Several guidance documents recommend that in addition to residential properties, shadow flicker impacts at offices neighbouring a wind energy development should also be assessed. Northern Ireland's Best Practice Guidance to PPS18 (2009), Predac (2004), and Irish Planning Guidelines (undated) all state that shadow flicker impacts should not exceed 30 hours per year or 30 minutes per day at neighbouring offices, with Irish Planning Guidelines (undated) limiting the survey area to within a 500m fixed-radius. Of the literature review carried out, no academic references to assessing shadow flicker in offices were found.

The shadow flicker case study (*Section 5.5*) received from our consultation was a complaint at an office premises, that was developed after the wind farm was built. In this situation, it was decided that no level of shadow flicker was acceptable, and shadow flicker timers were installed to shut down the turbines that caused the issue. This successful mitigation strategy solved the shadow flicker problem in this instance.

6.5 Shadow flicker – indoor assessment versus outdoor assessment

England's Companion Guide to PPS22 (2004), Northern Ireland's Best Practice Guidance to PPS18 (2009), and Scotland's PAN45 (2002) state categorically that shadow flicker impacts are limited to the interior of buildings. This assertion is also supported by Western United States guidance (2005), and Taylor & Rand (1991) who state that shadow flicker effect is confined to people inside buildings exposed to light from a narrow window source. Clarke (1991) claims that shadow flicker effect is pronounced in rooms facing the turbine especially if the window is the sole source of light.

German guidance (2002), however, suggests that shadow flicker assessments may need to be extended to outdoor locations, suggesting a reference height of 2m above ground level. Widing et al. (2005) state that a recent Federal Housing Agency document entitled Boverket (2003) recommends that shadow flicker should be assessed both on the façade of a building (eg. indoors), as well as on the plot of land (eg. the curtilage of the property). Widing et al. (2005) raise concerns that appropriate shadow flicker duration limits for interior and exterior locations would need to be adopted.

No industry respondents to the questionnaire have observed shadow flicker occurring outside buildings or in circumstances different from those set out in Companion Guide to PPS22. The majority of developers and consultants only assess shadow flicker impacts on users within residential properties, with two also assessing the impact on users within the curtilage of a property. It is also clear from the questionnaire, that developers and consultants are receptive to assessing non-residential properties, but have reservations (albeit with a few exceptions) about assessing road, footpath and bridleway users. One issue that was raised repeatedly by developers and consultants is the need to distinguish between the shadow flicker phenomenon that occurs inside a property through constrained openings, and an entirely different phenomenon, referred to as passing shadows in outdoor locations.

A number of LPA respondents (14) would like to see shadow assessments extended to cover users other than those inside residential buildings. Conversely to the industry responses, LPAs considered that the assessment should include road and bridleway users for safety reasons, as well as users of offices and commercial premises.

Canadian guidance (2006) states that farm animals and horses adapt to shadow flicker impacts within a brief acclimatization period. Gipe (2004) suggests that experience in North America has shown that shadow flicker may cause a horse to stop briefly until the rider urges them on.

6.6 Proposed mitigations

A summary of recommended mitigation measures from UK and international guidance documents is included in Table 7 below.

Table 7: Summary of mitigation measures in International guidance.

	Careful site design	Turbine shut-down	Installation of blinds	Landscaping / vegetation screening
United Kingdom guidance				
England	Yes			
Northern Ireland	Yes	Yes		
Wales	Yes	Yes	Yes	Yes
International guidance				
Ireland	Yes	Yes		Yes
Germany		Yes		
United States	Yes			Yes
Canada		Yes		
Non-governmental organisation guidance				
International Finance Corporation	Yes			

It is clear that the most commonly recommended mitigation measures in guidance are careful site design to minimise and where possible eliminate potential impacts, and implementation of a turbine shut-down strategy if necessary. Introduction of screening of wind turbines by landscaping and vegetation planting also feature strongly among recommendations, however installation of blinds in affected properties is exclusively advised by the Welsh guidelines (2010).

Verkuijlen & Westra (1984) state that in order to reduce shadow flicker effect, siting of new turbines is an important consideration. Verkuijlen & Westra (1984) also propose that in the Netherlands where the predominant wind direction is southwesterly (the same predominant wind direction as the UK), siting to the south of buildings would be a good compromise between maximising wind resource and minimising shadow flicker impact. Additional mitigation measures proposed by Verkuijlen & Westra (1984), Clarke (1991), and Taylor & Rand (1991) include installation of blinds and turbine shut-down strategies.

Of the questionnaire responses received from both industry and LPAs, the clear preference for mitigation options proposed at the pre-consent stage is careful site design, and implementation of a turbine shut-down strategy if required. Other mitigation measures that feature relatively strongly are introduction of screening through landscaping / vegetation planting, and installation of blinds. It was noted from the LPA questionnaire that installation of blinds and landscaping / vegetation screening are less acceptable as mitigation measures as they are harder to enforce and may not necessarily work.

The respondents who stated they had implemented both careful site design and turbine shut-down strategies noted that no complaints had been received and by virtue of this it could be assumed that the mitigation measures had been successful. In the case study (*Section 5.5*) relating to a complaint at an office premises, a dual approach was implemented involving a turbine shut-down strategy with radiation sensors and a direct shut-down request system between the complainant and Operation & Maintenance staff at the wind farm.

Freund (2002) notes that inaccuracies in shadow flicker modelling methodologies may result in wind turbine operators facing unnecessary turbine shut-down systems. It is important that a refined methodology is used to determine the necessity for turbine shut-down to ensure mitigation strategies are proportionate to the potential impact.

6.7 Health effects - epilepsy

UK advice relating shadow flicker to health effects vary in their finer detail but essentially suggest that approximately 0.5% of the UK's population suffers from epilepsy, and of these between 3.5% (BERR,2007) and 5% (Companion Guide to PPS22, 2004) are photo-sensitive. Less than 5% of photo-sensitive epileptics are sensitive to the lowest frequencies of 2.5 – 3 Hz (Companion Guide to PPS22, 2004; and Verkuijlen & Westra, 1984), although the remainder are sensitive to higher frequencies extending up to 30 Hz (BERR 2007). Verkuijlen & Westra (1984) state that higher frequencies of 15-20 Hz may also cause convulsions in some epileptics (Ginsburg, 1970).

Canadian guidance (2006) notes that shadow flicker can lead to inducing epilepsy in susceptible individuals, however the study team is not aware of any recorded incidents of this actually occurring. This statement is also supported by Verkuijlen & Westra (1984).

BERR (2007) also states that most commercial wind turbines in the UK rotate much more slowly than this, at between 0.3 and 1.0 Hz. Clarke (1991) distinguishes between single speed turbines with shadow frequencies of 1-3 Hz and variable speed turbines which may produce shadows of 2-6 Hz.

Parsons Brinckerhoff - Note to reader on turbine frequencies
Frequency of shadow flicker is related to the rotational speed of a wind turbine's blades and the number of blades. Commercial scale wind turbines being deployed on developments across the UK tend to have three blades. The rotational speed of a turbine depends on the generator technology used within the nacelle. Older turbine models used asynchronous generators which were essentially '**fixed speed**'. Modern turbines tend to use a generation technology that allows a limited degree of change in rotational speed – '**variable speed**'. Many of the major manufacturers are now developing '**direct drive**' wind turbines which can have a much larger range of speeds to optimise the energy that can be captured. Due to technical constraints, larger turbines tend to rotate slower than smaller turbines.

6.8 Health effects and nuisance

Several guidance documents – BERR (2007), Western United States (2005), Canada (2006) -make a distinction between health effects related to epileptic seizures and impacts on residential amenity.

Burton et al. (2001) note that of the general population, some 10% of adults and 15-30% of children are disturbed to some extent by light variations at frequencies of 15-20 Hz. The range of nuisance frequencies in most people who were tested is between 5 and 14 Hz (Collins & Hopkinson, 1957; Schreuder, 1964), and below 2.5 Hz and above 40 Hz, hardly any nuisance is caused. A typical wind turbine rotation frequency is 0.3 – 1Hz (BERR, 2007).

Psychology research by Pohl et al. (1999) into the impact of shadow flicker on indicators of performance, mental and physical well-being, cognitive processing and stress of the autonomic nervous system, demonstrates that shadow flicker effect does not constitute a significant harassment. However, under specific conditions the increased demands on mental and physical energy indicated that cumulative long term effects might meet the criteria of a significant nuisance. In this study, shadows were simulated using an lighting system set up to produce a similar effect to wind turbine blades.

6.9 Environmental and site-specific factors

As a general rule, most best practice guidance documents suggest that an astronomic worst case scenario is adopted when preparing shadow flicker assessments, and that no environmental and site-specific factors are built into the modelling stage.

However, there are exceptions to this rule, with several guidance documents suggesting that ameliorating factors should be taken into account during the modelling stage. Gipe (2004) provides evidence from Germany that shadow flicker duration under a worst case calculation would be 100 minutes per year, but under normal circumstances, the turbine only produces 20 minutes per year.

BERR (2007) (now DECC) states that the following factors should be considered in shadow flicker assessments:

- Window widths;
- Uses of the affected rooms;
- Intervening topography; and
- Intervening vegetation.

Best Practice Guidance for the Irish Wind Energy Industry (2008) also advocates that it is reasonable to include ambient environmental conditions such as wind direction and general climatic data in shadow flicker models. Furthermore, Predac (2004) notes that Danish guidance takes into account ‘average cloud cover’. German guidance (2002) stipulates that sun angles less than 3 degrees above the horizon should be removed from the analysis due to the likelihood that vegetation and buildings will remove the shadow impact. In addition, Clarke (1991) comments that the number of sunny hours is likely to be lower in October through to early February although this will likely be the windiest period.

German guidance (2002) proposes a methodology for undertaking a realistic shadow flicker assessment taking into account meteorological information such as luminosity.

There are obvious difficulties when introducing meteorological conditions into shadow flicker modelling. In particular, there would be a need to establish a clear set of guidelines detailing an assessment methodology and suitable data sources.

From the industry questionnaire, the vast majority of developers and consultants carry out assessments that adhere to the worst case scenario. A number of developers currently carry out realistic assessments. The industry questionnaire also revealed that when undertaking shadow flicker assessments, over half of the respondents introduced environmental data into their software models. It is clear from the questionnaire however that there is no consistent approach to developer methodologies. Environmental and site specific parameters that developers introduce include:

- Existing screening.
- Intervening topography
- Window widths;
- Wind direction;
- Orientation and size of the affected window;
- Uses of the affected rooms.

Of the LPA respondents, a significant majority considered that shadow flicker assessments based on the worst case scenario criteria are appropriate, with several commenting that a realistic assessment should also be carried out. A significant majority of LPA respondents also felt that introduction of field data would aid the assessment by making it more realistic and helping planners to make an informed decision.

6.10 Planning conditions

BERR (2007) proposes the following planning condition where shadow flicker may have a potentially significant impact:

> *"The operation of the turbines shall take place in accordance with the approved shadow flicker mitigation protocol unless the Local Planning Authority gives its prior written consent to any variation."*

German guidance also makes reference to adopting a planning condition for installation of automatic turbine shut-down timers.

Over half of the LPA respondents to the questionnaire have been involved with assigning a planning condition relating to shadow flicker. The wording of planning condition vary considerably, with some planning conditions providing prescriptive requirements for shadow flicker mitigation strategies, whilst others are more general and lack detail. This could be due to project specifics and the requirements of individual LPAs. Example planning conditions provided by LPAs during the questionnaire process are included below:

> *"At the request of the occupant of the affected property, any turbine producing shadow flicker at any occupied dwelling which existed at the time that this permission was granted shall be shut down and the blades remain stationary until the conditions causing those shadow flicker effects have passed. The development shall be carried out in accordance with the approved details."*

> *"The wind turbines hereby approved shall not begin operation until a scheme for the avoidance of any shadow flicker effect for dwellings within 10 rotor diameters of any turbine in the development has been submitted in writing to and approved by the Local Planning Authority. The approved scheme shall be implemented as approved."*

7 CONCLUSIONS

This report has looked at the issue of shadow flicker from wind turbines, and presents data from a literature review, survey of international guidance and the results of a questionnaire sent to industry stakeholders.

The extent of the impact that shadow flicker causes is given in a psychology study (Pohl, 1999). This study concludes that the shadow flicker effect did not constitute a significant harassment. However, under specific conditions the increased demands on mental and physical energy, indicated that cumulative long-term effects might meet the criteria of a significant nuisance. This demonstrates the need to reduce the impact where possible.

A key finding of this study is that in the UK there have not been extensive issues with shadow flicker, and the results of a questionnaire survey to the industry and planning authorities has yielded few complaints. In these cases, shadow flicker issues were resolved using turbine shut down systems which are the standard mitigation approach adopted across Europe.

Current guidance to assess shadow flicker in the Companion Guide to PPS22 (2004) states that impacts occur within 130 degrees either side of north from a turbine. This has been found to be an acceptable metric. Additionally, the 10 rotor diameter rule has been widely accepted across different European countries, and is deemed to be an appropriate assessment area, although there is potentially a need to differentiate between appropriate assessment areas at different latitudes. This is an area where the scientific evidence base could be readdressed.

Across Europe and further afield, different countries have varying guidance on shadow flicker assessment. In all countries investigated where shadow flicker is a perceived issue, it falls under the remit of 'best practice' guidelines rather than regulatory policy. Some countries have adopted quantitative guidance, with limits on the flicker that can result from a development. During our consultation with the wind industry and LPAs, concerns were raised about the practicalities of implementing such a system in the UK.

Mitigation measures adopted by developers have been successful. Careful site design to eliminate shadow impacts is important, with mitigation measures such as turbine shut down systems being used regularly. These systems are acceptable for all parties, and by virtue of their success, the issue of shadow flicker appears to be minor. Mitigation measures are often put into planning conditions.

It is clear that there is no standard methodology that all developers adopt when carrying out shadow flicker assessments, and different developers and local authorities have different ways of approaching the assessment. Developers tend to use a 'worst case' assessment, with some developers using environmental or site specific factors to produce a 'realistic' case. Whilst the industry software that we reviewed can only be used to carry out worst case shadow flicker assessments, there is perhaps a need to address worst-case and realistic shadow flicker in assessments.

8 REFERENCES

American Wind Energy Association, 2010, Wind Turbines and Health

Burton (2001), Wind Energy Handbook

Clarke A., 1988: Windfarm Location and Environmental Impact. NATTA, c/o EERU, Open University, Milton Keynes

Clarke A.D. 1991: A case of shadow flicker / flashing: assessment and solution. Techno Policy Group, Open University. Milton Keynes, UK

Collins J.B. & Hopkinson R.G., 1957: Intermittent Light Stimulation and Flicker Sensation. Ergonomics, 1, 61-76

Cornwall County Council, 1989: Planning Implications of Renewable Energy: Onshore Wind. Planning Department, County Hall, Truro

Danish Wind Energy Association, Shadow Casting from Wind Turbines (accessed 2010) [online] – Available at: http://guidedtour.windpower.org/en/tour/env/shadow/index.htm

Department of Environment, Heritage and Local Government [Ireland], Undated, Planning Guidelines

European Wind Energy Association, accessed 2010.

Freund H-D., 2002, Einflüsse der Lufttrübung, der Sonnenausdehnung und der Flügelform auf den Schattenwurf von Windenergieanlagen, [English translation - Influences of the Opaqueness of the Atmosphere, the Extension of the Sun and the Rotor Blade Profile on the Shadow Impact of Wind Turbines]

Garrad Hassan, Shadow Flicker Module, (accessed 2010) [online] – Available at http://www.gl-garradhassan.com/en/software/windfarmer/16206.php

Ginsburg N. 1970: Flicker Fusion Bibliography

Gipe, P. 1995. Wind energy comes of age. *Energy Policy*, 24, 5, 491-492.

Gipe P., 2004, Wind Power: Renewable Energy for Home, Farm and Business

Government of South Australia, 2002, Planning Bulletin – Wind Farms (Draft for Consultation)

Halifax Regional Municipality, 2006, Draft HRM Wind Energy Generation Plan

International Finance Corporation / World Bank Group, 2007, Environmental, Health, and Safety Guidelines for Wind Energy

Irish Wind Energy Association and Sustainable Energy Ireland, 2008, Best Practice Guidelines for the Irish Wind Energy Industry

Northern Ireland Department of the Environment, 2009, Best Practice Guidance to Planning Policy Statement 18 ‘Renewable Energy’

PREDAC, 2004, European Actions for Renewable Energies, Spatial Planning of Wind Turbines

Planning Division – Welsh Assembly Government 2010, Best Practice Guidance – Planning Implications of Renewable and Low Carbon Energy

Pohl et al., 1999, Belästigung durch periodischen Schattenwurf von Windenergieanlagen, [English translation - Harrassment by Periodic Shadow of Wind Turbines]

Office of the Deputy Prime Minister, 2004, Planning for Renewable Energy – A Companion Guide to PPS22

Renewables Advisory Board and BERR, 2007, Onshore Wind Energy Planning Conditions Guidance Note

Schreuder D.A., 1964: The Lighting of Vehicular Traffic Tunnels. Eindhoven – Dissertation

Scottish Executive, 2002, Planning Advice Note (PAN) 45: Renewable Energy Technologies

States Committee for Pollution Control – Nordrhein-Westfalen, 2002, Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines

Taylor D. & Rand M., 1991, Planning for Wind Energy in Dyfed

US Department of the Interior – Bureau of Land Management, 2005, Final Programmatic Environmental Impact Statement on Wind Energy Development on BLM- Administered Lands in the Western United States

Verkuijlen E. & Westra C.A. 1984: Shadow hindrance by wind turbines. Proceedings of European Wind Energy Association

Western Australian Planning Commission, May 2004, Western Australia Planning Bulletin – Guidelines for Wind Farm Development

Widing et al. (2005) Wind Power Environmental Impact (Sammanfattning: Vindkraftens miljöpåverkan) (Swedish)

9 APPENDICES

Appendix 1 Case study demonstrating Shadow Flicker Assessment – Taken from Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)

Appendix 2 Industry Questionnaire

Appendix 3 LPA Questionnaire (England)

Appendix 4 LPA Questionnaire (Scotland)

Appendix 5 LPA Questionnaire (Wales)

Appendix 6 LPA Questionnaire (Northern Ireland)

Appendix 1

Case study demonstrating Shadow Flicker Assessment – Taken from Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)

This literature document from Germany (detailed in Section 3) provides an example case study demonstrating how shadow flicker should be calculated.

To calculate the actual duration of shading, meteorological information needs to be taken into account. The first parameter taken into account is luminosity – see Table 8 and Table 9 for luminosity data from the German weather service.

Table 8: Data from the German Weather Service (taken directly from paper)

Sun [°]	Illuminance [lx]	Radiation Equivalent [lx/Wm^{-2}]
3	389	62
60	10.912	105

Table 9: A linear interpolation of the above metrological data. (taken directly from paper)

Sun [°]	Illuminance [lx]
3	389
5	664
10	1402
15	2207
20	3071
25	3986
30	4942
35	5929
40	6935
45	7949
50	8959
55	9951
60	10912

Day length is then calculated by using representative sunrise and sunset data for different locations across Germany and during different months of the year – see Table 10.

Table 10: Day lengths for different locations and months of year (taken directly from paper)

	Berlin	Essen	Hanover	Karlsruhe	Munchen	Schleswig	Schwerin
01-Jan	8:17; 16:03	8:37; 16:34	8:32; 16:18	8:21; 16:40	8:04; 16:31	8:44; 16:07	8:32; 16:05
01-Apr	5:41; 18:41	6:08; 19:07	5:56; 18:56	6:04; 18:59	5:52; 18:44	5:54; 18:58	5:48; 18:50
01-Jul	3:48; 20:32	4:20; 20:52	4:03; 20:47	4:26; 20:34	4:18; 20:17	3:51; 21:00	3:49; 20:47
01-Oct	6:07; 17:44	6:33; 18:10	6:22; 17:59	6:26; 18:06	6:13; 17:53	6:24; 17:58	6:16; 17:51

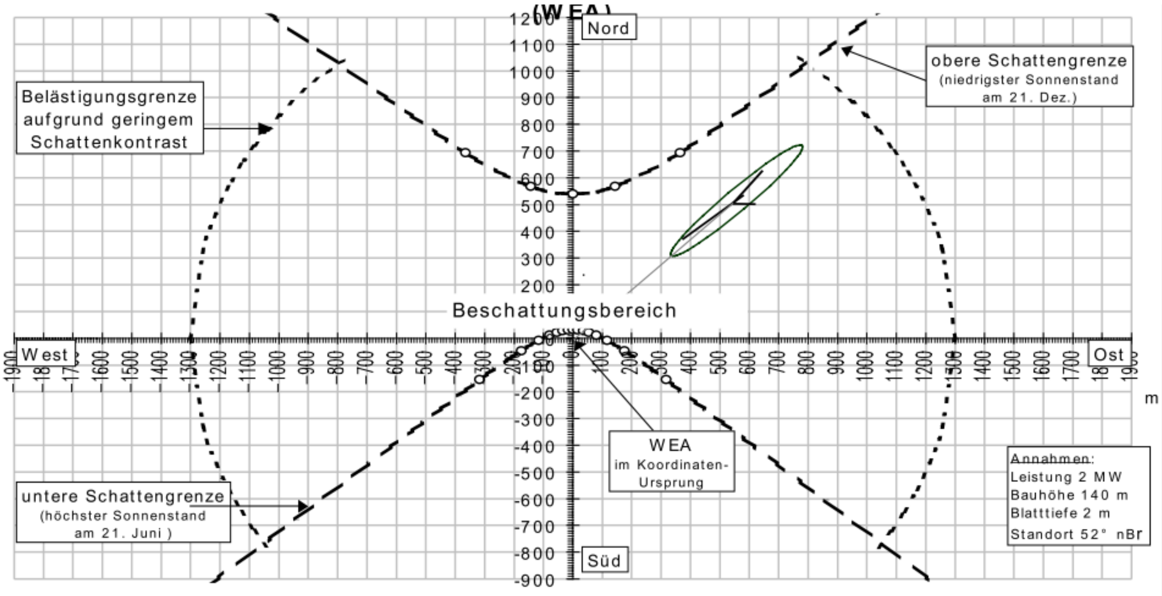
The shadow flicker study area is then calculated using variables such as hub height and rotor diameter of the turbine. The following table and figure have been produced for sample data with a turbine located in flat terrain in central Germany. The receptor is 2m above ground level and has an area of 0.1 x 0.1 m^2. Table 11 below summarises the parameters and results of the sample study.

Table 11: Summary of parameters and results for the sample study. (taken directly from paper)

ID No.	Hub height [m]	Rotor diameter [m]	Azimuth from north to east [°]	Distance between Turbine and receptor [m]	Hours / year	Days / year	Minutes / day
1	60	40	0°	150	90	124	60
2			40°	300	25	62	32
3			120°	450	15	49	22
4	90	60	0°	250	83	111	56
5			40°	400	28	61	36
6			120°	650	14	46	22
7	100	80	0°	300	98	108	62
8			40°	500	37	76	38
9			120°	750	20	54	26

Figure 11 shows the potential shading area of a large wind turbine. The dashed lines to the north represent the shadow limit on 21st December and the south dashed line represents the shadow limit on 21st June. The dotted lines to the east and west show the limit of impact due to shadow contrast. It can be seen that the shading region is symmetrical due to the path of the sun.

Figure 11: Possible shading area of a large wind turbine



APPENDIX 2

APPENDIX 3

APPENDIX 4

APPENDIX 5

APPENDIX 6