Appendix 14.2: Aviation Lighting and Mitigation Report

WPAC
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Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0

Our Reference: WPAC 067/22
Your Reference: An Carr Duibh LUC EIA Report

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Reference Documents

A. Civil Aviation Publication (CAP) 764 Civil Aviation Authority (CAA) Policy and Guidance on Wind Turbines Version 6, Feb 2016
B. CAP 764 Version 7 (Draft) issued for comment in June 2020 (to be released shortly)
C. Air Navigation Order (ANO) Article 222
D. CAA Policy Statement: Lighting of Onshore Wind Turbine Generators in the United Kingdom with a maximum blade tip height at or in excess of 150m Above Ground Level dated 01/06/17
E. NatureScot General pre-application and scoping advice for onshore wind farms dated Sep 2020
F. International Civil Aviation Organisation (ICAO) Annex 14 Vol 1 Chapter 6

Scope

1. This report is divided into two parts. Part 1 proposes a lighting design that is compliant with existing and draft (but soon to be ratified) regulations and guidance contained within References A to D and F as discussed with the CAA and the MOD. It explains the rationale behind the lighting design taking into account the requirement to minimise the number of turbines illuminated with aviation obstruction lights whilst maintaining flight safety and provides a detailed assessment of the brilliance of the lighting when viewed from a number of viewpoints provided by the LVIA consultant after consultation with the relevant stakeholders including NatureScot and the Local Planning Authority. Part 2 of the report identifies and explains those mitigation measures that can be utilised to minimise the environmental effect of the lights including an assessment of the historical meteorological data from which to predict the luminous intensity requirements for the lights. The entire report can be considered to fulfil the requirements for an Aviation Lighting Landscape and Visual Impact Mitigation Plan as proposed by NatureScot in their response to a recent Wind Farm Inquiry.

Part 1 Turbine Lighting Layout Design

Introduction

2. WPAC have designed a number of CAA and MOD compliant lighting layouts for wind farms and have also been in constant dialogue with the CAA regarding the proposed change to CAP 764 in terms of aviation lighting requirements. Whilst Reference A is technically the current publication for policy and guidance on this issue, Reference B was released for comment and is already being used by the CAA as the current *de facto* policy. Discussions with the CAA have clarified that the draft regulations will not be changing in terms of the overarching policy but the wording may be slightly amended in the interests of clarity.

Lighting Layout Starting Point and Assumptions

3. Statkraft have proposed a wind farm located on the Mid Argyle Peninsula, 7km NW of Inveraray. The site is named An Carr Dubh and sits between the Beinn Bhreac and Cruach Mhor Trig Points.

4. The proposed turbine site is within MOD Low Flying Area (LFA) 14 which is the largest of the MOD LFAs. At night this area converts to Night Allocated Region (NAR) 1A, an area primarily reserved for fast-jet low flying in the hours of darkness. In the area of An Carr Dubh, fast jet and tactical transport aircraft routinely operate down to 250ft (75m) above ground level (agl), and helicopters down to 30ft, (9m) and occasionally, down to ground level.

5. Because of its size and utility, LFA14 is regularly used for multi-nation exercises and operational training. Accordingly, the proposed An Carr Dubh site is in an important MOD/NATO training area and will require a comprehensive lighting arrangement that includes both visible and infra-red obstruction lights.

Note: An Carr Dubh is proposed in an area that has many existing and proposed turbine sites. Indeed, An Carr Dubh abuts the Blarghour Wind Farm which is due to be commissioned in 2023. This site may impact the An Carr Dubh lighting proposal and is shown in Figure 1 below.

Lighting Assessment Overview

- From a CAA perspective, An Carr Dubh will be assessed for visible lighting in accordance with Class G 'en-route' airspace requirements as detailed in CAP 764.
- Note, CAA advice has changed several times of recent with the introduction of the 764 (Draft) and various CAA lighting dispensations. This report will generate a lighting layout consistent with the CAA latest position.
- To accommodate MOD requirements, the site will be assessed for NVG compatible lighting in accordance with MOD published obstruction lighting specification (AL4).
- Where possible, the recommended lighting configuration will be optimised to reduce light impact on the local area.
- The An Carr Dubh wind turbine proposal is for 13 turbines at 180m to tip and a 102.5m hub.

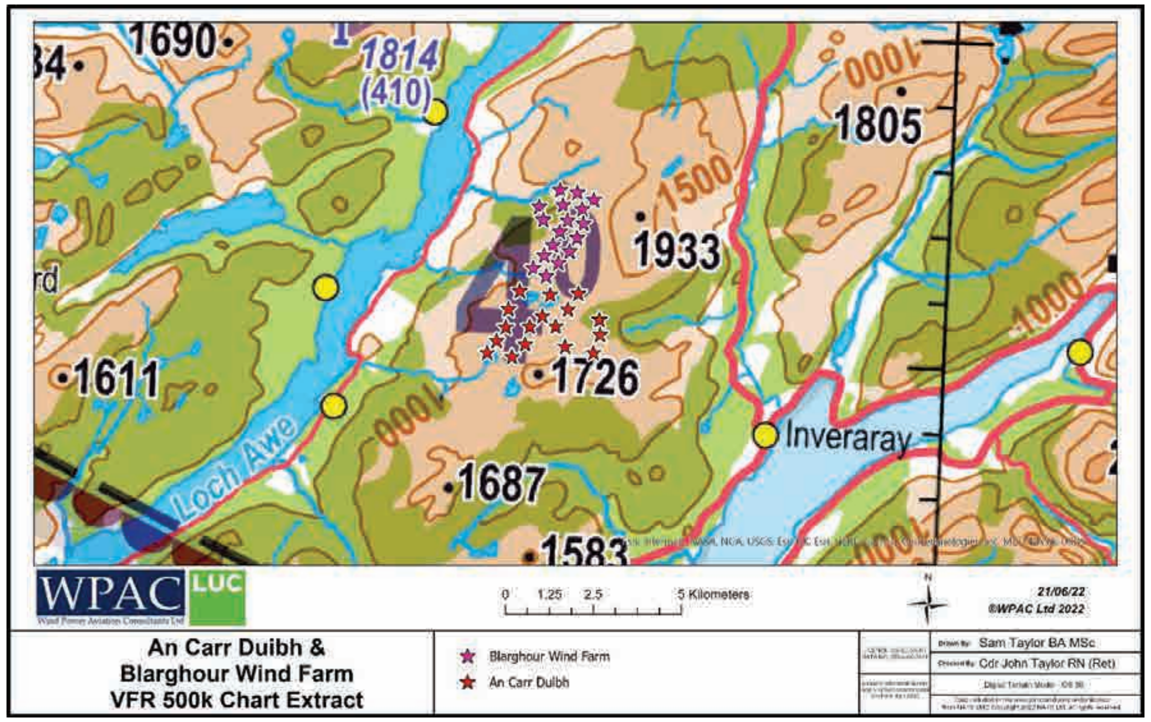

Figure 1 An Carr Duibh on an aviation chart with Blarghour

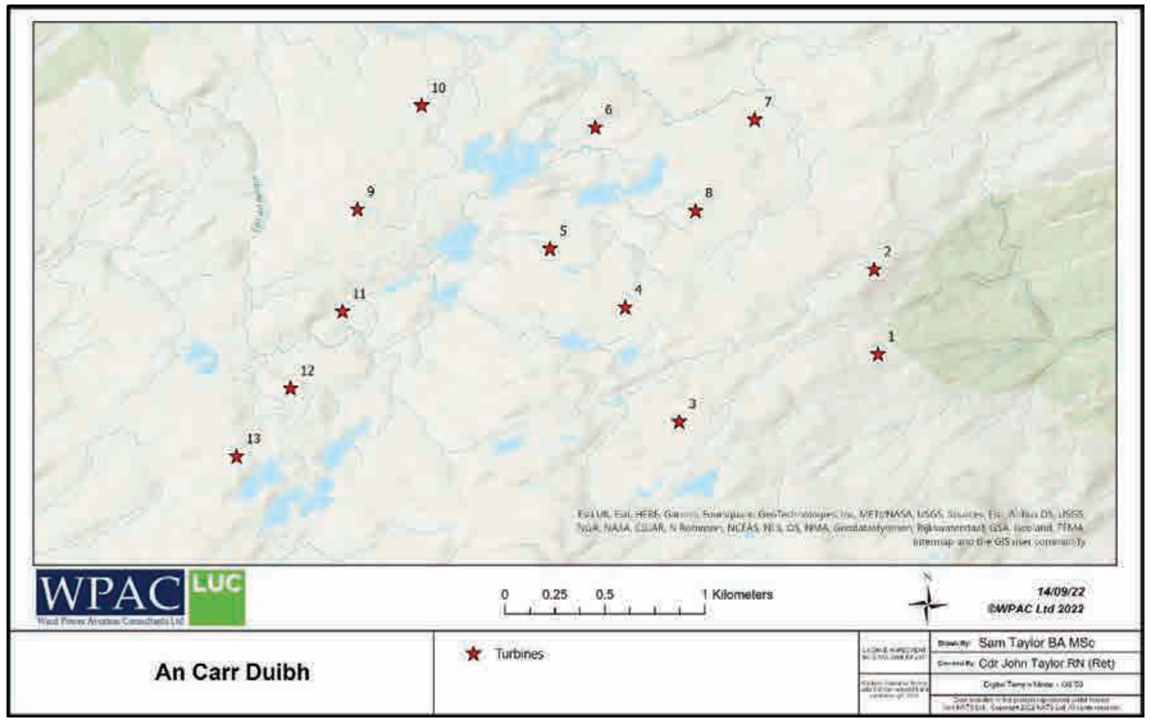

Figure 2 An Carr Duibh Wind Farm

CAA-ANO Red 2000/200cd Lighting (In compliance with CAA CAP 764 - Draft)

6. In accordance with the CAP 764 (draft) conditions, the CAA requires:

- That all perimeter turbines be lit unless removing a light will leave a gap of less than 900m total between the remaining lit turbines.
- That any turbine within 200m of a 'string perimeter' be lit unless the distance between adjacent turbines is less than 900m total.
- That any unlit turbine does not exceed a 10° up-slope from adjacent lit turbines.

Applying these criteria dictates that ten of the thirteen total turbines will be carrying visible ANO lights.

Turbines with 2000/200cd Lights: T1, T2, T3, T6, T7, T9, T10, T11, T12 and T13

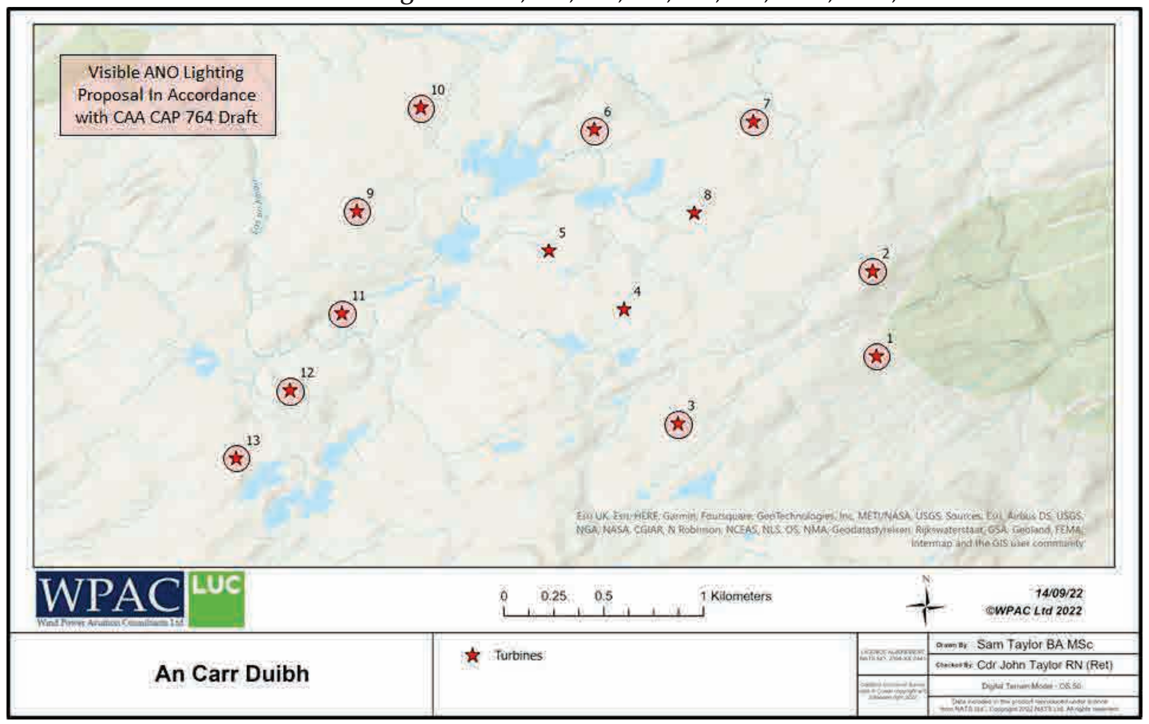

Figure 3 CAA-ANO CAP764 Compliant Lighting Arrangement

CAA-ANO Red 2000/200cd Lighting. (Reduced Lighting using CAA Dispensations)

7. The CAP 764 (Draft) compliant visible lighting proposal at Figure 3 results in a relatively high lighting density to the east and west of the site and visible from the populated areas around Inveraray to the east and Dalavich to the west..

8. The CAA does allow a dispensation of 10% on the Draft CAP inter-turbine distances (increasing the 900m range by 10% to 990m). Moreover, of late the CAA has allowed greater inter-light distances provided the perimeter of the turbine site remains clearly defined with no significant outliers.

9. Applying these criteria to the perimeter turbines of the An Carr Dubh site will leave ANO visible red lighting on seven turbines. This results in seven of the thirteen total turbines carrying visible ANO lights.

Turbines with 2000/200cd Lights: T1, T2, T3, T7, T10, T11 and T13

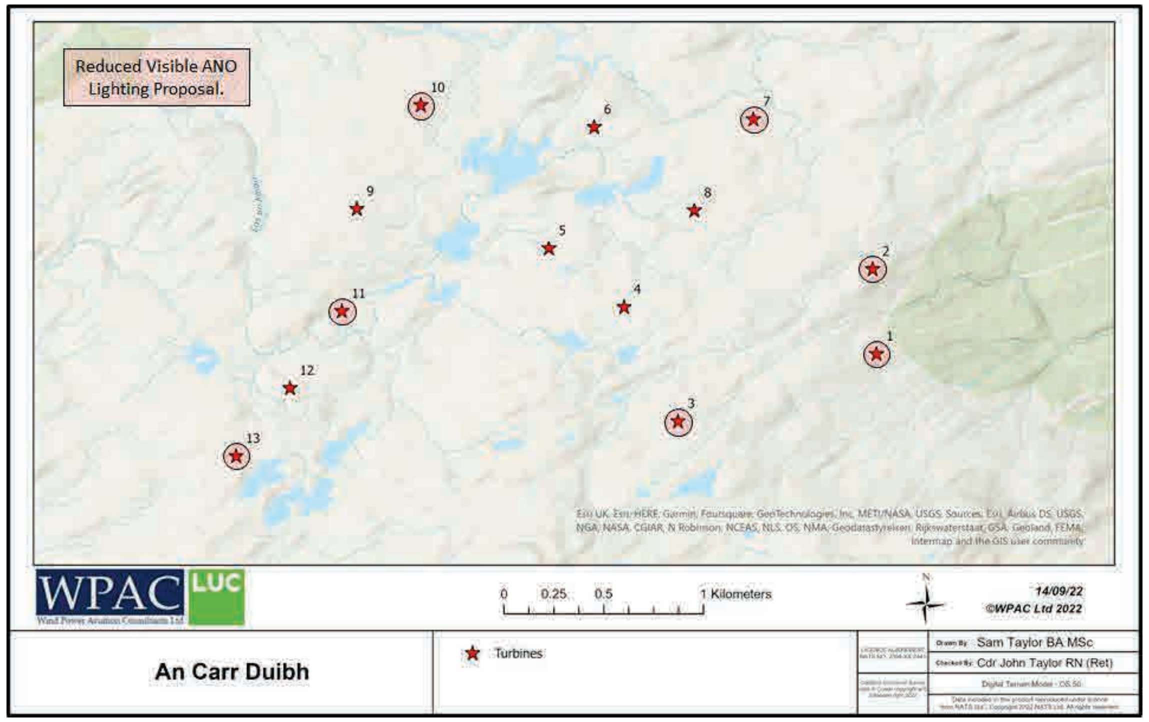

Figure 4 CAA-ANO CAP 764 Modified Lighting Arrangement

MOD Lighting Requirements

10. Early detection is important especially if the aircraft is manoeuvring hard and the air temperature profile causes the turbines to blend into the background. Suitable lighting is necessary for flight safety.

11. MOD IR lights have been developed to be invisible to the public at large but very detectable to aircrew night vision aids. As such the MOD IR lights can have a wide beam width and flash continuously without disturbing the environment.

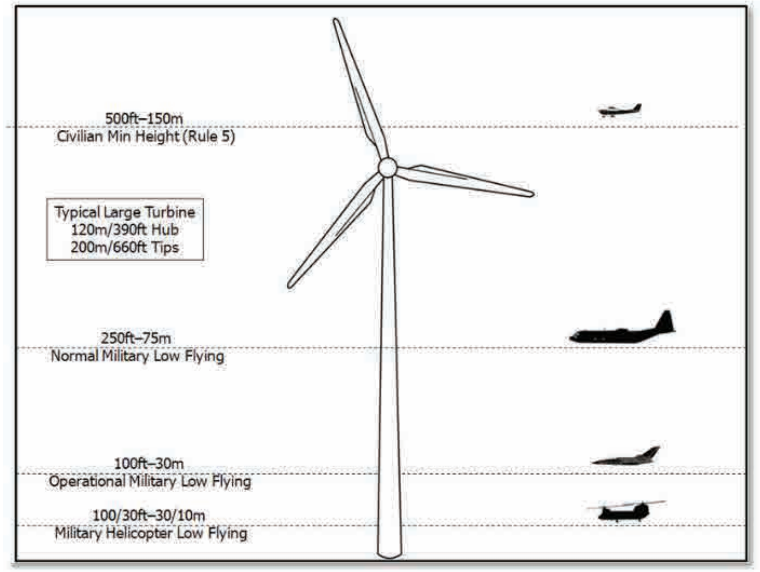

Figure 5 Wind turbine in context with MOD Low Flying

MOD Infra-Red Lighting Layout

12. The MOD requires:

- That all 'compound-perimeter' (see diagram) turbines be lit unless removing a light will leave a gap of less than 500m between the remaining perimeter lit turbines
- That any dominant turbine, by location or height, be lit. Note: here, the corner and highest turbines are lit.
- In addition to the perimeter turbines, the central turbine(s) be lit to provide 'depth perception' to approaching aircraft. Note: An Carr Dubh does not meet the MOD small site criteria and, therefore, does not meet the dispensation requirements to not light central turbines. Accordingly, the central turbines will also require IR lights.

Applying these criteria dictates that all of the compound perimeter turbines of the An Carr Duibh site will require IR lighting. Thirteen turbine IR lights in total. These lights are invisible to the naked eye.

Turbines with Infra-Red: : T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12 and T13

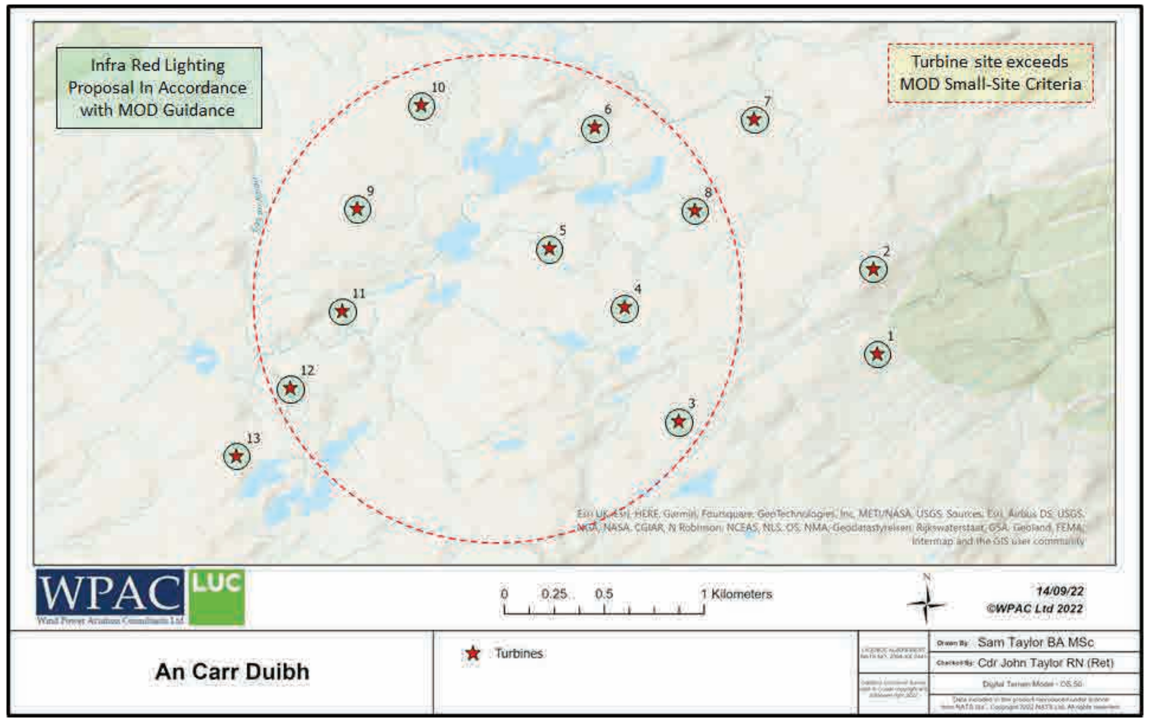

Figure 6 Proposed MOD Infra-Red Lighting Arrangement

Combined CAA Visible Lighting and MOD Infra-Red Lighting

An Carr Dubh Turbine Lighting Table						
Turbine	Easting	Northing	Tip Height	Hub Height	CAA ANO	MOD IR
1	204480	711431	180m	102.5m	2000/200cd	600mW/sr
2	204460	711855	180m	102.5m	2000/200cd	600mW/sr
3	203485	711094	180m	102.5m	2000/200cd	600mW/sr
4	203215	711665	180m	102.5m		600mW/sr
5	202838	711959	180m	102.5m		600mW/sr
6	203065	712565	180m	102.5m		600mW/sr
7	203863	712604	180m	102.5m	2000/200cd	600mW/sr
8	203567	712148	180m	102.5m		600mW/sr
9	201875	712156	180m	102.5m		600mW/sr
10	202196	712675	180m	102.5m	2000/200cd	600mW/sr
11	201800	711645	180m	102.5m	2000/200cd	600mW/sr
12	201540	711260	180m	102.5m		600mW/sr
13	201270	710920	180m	102.5m	2000/200cd	600mW/sr

Table 1 Proposed CAA and MOD Lighting Arrangement

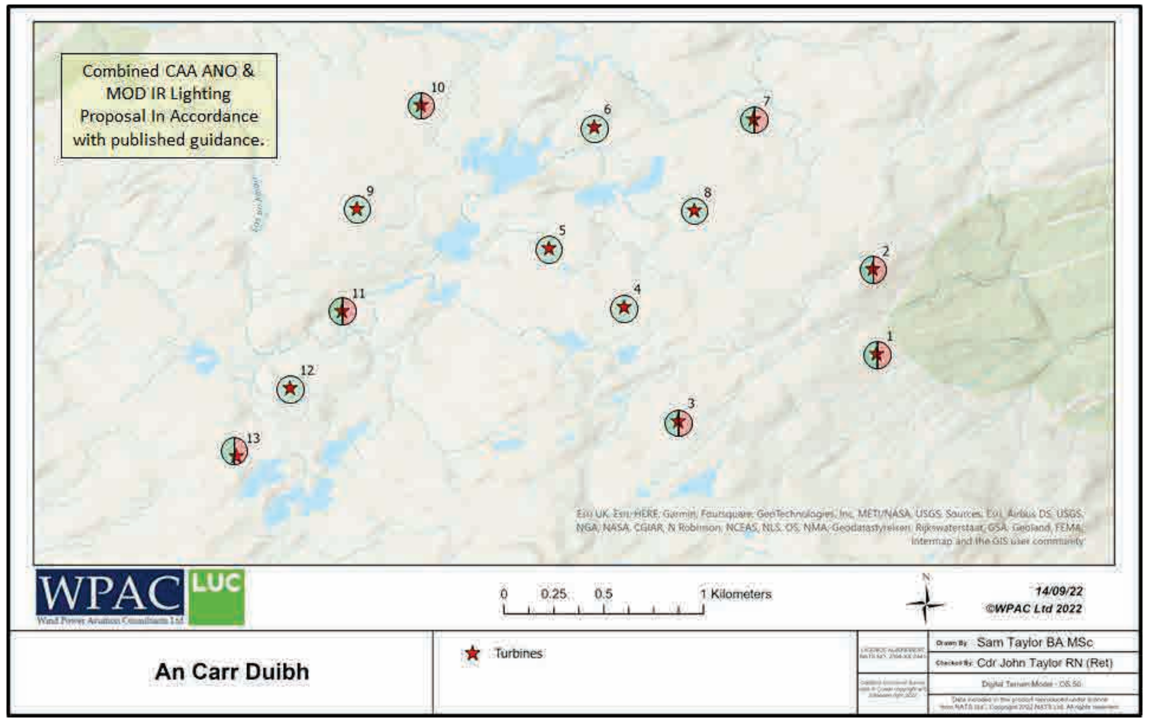

Figure 7 CAA-ANO Visible Red and MOD Infra-Red Lighting Arrangement

ANO Light Specifications

13. The ANO 2000/200cd Lights will conform to the ICAO specification as set out in Annex 14 Table 6-3. The lights will also be controlled such that when the met visibility is greater than 5km in all directions from all turbine hubs, the lights will be reduced to 200cd (10% of normal power). This reduction in power will not apply to MOD IR Lights.

ICAO Annex 14 Table 6-3 (excerpt)

Benchmark intensity	Minimum requirements					Recommendations				
	Vertical elevation angle (b)			Vertical beam spread (c)		Vertical elevation angle (b)			Vertical beam spread (c)	
	0°		-1°			0°	-1°	-10°		
	Minimum average intensity (a)	Minimum intensity (a)	Minimum intensity (a)	Minimum beam spread	Intensity (a)	Maximum intensity (a)	Maximum intensity (a)	Maximum intensity (a)	Maximum beam spread	Intensity (a)
2000	2000	1500	750	3°	750	2500	1125	75	N/A	N/A

a) 360° horizontal. All intensities are expressed in Candela. For flashing lights, the intensity is read into effective intensity, as determined in accordance with the Aerodrome Design Manual (Doc 9157), Part 4.
b) Elevation vertical angles are referenced to the horizontal when the light unit is levelled.
c) Beam spread is defined as the angle between the horizontal plane and the directions for which the intensity exceeds that mentioned in the "intensity" column.

Table 2 ICAO Annex 14 Table 6-3 Medium Intensity Lighting Specifications.

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

14. **<u>Low Intensity Mid Mast Lights</u>** – Mid mast lighting was originally intended to give an attitude/range reference (horizon indication) to pilots flying at night in the days before NVGs. Hub and mid mast lights will give a vertical reference (from which a horizontal reference can be gauged) when fitted to a single vertical structure. In contrast, a single light will not be able to give a vertical or horizontal reference or indication of range and range-rate. However, a series of single hub lights, on a group of structures, will provide a good horizon reference together with range and range-rate clues. Accordingly, the requirement for mid-masts lights is much diminished if not made redundant in the case of multiple vertical structures such as wind farms.

15. All of the current commercially available 32cd (supposedly focused) lights are over-engineered (up to 70cd between -30deg and +40deg to fit a multitude of aviation and marine applications) they induce a disproportionately large environmental impact, often significantly more than the focused hub 2000/200cd lights. WPAC requested that the CAA guidance requirement for 32cd (Type B) mid mast lights be removed for An Carr Duibh which was agreed by the CAA in their lighting approval letter at Appendix C.

Table 6-2. Light distribution for low-intensity obstacle lights

	Minimum intensity (a)	Maximum intensity (a)	Vertical beam spread (f)	
			Minimum beam spread	Intensity
Type A	10 cd (b)	N/A	10°	5 cd
Type B	32 cd (b)	N/A	10°	16 cd
Type C	40 cd (b)	400 cd	12° (d)	20 cd
Type D	200 cd (c)	400 cd	N/A (e)	N/A

Note.— This table does not include recommended horizontal beam spreads. 6.2.1.3 requires 360° coverage around an obstacle. Therefore, the number of lights needed to meet this requirement will depend on the horizontal beam spreads of each light as well as the shape of the obstacle. Thus, with narrower beam spreads, more lights will be required.

Table 3 ICAO Annex 14 Table 6-2 Low Intensity Obstacle Lights.

IR Light Specifications

16. The IR lights will conform to the MOD specification as set out in MOD Lighting Guidance and shown below in Table 4.

MOD Specification IR.

IR wavelength – 750 to 900nm.
But ideally concentrated within 800 to 850nm for optimum detection by all military NVG types.

IR intensity – 600mW/sr minimum at peak flash but not above 1200mW/sr.
(Note: Typically a 300mW/sr steady burn LED IR light will generate 600mW/sr at peak flash)
This will generate a 7-8 nm NVG pick-up range - remaining above 5nm as the light ages.

Horizontal Pattern – unrestricted 360 deg.

Vertical Pattern – Minimum flash intensity of 600 mW/sr between +30 deg and -15 deg elevation.
– up to 50% reduction between +25 to +30 deg and -10 to -15 deg is acceptable.
– Maximum intensity of 1200 mW/sr for all angles of elevation.
– Vertical overspill is acceptable.

Flash Pattern – 60 flashes per min at 100-500 ms duration (ideally 250ms)

Synchronisation – all lights to be visually synchronised across a wind farm site

Table 4 MOD Specification for IR Obstacle Lights

Timings

17. The lights (IR and ANO) will be switched on between Evening Civil Twilight and Morning Civil Twilight in accordance with the UK Almanac; approximately 11 hours per day when averaged over the year.

Assessment of Aviation Lighting and Potential Mitigation Measures Designed into the Lights

18. Having defined a layout of turbines to be fitted with visible lighting, an assessment has been undertaken to calculate the brilliance of the lights when seen from a number of viewpoints. The standard aviation lights to be fitted to the nacelle of the turbines are required to fulfil certain design criteria in terms of brilliance and coverage as per Table 2. They are designated 'medium intensity obstruction lights' and have a **minimum** luminous intensity of 2000 candela[1] at horizontal and slightly above. The LED lights are also required to be able to shine a beam that reduces in intensity above and below the horizontal. One manufacturer of such obstruction lights, CEL, have tested their light, the CEL MI-ACWGAM[2] in a calibration chamber and produced results showing precisely how much the beam reduces in brilliance at any specified elevation angle. The results are provided to every 0.1°. These lights are already fitted in a number of locations around the UK.

[1] Candela is the SI Unit of luminous intensity and refers to the amount of light emitted in a particular direction.
[2] The Technical Specification is at: https://www.aircraftwarninglights.co.uk/datasheets/CEL-MI-ACWGAM - datasheet rev10.pdf

19. Figure 8 demonstrates the reduction in luminous intensity below the horizontal and also above 1° in elevation. The various coloured lines are the candela measured from different angles in the horizontal in order to measure the performance all around the light.

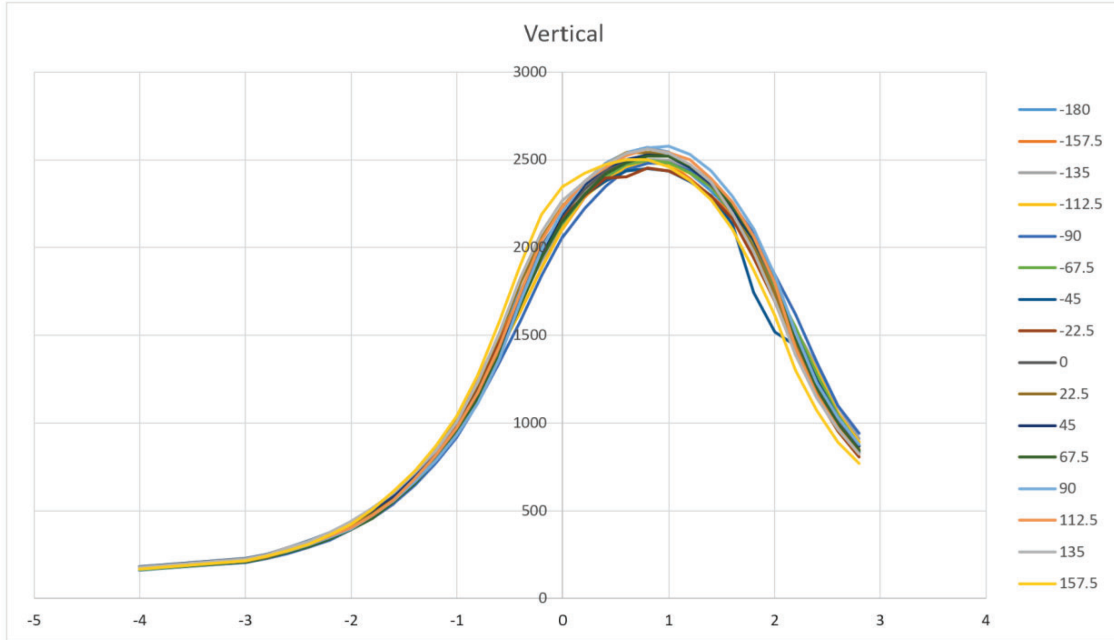

Figure 8 (MI ACWGAM Light Measurement Results)

20. WPAC have utilised their propagation modelling system (Rview) to calculate the precise angle of elevation between the turbine light and a viewpoint assuming a height of eye of 1.5 metres and a turbine hub height of 102.5 metres. The system utilises a standard atmospheric model and an earth model that uses actual earth curvature between the turbine light and the viewpoint. Ordnance Survey OS50 DTM is used as the terrain model. The calculations have been undertaken for each designated lit turbine against all designated An Carr Duibh Wind Farm viewpoints. The locations of the viewpoints are shown in Figure 9 and Table 5. The assessment has been undertaken utilizing the turbine lighting layout shown in Figure 4 and Table 1. It is possible that one or two viewpoint locations may be moved very slightly when the on site photography is undertaken, but for all practical considerations, the results for each point will remain the same.

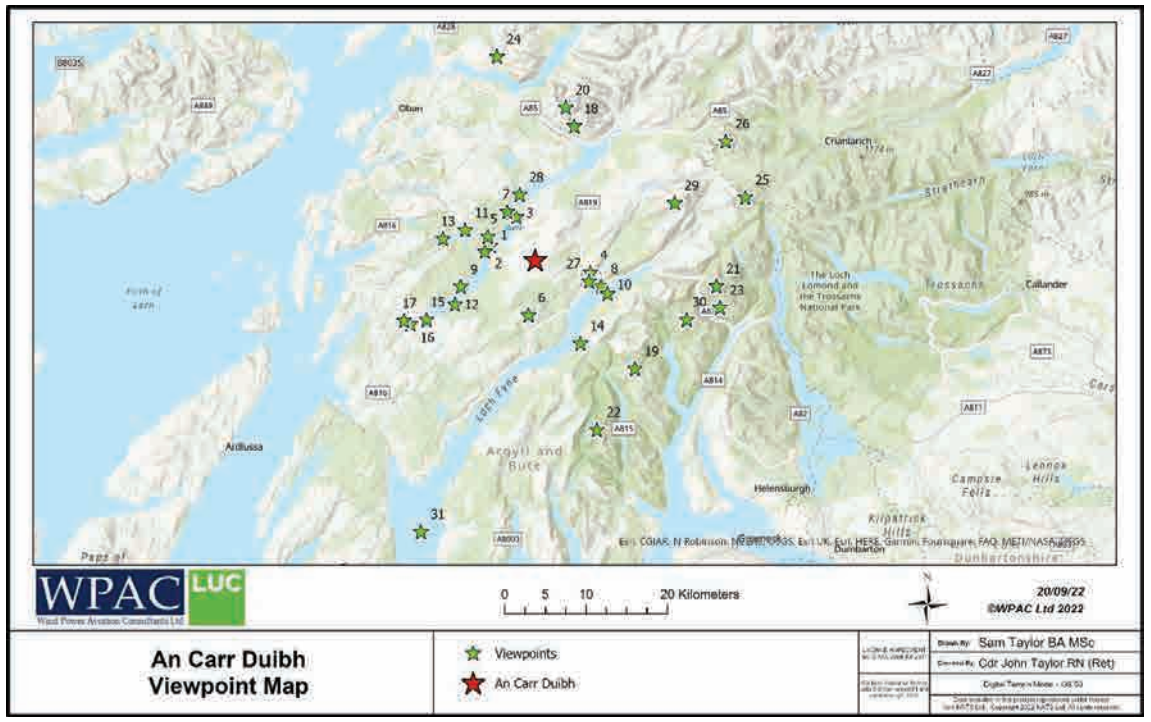

Figure 9 Viewpoint Locations

21. The next stage in the process is to take the candela figures radiated towards a viewpoint and taking into account the distance, calculate the lumens per square metre (also known as Lux) that will be experienced by the human eye at the viewpoint. The figure produced is in micro-lumens per square metre or lumen$^{(10\text{-}6)}$/m^2) or lux$^{(10\text{-}6)}$. These are perfect clear-air figures and therefore worst case results from an LVIA perspective. Figures obtained by this method enable comparisons to be made with commonly understood light sources such as stars or planets. In practice the light intensity at the observation points will be further attenuated by scatter and absorption by airborne dust, droplets and aerosols in the atmosphere. This attenuation is typically in the order of 10 to 20% but can be as high as 75% at the more distant observation ranges.

22. The results for every lit turbine from all of the viewpoints are shown in the results tables in Appendix A to this report. Viewpoints where lights are obstructed by terrain are shaded in green, when the viewpoint is too close to a turbine to get an accurate assessment it is shaded red. **To take into account any limitations within the terrain model we have highlighted in purple any viewpoints where the line of sight is under 10 metres above ground level but above 1.5 metres and should therefore, still be screened by terrain but may be visible within the vicinity of the viewpoint**.

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Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Viewpoint Number	Viewpoint Name	Easting	Northing
1	Loch Awe	197750	713480
2	Dalavich Jetty (Dusk)	197026	712767
3	B840, North of Balliemeanoch	200886	716995
4	Folly at Dun na Cuaiche (Inveraray Castle GDL) (Dusk)	210016	710131
5	Minor road to west of Loch Awe (north of Dalavich)	197368	714469
6	Beinn Dearg	202389	704908
7	Core Path above Inverinan	199781	717634
8	Loch Fyne	211310	708460
9	Kilmaha Viewpoint	194062	708449
10	Jetty at St. Catherines	212109	707566
11	Loch Avich, east of Loch Avich House	194597	715378
12	Parking spot, Loch Awe	193354	706259
13	Loch Avich	191875	714316
14	A886 at Strachur	208779	701453
15	Fincharn Castle, Loch Awe	189860	704364
16	B840, East of Ford	187868	703841
17	North of Ford	187102	704247
18	Cruachan Dam	208006	728140
19	Beinn Bheula	215475	698322
20	Ben Cruachan (1126m)	206967	730465
21	Ben Ime	225497	708480
22	Beinn Mhor (Cowal Peninsula and LLTNP)	210784	690825
23	The Cobbler (Ben Arthur)	225927	705827
24	B845, Loch Etive	198504	736713
25	Troisgeach	229034	719385
26	Ben Lui (1130m)	226628	726279
27	Bridge on Old Military Road	209832	709075
28	Road summit view travelling SW on minor road to west of Loch Awe	201300	719720
29	Beinn Bhuidhe - DUSK	220364	718719
30	Ben Donich	221837	704362
31	Waverley Paddle Boat	189148	678299

Table 5 Viewpoints

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Interpreting the Results

23. The results show that there is a significant decrease in the luminous intensity (candela) of the light emanating towards those viewpoints which are at lower angles of elevation in relation to the turbine hub. However, when considering the perception of the light from a viewpoint in general, the distance between the light and the viewpoint is the dominant factor and the resultant figure in micro-lumens is the most relevant figure to consider. This report provides the results and anticipates that the Landscape and Visual Impact Assessment (LVIA) consultants will be able to put them into the correct context for visualisations in terms of background environmental lighting and atmospheric conditions. Table 6 shows the turbine with the greatest potential perceived luminous intensity expressed in micro-lumens per m^2 (Lux $^{(10-6)}$) at each viewpoint.

Viewpoint	Brightest Lit Turbine	Distance (km)	microlumens per m^2 (lux$^{10-6}$)	Microlumens at 10%	Obscured
1	13	4.352	4.0	0.4	
2	11	4.904	4.7	0.5	
3					X
4	7	6.631	10.2	1.0	
5	10	5.151	6.8	0.7	
6	13	6.115	62.3	6.2	
7	10	5.516	5.6	0.6	
8	2	7.645	3.1	0.3	
9	11	8.372	6.9	0.7	
10	2	8.769	2.7	0.3	
11	11	8.113	4.4	0.4	
12	10	10.925	3.0	0.3	
13	11	10.278	4.6	0.5	
14					X
15	11	13.985	2.7	0.3	
16	13	15.157	2.5	0.3	
17	13	15.661	2.5	0.3	
18	7	16.079	7.2	0.7	
19	1	17.11	8.6	0.9	
20	2	18.778	5.7	0.6	
21	1	21.223	5.3	0.5	
22	3	21.543	5.3	0.5	
23	1	22.167	5.1	0.5	
24	2	25.562	1.7	0.2	
25	2	25.702	3.7	0.4	
26	2	27.68	3.5	0.3	
27					X
28					X
29	2	17.322	7.8	0.8	M
30	1	18.741	7.1	0.7	
31	3	35.792	0.8	0.1	

Table 6 Brightest Turbine Hub Light from each Viewpoint (measured in micro-lumens)

24. In order to place the values in microlumens per m^2 (lux$^{10-6}$) in context, Table 7 provides some examples of approximate values placed on a number of environmental comparators, however these are just an illustration to place the results in a real world environment. The actual perceived brightness will depend upon a number of factors including bulb manufacturer, bulb type, specific construction (single/multiple colour LEDs etc) atmospheric conditions, absorption spectrum, individual eye characteristics and capabilities.

Comparison Object	Approximate Illuminance (micro-lumens per m^2)
Car Halogen main beam approaching 1km	Up to 1,000,000 (can vary significantly between cars)
International Space Station (400km up)	1000 (depends upon relative position of sun)
Car Brake Light at 0.5km	400
Car Brake Light at 0.7km	200
Car Brake Light at 1.0km	100
Car Brake Light at 2.0km	25
Car Brake Light at 5.0km	4
Car Brake Light at 10km	1
Front Cycle Light at 0.5km	140 (Modern high power white LED)
Front Cycle Light at 0.7km	70
Front Cycle Light at 1.0km	35
Front Cycle Light at 2km	9
Front Cycle Light at 5km	2
White LED Street Light at 0.5km	500 (Viewed from the horizontal)
White LED Street Light at 0.7km	250
White LED Street Light at 1.0km	120
White LED Street Light at 2.0km	30
White LED Street Light at 5.0km	8
Sodium Street Light at 0.5km	300 (Viewed from the horizontal)
Sodium Street Light at 0.7km	150
Sodium Street Light at 1.0km	75
Sodium Street Light at 2.0km	20
Sodium Street Light at 5.0km	5
Brightest Star in the Sky (Sirius)	13
Airliner flying at 30,000ft)	Nav Lights 0.4 to 5; anti-collision lights 2 to 20
Typical bright star (e.g. Orion)	0.5 to 2.0
Faintest light visible from street lit area	0.4
Visible limit for fully dark-adapted eyes	0.02

Table 7 Comparisons of approximate micro-lumens values

25. If there is a requirement to consider the brightest turbine in terms of emitted candela rather than micro-lumens, Table 8 provides data on which turbine emits the most candela towards each viewpoint but takes no account of the distance between light and viewpoint.

Viewpoint	Brightest Lit Turbine	Distance (km)	Candela	Candela at 10%	Obscured
1	13	4.352	75	8	
2	3	6.672	122	12	
3					X
4	7	6.631	448	45	
5	1	7.734	228	23	
6	11	6.763	2379	238	
7	13	6.877	199	20	
8	2	7.645	181	18	
9	7	10.645	576	58	
10	2	8.769	204	20	
11	11	8.113	291	29	
12	10	10.925	357	36	
13	7	12.11	530	53	
14					X
15	10	14.874	576	58	
16	10	16.832	691	69	
17	2	18.952	691	69	
18	7	16.079	1851	185	
19	2	17.449	2515	252	
20	3	19.681	2205	221	
21	3	22.167	2471	247	
22	1	21.549	2475	248	
23	1	22.167	2509	251	
24	2	25.562	1087	109	
25	7	26.068	2452	245	
26	3	27.68	2471	247	
27					X
28					X
29	3	18.521	2439	244	M
30	3	19.548	2515	252	
31	3	35.792	982	98	

Table 8 Brightest Turbine Hub Light measured in Candela emitted towards a viewpoint

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Part 2 Mitigation

Intensity Reduction (ANO Lighting: 2000cd down to 200cd)

26. The lights (IR and visible red lights) will be switched on between Evening Civil Twilight and Morning Civil Twilight in accordance with the UK Almanac; approximately 11 hours per day averaged over the year.

27. The primary mitigation consideration in addition to the already described reduction in brilliance due to elevation angle, is taken from Reference D which states:

> *'If the horizontal meteorological visibility in all directions from every wind turbine generator in a group is more than 5 km, the intensity for the light positioned as close as practicable to the top of the fixed structure required to be fitted to any generator in the windfarm and displayed may be reduced to not less than 10% of the minimum peak intensity specified for a light of this type'.*

28. It is therefore possible to take advantage of the CAA SARG Policy Statement dated 01/06/2017 and incorporate the option to reduce the hub height lighting to not less than 10% of the minimum peak intensity specified for the installation in good weather. In essence, reducing the 2000cd obstruction lights to 200cd in meteorological visibilities greater than 5km. It should be noted that this does not apply to any low intensity 32cd lights installed halfway up the turbine towers.
Note: This concession is not applicable to MOD specification IR lighting, which is covered separately.

29. It will be necessary to calculate how much time the lights would spend at 2000cd and at 200cd. To assess historical visibility in this Argyll & Bute region, the closest meteorological stations to An Carr Dubh are at Tiree Airfield and Glasgow Airport. Note: there are no meteorological stations that provide historical data closer to An Carr Dubh. However, although the visibility will not be identical at the three locations it will be in the same air-mass for the majority of the time and will give similar observations. On the following page are tables of visibilities throughout the year for Tiree and Glasgow which are averaged over a 20 or 30-year period.

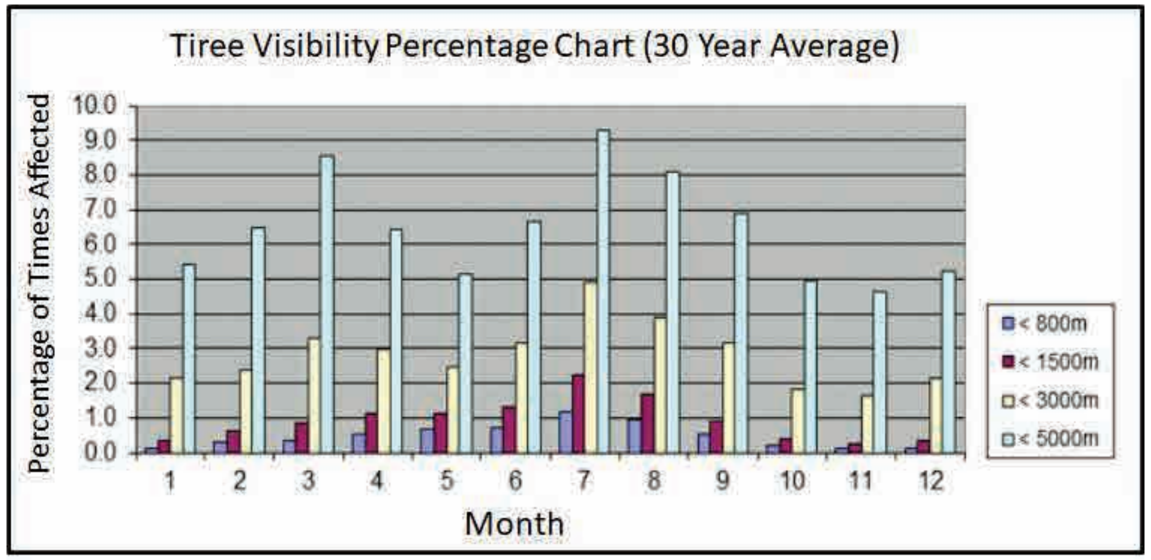

Table 9 Visibility Table for Tiree (Light Blue is 5km Indicator)

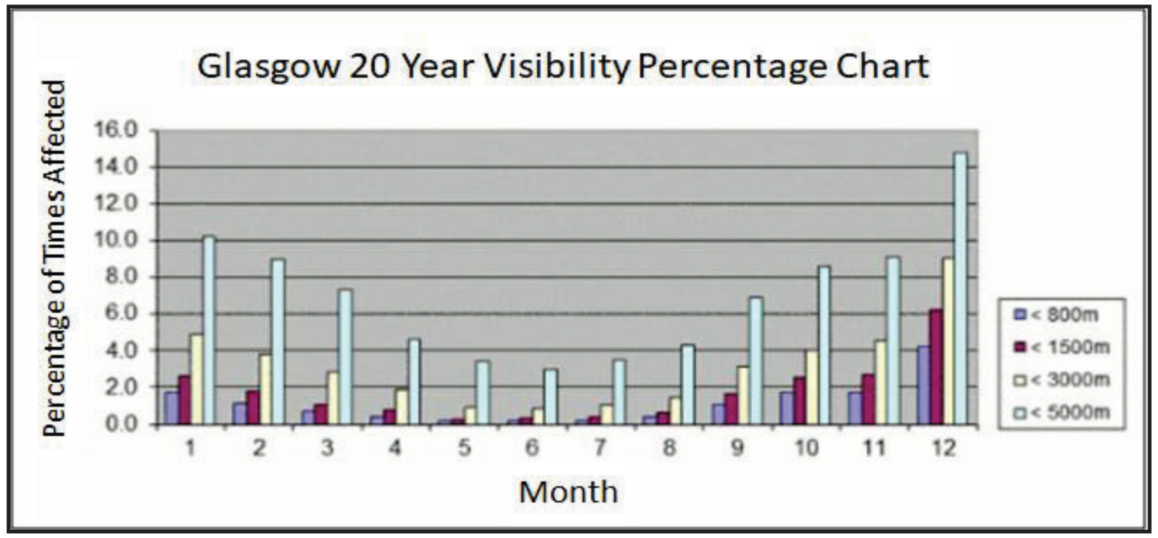

Table 10 Visibility Table for Glasgow (Light Blue is 5km Indicator)

30. These Met Office tables show us that the visibility is below 5km (light blue bar) for an average of 7% of the time averaging both Tiree and Glasgow. This suggests that the lights will be at 2000cd for 7% of the time and 200cd for 93% of the time.

31. Whilst Tiree and Glasgow are not An Carr Dubh, met visibility improves with height since the concentration of particles (dust, haze) and liquid droplets (water) reduces with height and the air also becomes thinner. It could be argued that the An Carr Dubh visibility, situated on a 400-500m hill, will be better than that at Tiree and Glasgow.

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Obstruction Light: Weather (Cloud) Obscuration.

32. On occasion, the visibility in the area of An Carr Duibh will reduce significantly due to the presence of cloud on the hills. If the An Carr Duibh turbines are in cloud, then the obstruction lights will not be seen. In a similar vein, if the turbines are partially shrouded in cloud, then the light intensity will be much reduced.

33. The average height of the turbine hubs (where the lights are mounted) will be around 500m amsl. Met cloud bases are quoted in feet (ft) so measurements will now be given in ft. (500m = 1600ft approx).

34. It is now possible to compare the average **turbine hub/light** height of **1600ft** amsl with the actual cloud bases recorded by the Met Office at Tiree and Glasgow Airfields, again, over a 20 or 30-year period as shown in the diagrams below. The maroon bars show when the cloud-base first drops below the lights.

35. The maroon columns (600-1000ft) indicate that the cloud base will range from approximately 800ft to 1300ft below turbine hub heights on around 500 occasions a month. Again, the hub mounted lights will be obscured, even when the cloud base is towards the upper level (1000ft amsl).

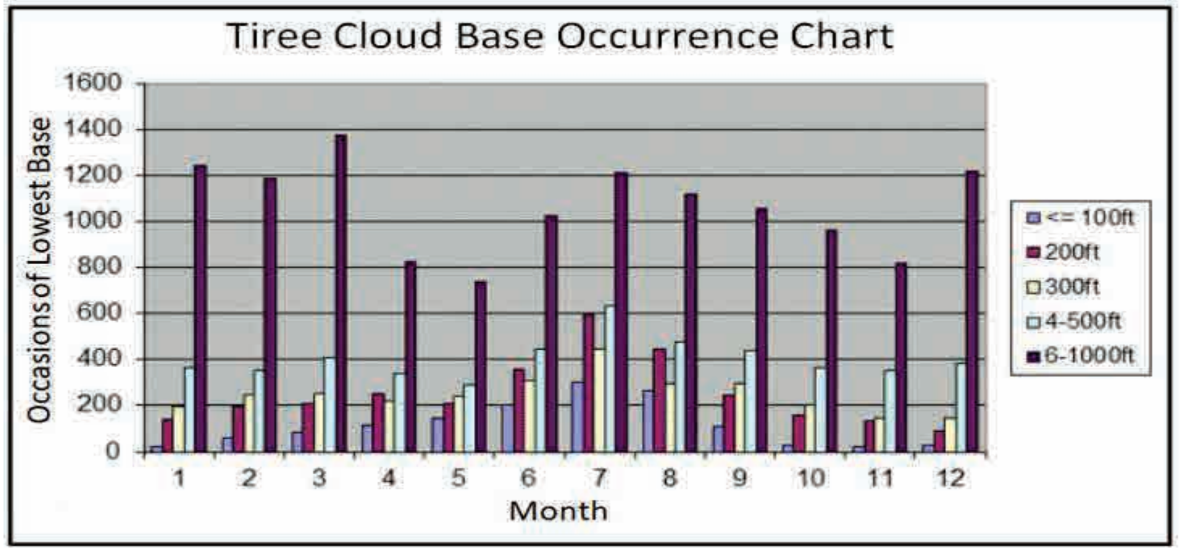

Table 10 Cloud Base Table for Tiree

WPAC
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Commercial-in-Confidence

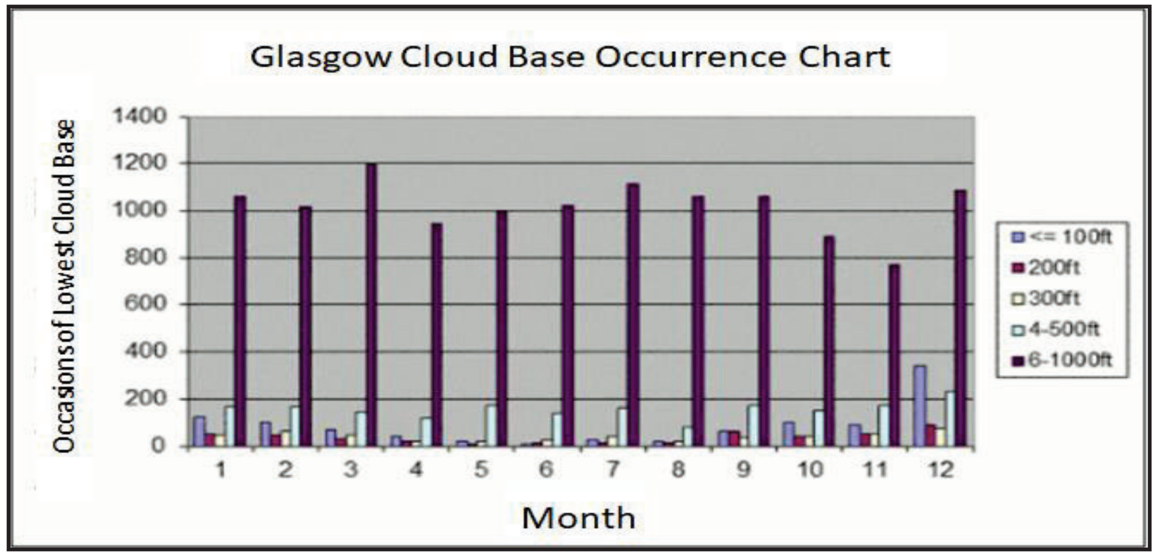

Table 11 Cloud Base for Glasgow Airport

36. The maroon columns (600-1000ft) indicate that the cloud base will range from approximately 600-1000ft below turbine hub heights on around 1000 occasions a month. At this distance below the turbine hubs the lights will be significantly or, more likely, completely obscured to the general public.

37. The other columns (light blue in particular 400-500ft) indicate that on a further 200-400 or more occasions a month the lights will be obscured by cloud. Note: met office statistics report cloud base in occurrences (observations) as opposed to total duration.

38. Again, whilst Tiree and Glasgow are not An Carr Dubh, Met Office statistics show that the cloud-base reduces in the region of hills. It could be argued that at An Carr Dubh, located on a 400 - 500m (average) hill, the cloud-base would be lower than at Tiree or Glasgow thus providing even greater degree of light obscuration than calculated here.

Weather Obscuration Conclusion

39. It is most important not to try and combine the two different observations, visibility and cloud-base, into a single statement. Informal advice direct from Met Office and Airport forecasters indicate that the information so gathered, should be presented as follows:

> *Meteorological observations suggest that the turbine hubs will be obscured on several hundred occasions a month by cloud. (Obstruction lights not visible by the public)*
>
> *When not obscured by cloud, the visibility in the area of the turbines can be expected to exceed 5km for up to 93% of the time. (Obstruction lights switched down to 200cd for 93% of the time)*

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Conclusion

40. The current CAA CAP 764 (Draft) dictates that the An Carr Dubh Wind Farm should be fitted with ten ANO visible red obstruction lights. However, applying the published CAA dispensations (and a little more through discussion with the CAA) results in a layout with seven ANO visible lights. This layout has now been approved by the CAA as shown in Appendix C.

41. The presence of the Blarghour Turbine Site does not currently make a significant difference to the lighting options for An Carr Dubh.

42. Finally, An Carr Dubh is in an area where it will positively benefit from the weather obscuration of its visible ANO lighting. This obscuration benefit is potentially quite significant. Moreover, when the lights are not obscured by cloud, they can expect to be set at the lower 200cd for 93% of the time.

Technical Mitigation

43. One other form of potential mitigation commonly discussed is the installation of an Aircraft Detection Lighting System (ADLS). There are two possible methods of detecting an aircraft approaching a wind farm that will automatically turn on the aviation obstruction lights, firstly through the use of a suitable primary surveillance radar (PSR) or secondly, the use of aircraft installed Electronic Conspicuity (EC) equipment with a suitable receiver at the wind farm. There are some significant technical and regulatory issues to be overcome before any such system can be installed and operated in the UK.

44. In the case of PSR, this is already in use at wind farms in Europe; as an example the Terma Scanter 5002 radar is installed at a number of sites as shown in Figure 10. The main regulatory constraint is that although such systems are in use in Europe, in the UK, where airspace tends to be shared to a much greater extent between users, the CAA have yet to mandate the performance parameters that such a system must be capable of fulfilling. For example, the coverage requirement will need to be defined in terms of maximum range of detection and activation (which may vary depending upon the speed of the aircraft), base of cover (above ground level) and almost certainly a maximum height coverage to avoid unnecessary activations, which a PSR on its own cannot ascertain. An initial set of draft requirements was promulgated in 2018 but these were for discussion with aviation stakeholders and the wind industry and it cannot be assumed that these are going to be the final criteria. Even if the standards are defined, it may be that any single radar will not be capable of delivering the required coverage where, for example, a wind farm is located on a hill and aircraft may approach below the wind farm from any direction. It may then become necessary to install multiple radars in order to achieve the required coverage at low level. This in itself may lead to limitations due to mutual interference in what is already a crowded part of the electro-magnetic spectrum, (although the Terma radar does have some anti-interference capabilities) but the additional radars may affect other systems working in the same frequency band. There would also be additional planning issues to consider, such as the visual impact of additional aerials, and rotating arrays. Technical constraints also mean that it will be necessary to position the radars some distance outside the windfarm as shown in the example below in order to avoid turbines screening the radar and to provide the required height coverage.

Figure 10 Terma 5002 Radar at a Wind Farm in Germany

45. The one major advantage of PSR is that it will detect any aircraft, both those transponding and those that are not, known as non-co-operative targets. Depending upon how the regulatory process moves forwards, this may have a major effect on which systems to use for ADLS. In response to a recent planning inquiry paper the CAA responded stating in a letter dated 21 April 2021: *For the UK, there are some challenges to be resolved. The cost/benefit of the use of primary surveillance radar for the active detection of aircraft, spectrum availability, incentive pricing cost and geographical separation required before frequencies can be re-used potentially makes this a less than optimal solution.*

46. The alternate system is one based upon a reliance on aircraft carried Electronic Conspicuity (EC) transponders. Currently light aircraft flying clear of regulated airspace in the UK below 10,000ft are not required to carry a transponder (one example being Secondary Surveillance Radar or SSR). Most aircraft do, but not all. The CAA has been encouraging fitment by all aircraft and hope to have a regulatory system in place within the next few years requiring all flying machines to be fitted. Unfortunately this is not as simple a process as one might imagine. This issue has been running for at least 20 years so far, however some limited progress is now being made. In the same response to a recent planning inquiry paper the CAA stated: *'At the same time, the lack of interoperability between the wide variety of electronic conspicuity devices currently available may require careful consideration of the specification of any passive system receivers and how they are deemed compliant to be deployed and operated.'* The letter goes on to state: '*We concur that not every situation may require ADLS to be fitted and operated; Article 222 or 223 requirements of the Air Navigation Order will remain, and the CAA may agree a specific solution under Section 7 of Article 222 and Section 11 of Article 223. However, ADLS could potentially provide an acceptable means of compliance that could provide greater certainty for developers when developing planning proposals on CAA acceptance and assist with discussions with communities during planning consultation.'* What this letter is saying is that ADSL using EC is technically feasible but that until the regulatory actions concerning the mandatory carriage of a compatible EC system have been completed and signed into law, and the coverage requirements agreed, nothing can be done unless a planning condition to require the retrospective installation of a system is considered appropriate. The length of time that this is likely to take is difficult to estimate, however, realistically it is likely to be within a two to five year timeframe as it is a small part of a much wider airspace modernisation programme currently under way. Additionally, the CAA also issued a Guidance Notice dated 26/10/21 entitled: *'Electronic continuity specifications: enabling interoperability between airspace users'*. This announced the establishment of a task force to jointly develop electronic conspicuity specifications to enable interoperability between airspace

users. It goes on to state: '*The adoption of EC specifications will not be mandated UK wide. Users of other systems can continue to benefit from the functionality that those products offer*'. This does not mean that an EC triggered ADLS system will not be feasible, but the regulatory challenges mentioned above may take longer to resolve.

47. What is clear is that once the carriage of compatible transponders is mandated and all aircraft fitted with them, this is likely to be a realistic way of triggering an ADLS system. Such systems are passive at the wind farm and will not, therefore cause any interference. As shown in Figure 11 they require unobtrusive small aerials, approximately 1.2 metres long that are very reliable and relatively inexpensive to install and operate.

Figure 11 ADSB/SSR Passive Aerial

48. Bearing the above in mind, it would be prudent to ensure that lighting installed on the turbines is compatible with any future EC triggered ADSL system, so that when the regulatory process and aircraft equipage has been completed, it will be a relatively cheap and simple exercise to retro-fit such a system. Alternately, the ADSB/SSR aerials and system could be installed when the wind farm is constructed, ready for activation when required. It may therefore be suitable for use as the basis of a planning condition requiring the activation of the system once the regulatory and equipage hurdles have been overcome.

49. An ADSL system may not be suitable for every location, depending upon the nature of aviation operations at night in the area around the wind farm and the activation criteria that are finally mandated by the CAA. If located close to the approach for a major airport for example, the lights might be required to be turning on and off continuously, however, in a location like An Carr Duibh, with limited night low level civilian traffic, the number of times the lights will activate is likely to be so small. The EC activated ADLS system will be able to differentiate between civil traffic and SAR/HEMS/military traffic using NVD and not therefore activate when these types of aviation operations are taking place within the activation zone for the system. The infra-red lights that these

types of operations rely on will always be on at night, but of course are invisible to the naked eye and will have no effect on the visual impact of the development.

Comment

50. In recent months various briefing documents have been in circulation suggesting that visible obstruction lights are not required in the current aviation environment. The CAA have briefed WPAC that they do not support this position and would consider prosecuting organisations that do not follow the existing guidance and regulations. However, change will come; this will be led by the CAA and be centred on the new draft CAP 764 (as adhered to in this report) and the future development of ADLS.

51. From the direct experience of WPAC staff who have over 40 years of day/night low flying over land and sea both with and without NVG/Ds, the inclusion of adequate visible red lighting is important to cater for both routine operations and the inevitable unplanned outcome. Pilots uncertain of their location together with emergency situations and system failures of critical night low flying equipment are circumstances that require a degree of visible obstruction lighting on large wind turbines.

52. In addition, future green energy aircraft (hydrogen/electric and battery powered) will fly considerably lower and slower than current aircraft and will be significantly limited in track variation by much shorter ranges. Good visible obstruction lighting will become more, not less important in this low direct flight environment.

53. Finally, an aircraft colliding with a wind turbine is thankfully an extremely rare event but one with enormous consequences. A standard risk assessment as part of an aviation safety case would conclude that even a very low probability of a significant dangerous event is still unacceptable and must be mitigated, in this case by the fitting of visible obstruction lights.

Conclusion

54. This report has assessed the requirements for both visible, CAA approved aviation lighting and MOD approved Infra-Red lighting for the An Carr Duibh Wind Farm. The resulting layout is set out in Figures 4 and 6 and makes use of both CAA/ANO Red lights and MOD IR lights. The proposed layouts were sent to the CAA and MOD DIO for approval. The MOD will approve the IR lighting layout as there is no significant concession required and the CAA have responded approving the seven lit turbine layout as per the CAA approval letter at Appendix C.

55. The report also provides the brilliance of lights that will be visible taking into account the elevation angle between the turbine hub obstruction light and the viewpoints and the distance between each turbine and each viewpoint. The report shows that for up to 93% of the time, the lights will only be required to operate at 10% luminous intensity, which will significantly reduce obstruction light effects in the area. Further interpretation of these results can be undertaken by a Landscape and Visual Impact Assessment expert.

56. The report then identifies additional mitigation options that, should the regulatory process allow, enable the visible medium intensity turbine lights to be switched off for the vast majority of the

time and activated only on those rare occasions in this location when an aircraft activates the system. A suitably worded planning condition will enable the future lighting effects to be mitigated to the extent of becoming almost non-existent.

Authors

Cdr John Taylor RN (Ret) – after a career in the Royal Navy specialising in Air Traffic Control (ATC), Airspace Management and Air Defence which culminated in leading both the ATC and Fighter Control Specialisations, John worked for Lockheed Martin UK for three years as a Principal Consultant and Business Area Manager responsible for Air Traffic Management Consultancy, including the provision of advice to wind farm developers. In 2008 he founded WPAC Ltd and since then he and his team have provided aviation advice in relation to over 2000 wind farm and wind turbine sites, given evidence at a number of planning inquiries and enabled many sites to overcome aviation objections where it was feasible to do so. He and his team have also provided advice to a number of Local Planning Authorities, Renewable UK and the Aviation Fund Management Board, including organising workshops and the provision of guidance documents. John also advises planners and developers in relation to physical and technical safeguarding of non-wind farm developments in the vicinity of aviation facilities.

Sqn Ldr Mike Hale RAF (Rtd) has over 45 years, piloting, instructing and examining experience on numerous military fast jet aircraft through to a range of civilian and military general aviation training aircraft and gliders. He has held many posts including Flying Instructor, Training Officer, Flight Commander, Squadron Commander and Principal Tornado AD Force Examiner. He has amassed over 10,000 flying hours of experience when operating at many locations around the world. In parallel to his flying duties, Mike held the post of Officer Commanding the MOD Low Flying Operations Squadron (OC LFOS). In this post he was both Low Level Airspace Manager for the MOD & Wind-Farm Subject Matter Expert for the Defence Infrastructure Organization (DIO). During that period, he assessed over 14,000 wind-farm pre-applications and 2000 full applications against low flying, weapons range, specialist airspace, local community and aerodrome safeguarding criteria. Mike also instigated two Qinetiq ground based Infra Red obstruction lighting trials. These were followed by instigating and managing the MOD Infra Red/Low Intensity (Henlow) flight trials and the CAA/MOD/Trinity-House/RUK off-shore IR/Morse (North Hoyle) flight trials. In conjunction, Mike organised numerous and various supporting trials including night vision equipment compatibility and detailed lighting beam overspill analysis (where light is emitted outside the required specification envelope). In 2012, he was awarded an MBE for generating a proactive and mutually successful working relationship between the Wind Power Industry and the MOD Air Staff.

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Appendix A Lighting Results Tables

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	7.035	-2.6	273	27	5.5	0.6	X
2	6.904	-3.3	204	20	4.3	0.4	X
3	6.212	-4.7	112	11	2.9	0.3	M
7	6.175	-3.9	176	18	4.6	0.5	X
10	4.518	-5.2	75	8	3.7	0.4	
11	4.446	-5.2	75	8	3.8	0.4	
13	4.352	-5.6	75	8	4.0	0.4	

Viewpoint 1 Loch Awe

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	7.573	-2.5	291	29	5.1	0.5	X
2	7.49	-3.0	217	22	3.9	0.4	X
3	6.672	-4.4	122	12	2.7	0.3	
7	6.839	-3.5	194	19	4.1	0.4	X
10	5.171	-4.5	119	12	4.5	0.4	
11	4.904	-4.7	112	11	4.7	0.5	
13	4.628	-5.2	75	8	3.5	0.4	

Viewpoint 2 Dalavich Jetty (Dusk)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	6.624	-1.8	484	48	11.0	1.1	X
2	6.26	-2.3	333	33	8.5	0.8	X
3	6.448	-3.4	199	20	4.8	0.5	X
7	5.305	-2.5	291	29	10.3	1.0	X
10	4.514	-4.4	122	12	6.0	0.6	X
11	5.428	-3.6	190	19	6.4	0.6	X
13	6.087	-3.5	194	19	5.2	0.5	X

Viewpoint 3 B840, North of Balliemeanoch

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	5.687	-2.5	291	29	9.0	0.9	
2	5.817	-2.6	273	27	8.1	0.8	
3	6.602	-2.6	273	27	6.3	0.6	
7	6.631	-1.9	448	45	10.2	1.0	
10	8.223	-1.1	902	90	13.3	1.3	X
11	8.354	-0.2	1982	198	28.4	2.8	X
13	8.782	0.3	2379	238	30.8	3.1	X

Viewpoint 4 Folly at Dun na Cuaiche (Inveraray Castle GDL) (Dusk)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	7.734	-2.9	228	23	3.8	0.4	
2	7.558	-3.1	213	21	3.7	0.4	
3	6.986	-3.7	185	19	3.8	0.4	
7	6.757	-3.1	213	21	4.7	0.5	
10	5.151	-3.8	181	18	6.8	0.7	
11	5.255	-3.7	185	19	6.7	0.7	
13	5.275	-3.9	176	18	6.3	0.6	

Viewpoint 5 Minor road to west of Loch Awe (north of Dalavich)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	6.85	0.9	2509	251	53.5	5.3	X
2	7.249	0.0	2185	219	41.6	4.2	X
3	6.282	-0.6	1443	144	36.6	3.7	
7	7.836	0.3	2379	238	38.7	3.9	X
10	7.769	0.3	2379	238	39.4	3.9	
11	6.763	0.3	2379	238	52.0	5.2	
13	6.115	0.2	2330	233	62.3	6.2	

Viewpoint 6 Beinn Dearg

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	1	7.782	-2.0	413	41	6.8	0.7
2	2	7.436	-2.5	291	29	5.3	0.5
3	3	7.516	-3.6	190	19	3.4	0.3
7	7	6.478	-2.7	254	25	6.1	0.6
10	10	5.516	-4.0	171	17	5.6	0.6
11	11	6.32	-3.5	194	19	4.9	0.5
13	13	6.877	-3.4	199	20	4.2	0.4

Viewpoint 7 Core Path above Inverinan

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	7.448	-2.8	239	24	4.3	0.4	X
2	7.645	-3.8	181	18	3.1	0.3	
3	8.256	-2.4	309	31	4.5	0.5	X
7	8.522	-2.2	357	36	4.9	0.5	X
10	10.041	-0.5	1582	158	15.7	1.6	X
11	10.029	0.7	2435	244	24.2	2.4	X
13	10.337	0.9	2509	251	23.5	2.3	X

Viewpoint 8 Loch Fyne

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	1	10.836	-1.1	902	90	7.7	0.8
2	2	10.942	-1.7	530	53	4.4	0.4
3	3	9.787	-2.2	357	36	3.7	0.4
7	7	10.645	-1.6	576	58	5.1	0.5
10	10	9.166	-1.7	530	53	6.3	0.6
11	11	8.372	-1.8	484	48	6.9	0.7
13	13	7.62	-2.1	385	39	6.6	0.7

Viewpoint 9 Kilmaha Viewpoint

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	8.552	-3.2	208	21	2.8	0.3	M
2	8.769	-3.3	204	20	2.7	0.3	
3	9.318	-2.2	357	36	4.1	0.4	X
7	9.663	-2.0	413	41	4.4	0.4	X
10	11.152	-0.6	1443	144	11.6	1.2	X
11	11.087	1.0	2503	250	20.4	2.0	X
13	11.346	1.3	2393	239	18.6	1.9	X

Viewpoint 10 Jetty at St. Catherines

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	10.642	-2.0	413	41	3.6	0.4	X
2	10.473	-2.0	413	41	3.8	0.4	X
3	9.867	-2.6	273	27	2.8	0.3	
7	9.672	-1.7	530	53	5.7	0.6	X
10	8.065	-2.2	357	36	5.5	0.5	X
11	8.113	-2.5	291	29	4.4	0.4	
13	8.025	-2.6	273	27	4.2	0.4	

Viewpoint 11 Loch Avich, east of Loch Avich House

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	12.269	-0.5	1582	158	10.5	1.1	X
2	12.436	-1.5	622	62	4.0	0.4	X
3	11.226	-2.1	385	39	3.1	0.3	X
7	12.276	-1.8	484	48	3.2	0.3	X
10	10.925	-2.2	357	36	3.0	0.3	
11	10.017	-2.3	333	33	3.3	0.3	M
13	9.186	-2.6	273	27	3.2	0.3	M

Viewpoint 12 Parking spot, Loch Awe

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	12.931	-1.7	530	53	3.2	0.3	
2	12.823	-1.8	484	48	2.9	0.3	
3	12.049	-2.1	385	39	2.7	0.3	
7	12.11	-1.7	530	53	3.6	0.4	
10	10.451	-1.8	484	48	4.4	0.4	
11	10.278	-1.8	484	48	4.6	0.5	
13	9.99	-2.0	413	41	4.1	0.4	

Viewpoint 13 Loch Avich

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	10.865	0.1	2257	226	19.1	1.9	X
2	11.263	-1.1	902	90	7.1	0.7	X
3	10.999	-2.1	385	39	3.2	0.3	X
7	12.187	0.7	2435	244	16.4	1.6	X
10	13.01	0.8	2515	252	14.9	1.5	X
11	12.352	2.7	936	94	6.1	0.6	X
13	12.083	-0.8	1192	119	8.2	0.8	X

Viewpoint 14 A886 at Strachur

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	16.238	-0.5	1582	158	6.0	0.6	X
2	16.41	-1.5	622	62	2.3	0.2	X
3	15.196	-2.0	413	41	1.8	0.2	
7	16.248	-1.6	576	58	2.2	0.2	
10	14.874	-1.6	576	58	2.6	0.3	
11	13.985	-1.7	530	53	2.7	0.3	
13	13.159	-1.9	448	45	2.6	0.3	

Viewpoint 15 Fincharn Castle, Loch Awe

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Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	18.264	-0.6	1443	144	4.3	0.4	X
2	18.426	-1.5	622	62	1.8	0.2	
3	17.219	-1.7	530	53	1.8	0.2	
7	18.238	-1.4	691	69	2.1	0.2	
10	16.832	-1.4	691	69	2.4	0.2	
11	15.969	-1.5	622	62	2.4	0.2	
13	15.157	-1.6	576	58	2.5	0.3	

Viewpoint 16 B840, East of Ford

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	18.804	-0.9	1087	109	3.1	0.3	X
2	18.952	-1.4	691	69	1.9	0.2	
3	17.756	-1.6	576	58	1.8	0.2	
7	18.729	-1.3	756	76	2.2	0.2	M
10	17.288	-1.3	756	76	2.5	0.3	M
11	16.455	-1.4	691	69	2.6	0.3	M
13	15.661	-1.5	622	62	2.5	0.3	

Viewpoint 17 North of Ford

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux$^{10-6}$)	Microlumens per square metre (lux$^{10-6}$) at 10%	Obscured
1	17.077	0.3	2379	238	8.2	0.8	X
2	16.667	-0.1	2083	208	7.5	0.7	X
3	17.635	-0.6	1443	144	4.6	0.5	
7	16.079	-0.3	1851	185	7.2	0.7	
10	16.52	0.3	2379	238	8.7	0.9	X
11	17.624	0.2	2330	233	7.5	0.8	X
13	18.491	-0.1	2083	208	6.1	0.6	X

Viewpoint 18 Cruachan Dam

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Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	17.11	0.9	2509	251	8.6	0.9	
2	17.449	0.8	2515	252	8.3	0.8	
3	17.518	0.7	2435	244	7.9	0.8	
7	18.407	0.9	2509	251	7.4	0.7	
10	19.554	1.0	2503	250	6.5	0.7	X
11	19.092	1.6	2205	221	6.1	0.6	X
13	18.987	0.9	2509	251	7.0	0.7	

Viewpoint 19 Beinn Bheula

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	19.196	1.8	1994	199	5.4	0.5	
2	18.778	1.8	1994	199	5.7	0.6	
3	19.681	1.6	2205	221	5.7	0.6	
7	18.129	2.0	1747	175	5.3	0.5	
10	18.419	2.0	1747	175	5.1	0.5	M
11	19.516	1.9	1870	187	4.9	0.5	X
13	20.358	1.8	1994	199	4.8	0.5	M

Viewpoint 20 Ben Cruachan (1126m)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	21.223	1.3	2393	239	5.3	0.5	
2	21.306	1.3	2393	239	5.3	0.5	
3	22.167	1.1	2471	247	5.0	0.5	
7	22.024	1.3	2393	239	4.9	0.5	
10	23.676	1.3	2393	239	4.3	0.4	
11	23.907	1.3	2393	239	4.2	0.4	
13	24.35	1.2	2439	244	4.1	0.4	

Viewpoint 21 Ben Ime

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	21.549	0.6	2475	248	5.3	0.5	
2	21.96	0.5	2452	245	5.1	0.5	
3	21.543	0.5	2452	245	5.3	0.5	
7	22.852	0.8	2515	252	4.8	0.5	X
10	23.477	1.0	2503	250	4.5	0.5	X
11	22.676	0.7	2435	244	4.7	0.5	
13	22.233	0.7	2435	244	4.9	0.5	

Viewpoint 22 Beinn Mhor (Cowal Peninsula and LLTNP)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	22.167	0.9	2509	251	5.1	0.5	
2	22.297	0.9	2509	251	5.0	0.5	
3	23.052	0.7	2435	244	4.6	0.5	
7	23.081	0.9	2509	251	4.7	0.5	
10	24.699	0.9	2509	251	4.1	0.4	
11	24.819	0.9	2509	251	4.1	0.4	
13	25.177	0.9	2509	251	4.0	0.4	

Viewpoint 23 The Cobbler (Ben Arthur)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	25.979	-0.6	1443	144	2.1	0.2	X
2	25.562	-0.9	1087	109	1.7	0.2	
3	26.099	-0.9	1087	109	1.6	0.2	
7	24.697	-0.7	1317	132	2.2	0.2	X
10	24.32	-0.7	1317	132	2.2	0.2	X
11	25.284	-0.5	1582	158	2.5	0.2	X
13	25.941	-0.4	1721	172	2.6	0.3	X

Viewpoint 24 B845, Loch Etive

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	25.81	0.6	2475	248	3.7	0.4	X
2	25.702	0.4	2429	243	3.7	0.4	
3	26.861	0.3	2379	238	3.3	0.3	X
7	26.068	0.5	2452	245	3.6	0.4	
10	27.664	1.1	2471	247	3.2	0.3	X
11	28.313	0.5	2452	245	3.1	0.3	
13	29.026	0.4	2429	243	2.9	0.3	

Viewpoint 25 Troisgeach

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	26.665	1.3	2393	239	3.4	0.3	
2	26.448	1.2	2439	244	3.5	0.3	
3	27.68	1.1	2471	247	3.2	0.3	
7	26.557	1.7	2099	210	3.0	0.3	
10	27.964	1.8	1994	199	2.5	0.3	X
11	28.82	1.3	2393	239	2.9	0.3	X
13	29.647	1.2	2439	244	2.8	0.3	

Viewpoint 26 Ben Lui (1130)

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	5.848	-2.8	239	24	7.0	0.7	X
2	6.049	-3.9	176	18	4.8	0.5	X
3	6.66	-2.6	273	27	6.2	0.6	X
7	6.934	-2.1	385	39	8.0	0.8	X
10	8.442	-0.5	1582	158	22.2	2.2	X
11	8.433	0.5	2452	245	34.5	3.4	X
13	8.759	0.9	2509	251	32.7	3.3	X

Viewpoint 27 Bridge on Old Military Road

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Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	8.878	-1.4	691	69	8.8	0.9	1
2	8.476	-1.6	576	58	8.0	0.8	2
3	8.898	-2.5	291	29	3.7	0.4	3
7	7.563	-1.5	622	62	10.9	1.1	7
10	7.102	-2.5	291	29	5.8	0.6	10
11	8.09	-2.2	357	36	5.5	0.5	11
13	8.8	-2.3	333	33	4.3	0.4	13

Viewpoint 28 Road summit view travelling SW on minor road to west of Loch Awe

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	17.476	1.4	2347	235	7.7	0.8	M
2	17.322	1.4	2347	235	7.8	0.8	M
3	18.521	1.2	2439	244	7.1	0.7	M
7	17.598	1.5	2276	228	7.3	0.7	M
10	19.147	1.7	2099	210	5.7	0.6	X
11	19.866	1.4	2347	235	5.9	0.6	M
1	17.476	1.4	2347	235	7.7	0.8	M

Viewpoint 29 Beinn Bhuidhe - DUSK

Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux10-6)	Microlumens per square metre (lux10-6) at 10%	Obscured
1	18.741	1.0	2503	250	7.1	0.7	
2	18.924	1.0	2503	250	7.0	0.7	
3	19.548	0.8	2515	252	6.6	0.7	
7	19.774	1.0	2503	250	6.4	0.6	
10	21.328	1.0	2503	250	5.5	0.6	
11	21.32	1.0	2503	250	5.5	0.6	
13	21.587	1.4	2347	235	5.0	0.5	X

Viewpoint 30 Ben Donich

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Turbine	Distance (km)	Elevation Angle	Candela	Candela at 10%	Microlumens per square metre (lux^{10-6})	Microlumens per square metre (lux^{10-6}) at 10%	Obscured
1	36.508	0.4	2429	243	1.8	0.2	X
2	36.884	-0.4	1721	172	1.3	0.1	X
3	35.792	-1.0	982	98	0.8	0.1	
7	37.328	0.7	2435	244	1.7	0.2	X
10	36.769	0.6	2475	248	1.8	0.2	X
11	35.666	0.7	2435	244	1.9	0.2	X
13	34.8	0.4	2429	243	2.0	0.2	X

Viewpoint 31 Waverley Paddle Boat

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

Appendix B – Abbreviations and Definitions

ADSB……………………………………..………Automatic Dependent Surveillance Broadcast
AGL..Above Ground Level (Height)
ANO..Air Navigation Order
AMSL...Above Mean Sea Level (Elevation)
ASG...Aviation Steering Group
CAA...Civil Aviation Authority
CAP..Civil Aviation Publication (Referrers to Specific Documents)
cd...Candela, a measure of light intensity
DIO...Defence Infrastructure Organisation
HNTA..Helicopter Night Training Area
In Flight Visibility....................The distance a pilot can see ahead to fly & navigate the aircraft
IR...Infra-Red
Kts...Knots: a measure of airspeed (10 kts = 12mph = 19 kph)
LED...Light Emitting Diode
MOD..Ministry of Defence
mW/sr.............milliWatts per steradian: electromagnetic energy output related to solid angle
Nm..Nautical Mile
NVD ....Night Vision Devices - Aircraft Mounted
NVG...Night Vision Goggles - Operator Worn
Radar Altimeter........An altimeter that uses radar to accurately measure height above ground
QFE ....Setting on Altimeter that gives Height above Airfield
RoAR...Rules of the Air Regulations
Rule 5..The Low Flying Rule – part of RoAR
Rule 28...VFR Rules Outside Controlled Airspace – part of the RoAR
ReUK..Renewables UK – The UK Wind Industry Body
SAR Box..Night Training Area for Search and Rescue Helicopter Units
SSA..Sector Safety Altitude
SSR…………………………………………………………………….Secondary Surveillance Radar
UKAB..............................United Kingdom Air Prox Board – Investigates Aircraft Near Misses
VFR...................................Visual Flight Rules (Flight without ATC on a see-and-be-seen basis)
VMC..................................Visual Meteorological Conditions (Weather suitable for VFR flight)

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Appendix C CAA Response

Safety and Airspace Regulation Group
Safety and Business Delivery

Civil Aviation Authority

Mike Hale
Aviation Consultant
Wind Power Aviation Consultants Ltd.
38 Hadrian Way
Chilworth
Southampton
SO16 7HX

13 March 2023
Ref Windfarms/An Carr Dubh

Dear Mike,

Proposed Obstacle Lighting Scheme for An Carr Dubh Wind Farm

Reference: An Carr Dubh Wind Farm Updated Brief, dated 28 February 2023

1. Thank you for the e-mail at reference. The attached report discusses the proposed obstacle lighting plan for the An Carr Dubh Wind Farm.

2. The proposed An Carr Dubh Wind Farm consists of 13 turbines, with tip heights 180m above ground level, which brings them within scope of the Air Navigation Order (ANO) Article 222 obstacle lighting requirements.

3. We have considered the report carefully and take note of the intent to address concerns relating to adverse visual impacts of aviation lighting on non-aviation receptors while ensuring that the lighting installed on the turbines meets air safety requirements.

4. We note the proposed lighting scheme identifies the perimeter outline and that some mitigation is proposed to be provided by the provision of infra-red lighting for those operators who carry Night Vision Device capability.

5. Under provisions given in the Air Navigation Order (ANO) Article 222 section 6, the CAA provides for the following variation:

- medium intensity steady red (2000 candela) lights on the nacelles of turbines T01, T02, T03, T07, T10, T11 and T13;
- a second 2000 candela light on the nacelles of the above turbines to act as alternates in the event of a failure of the main light;

Civil Aviation Authority
1W Aviation House Beehive Ring Road Crawley West Sussex RH6 0YR www.caa.co.uk
Telephone 0330 138 3166 andy.wells@caa.co.uk

- the lights on these turbines to be capable of being dimmed to 10% of peak intensity when the lowest visibility as measured at suitable points around the wind farm by visibility measuring devices exceeds 5km;
- infra-red lights to MoD specification installed on the nacelles of turbines T01, T02, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12 and T13.

6. Intermediate level 32 candela lights are not required to be fitted on the turbine towers.

7. If the proposed design of the wind farm changes (other than variations due to micrositing etc.) this is likely to require a revision to this aviation obstacle lighting variation. We note also the proximity of the Blarghour Wind Farm; however this lighting proposal has been considered on its own merits (i.e. without consideration of the potentially neighbouring wind farm).

8. Please let me know if you have any further queries.

Yours sincerely,

Andy Wells, Manager Rulemaking and Safety Publications

Continued (2 of 2 pages)

Wind Power Aviation Consultants Ltd
Wind Farm Aviation Lighting and Mitigation Report for An Carr Duibh Wind Farm V4.0
Our Ref: WPAC/067/22 Date:22/03/23

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