

Buckingham Group Contracting Ltd

**170248 Headbolt Lane New
Station**

Light Obtrusion Assessment

170248-ARU-REP-EEN-000023

Final | 25 June 2021

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 276736

Ove Arup & Partners Ltd
6th Floor 3 Piccadilly Place
Manchester M1 3BN
United Kingdom
www.arup.com

ARUP

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1 Introduction

1.1 Background

Headbolt Lane is an infrastructure project that will extend the Merseyrail network from the existing terminating station at Kirkby to a new station to be constructed at Headbolt Lane.

Figure 1: Site Location (boundary in red)



Arup has been instructed to survey and report on the existing and likely artificial lighting conditions due to the Headbolt Lane Project (HBL) in relation to current guidance for limiting the effects of light obtrusion. One key objective is to ensure minimum impact on adjacent residents. This report outlines the baseline lighting performance and compares it with the performance of the GRIP4 external lighting design proposals.

1.2 Light Obtrusion

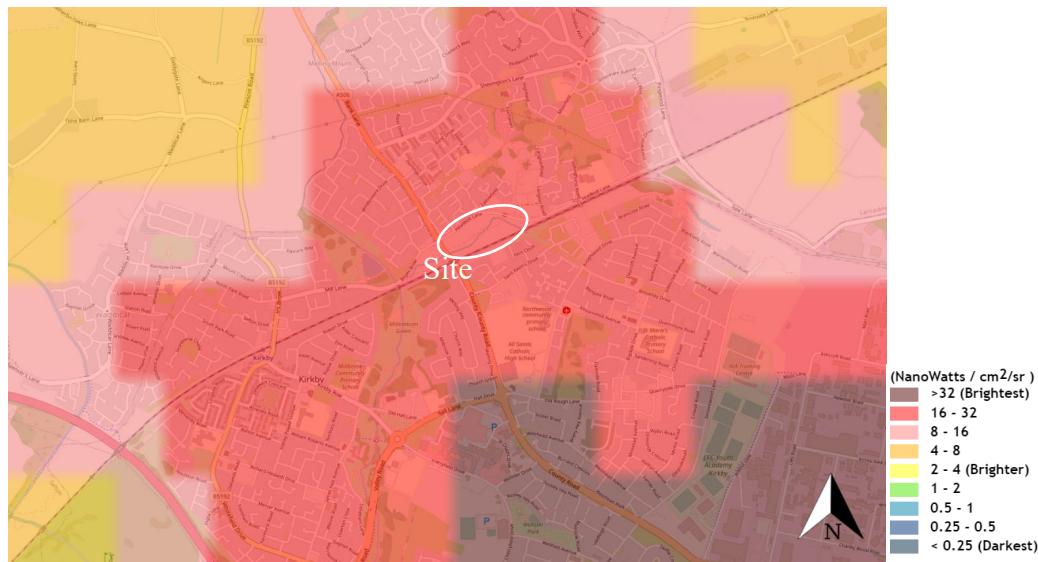
Consequences commonly associated with light obtrusion are the loss of dark night skies and views of the stars, perception of an unsatisfactory nocturnal environment and the harm to wildlife habitats. Light obtrusion has also been shown to have detrimental effects on human health and can present serious physiological and ecological problems. Furthermore, light obtrusion manifests itself as unnecessary energy waste and a contributor to climate change.

Obtrusive light effects can normally be mitigated against through sound design principles and adherence to current best practice design guidance from national and international professional lighting institutions.

1.2.1 Light obtrusion in the locality

The map below (Figure 2) illustrates local light obtrusion magnitude in Merseyside in the context of light emitted into the night sky. This map is an extract from the detailed satellite maps of England's dark skies released by the Campaign to Protect Rural England (CPRE)¹. It can be seen that the area already experiences light obtrusion typical of an urban environment.

Figure 2: Local light obtrusion characteristics (mapping © Natural England)



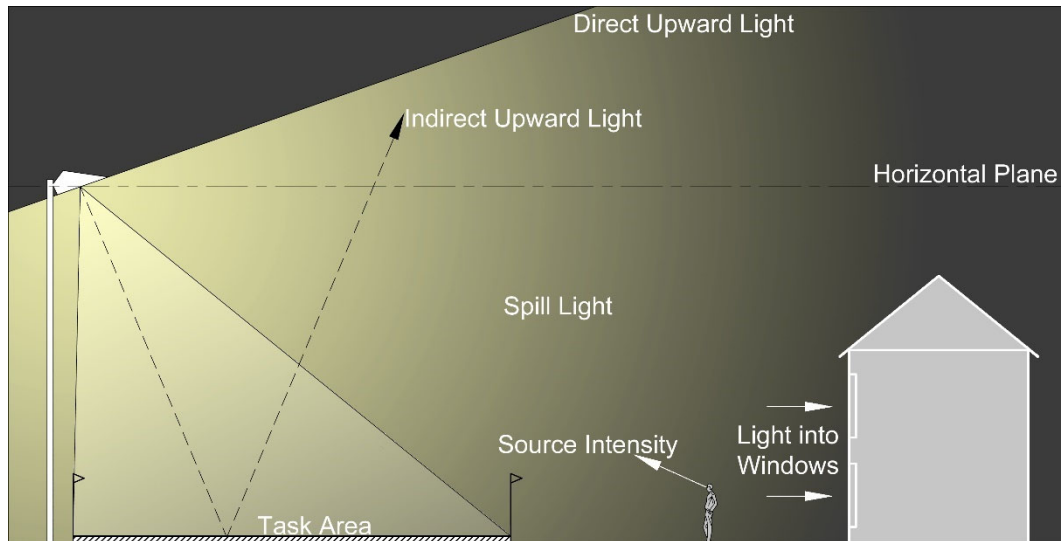
1.2.2 Light Obtrusion Characteristics

The characteristics of light obtrusion are defined below (refer also to Figure 3):

- **Light Intrusion:** stray light beyond the task area onto neighbouring dwellings or sensitive receptors. Units: illuminance (E), measured in lux.
- **Source Intensity:** how bright the light source appears to an observer. Units, Intensity (I), measured in candelas (cd).
- **Sky Glow:** a combination of Direct Upward Light and Indirect Upward Light. This effect is often seen as a bright glow in the night sky e.g. Figure 4. The sky glow is quantified in the guidance notes by ratio of light emitted above the horizontal plane, i.e. into the night sky.
- **Building Luminance:** how bright an illuminated facade appears to the observer. Units: Luminance (L) measured in cd/m^2 . It is important to note that this metric is applicable to buildings purposely illuminated as a night-time feature rather than illumination caused by spill light from adjacent luminaires or luminaires fixed to the building but used to light an adjacent area.

¹ <https://www.nightblight.cpre.org.uk/maps/>

Figure 3: Light obtrusion characteristics



Excessive sky glow is the most obvious indication of light obtrusion and obscures a clear view of the night sky. It can also negatively affect the daily patterns of human and animal behaviour. Figure 4 indicates the impact of light obtrusion on our view the night sky. These images were captured in Ontario on two consecutive nights. The first photograph was taken on 14 August during ‘The Northeast Blackout’ in 2003 where a widespread power outage occurred. The other photo was taken on 15 August, after power was restored.

Figure 4: Sky glow example, Ontario August 2003



In many cases, light obtrusion can be significantly reduced without detriment to the lighting task by optimising illumination of task areas, aiming luminaires below the horizontal plane, selecting efficient optical systems, applying a control strategy, or simply extinguishing unnecessary external lighting.

1.3 Assessment overview

The nocturnal baseline lighting conditions around the proposed development site have been surveyed and the data used in comparison with computer simulations of the proposed lighting design scheme to characterise the potential impact and significance of the scheme.

At this stage in the design process, the final details of the external lighting scheme are not confirmed. In order to understand the performance artificial lighting and predict if and where mitigation may be necessary, the GRIP4 lighting design has been assessed and it sets out the performance expected of the final scheme, which will be finalised at GRIP5.

1.3.1 Supporting design documents

This document refers to the external lighting design information contained in the following GRIP4 Form documents (and those referenced therein), in connection with this project.

170248-ARU-REP-ECV-000004 - Platform Form 001

170248-ARU-REP-ECV-000005 - Car park Form 001

2 Legislation, Policy and Guidance

The following section identifies the legislation, planning policy and light obtrusion guidance that was used to frame this light obtrusion assessment.

2.1 Legislation

2.1.1 Environmental Protection Act

The Environmental Protection Act 1990 (Part III Statutory Nuisance and Clean Air, section 79 of Statutory nuisance and inspections thereof), gives local authorities the power to consider obtrusive artificial light as a Statutory Nuisance. The Act states that *‘any artificial light emitted from premises so as to be prejudicial to health or a nuisance, constitutes “statutory nuisance” for the purpose of this Part, and it shall be the duty of every local authority to cause its area to be inspected from time to time to detect any statutory nuisances which ought to be dealt with under section 80 and, where a complaint of a statutory nuisance is made to it by a person living within its area, to take such steps as are reasonably practicable to investigate the complaint’*.

2.1.2 Clean Neighbourhood and Environmental Act

The Clean Neighbourhood and Environmental Act 2005 (section 102 of the Clean Neighbourhoods and Environmental Act 2005), gives local authorities the power to consider obtrusive artificial light as a Statutory Nuisance. The Act makes

‘exterior light emitted from premises so as to be prejudicial to health or a nuisance’ a criminal offence’.

2.1.3 National Planning Policy Framework - February 2019

The National Planning Policy Framework acts as a guidance for the local planning authorities and the National Planning Practice Guidance supporting the framework encourages best practice design so as to limit the impact of light obtrusion on local amenity, intrinsically dark landscapes and nature conservation. Paragraph 180 states that *‘planning policies and decisions should also ensure that new development is appropriate for its location taking into account the likely effects (including cumulative effects) of pollution on health, living conditions and the natural environment, as well as the potential sensitivity of the site or the wider area to impacts that could arise from the development. In doing so they should:[...] c) limit the impact of light pollution from artificial light on local amenity, intrinsically dark landscapes and nature conservation’.*

2.2 Guidance

The light obtrusion assessment has considered the guidance and recommendations of the following documents:

- ILP² Guidance Note GN01 (2020): Guidance Notes for the Reduction of Obtrusive Light.
- ILP Guidance Note GN08 (2018): Bats and artificial lighting in the UK; Bats and the Built Environment series.
- ILP Professional Lighting Guide PLG 04 (2013): Guidance on Undertaking Environmental Lighting Impact Assessments.
- CIE³ 150 (2017): Guide on the limitation of the effects of light obtrusion from Outdoor Lighting Installations.
- CIE 126 (1997): Guidelines for Minimising Sky Glow.
- CIE 136 (2000): Guide to the Lighting of Urban Areas.
- BS EN 12464, Part 2 (2014): Outdoor Lighting.
- BS 5489, Part 1 (2020): Code of Practice for the design of road lighting.
- SLL⁴ LG6 (2016): The Exterior Environment

These guides provide design advice for the appropriate illumination of external spaces and design limits to limit light obtrusion effects.

² Institute of Lighting Professionals

³ Commission Internationale de L’Eclairage

⁴ Society of Light and Lighting

2.2.1 ILP Guidance Note 01

The ILP GN01 summarises CIE 150 and offers guidance for designers to ensure their lighting schemes reduce light obtrusion and is the document most widely referred to by planning authorities in the context of light obtrusion. These two documents are the most authoritative, widely recognised and adopted best practice guides for the minimisation of light obtrusion.

ILP GN01 proposes lighting design limits against a set of defined environmental zones E0 to E4. These are described in Table 1 below.

The proposed development site has been assessed to be Environmental Zone E3 'suburban' based on the lighting survey that was undertaken and described in Section 5 of this report and the data illustrated in Figure 2. Refer to Table 1 for the characterisation of Zone E3.

Table 1: Environmental designation

Environ. Zone	Surrounding	Lighting Environment	Examples
E0	Protected	Dark	UNESCO Starlight Reserves, IDA Dark Sky Parks
E1	Natural	Intrinsically dark	National Parks, Areas of Outstanding Natural Beauty etc
E2	Rural	Low district brightness	Village or relatively dark outer suburban locations
E3	Suburban	Medium district brightness	Small town centres or suburban locations
E4	Urban	High district brightness	Town/city centres with high levels of night- time activity

There are recommended light obtrusion limits defined in ILP GN01 for Zone E3 and these are described in Table 2 and Table 3 below. Light intrusion and source intensity have been assessed in this report from the windows of properties overlooking the site. While limits are proposed, the design should always seek to optimise below the limits where possible as best practice.

A curfew is defined as a time after which stricter requirements for the control of light obtrusion may apply. This may be a condition applied by the local planning authority and is typically around 2300hrs. A curfew may be possible for this site as it is anticipated that trains will not terminate late into the night. Post curfew, lower level lighting will be required to keep the car park continuously accessible and to support security requirements of the station.

Table 2: Limits for upward light, illuminance and luminance

Env. Zone	Upward Light Ratio	Upward Flux Ratio (road/amenity)	Light Intrusion (into Windows) Ev (lux)		Building Luminance Pre-curfew
			Pre- curfew	Post- curfew	Average L (cd/m2)
E0	0	n/a	0	0	<0.1
E1	0	2 / n/a	2	<0.1 (1*)	<0.1
E2	2.5	5 / 6	5	1	5
E3	5.0	8 / 12	10	2	10
E4	15	12 / 35	25	5	25

Note: * is permitted only from public road lighting installations

Upward Light Ratio is used to define the percentage of light directly emitted above the horizontal plane from a single luminaire. It can be used to compare luminaires and identify the suitability of its use in a lighting scheme where the minimising obtrusive light is preferred. Upward Flux Ratio combines reflections from ground/massing with direct light emission into the sky to describe the upward light performance from the whole lighting scheme.

The limits for intensity of a light source from any given observer are described in terms of the intensity of the source and visible area of the luminaire. Refer to Table 3 for the source intensity limits in each zone.

Table 3: Limits for light source intensity (cd) from observer positions

Zone	Curfew?	$0 < A_p \leq 0.002$	$0.002 < A_p \leq 0.01$	$0.01 < A_p \leq 0.03$	$0.03 < A_p \leq 0.13$	$0.13 < A_p < 0.50$	$A_p > 0.5$
E0	Pre	0	0	0	0	0	0
	Post	0	0	0	0	0	0
E1	Pre	0.29 d	0.63 d	1.3 d	2.5 d	5.1 d	2,500
	Post	0	0	0	0	0	0
E2	Pre	0.57 d	1.3 d	2.5 d	5.0 d	10 d	7,500
	Post	0.29 d	0.63 d	1.3 d	2.5 d	5.1 d	500
E3	Pre	0.86 d	1.9 d	3.8 d	7.5 d	15 d	10,000
	Post	0.29 d	0.63 d	1.3 d	2.5 d	5.1 d	1,000
E4	Pre	1.4 d	3.1 d	6.3 d	13 d	26 d	25,000
	Post	0.29 d	0.63 d	1.3 d	2.5 d	5.1 d	2,500

Notes to table:

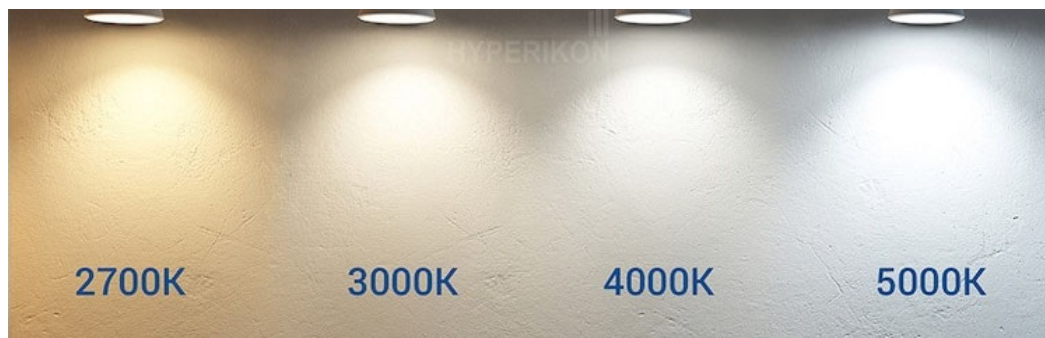
1. 'd' is the distance between the observer and the glare source in metres
2. A_p is the apparent surface of the light source seen from the observer position
3. Upper limits for each zone shall be taken as those with column $A_p > 0.5$

2.2.2 ILP Guidance Note 08

ILP GN08 considers other characteristics of artificial light which may have a detrimental effect on the nocturnal environment. In particular, the colour temperature of the light source and its spectrum.

Colour temperature is quoted in Kelvin and Figure 5 shows how this metric may be visually perceived.

Figure 5: Colour temperature examples



Early generations of LED technology used in external lighting systems were often circa 5000K, harsh in tone and with a high blue spectral component. Nowadays, manufacturers are producing a range of products, some even extending as low as 2200K with the aim of reducing environmental impact on nocturnal flora and fauna.

ILP GN08 recommends that the colour temperatures (<2700K), commonly referred to as warm-white should be used in the external environment and this recommendation is also supported by the International Dark Sky Association⁵.

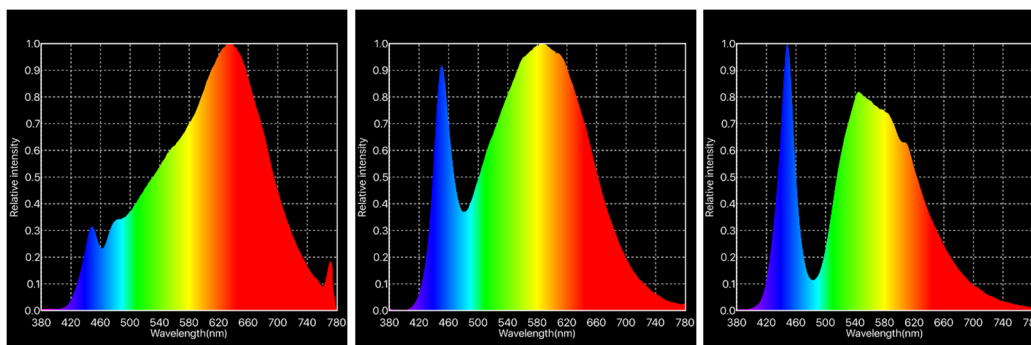
In addition, the guidance recommends that the amount of blue light in the light source should also be limited. Typically, low blue light quantities are also found in warm-white light sources. This can be observed in Figure 6. The recommendation is to minimise wavelengths in the sub-550nm range.

ILP GN08 recommends that all luminaires should lack UV spectral elements and this precludes the use of metal halide and fluorescent light sources. It also recommends that LED luminaires should be used due to their sharp cut-off, lower intensity, good colour rendition and dimming capability.

Currently, 2700K LED light sources are not widely available with all external lighting manufacturers. 3000K is more common and has been specified for this project and it does significantly limit blue wavelengths (Figure 6). The exception is the pedestrian crossings, which are recommended to be visually differentiated from the rest of the scheme. The crossings are therefore provided with 4000K luminaires, but these are a relatively small number compared to the whole lighting scheme.

⁵ <https://www.darksky.org/our-work/lighting/lighting-for-citizens/3k/>

Figure 6: Spectrum of typical LED light sources left-right: 3000K , 4000K and 5000K



3 Assessment Methodology

3.1 Introduction

This section sets out the background information i.e.:

- Proposed site and surroundings
- Measurement/simulation viewpoints and locations

The section continues with the description of the assessment methodology for the following scenarios:

- Baseline condition
- Proposed condition

Finally, this section presents an assessment methodology to characterise any potential impact from the proposed lighting.

3.2 Assessment points

The scope of the assessment is to establish the likely effects of the proposed development lighting installation on the surrounding area and the environment and test whether the recommendations of CIE 150/ILP GN01 can be upheld. Baseline nocturnal lighting conditions were recorded at selected points around the proposed development. Lighting performance data was simulation data at the same locations for comparison, based on the GRIP4 external lighting scheme.

The study area of HBL for this assessment is illustrated in Figure 7. Blue indicates the footpaths where illuminance measurements were recorded, and the potential illuminance from the site was simulated. Yellow indicates observer viewpoints on adjacent houses where source intensity and was simulated (at bedroom window height). The orange zone was not considered safely accessible for a nocturnal site survey. The distribution of survey/assessment points is of sufficient resolution to captures the performance of the existing and proposed light sources.

It not possible to access private properties to collect illuminance data. Therefore, illuminance was recorded on the footpaths in front of the properties. The

illuminance on the properties behind the footpaths will be lower as they are further from the site than the footpaths.

Figure 7: Light obtrusion measurement and simulation points



3.2.1 Measuring the Baseline Scenario

Illuminance data was collected at ground level (horizontal plane) and at 2m and 4m above ground in the vertical plane, facing the site and parallel to each footpath. The objective of the 4m measurements was to gather illuminance data approximating to the bedroom window height of each property.

Photographs were taken at various points around the site to capture the nocturnal lighting scene. Refer to Appendix A.

Colour spectrum, colour temperature and colour rendering index measurements were recorded beneath sample luminaires of each existing street lantern type. Refer to Appendix B.

3.3 Simulating the Proposed Scenario

3.3.1 GRIP 4 Lighting Design

A lighting design for the site was created by Arup for GRIP4 and is used for testing artificial lighting performance in the proposed development in this impact assessment. The lighting design strategy is described in the Form 001 documents.

3.3.2 Methodology

This section sets out the methodology for the assessment of likely significant effects relating to light obtrusion from the proposed development. The light obtrusion assessment for the proposed development provides a prediction of

potential changes to the nocturnal lighting conditions that could arise from lighting the proposed development.

The lighting strategy for the proposed development was simulated and analysed using Radiance simulation software, to examine possible obtrusive light effects. The objective was to illustrate that light obtrusion compliance is possible or to identify where likely significant effects may occur.

The simulation enables the lighting strategy to be examined in terms of the relevant light obtrusion guidance and provides accurate predictions on the following light obtrusion characteristics:

- Simulate the performance of the lighting scheme in a 3D environment, including the effects of changing terrain/elevation on the observer's perspective towards the site
- Illustrate the effect of the lighting scheme on any sensitive receptors nearby, e.g. dwellings, watercourse.
- Enable a comparison of the proposed development with the baseline survey to assess the impact

The simulation comprised the following steps:

- Use of a 3D computer model of the existing site massing and terrain using LiDAR data.
- Use of a 3D computer model of proposed development landscape layout
- Use the GRIP4 lighting design strategy prepared by Arup (luminaire coordinates, orientation data and photometric data) into the lighting simulation model.
- Apply the virtual viewpoints described in Figure 7
- Perform analysis using the 3D computer lighting models to identify potential light obtrusion effects.

The simulation was used to examine the lighting design in terms of the relevant guidance and provide accurate predictions on the following light obtrusion characteristics:

- Light source intensity visible from each observer (Figure 7) measured in candelas
- Light intrusion experienced by each observer measured in lux
- Isoline diagram/rendering to describe the illuminance conditions at ground level
- Upward Flux Ratio calculation
- Upward Light Ratio analysis
- There is no specific façade lighting scheme. Therefore, it was not necessary to evaluate any façade lighting luminance

3.4 Environmental Impact Assessment Method

3.4.1 Significance criteria

The significance of the effects is based on the magnitude of change (or impact) as result of the proposed development and the importance of the affected receptor/receiving environment. 'Magnitude' is assessed on a scale of High, Medium, Low or Very Low. 'Importance' of each receptor is assessed on a scale of Very High, High, Medium, or Low. Further details regarding the evaluation criteria are provided below.

The criteria for receptor sensitivity are described in Table 4.

To determine the magnitude/scale of the change in lighting levels at the sensitive receptors, the following criteria have been evaluated using professional judgement: Type of lighting installation during construction or operation.

The distance between the proposed lighting installations and the sensitive receptors.

- Type of view (e.g. direct, intermittent or restricted).
- Any existing and proposed screening.
- Satisfaction of ILP Guidance.
- Likelihood of statutory nuisance.

Table 4: Designation and sensitivity of receptors

Receptor Sensitivity	Typical Example	Commentary
Very High	Protected habitats e.g. bat roosts. IDSR Zone E0.	Receptor has negligible ability to absorb change without fundamentally altering its present character and is of very high environmental value/importance.
High	Unprotected nocturnal wildlife habitat. National Park. IDSR Zone E1	Receptor has low ability to absorb change without fundamentally altering its present character and is of high environmental value/importance.
Medium	Dwelling	Receptor has moderate capacity to absorb change without significantly altering its present character, has some environmental value/importance.
Low	Commercial Premises	The receptor is tolerant of change without detriment to its character, is of low environmental value/importance.

The magnitude of the environmental effect is expressed in terms of deviation from the ILP GN01 recommendations. The proposed development site is considered to be in Zone E3 light obtrusion limits (Section 2.2.1).

Table 5 below describes the process for determining the magnitude of an environmental impact.

Table 5: Designation and magnitude definition for light obtrusion impact

Impact Magnitude	Definition	Magnitude Quantified
High	Total loss or major alteration to key features of the baseline conditions which will be fundamentally changed.	All light obtrusion characteristics above Zone E4 recommended limits.
Medium	Loss or alteration to one or more key features of the baseline conditions which will be fundamentally changed.	One or more light obtrusion characteristics exceed the Zone E3 limits by more than 20%.
Low	Minor shift away from baseline conditions. Changes arising from the alteration will be detectable; the underlying character of the baseline condition will be similar.	No light obtrusion characteristics exceed the Zone E3 limits by more than 10%.
Very low	Very little change from baseline conditions. Change is barely distinguishable, approximating to a “no change” situation.	Light obtrusion characteristics unchanged or below Zone E3 limits.

The interaction of sensitivity and magnitude are considered to determine the significance of an environmental effect using the matrix described in Table 6.

As a general principle, major and moderate effects are considered to be significant, whilst minor and negligible effects are considered to be not significant; however, professional judgement may be applied.

Table 6: Determining the significance of an environmental effect

Receptor Sensitivity (Table 4)	Impact Magnitude (Table 5)			
	High	Medium	Low	Very low
Very High	Major	Moderate	Moderate	Minor
High	Major	Moderate	Minor	Negligible
Medium	Moderate	Moderate	Minor	Negligible
Low	Moderate	Minor	Minor	Negligible

These significance criteria are referred to in the analysis of the baseline/proposed scenario in Section 6.2.

4 Assumptions and Limitations

4.1 Site Survey

Atmospheric conditions may marginally affect the recorded luminance and illuminance measurements. Based on the conditions (i.e. clear sky, with full moonlight) observed during the site survey there could be deviations of up to 1lux in the measured data.

4.2 Computation and modelling

The ray-tracing software is considered to be highly accurate, however, certain assumptions have to be incorporated into the model in terms of material existing surface reflectivity factors.

Trees and other organic planting are excluded from this analysis (and are not required as a part of the ILP GN01 based analysis), meaning that the assessment presents the worst-case scenario. It is anticipated that obtrusive light in some applications may be mitigated by existing trees, foliage or other vegetation, however this mitigation can be seasonal in the case of deciduous vegetation.

The lumen maintenance factor applied to the calculation is $MF=1$ and represents the installation performing at maximum (100%) output on day one of the installation and is potentially the worst-case scenario.

During the operational phase of the proposed development, it has been assumed that the lighting specification in terms of column/mounting heights, luminaire performance and luminaire design will be selected based on the GRIP4 lighting design presented in this report and ILP GN01 recommendations in order to minimise the effects of obtrusive light.

The assessment presented in this report is based on the GRIP4 lighting strategy produced for the purpose of this assessment. The lighting performance assumptions (usage, illuminance levels, etc.) can be found in the Form 001 documents.

5 Baseline Conditions

5.1 Data Gathering/Survey

Measurements were recorded in accordance with the guidelines of ILP GN01.

Light measurements were taken using the following calibrated test equipment:

- Minolta T10 illuminance meter
- Lighting Passport Asensetek ALP-01, spectrometer

5.2 Survey Notes

A quantitative and visual survey of the existing lighting around the site was undertaken on 26 May 2021 from 2230hrs to 0200hrs. The ambient temperature was 8°C.

- Clear sky, full moon rising
- Good visibility, stars visible with moonlight
- All stars visible in the Orion constellation (ILP PLG04, Appendix 2, sky clarity assessment)
- Moon rise time, approximately 2200hrs

5.3 Survey Illuminance Measurements

The measured values of vertical and horizontal plane illuminance and peak luminance at the selected viewpoints are provided in Appendix C.

A summary of the findings is provided below:

Table 7: Survey illuminance summary (refer also to Figure 7)

Measurement Points	Ground Level (horiz.)		2m (vertical)		4m (vertical)	
	Average	Maximum	Average	Maximum	Average	Maximum
Orange Points	6.0	31.9	4.0	21.7	3.8	22.7
Yellow Points	0.5	13.5	0.2	1.1	0.2	1.0
Red Points	2.9	11.2	3.1	20.2	1.7	10.9

The yellow points follow the footpath which is presently unlit, so majority of measurements are only attributable to ambient lighting and moonlight. The average illumination of the footpath gives an indication of the contribution of moonlight to the other measurements on the red and orange points.

The illumination of the orange points at ground level are typical of a lighting scheme for this type of suburban area where an average of 5lux is expected. The lighting measured on the red points was lower than expected average, however this area only allows access to 2/3 properties and there is no through route for a footpath or road.

Relatively high levels of vertical plane illumination were recorded on the red/orange points. This is primarily due to the street lighting provision and this was observed to spill onto some properties in close proximity to the street lighting, e.g. Devonshire Close/Fallowfield, see Appendix A.

5.4 Existing Lighting Equipment

Observations of existing light sources and measurements of the spectrum lighting equipment were made during the site survey. In the vicinity of the site, three luminaire types were observed. Note 'Ra' is a measure of colour rendering, i.e. the ability of a light source to accurately replicate colours. A perfect light source would be Ra=100, lower scores indicate less accurate colour rendition. Ra>80 is generally accepted to offer good quality colour rendering.

- Low pressure sodium lighting to the north of the site e.g. Headbolt Lane, typically 2000K, Ra<10, monochromatic, no blue light component
- High pressure sodium lighting to north of site, e.g. Fallowfield, typically 2500K, Ra 71, relatively small blue light component
- LED lighting to the west of the site e.g. around the A506/Headbolt Lane road junction, typically 3800K, Ra 70, significant blue light component
- LED light on the new housing to the east of the site, e.g. Southcroft Drive, typically 3800K, Ra 70, significant blue light component

Detailed spectrum, colour temperature and colour rendering data measured for these luminaire types can be found in Appendix B.

The sodium lamp luminaires had a 'bowl' type glass. This type of older luminaire technology is not 'horizontal cut-off' and emits light directly up into the sky. The existing LED sources appeared to have better horizontal cut off characteristics.

5.5 Observations

With reference to Appendix A, the following observations were made on the lighting conditions in the vicinity of the site:

- Light spill onto the houses was observed on most properties due to the street lighting provision. For example, this was particularly noticeable on Devonshire Close/Fallowfield (Figure A18), Bridgeview Drive (Figure A14) and to a lesser extent on the new properties on Headbolt Lane (Figure A23) and Apollo Crescent (Figure A2)
- There is no lighting provision along the existing footpath traversing east/west across the site. Examination of Google Streetview (Figure 8) indicates that lighting was once provided for the footpath.
- No other lighting is provided within the proposed site.
- There is negligible lighting visible from the properties on Appleton Road, which are almost entirely obscured from view across site from the north (Figure A12/A17).
- Few houses displayed porch or other external lighting luminaires with the exception of one property on Headbolt Lane (Figure A24)

Figure 8: Google Streetview of the footpath (east end), lighting columns clearly visible



6 Lighting Impact Assessment

This section presents the findings of the simulation and compares them with the findings of the baseline survey. A commentary is provided and an assessment of the significance of the light obtrusion impact.

Both nearby dwellings and the survey points were assessed in the simulation. The

Figure 9: Dwellings assessed (blue) and simulation test points (red/orange/yellow)



6.1 Simulation Results

A lighting assessment was completed to simulated lighting characteristics of the GRIP4 scheme, to compare the findings with the baseline and to evaluate in context with the ILP GN01 recommendations for the reduction of obtrusive light.

The characteristics assessed in the simulation are:

- Upward Flux Ratio (ULR)
- Upward Light Ratio (UFR) of proposed luminaires
- Source intensity at dwelling windows
- Illuminance at survey points and dwelling windows

Using the methodology provided in Section 3.3, a computer simulation was used to predict the performance of the lighting scheme described in Appendix A8, and to provide accurate predictions of light obtrusion performance. The results are described in the following section.

6.1.1 ULR / UFR

Each of the luminaires proposed was assessed for ULR by evaluation of their photometry. All luminaires used in the project have a ULR of 0% and are therefore compliant with the ILP guidance for Zone E3.

The UFR for the site was analysed using the 3D computer model for the whole lighting scheme and was found to be 1.7% and is therefore compliant with the ILP guidance for Zone E3.

6.1.2 Source Intensity

Each group of dwellings was analysed using the 3D computer model and the findings are provided below:

Table 8: Light source intensity limits, distance d=50m source-observer

Location	Maximum Intensity
Devonshire Close (nr Fallowfield)	0.3cd
Fern Close	10.2cd
Oakworth Close	1.9cd
Apollo Crescent	4.2cd
Ashburn Avenue	4.4cd
Devonshire Close (west)	2.4cd
Headbolt Lane / Southcroft Drive	5.5cd

The highest source intensity values were found to be attributable to the platform luminaires facing Fern Close. However, these luminaires are approximately 50m from the windows of the Fern Close properties at the closest point. This is evaluated in the context of the ILP GN01 guidance for source intensity in Table 9 below. Substituting a 50m distance into the criteria in Table 3, gives a limit of 14.5cd in the post curfew scenario for the most onerous condition for source intensity i.e. smallest visible surface area of a luminaire, A_p . This means Fern Close is compliant.

Table 9: Light source intensity limits, distance d=50m to observer e.g. Fern Close

Curfew	$0 < A_p \leq 0.002$	$0.002 < A_p \leq 0.01$	$0.01 < A_p \leq 0.03$	$0.03 < A_p \leq 0.13$	$0.13 < A_p < 0.50$	$A_p > 0.5$
Pre	43cd	95cd	190cd	375cd	750cd	10,000cd
Post	14.5cd	31.5cd	65cd	125cd	255cd	1,000cd

Similarly, the closest dwellings to other luminaires on the proposed site are Headbolt Lane and Ashburn Avenue. The closest properties are in excess of 20m from the nearest luminaire. Substituting a 20m distance into the criteria in Table 3, gives a limit of 5.8cd in the post curfew scenario for the most onerous condition for source intensity i.e. smallest visible surface area of a luminaire, A_p . This means Headbolt Lane and Ashburn Avenue are compliant.

Table 10: Light source intensity limits, distance d=20m to observer, e.g. Headbolt Lane

Curfew	$0 < AP \leq 0.002$	$0.002 < AP \leq 0.01$	$0.01 < AP \leq 0.03$	$0.03 < AP \leq 0.13$	$0.13 < AP < 0.50$	$AP > 0.5$
Pre	17.2cd	38cd	76cd	150cd	300cd	10,000cd
Post	5.8cd	12.6cd	26cd	50cd	102cd	1,000cd

All other properties assessed are further from the site than the Headbolt Lane and Ashburn Avenue properties and are therefore also compliant.

Measuring light source intensity requires the luminaire to be photometered in a laboratory. It is not possible to measure light source intensity on site. However, the data can be compared with the ILP recommendations in absolute terms. The simulation results indicate that the luminous intensity observed from all the viewpoints is relatively low and compliant with the ILP recommended limits for Zone E3.

6.1.3 Illuminance to dwellings

Each group of dwellings was analysed using the 3D computer model to determine the illuminance received at their bedroom windows, where the occupants will be most sensitive to nuisance light at night. The findings are provided below:

Table 11: Maximum illuminance resultant from the proposed development

Location	Maximum Illuminance
Devonshire Close (nr Fallowfield)	<0.1lux
Fern Close	<0.1lux
Oakworth Close	<0.1lux
Apollo Crescent	<0.1lux
Ashburn Drive	<0.1lux
Devonshire Close (west)	<0.1lux
Headbolt Lane / Southcroft Drive	<0.1lux

The light intrusion onto all dwellings is less than 1.0 lux and therefore compliant with the most onerous post-curfew E3 conditions of 2.0lux post-curfew. Furthermore, it can be considered that the contribution from the site-wide lighting is negligible above the baseline.

6.1.4 Simulated illuminance at survey points

The simulation results of illuminance at the survey points are provided below:

Table 12: Maximum illuminance resultant from the proposed development

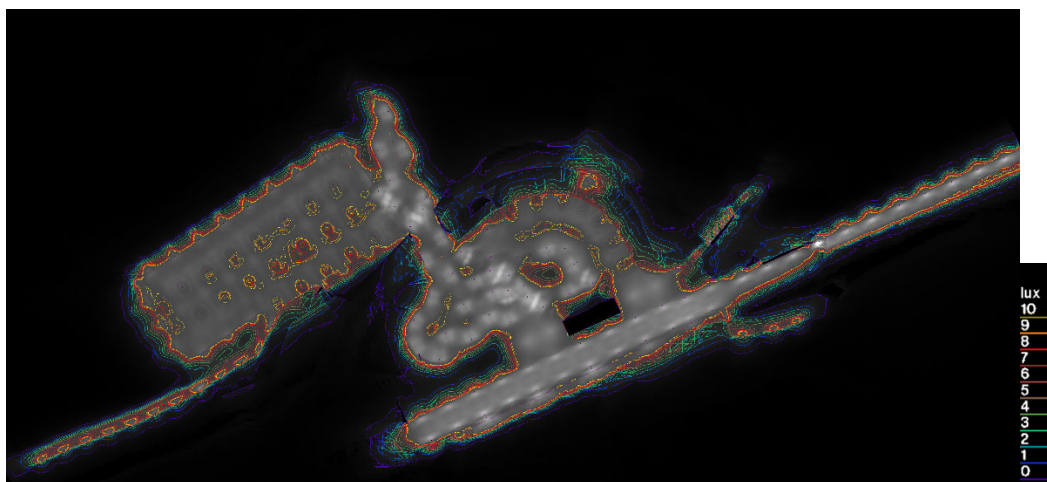
Location	Maximum Illuminance
Orange Route (North/East of Site)	<0.2lux (all planes, ground level/2m/4m)
Red Route (Fern Close)	<0.1lux (all planes, ground level/2m/4m)
Yellow Route (Footpath Through Site)	15.8lux, ground level, 0m 23.2lux, vertical plane, 2m 11.1lux, vertical plane, 4m

The simulation indicates that the survey points on the orange and red routes will receive negligible additional light above the baseline conditions as a result of the proposed lighting scheme.

The yellow route (footpath through the site) will receive a significant increase in artificial light, because it is presently unlit. A full dataset for comparison of the lighting conditions with the baseline is not possible in many cases because the footpath is significantly different in elevation and route, particularly through the centre of the site, in the new landscape scene.

However, lighting conditions around the watercourse can be visually interpreted with reference to Figure 10 (high resolution image in Appendix C and overlaid with a site plan). It can be seen that the optical control of the luminaires constrains light close to the road/car-park and footpath areas; the 1lux contour does not extend significantly beyond the task areas or over the watercourse

Figure 10: Illuminance contours – overhead view



6.1.5 Summary

The results of the simulation indicate that there will be negligible increase in illuminance experienced on the neighbouring dwellings as a result of the proposed lighting scheme.

The source intensity visible by the neighbouring dwellings is also below the recommended threshold limits for Zone E3, primarily due to the optical control of

the selected luminaires constraining light close to the task areas as well as their ‘horizontal cut-off’ characteristics.

The luminaires exhibit zero upward light emissions, which is compliant with the recommendations in ILP GN01 for reduced contribution to sky glow.

Furthermore, the lighting scheme has been evaluated to have a low upward flux ratio, which also indicates the potential for noticeable sky glow effects is reduced.

6.2 Significant Assessment

Table 13 presents the results of the assessment for each dwelling group in relation to ILP guidance (source intensity, sky glow and light intrusion, ULR, UFR), and applies the methodology described in Section 3 to each dwelling to determine the significance of the Environmental effect.

As described in Section 6.1, all of the dwellings meet ILP guidance on source intensity, sky glow and light intrusion. The luminaires and lighting scheme satisfy the requirements for ULR and UFR and in fact satisfy the requirements for more onerous environmental Zones. Therefore, for all the viewpoints considered, the predicted effects are considered to be negligible.

Table 13: Assessment of impact significance

Dwellings	ILP Guidance met (Yes/No)	Magnitude	Receptor Sensitivity	Impact Significance
Devonshire Close (nr Fallowfield)	Yes	Very low	Medium	Negligible
Fern Close	Yes	Very low	Medium	Negligible
Oakworth Close	Yes	Very low	Medium	Negligible
Apollo Crescent	Yes	Very low	Medium	Negligible
Ashburn Avenue	Yes	Very low	Medium	Negligible
Devonshire Close (west)	Yes	Very low	Medium	Negligible
Headbolt Lane	Yes	Very low	Medium	Negligible
Footpath	n/a	High	Medium	Moderate

6.3 Construction Phase Lighting

It is anticipated that light obtrusion mitigation and management measures will be applied through the implementation of an Environmental Management Plan during the construction phase. This will identify plans for the construction phase lighting and measures to minimise and control potential adverse impacts.

Typically, the potential sources of obtrusive light on a construction site are:

- Floodlighting at site compound
- Security lighting at site perimeter
- Task lighting at work sites

- Vehicle headlights

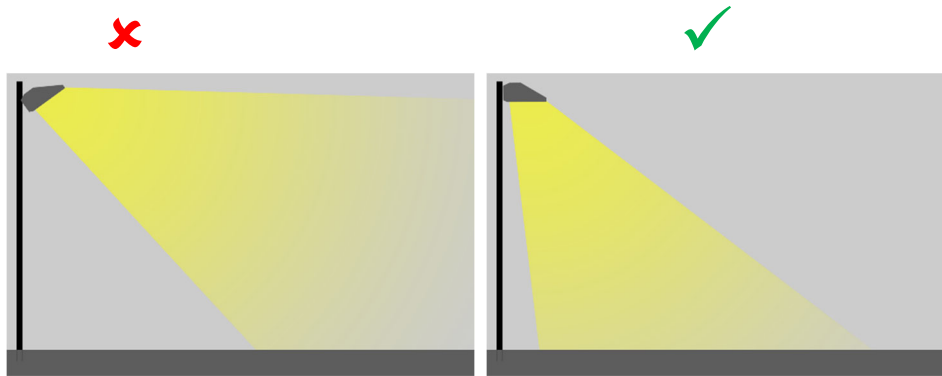
To mitigate against these potential sources of obtrusive light, the same guidance and recommendations for best practice lighting outlined in ILP GN01 shall be applied to the construction phase lighting. Control and mitigation shall include, but not be limited to:

- Use of fully-shielded, full horizontal cut-off luminaires for area lighting e.g. asymmetric floodlights. Ensure floodlights are correctly aimed, particularly asymmetric types (Figure 12).
- Avoid unshielded bulkhead type luminaires, which are commonly found on construction sites. Select shielded bulkheads, ideally with occupancy sensors, if practicable, (Figure 11).
- Test and check illumination levels are appropriate (e.g. BS EN 12464 Pt 2) when installing construction site lighting and avoid over-lighting task areas
- Avoid lighting over watercourses and any identified sensitive visual receptors
- Consider occupancy sensor-controlled lighting in non-safety critical areas
- Use of 3000K 'warm white' light sources
- Use of internal window blinds in site accommodation
- Minimise temporary works requiring floodlighting after dusk
- Observe a lighting curfew when practicable
- Visually check construction lighting from near local dwellings and make adjustments where necessary to reduce the visibility and intensity of the lighting system
- Respond promptly to complaints with corrective action
- Switch off vehicle headlights promptly when not in use
- Submit construction phase lighting plans to the local authority planning officer for consideration and approval.

Figure 11: Bulkhead luminaires



Figure 12: Asymmetric floodlight aiming



The scope of the construction phase lighting is not anticipated to be as extensive as the operational phase lighting scheme and will likely be focused around the site compound. On this basis, and under the assumption that the above recommendations, and those of ILP GN01 are adhered to, it is considered that the significance of the construction phase effects will be negligible.

7 Conclusions

7.1 Lighting Technology

The existing lighting scheme around the site uses a mixture of older lighting technologies and some modern LED sources. The older luminaires are characteristic of their age and feature glass bowl type housings which emit direct upward light.

The existing modern LED luminaires have enhanced optical control, with reduced direct upward light potential, but were measured to contain relatively high blue wavelength light which is less desirable for the nocturnal environment. ILP Guidance Note 8, and the International Dark Sky Association recommend warm white light with minimised blue light component for reduced impact on human and wildlife at night.

The proposed luminaires have a 3000K light source with minimised blue wavelength light, full horizontal cut-off optical characteristics and efficient optical control. Additional mitigation is also offered by the lighting controls, which can reduce lighting levels when the station is off-peak (e.g. post-curfew) and can also respond to low usage with dimming in response to occupancy sensing. These measures will offer improved mitigation of light obtrusion effects versus the existing street lighting LED luminaires near the site.

7.2 Light obtrusion effects

The GRIP4 lighting strategy has been simulated within a 3D computer model of the Headbolt Lane New Station development. The simulation assumes a worst-case scenario with a maintenance factor of 100% (as per day one of the installation) which means that all luminaires were simulated at full output and with no mitigation of lighting controls.

The simulation has demonstrated how the provision of external lighting on the site will contribute negligible additional light intrusion onto the neighbouring dwellings. The simulation also indicates that the light source intensity visible to the neighbours will also satisfy the requirements of ILP GN01 for minimising obtrusive light, and it is unlikely that nearby residents will experience glare effects from the proposed lighting scheme.

The selected equipment photometry does not emit direct upward light and therefore does not contribute directly to sky glow. Furthermore, the scheme has demonstrated a low upward flux ratio, which satisfies the recommendations of ILP GN01 for a suburban area Zone E3.

The footpath area will see a significant change because it is presently unlit. However, the most likely nocturnal wildlife habitats in this area are near to the watercourse running east-west through the site. The simulation indicates that there will be some light spill on the watercourse in excess of 1lux around the road bridge in the centre of the site. Other sections of the watercourse will experience <1lux of spill light.

Construction phase lighting is anticipated to be of a reduced scope compared to the operation phase lighting. On this basis, and by the application of best practice lighting guidance, it is anticipated that the construction phase lighting will have a negligible adverse impact. The onus is on the contractor to regularly monitor the lighting and take corrective actions where necessary.

7.3 Summary

It is therefore considered that the impact of the GRIP4 lighting design proposals will be negligible on the occupants of the nearby dwellings when considered with respect to the assessment metrics set out in ILP Guidance Note 1.

The light source technology supports the minimisation of light obtrusion effects, by limiting upward light and offering effective optical control to constrain light close to the task areas. The minimisation of blue wavelength light in the light source spectrum also helps reduce the adverse effects on nocturnal wildlife.

As the external lighting design is developed through the subsequent GRIP5 design stages, the performance of the finalised scheme must uphold the findings of this study (and also the recommendations of the ILP GN01 etc.) in terms of strategy, illumination targets, lighting technology and lighting spectral quality in order that the light obtrusion effects are minimised in the delivered project.

Appendix A

Site Nocturnal Photographs

Viewpoints

The location of the photographs on the following pages of the appendix are summarised below.

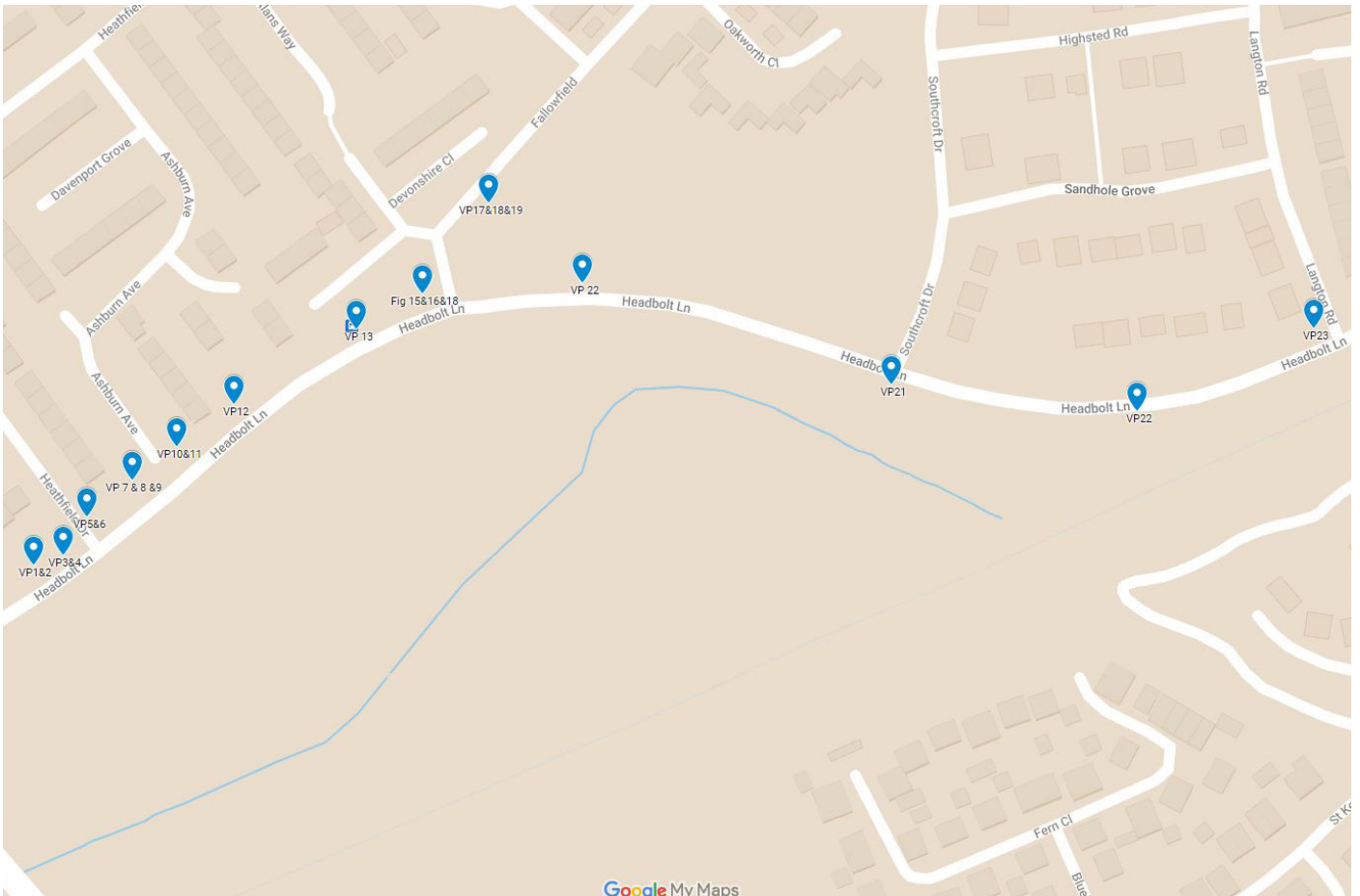


Figure A1 Viewpoints

Viewpoints

This appendix includes nocturnal photographs from various points around the site. Each photograph is provided with the camera settings to enable visual comparison.



Figure A2 VP1 f/11, 15sec., ISO-400



Figure A3 VP2 f/11, 15sec., ISO-400



Figure A4 VP3 f/11, 8sec., ISO-400



Figure A5 VP4 f/11, 15sec., ISO-400



Figure A6 VP5 f/11, 15sec., ISO-400



Figure A7 VP6 f/11, 15sec., ISO-400



Figure A8 VP7 f/11, 15sec., ISO-400



Figure A9 VP8 f/11, 15sec., ISO-400



Figure A10 VP9 f/11, 15sec., ISO-400



Figure A11 VP10 f/11, 15sec., ISO-400



Figure A12 VP11 f/11, 8sec., ISO-400



Figure A13 VP12 f/11, 15sec., ISO-400



Figure A14 VP13 f/11, 15sec., ISO-400



Figure A15 VP14 f/11, 8sec., ISO-400



Figure A16 VP15 f/11, 8sec., ISO-400



Figure A17 VP16 f/11, 15sec., ISO-400



Figure A18 VP17 f/11, 15sec., ISO-400



Figure A19 VP18 f/11, 15sec., ISO-400



Figure A20 VP19 f/11, 10sec., ISO-400



Figure A21 VP20 f/11, 15sec., ISO-400



Figure A22 VP21 f/11, 15sec., ISO-400



Figure A23 VP22 f/11, 15sec., ISO-400



Figure A24 VP23 f/11, 10sec., ISO-400

Appendix B

Lighting Quality Measurements

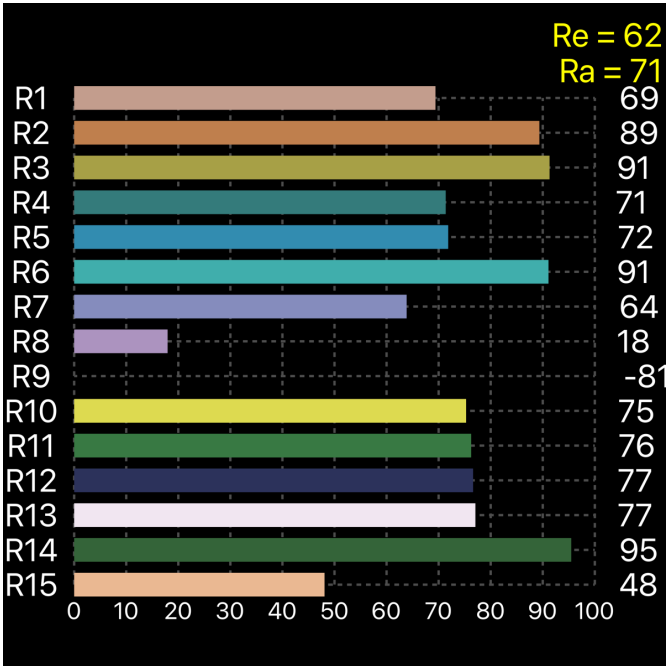


Figure B25 Colour Rendering Index

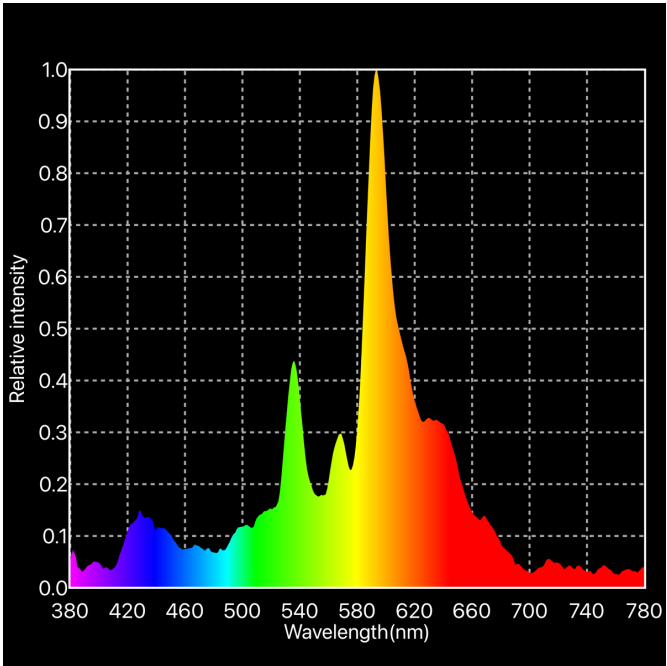


Figure B26 Spectrum

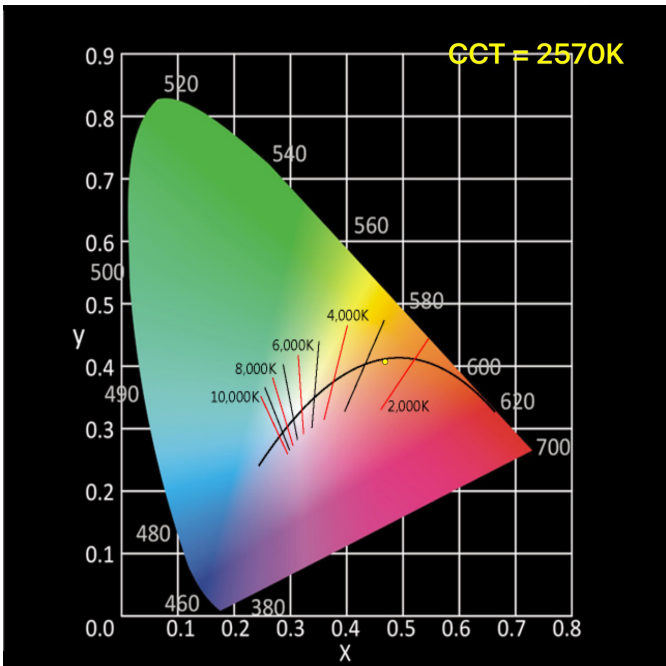


Figure B27 Colour Point



Figure B28 Luminaire: Fallowfield

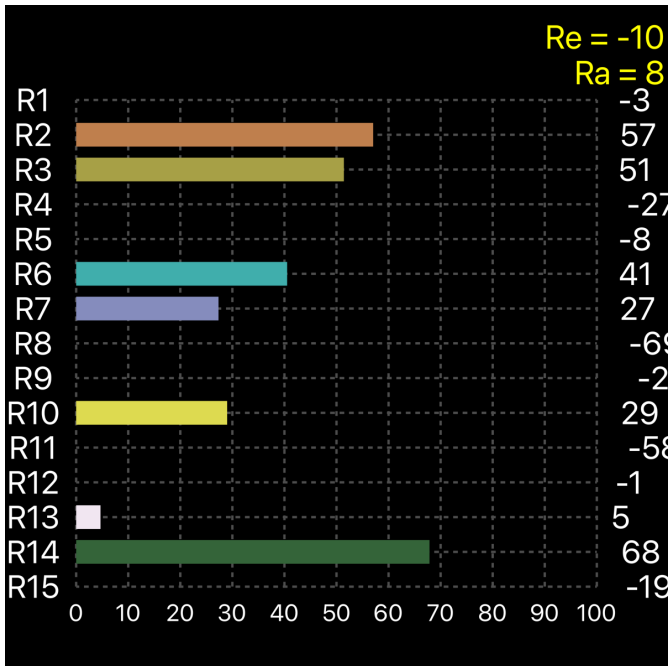


Figure B29 Colour Rendering Index

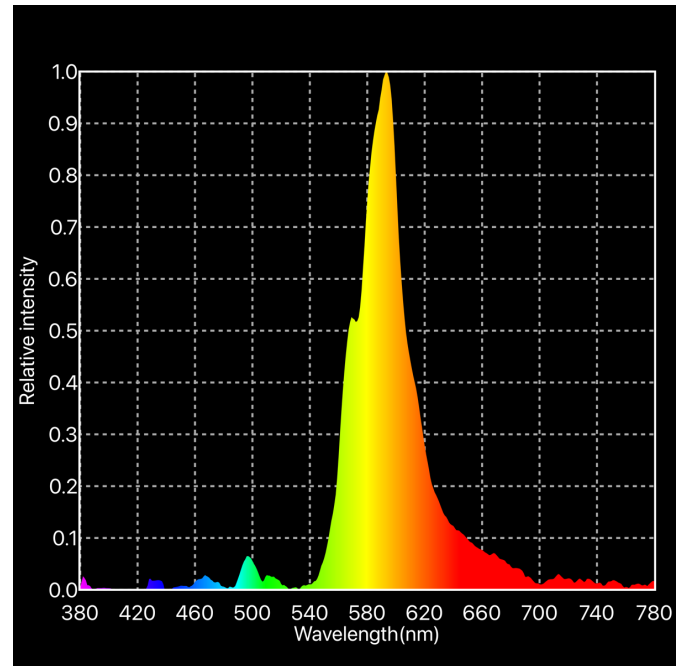


Figure B30 Spectrum

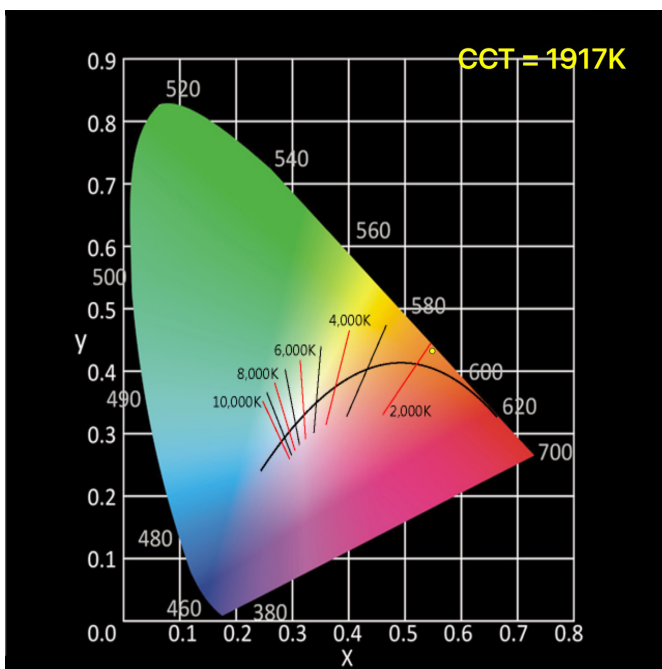


Figure B31 Colour Point



Figure B32 Luminaire, Fallowfield/Headbolt Ln.

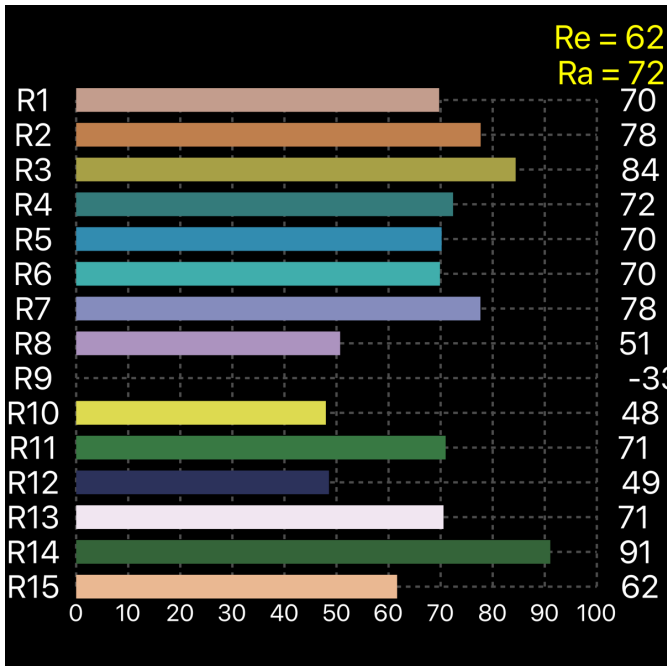


Figure B33 Colour Rendering Index

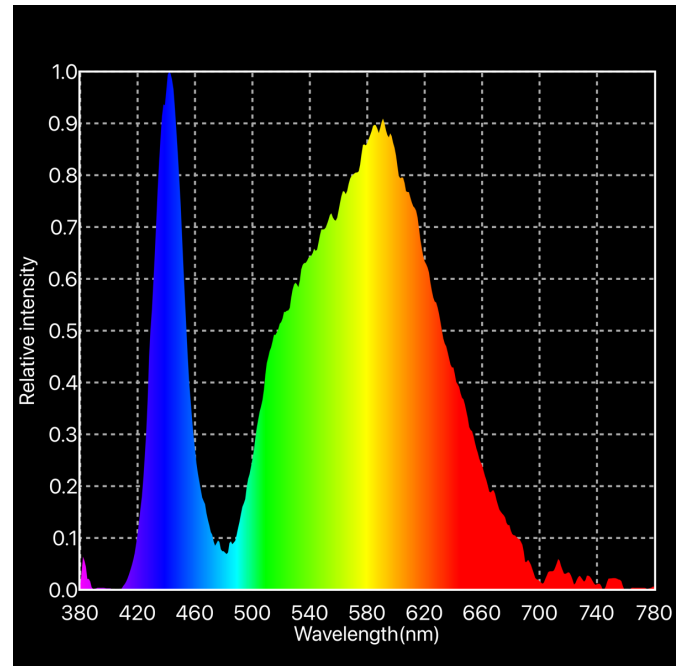


Figure B34 Spectrum

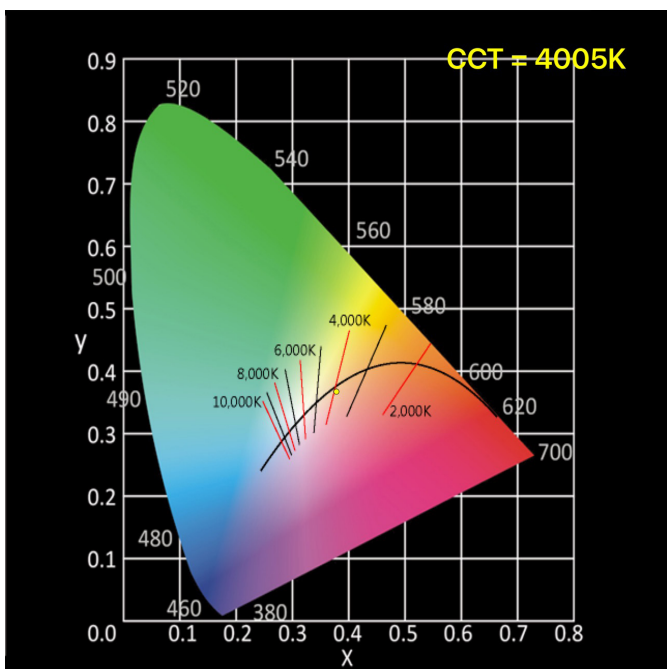


Figure B35 Colour Point



Figure B36 Luminaire, Southcroft Drive

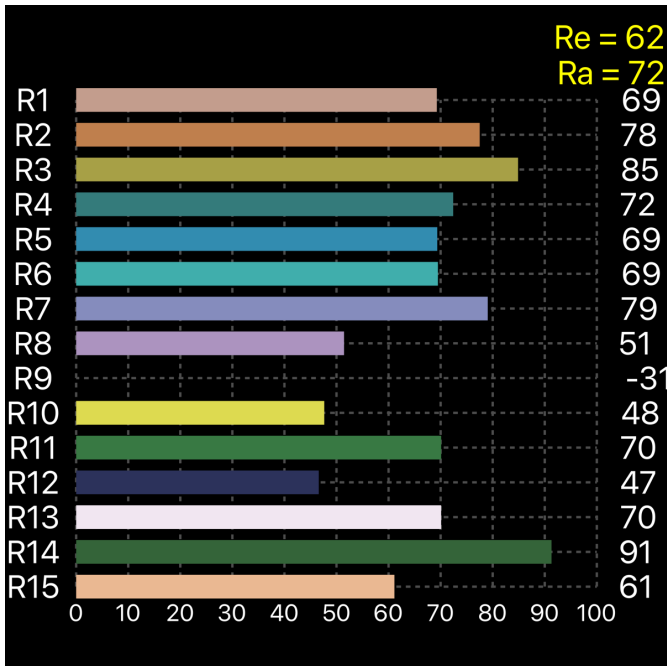


Figure B37 Colour Rendering Index

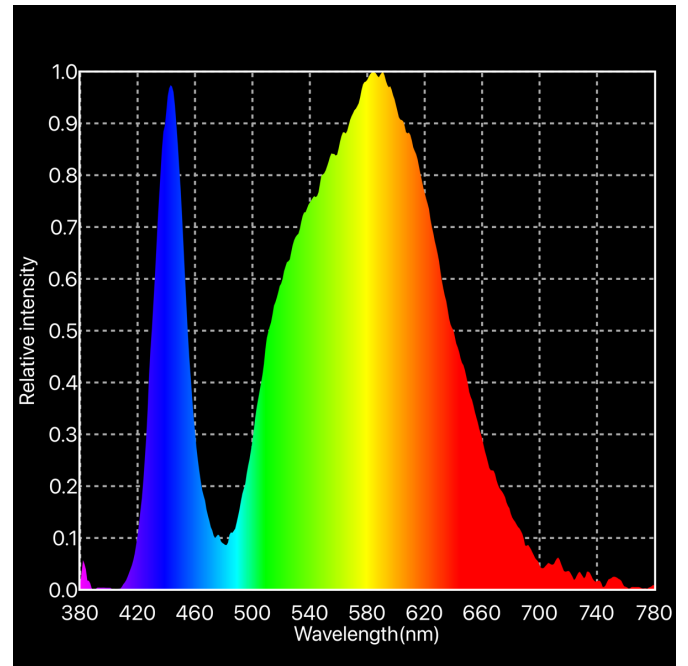


Figure B38 Spectrum

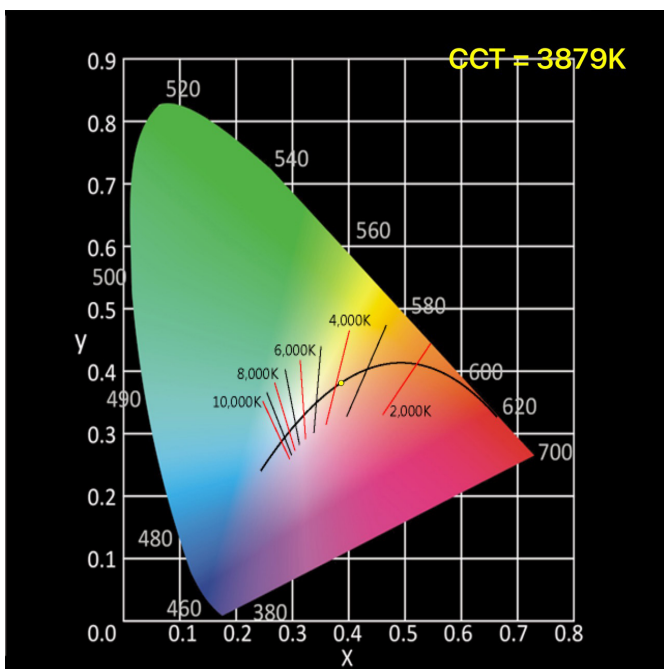


Figure B39 Colour point

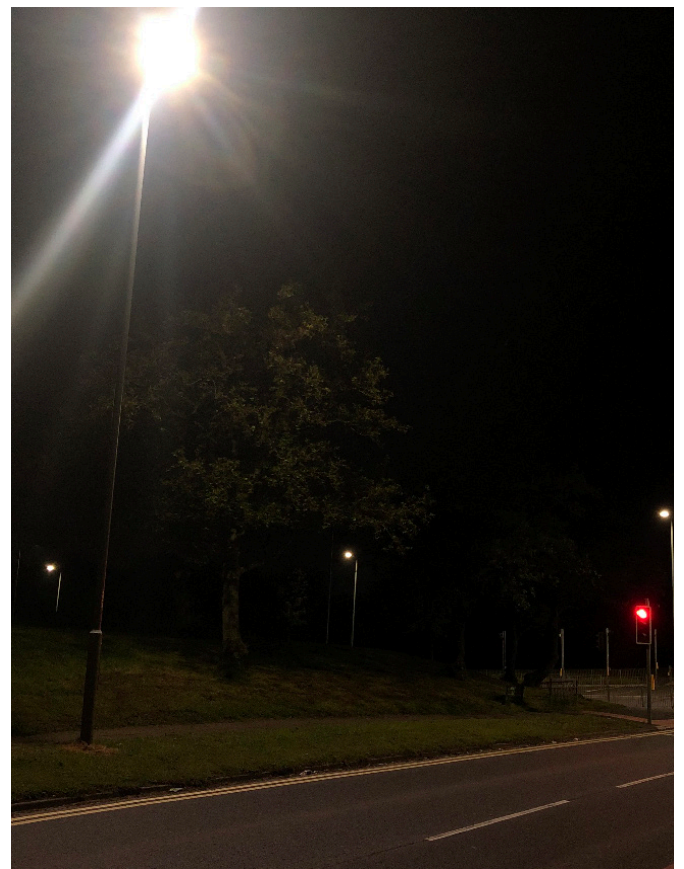


Figure B40 Luminaire, Headbolt Lane/ Bank Ln.

Appendix C

Illuminance Measurements

Survey/Simulation Illuminance Data - Viewpoint Plan



Figure C41 Measurement point locations

Illuminance Data From Survey, 26 May 2021 2230hrs to 0200hrs

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	1	4.61	1.70	1.14
	2	11.36	8.67	6.02
	3	11.17	4.56	2.96
	4	21.90	21.20	22.67
	5	31.90	10.36	10.31
	6	19.01	20.47	20.35
	7	23.66	21.65	20.57
	8	8.67	11.40	8.68
	9	10.89	11.66	9.58
	10	3.56	2.12	1.89
	11	3.60	2.17	2.54
	12	1.84	2.23	1.70
	13	2.80	2.46	2.04
	14	2.44	1.74	1.51
	15	1.15	3.35	2.75
	16	15.08	10.16	13.48
	17	10.74	3.42	4.36
	18	3.45	0.90	1.02
	19	0.46	0.37	0.45
	20	7.14	8.03	8.86
	21	0.38	0.59	0.98
	22	0.22	0.32	0.42
	23	2.33	2.86	3.62
	24	18.33	3.23	4.58
	25	8.05	1.67	1.25
	26	6.82	7.22	5.30
	27	2.59	1.42	1.06
	28	7.54	7.20	11.30
	29	5.45	0.42	0.41
	30	4.02	0.33	0.28
	31	3.92	0.35	0.32
	32	4.56	0.31	0.27
	33	2.57	0.24	0.23
	34	2.03	0.37	0.24
	35	4.68	0.37	0.34
	36	5.11	1.60	1.24
	37	2.59	3.39	1.38
	38	14.35	4.24	7.89
	39	2.68	0.27	0.23
	40	0.31	0.35	0.26
	41	1.52	0.51	0.60
	42	8.23	5.02	7.15
	43	8.18	0.23	2.66
	44	0.32	0.07	0.07
	45	6.25	2.92	3.14
	46	3.52	3.97	4.20
	47	4.06	4.50	4.78
	48	2.46	1.87	1.68

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	49	1.64	1.70	1.00
	50	3.82	4.63	4.61
	51	3.63	3.50	3.85
	52	2.33	1.42	1.32
	53	1.44	1.18	0.90
	54	3.01	3.54	3.75
	55	3.82	3.63	3.98
	56	0.93	0.13	0.12
	57	0.05	0.52	0.68
	58	0.52	1.06	0.93
	59	0.62	1.05	1.02
	60	7.10	0.87	0.71
	61	4.67	6.75	1.27
	62	11.40	0.83	0.58
	63	6.31	14.96	10.55
	64	11.65	1.65	1.41
	65	7.17	4.55	3.87
	66	7.12	5.28	4.33
	67	4.60	2.65	1.99
	68	4.30	2.69	2.65
	69	6.33	5.07	4.15
	70	3.52	4.10	2.35
	71	4.20	2.86	2.04
	72	4.30	3.14	5.72
	73	6.23	5.86	5.18
	74	5.55	3.13	2.28
	75	5.54	4.48	3.42
	76	7.01	6.47	4.52
	77	5.55	4.05	2.39
	78	5.40	5.08	2.95

Summary		Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	Ave	6.00	3.99	3.76
	Ave	0.54	0.16	0.15
	Ave	2.94	3.05	1.70

Summary		Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	Max	31.90	21.65	22.67
	Max	13.48	1.06	1.00
	Max	11.20	20.21	10.93

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	1	13.48	1.06	0.73
	2	0.80	0.09	0.09
	3	0.32	0.06	0.06
	4	0.10	0.06	0.06
	5	0.10	0.06	0.06
	6	0.09	0.05	0.05
	7	0.05	0.05	0.05
	8	0.10	0.05	0.05
	9	0.05	0.06	0.06
	10	0.06	0.05	0.05
	11	0.07	0.05	0.05
	12	0.08	0.07	0.06
	13	0.05	0.07	0.07
	14	0.06	0.06	0.06
	15	0.05	0.05	0.05
	16	0.04	0.05	0.05
	17	0.06	0.07	0.06
	18	0.08	0.06	0.07
	19	0.06	0.07	0.07
	20	0.08	1.00	1.00
	21	0.08	0.07	0.11
	22	0.06	0.06	0.04
	23	0.05	0.07	0.07
	24	0.08	0.11	0.13
	25	0.07	0.14	0.11
	26	0.68	0.11	0.09
	27	0.09	0.09	0.11
	28	0.08	0.13	0.10
	29	0.09	0.11	0.13
	30	0.10	0.15	0.13
	31	0.19	0.15	0.15
	32	0.11	0.16	0.14
	33	0.19	0.27	0.20
	34	0.59	0.36	0.45
	35	0.59	0.36	0.45

	1	11.20	20.21	10.93
	2	3.22	0.23	0.12
	3	1.77	0.18	0.11
	4	0.15	0.05	0.10
	5	0.21	0.07	0.14
	6	0.44	0.10	0.08
	7	1.29	2.05	0.45
	8	5.22	1.53	1.69

Simulation Illuminance Data

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	1	0.00	0.00	0.01
	2	0.00	0.01	0.04
	3	0.00	0.00	0.00
	4	0.00	0.00	0.00
	5	0.00	0.00	0.00
	6	0.00	0.00	0.00
	7	0.00	0.00	0.00
	8	0.00	0.01	0.02
	9	0.00	0.02	0.04
	10	0.00	0.01	0.03
	11	0.00	0.02	0.06
	12	0.00	0.02	0.06
	13	0.00	0.03	0.07
	14	0.00	0.03	0.06
	15	0.00	0.03	0.06
	16	0.00	0.02	0.06
	17	0.00	0.02	0.06
	18	0.00	0.02	0.05
	19	0.00	0.03	0.06
	20	0.00	0.03	0.06
	21	0.00	0.04	0.07
	22	0.01	0.06	0.09
	23	0.02	0.09	0.12
	24	0.05	0.14	0.14
	25	0.08	0.16	0.11
	26	0.02	0.06	0.07
	27	0.01	0.03	0.05
	28	0.03	0.08	0.08
	29	0.00	0.02	0.03
	30	0.00	0.01	0.02
	31	0.00	0.01	0.02
	32	0.00	0.01	0.01
	33	0.00	0.01	0.01
	34	0.00	0.01	0.01
	35	0.00	0.00	0.01
	36	0.00	0.00	0.01
	37	0.00	0.00	0.01
	38	0.00	0.00	0.01
	39	0.00	0.00	0.01
	40	0.00	0.00	0.01
	41	0.00	0.01	0.02
	42	0.00	0.01	0.02
	43	0.00	0.01	0.01
	44	0.00	0.01	0.02
	45	0.03	0.06	0.07
	46	0.02	0.07	0.06
	47	0.00	0.03	0.04
	48	0.00	0.02	0.03

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	49	0.00	0.02	0.03
	50	0.00	0.01	0.03
	51	0.00	0.01	0.02
	52	0.00	0.01	0.03
	53	0.00	0.00	0.02
	54	0.00	0.00	0.02
	55	0.00	0.00	0.02
	56	0.00	0.02	0.03
	57	0.00	0.03	0.03
	58	0.00	0.03	0.03
	59	0.00	0.02	0.03
	60	0.00	0.02	0.02
	61	0.00	0.02	0.03
	62	0.00	0.02	0.02
	63	0.00	0.01	0.01
	64	0.00	0.02	0.03
	65	0.00	0.02	0.03
	66	0.00	0.02	0.03
	67	0.01	0.03	0.03
	68	0.01	0.02	0.03
	69	0.00	0.02	0.02
	70	0.00	0.01	0.02
	71	0.00	0.02	0.03
	72	0.00	0.02	0.03
	73	0.00	0.01	0.03
	74	0.00	0.02	0.04
	75	0.00	0.02	0.05
	76	0.00	0.02	0.04
	77	0.00	0.01	0.04
	78	0.00	0.02	0.04

Summary		Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	Ave	0.00	0.02	0.03
	Ave	2.93	4.05	1.43
	Ave	0.01	0.05	0.07

Summary		Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	Max	0.08	0.16	0.14
	Max	15.75	23.15	11.11
	Max	0.01	0.06	0.09

Colour	VP	Ground Level	2m	4m
		<i>Horizontal</i>	<i>Vertical</i>	<i>Vertical</i>
	1	0.96	2.53	0.08
	2	11.58	21.26	1.16
	3	8.29	18.80	0.25
	4	6.27	10.98	0.16
	5	6.75	7.59	0.16
	6	9.48	0.75	0.17
	7	15.75	0.29	0.18
	8	15.26	23.15	0.21
	9	8.71	20.72	0.25
	10	0.00	13.97	0.35
	11	0.00	0.00	6.92
	12	0.00	0.00	3.72
	13	0.00	0.00	4.54
	14	0.00	0.00	11.11
	15	0.00	0.28	0.12
	16	2.93	0.37	0.16
	17	3.84	0.29	0.18
	18	0.00	0.58	0.21
	19	0.00	0.00	0.27
	20	0.00	0.00	0.30
	21	0.00	0.00	0.55
	22	0.00	0.00	1.32
	23	1.67	3.50	2.36
	24	3.47	2.21	5.49
	25	0.00	0.00	0.00
	26	0.01	0.00	0.00
	27	0.00	0.00	0.00
	28	0.00	0.00	0.00
	29	0.00	0.00	0.00
	30	0.00	0.00	0.00
	31	0.00	0.00	0.00
	32	0.00	0.00	0.00
	33	0.00	0.00	7.52
	34	5.33	8.57	1.79
	35	2.24	5.88	0.51

	1	0.00	0.04	0.07
	2	0.00	0.06	0.08
	3	0.01	0.06	0.09
	4	0.01	0.06	0.08
	5	0.01	0.06	0.08
	6	0.01	0.05	0.07
	7	0.01	0.05	0.06
	8	0.00	0.02	0.04

Simulation Illuminance Data

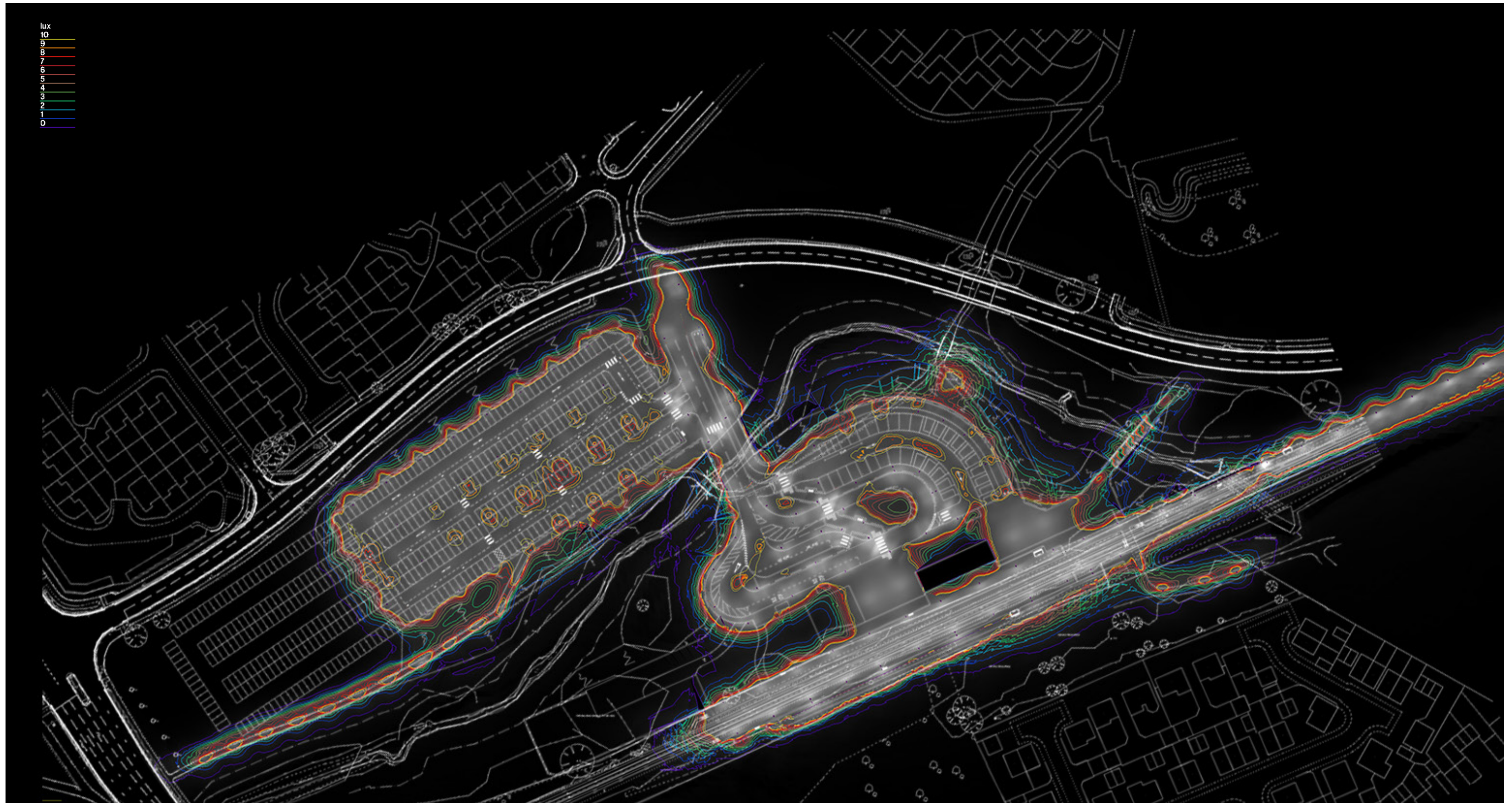


Figure C42 Measurement point locations

The same image is presented on the following page without the map background to show the isolines with greater clarity.

Simulation Illuminance Data

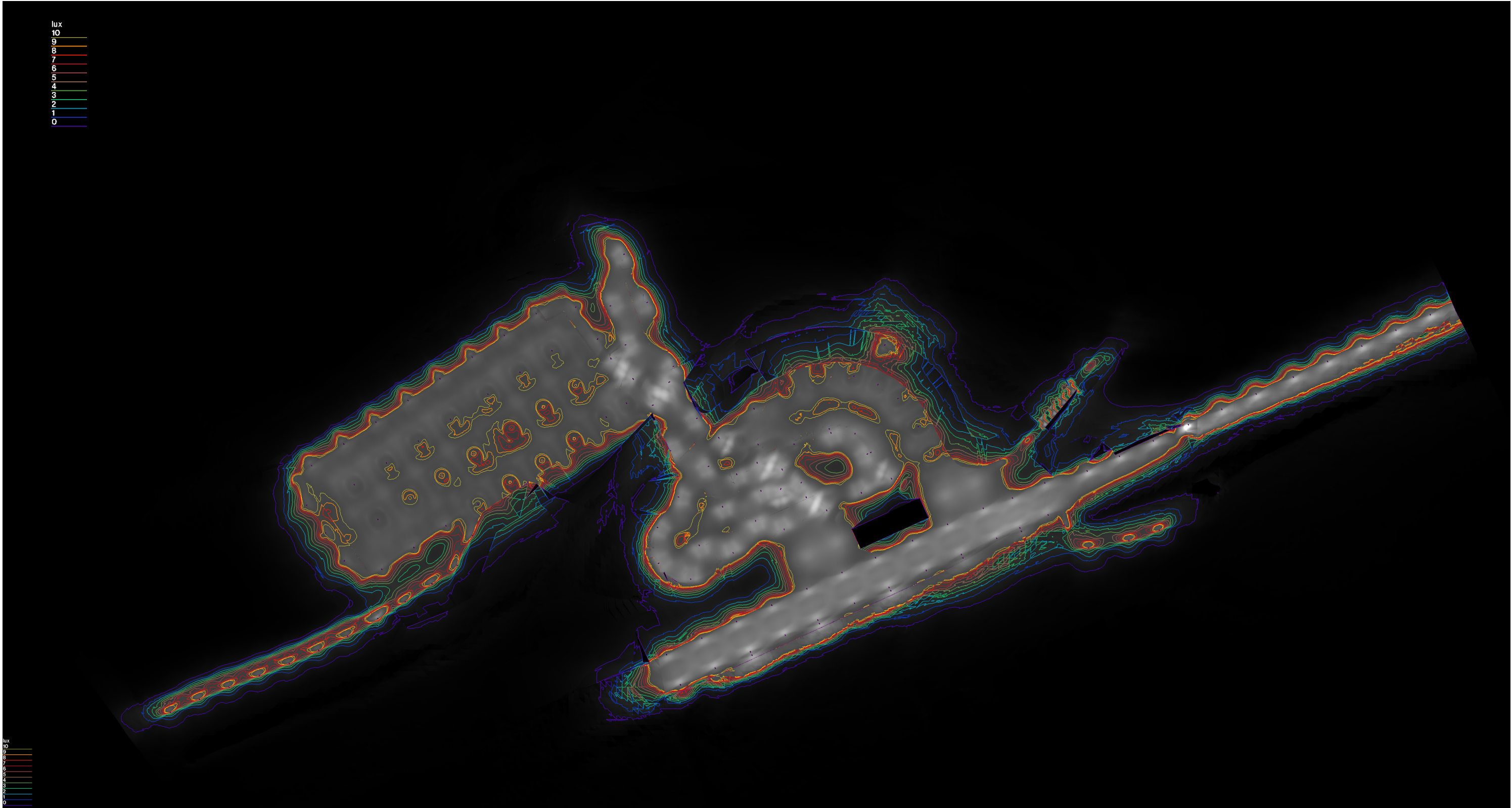


Figure C43 Measurement point locations

Appendix D

Simulation Intensity Tables

Sensor	X	Y	Intensity
House_Devonshire_908	149562	132601	0.32
House_Devonshire_913	149564	132605	0.33
House_Devonshire_915	149569	132608	0.00
House_Devonshire_916	149572	132609	0.00
House_Devonshire_920	149574	132612	0.08
House_Devonshire_921	149578	132613	0.08
House_Devonshire_923	149582	132615	0.16
House_Devonshire_926	149583	132618	0.17
House_Devonshire_927	149587	132619	0.26
House_Devonshire_930	149589	132623	0.28
House_Devonshire_931	149593	132624	0.29
House_Devonshire_932	149595	132627	0.31
House_Fern_Close_753	149712	132379	3.15
House_Fern_Close_755	149718	132382	2.64
House_Fern_Close_749	149734	132389	2.06
House_Fern_Close_751	149739	132391	2.11
House_Fern_Close_752	149742	132396	2.52
House_Fern_Close_754	149747	132398	2.62
House_Fern_Close_743	149754	132401	2.89
House_Fern_Close_744	149760	132404	3.23
House_Fern_Close_746	149766	132406	2.95
House_Fern_Close_747	149772	132409	4.42
House_Fern_Close_730	149779	132412	8.93
House_Fern_Close_731	149784	132414	10.21
House_Fern_Close_732	149790	132414	8.27
House_Fern_Close_734	149795	132417	7.54
House_Fern_Close_729	149814	132421	4.19
House_Fern_Close_733	149817	132426	4.73
House_Ashburn_852	149408	132465	3.78
House_Ashburn_856	149414	132469	3.64
House_Ashburn_861	149420	132473	3.51
House_Ashburn_866	149425	132477	4.24
House_Ashburn_868	149430	132480	4.22
House_Ashburn_874	149454	132499	4.40
House_Ashburn_885	149488	132513	0.00
House_Ashburn_902	149499	132544	0.42
House_Ashburn_912	149520	132562	1.87
House_Ashburn_905	149521	132546	2.40
House_Ashburn_917	149526	132566	1.80
House_Ashburn_919	149527	132569	1.79
House_Ashburn_922	149532	132571	1.16

Sensor	X	Y	Intensity
House_Ashburn_925	149534	132574	1.15
House_Ashburn_933	149553	132579	0.50
House_Headbolt_773	149762	132540	4.53
House_Headbolt_779	149765	132546	4.39
House_Headbolt_780	149784	132530	3.98
House_Headbolt_781	149799	132530	3.61
House_Headbolt_782	149789	132530	3.69
House_Headbolt_783	149802	132530	3.11
House_Headbolt_785	149822	132533	3.17
House_Headbolt_786	149826	132533	3.27
House_Headbolt_787	149764	132554	4.79
House_Headbolt_788	149810	132534	3.65
House_Headbolt_791	149765	132557	5.19
House_Headbolt_792	149848	132537	3.76
House_Headbolt_793	149834	132537	3.25
House_Headbolt_794	149840	132538	3.43
House_Headbolt_795	149853	132538	3.56
House_Headbolt_796	149864	132540	3.22
House_Headbolt_798	149868	132540	3.09
House_Headbolt_802	149771	132566	5.10
House_Headbolt_803	149772	132569	5.53
House_Oakworth_928	149655	132636	0.45
House_Oakworth_902	149658	132637	1.96
House_Oakworth_929	149658	132637	0.45
House_Oakworth_918	149666	132635	0.18
House_Oakworth_909	149672	132625	0.42
House_Oakworth_934	149676	132626	0.00
House_Oakworth_863	149686	132618	1.09
House_Oakworth_924	149690	132618	0.26
House_Oakworth_897	149699	132618	0.65
House_Oakworth_896	149704	132617	0.66
House_Oakworth_900	149711	132624	1.11

Appendix E

Calibration Certificates

CERTIFICATE OF CALIBRATION

ISSUED BY OPTICAL TEST and CALIBRATION LTD.

DATE OF ISSUE: 26 January 2021 Certificate Number 131368/ACU



0286



Optical Test and Calibration Ltd.

19-23 Campus Road
Listerhills Science Park
Bradford BD7 1HR
Tel +44(0)1274 393857
Fax +44(0)1274 393336

Email: calibration@otc.co.uk
Web: www.otc.co.uk

Page 1 of 2 Pages

Approved Signatory

Name Jenny Harris

Signature QC028

Customer: Ove Arup & Partners Ltd
6th Floor
3 Piccadilly Place
off Aytoun Street
MANCHESTER
M1 3BN

Equipment Information

Make: MINOLTA

Model:

T10

T-10

Description:

LUXMETER

SENSOR

Serial No:

32121013

54131010

Reference No:

029560

Date of Calibration: 26 January 2021

Calibrated By: J Haithwaite

This instrument has been calibrated by direct intercomparison to traceable standards in accordance with approved procedure RAD02 which follows the general principles of BS 667:2005.

The calibration was undertaken with the instrument being operated in accordance with the manufacturer's handbook where appropriate.

The uncertainties shown are consistent with the requirements of M3003 and are inclusive of the uncertainty contribution of the instrument under test. The results, statements and uncertainties relate only to the measured values as displayed by the instrument, and do not carry any implication regarding the stability of the instrument or its performance outside the measured range.

Laboratory Conditions: Temperature $21^{\circ}\text{C} \pm 2^{\circ}\text{C}$
Relative Humidity $50\% \text{rh} \pm 20\% \text{rh}$

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor of $k = 2$ unless otherwise shown, providing a confidence level of approximately 95 %. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No 0286

Certificate number
131368/ACU

Page 2 of 2 Pages

Calibration Undertaken

Illuminance in the range 1 lux to 20000 lux using a tungsten lamp at a colour temperature of 2856 K.

The reference plane of the sensor was taken to be the front face of the diffuser, with a diameter of 25 mm.

This unit has an auto-zero function. The zero offset has not been taken into account.

Results shown on receipt, no adjustment made

Manufacturer specification: $\pm 2\% + 1$ digit of displayed value (Ref: 2211)

Calibration Results

Reference Meter CAL1070 & CAL390A	Unit Under Test			
	Range	As Received		
Applied		Displayed		p _c
0.00 lux	Auto	0.00 lux *		
0.10 lux	Auto	0.10 lux *	PASS	N/A
1.00 lux	Auto	1.01 lux	PASS	80.7%
2.00 lux	Auto	2.02 lux	PASS	76.8%
5.00 lux	Auto	5.04 lux	PASS	76.4%
10.0 lux	Auto	10.03 lux	PASS	84.2%
50.0 lux	Auto	50.0 lux	PASS	93.3%
150.0 lux	Auto	149.7 lux	PASS	92.8%
500.0 lux	Auto	498 lux	PASS	96.8%
1500 lux	Auto	1491 lux	PASS	89.4%
5000 lux	Auto	4950 lux	PASS	84.9%
15000 lux	Auto	14810 lux	PASS	71.7%

Calibrations marked "*" in this certificate are not UKAS accredited and have been included for completeness.

'p_c' indicates probability of conformance to the specification used.

Calibrated by: J. Haithwaite

Date: 26 January 2021

UNCERTAINTY OF MEASUREMENT

The estimated uncertainty in the measured value of illuminance from 1 lux to 20000 lux when the instrument is used under the same conditions as when calibrated is ± 1 incremental digit in the least significant figure of the displayed value due to the resolution of the meter plus:

- | | |
|---|--|
| a) $\pm 3.1\%$ in the 1.0 lux to 10.0 lux range ($k = 2.00$) | b) $\pm 2.8\%$ in the 10 lux to 20 lux range ($k = 2.00$) |
| c) $\pm 2.2\%$ in the 20 lux to 200 lux range ($k = 2.00$) | d) $\pm 1.7\%$ in the 200 lux to 1000 lux range ($k = 2.00$) |
| e) $\pm 2.2\%$ in the 1000 lux to 2000 lux range ($k = 2.00$) | f) $\pm 2.3\%$ in the 2000 lux to 10000 lux range ($k = 2.00$) |
| g) $\pm 2.7\%$ in the 10000 lux to 20000 lux range ($k = 1.99$) | |