



Highways England

PHOTOBIOLOGICAL EFFECTS

DFT2 156 (4-45-12) & SPaTS1 479



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1 EXECUTIVE SUMMARY

WSP has been commissioned by Highways England (HE) to undertake a study in to the potential photo-biological effects of metal halide lamps on Highways England workforce during the bulk clean and change re-lamping process. The study arose following publication of the Health and Safety Executive's (HSE's) document 'Guidance for Employers on the Control of Artificial Optical Radiation at Work Regulations (AOR) in which there is a requirement for a risk assessment to be undertaken when people are in proximity/close to an intense source of optical radiation.

WSP assembled a team of industry recognised experts in their respective areas of expertise to undertake the required elements of the task. Analysis of the identified and supplied metal halide lamps (WP1000) was undertaken by Marina Khazova of Public Health England (PHE). The rationalisation of BS EN62471 'Photobiological safety of lamps and lamps systems' (WP2000) was compiled by John O'Hagan of PHE with the construction of a Ready Reckoner based on the gathered data from (WP1000) being carried out by Peter Raynham of University College London (UCL).

WP1000 was undertaken at PHE laboratories located near Didcot, Chilton, utilising specialist monitoring and measuring equipment. The results of the various tests are summarised in Section 3 of this report. Testing revealed that exposure to certain wattages of metal halide lamps over a prolonged period could cause damage to the eye such as Photoretinitis or Cataractogenesis. However, the effects are cumulative over a long period of time, and these effects can be mitigated by employing suitable best practice and provision of UV filtered eyewear where practicable.

WP2000 has been compiled to provide an understanding of BS EN62471 that can be understood and interpreted by designers and supervisors responsible for making decisions on the processes to be followed during a lamp clean and change operation, and the associated hazards applicable to the identified light source which may alter the way in which the task is to be carried out.

WP3000 has been derived based on the data gathered during the lamp testing programme associated with WP1000. WP3000 has been based on the worst-case scenario associated with a lamp change operation i.e. a hot lamp change, to determine the maximum number of operations that could be carried out in an eight-hour shift without exceeding the maximum permissible radiation dose associated with the tested wattage of metal halide lamps and as recommended by HSE document 'Guidance for Employers on the Control of Artificial Optical Radiation' at Work Regulations (AOR). The results have been summarised in to the table shown below and can be utilised as a Ready Reckoner by lighting design and supervisory staff in determining the number of lamp change operations associated with a particular wattage of metal halide that can safely be carried in an eight-hour shift without exceeding the maximum permissible radiation dose. As can be seen from the table below a RAG (Red, Amber and Green) system has been utilised to convey the level of hazard associated with a particular wattage.

	Lamp Type (Metal Halide)					
	100W	140W	150W	210W	250W	315W
Risk						
UV-A	540	369	410	129	247	119
Blue Light	132	108	97	42	51	30
Number of hot lamp changes for the maximum dose to be reached						

Following completion of Task 156 and now gaining a further understanding of the level of hazard associated with HID and emerging LED technologies, a better understanding of the types of operation being undertaken in close proximity to high output luminaires and the level and duration of exposure of operatives in a tunnel environment was needed. The tasks being undertaken within the roof space of a tunnel vary greatly from principle inspection work, VMS/lane drop matrix sign maintenance, to complete fan refurbishment and replacement; all of which have potential to place operatives near roof mounted lighting systems.

Two tunnel visits were undertaken to observe tunnel maintenance operations under a full closure; A3 Hindhead and A27 Southwick. Video and still images of the operations were captured, in addition to luminance mapping images, which were later analysed by Peter Raynham of UCL to determine distance, duration and level of exposure from the light source in proximity of the observed operatives.

Photometric file compilation of a Philips (nee Signify) Flow Star LED tunnel luminaire was undertaken by the LIA (Lighting Industry Association) laboratory in order for analysis of the data to understand the intensities at given angles which could potentially be experienced by an operative working in the vicinity of a tunnel luminaire.

Analysis revealed that whilst from certain directions of view the light source may prove to be hazardous, it is very unlikely that an operative would be able to maintain a direct sight of the light source due to the intensities which trigger the natural human reaction to look away/close eyes and avoid direct light penetration in to the eye.

In summary, all lamp change operations should not be carried out with the lamp still being in operation to significantly reduce the photo-biological hazards associated with such light sources; this will also reduce the risk of other injuries such as burns caused by the high temperatures of the lamps outer glass sheathing.

Additional Personal Protective Equipment (PPE) measures can be used as a last resort to reduce the photo-biological hazards from being in close proximity of metal halide lamps in the form of UV filtered glasses manufactured in accordance with EN166 1F. However, the first and recommended measure would be to isolate the lamp prior to any activity associated with the lamp change or inspection process, where practicable.

2 PROJECT BACKGROUND

In 2010 the HSE published the document 'Guidance for Employers on the Control of Artificial Optical Radiation at Work Regulations (AOR), in which there is a requirement for a risk assessment to be undertaken when people are in proximity/close to an intense source of optical radiation. Given the nature of the operations associated with bulk clean and change of lamps throughout the Highways England motorway and primary route network i.e. operatives in close proximity to the light source at certain times during the operation, Highways England has rightly taken the view that all practicable steps should be implemented in terms of best practice to mitigate the hazards presented in terms of optical radiation from such light sources that are categorised as RG2 or RG3 lamps.

Highways England provided the following breakdown of lamp wattages and the percentage share of the network:

- 100w – 6% of HE lighting asset;
- 140w - <1% at present but increasing with scheme renewals;
- 150w – 23%;
- 250w – 43%;
- 210w - <1% at present but increasing with scheme renewals;
- 400w – 21%
- Remaining 6% includes for old SOX (low pressure sodium) installations.
- It should be noted that the wattages stated above are for high pressure sodium and metal halide combined.
- Task 156 has been commissioned by Highways England to investigate the likely optical radiation and blue light which is recognised as having potential to cause damage to the human eye, associated with Metal Halide light sources only. Any other light sources which are currently installed on Highways England network such as high-pressure sodium or LED would be subject of separate review under another Task brief.

The primary objectives of Task 156 are as follows:

- Assessment of photo-biological hazards associated with the maintenance of metal halide light sources (WP1000);
- Rationalisation of the British and European Standard EN62471 to enable ease of understanding and implementation of the requirements by lighting supervisors or designers (WP2000); and
- Provisions of guidance in the form a spreadsheet (Ready Reckoner) to readily assess the hazards associated with individual metal halide lamp wattages and provide a readily understood output (WP3000).

In order to undertake and produce the required technical and scientific output, WSP assembled a team of experts from Public Health England (PHE) and University College London (UCL). Marina Khazova of PHE performed the required controlled laboratory experiments on the identified metal halide wattages as part of WP1000. John O'Hagan of PHE undertook the rationalisation of BS EN62471 (WP2000) and Peter Raynham of UCL undertook the compilation of the Ready Reckoner based on the data produced as part of WP1000.

3 WP1000 - MEASUREMENTS FOR THE ASSESSMENT OF PHOTO-BIOLOGICAL SAFETY OF METAL-HALIDE LIGHTING

Introduction

As previously stated, the common metal halide wattages currently utilised throughout the HE motorway and principle route network were identified and suitable samples requested from three manufacturers for inclusion in the testing programme. Philips, Osram and GE were identified as the main suppliers of such lamps to the UK highway lighting market and were accordingly approached for a minimum of three of each identified lamp. The wattages requested were as follows:

- 100w
- 140w
- 150w
- 210w
- 250w
- 400w

It should be noted that none of the selected manufacturers were able to provide a 400w sample for testing. As a result, this wattage was excluded from the testing programme with the HE's agreement. Philips did however provide the recently developed and new to the market 315w CPO-TW lamp for inclusion in the testing programme. Philips provided suitable luminaires for inclusion in the test and all the electronic control gear appropriate for each lamp wattage. Refer to **Appendix A** for a list of lamps utilised within the testing programme which are correlated to the results tables detailed in the content of this section.

Methodology

The required measurements relevant to the task were undertaken by PHE under controlled conditions at their laboratories based on Didcot, Chilton. Measurements were carried out on the bare lamp to represent the luminaire canopy being open during a lamp change process

The following measurements were completed:

- Spectral irradiance $E_{\lambda}(\lambda)$ of the lamp without luminaire at 1m; 3 lamps of each type were used;
- Spectral irradiance $E_{\lambda}(\lambda)$ at 2m from luminaires; and
- Spectral transmittance of front cover of the luminaires; 1000W tungsten-halogen lamp was used as a reference source.

Illuminance, total UV-A, UV and Blue Light weighted irradiance were calculated according to:

$\text{UV weighted irradiance } E_{\text{eff}} = \sum_{180\text{nm}}^{400\text{nm}} E_{\lambda}(\lambda) S(\lambda) \Delta\lambda$	(1)
$\text{UVA irradiance } E_{\text{UVA}} = \sum_{315\text{nm}}^{400\text{nm}} E_{\lambda}(\lambda) \Delta\lambda$	(2)

Blue Light irradiance $E_B = \sum_{300\text{nm}}^{700\text{nm}} E_{\lambda}(\lambda) B_{\lambda}(\lambda) \Delta\lambda$	(3)
--	-----

where $E_{\lambda}(\lambda)$ – measured spectral irradiance;
 $S(\lambda)$ – the UV spectral weighting values;
 $B(\lambda)$ – the Blue Light hazard spectral weighting values
 $\Delta\lambda$ – the wavelength interval of the measurements.

Values (1)-(3) were compared with ICNIRP (International Commission on Non-Ionizing Radiation Protection) Exposure Limit Values (ELVs) to estimate maximum permissible exposure time (MPE time).

The ELVs take account of the biological effectiveness of the optical radiation in causing harm at different wavelengths, the duration of exposure to the optical radiation and the target tissue. The ELVs represent levels at which ICNIRP considers most of the working population can be repeatedly exposed without suffering any acute adverse health effects and without noticeable risk of long term effects.

To protect the cornea, conjunctiva and skin, ICNIRP sets a maximum effective radiant UVR exposure for the eyes and skin within an 8-hour working day of 30 J m^{-2} .

$$\text{MPE time} = \frac{30 \text{ Jm}^{-2}}{E_{\text{eff}}}, \text{ in seconds} \quad (4)$$

To protect the eye lens, ICNIRP sets a maximum radiant UV-A (315-400 nm) exposure to the eye within an 8-hour period of 10 kJ m^{-2} .

$$\text{MPE time} = \frac{10000 \text{ Jm}^{-2}}{E_{\text{UVA}}}, \text{ in seconds} \quad (5)$$

To protect the eye retina from photochemical damage, ICNIRP sets a maximum radiant exposure to the eye of $10^6 \text{ J m}^{-2} \text{ sr}^{-1}$.

$$\text{MPE time} = \frac{10^6 \text{ J m}^{-2} \text{sr}^{-1}}{E_B / \text{sr}}, \text{ in seconds} \quad (6)$$

Instrumentation

All measurements were carried out in the temperature-controlled laboratory at PHE, Chilton. Spectral irradiance was measured in 250nm – 800nm with 1 nm step by scanning double-grating monochromator D3 180 (JobinYvon, Longjumeau, France), S/N 0116B-09-00. This instrument was calibrated with a 1000 W tungsten-halogen lamp, calibrated for spectral irradiance to the Physikalisch-Technische Bundesanstalt (PTB) traceable reference standards.

Stability of the emission was monitored by CCD array spectroradiometer Exemplar LS (B&W Tek Inc, Newark, USA), S/N 130328351.



Results – UV-A

There is no foreseeable risk of overexposure to UV_{eff} based on the results presented in **Table 1** below.

Table 1 - UVe_{eff} results summary

MPE time, min	UV-A											
	100W			140W	150W			210W	250W		315W	
Lamp Number	3	22	32	38	6	27	41	12	21	29	47	
2m												
bare lamp												
SGS 253	2106	3248	2223	1277	1985	2692	1456					
SGS 254					2710	3446	2160	568	939	2472	407	
1m												
bare lamp	964	1250	949	521	840	1080	577	227	344	955	165	
SGS 253	527	812	556	319	496	673	364					
SGS 254					677	861	540	142	235	618	102	
0.5m												
bare lamp	241	313	237	130	210	270	144	57	86	239	41	
SGS 253	132	203	139	80	124	168	91					
SGS 254					169	215	135	35	59	155	25	
0.3m												
bare lamp	88	114	86	47	76	98	52	21	31	87	15	
SGS 253	48	74	51	29	45	61	33					
SGS 254					62	78	49	13	21	56	9	

Note: UV-A exposure is accumulative over 8hr working day

Results – Bare Lamps at 1 metre UV-A, Blue Light (BL) & UV_{eff}

Table 2 - Results of 100w bare lamp measured at a distance of 1 metre

1m	100W								
Lamp Number	1	3	7	22	23	24	32	34	35
Total UVA, W/m ²	0.17	0.17	0.23	0.13	0.12	0.13	0.18	0.15	0.19
Total BL, W/m ²	0.34	0.31	0.26	0.39	0.39	0.39	0.32	0.30	0.34
Total UV _{eff} , W/m ²	4.8E-05	4.9E-05	7.7E-05	7.1E-05	8.9E-06	1.0E-06	1.7E-04	1.4E-04	2.5E-04
illuminance, lx	1048	1031	848	936	886	943	941	867	961
UVA hazard ratio, W/lm	1.6E-04	1.7E-04	2.8E-04	1.4E-04	1.3E-04	1.4E-04	1.9E-04	1.7E-04	1.9E-04
BL hazard ratio, W/lm	3.2E-04	3.0E-04	3.1E-04	4.1E-04	4.4E-04	4.1E-04	3.4E-04	3.4E-04	3.5E-04
UV _{eff} hazard ratio, W/lm	4.5E-08	4.8E-08	9.1E-08	7.6E-08	1.0E-08	1.1E-09	1.8E-07	1.6E-07	2.6E-07
	GE			Osram			Philips		

Table 3 - Results of 140w bare lamp measured at a distance of 1 metre

1m	140W		
Lamp Number	37	38	40
Total UVA, W/m ²	0.33	0.32	0.32
Total BL, W/m ²	0.46	0.46	0.47
Total UV _{eff} , W/m ²	3.6E-04	3.2E-04	9.8E-05
illuminance, lx	1653	1644	1684
UVA hazard ratio, W/lm	2.0E-04	1.9E-04	1.9E-04
BL hazard ratio, W/lm	2.8E-04	2.8E-04	2.8E-04
UV _{eff} hazard ratio, W/lm	2.2E-07	2.0E-07	5.8E-08
	Philips		

Table 4 - Results of 150w bare lamp measured at a distance of 1 metre

1m	150W								
Lamp Number	4	6	9	25	26	27	41	43	44
Total UVA, W/m ²	0.19	0.20	0.21	0.16	0.14	0.15	0.29	0.26	0.30
Total BL, W/m ²	0.44	0.43	0.44	0.49	0.46	0.48	0.51	0.51	0.53
Total U _{veff} , W/m ²	1.5E-05	3.3E-05	1.6E-04	1.0E-06	1.3E-04	1.0E-06	4.0E-04	2.5E-04	3.2E-04
illuminance, lx	1665	1637	1667	1274	1264	1270	1461	1487	1492
UVA hazard ratio, W/lm	1.1E-04	1.2E-04	1.2E-04	1.2E-04	1.1E-04	1.2E-04	2.0E-04	1.8E-04	2.0E-04
BL hazard ratio, W/lm	2.6E-04	2.6E-04	2.6E-04	3.8E-04	3.6E-04	3.8E-04	3.5E-04	3.4E-04	3.5E-04
U _{veff} hazard ratio, W/lm	9.0E-09	2.0E-08	9.7E-08	1.3E+09	1.1E-07	7.9E-10	2.8E-07	1.7E-07	2.1E-07
	GE			Osram			Philips		

UV emission of measured 100W (**Fig.1**) and 150W (**Fig.2**) Philips lamps is higher than Osram and GE; UV emission of measured 250W (**Fig.3**) Philips lamps is higher than Osram. All figures shown below and on following pages.

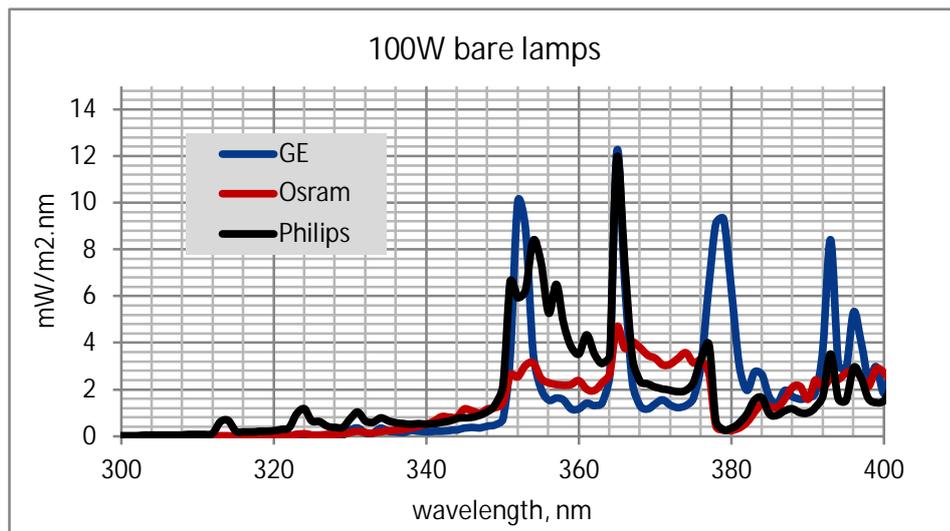


Fig. 1 - Spectral irradiance of 100W bare lamps at 1m

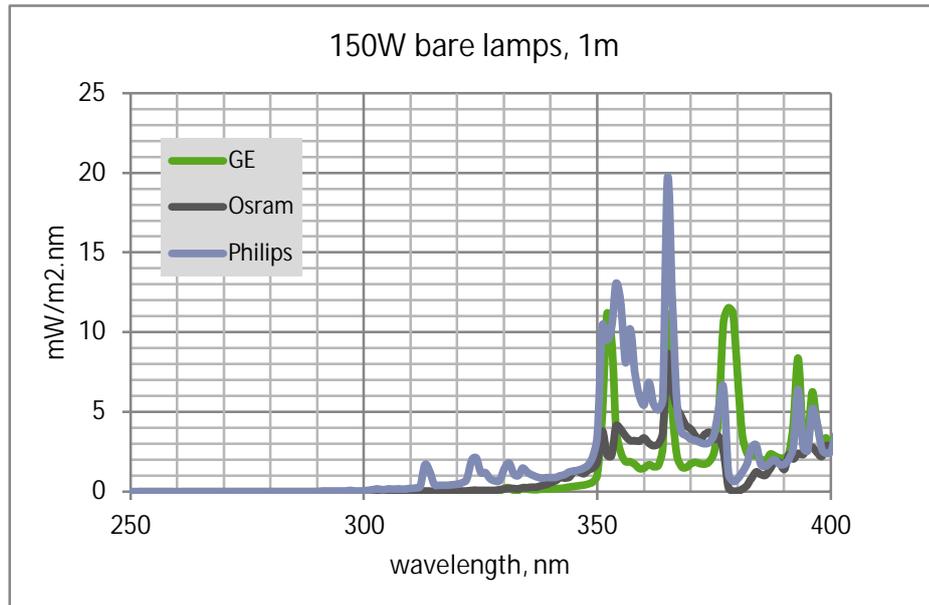


Fig. 2 - Spectral irradiance of 150W bare lamps at 1m

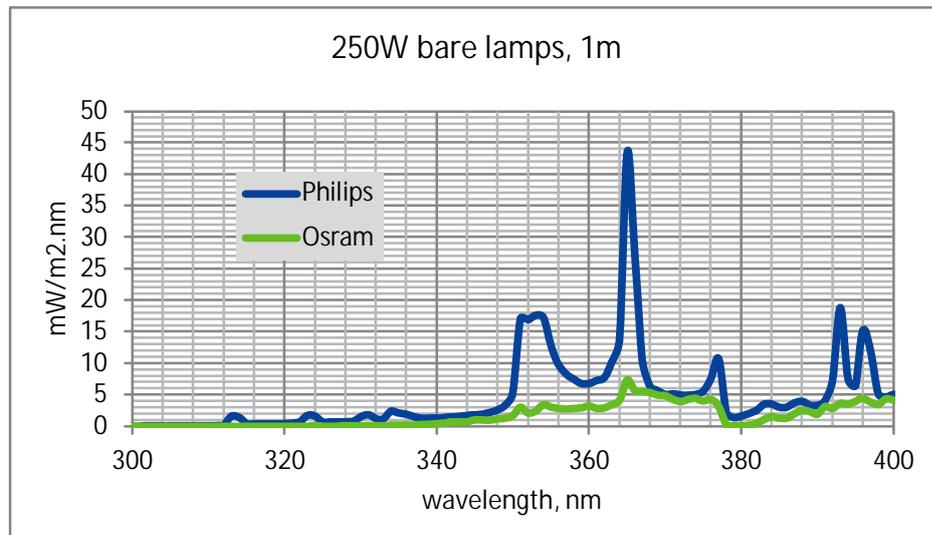


Fig. 3 - Spectral irradiance of 250W bare lamps at 1m

Table 5 - Results of 210w bare lamp measured at a distance of 1 metre

1m	210W		
Lamp Number	12	13	16
Total UVA, W/m ²	0.73	0.65	0.74
Total BL, W/m ²	1.20	1.09	1.18
Total U _{veff} , W/m ²	5.9E-04	6.8E-04	9.9E-04
illuminance, lx	1917	1784	1903
UVA hazard ratio, W/lm	3.8E-04	3.6E-04	3.9E-04
BL hazard ratio, W/lm	6.2E-04	6.1E-04	6.2E-04
U _{veff} hazard ratio, W/lm	3.1E-07	3.8E-07	5.2E-07
	Philips		

Table 6 – Results of 250w bare lamp measured at a distance of 1 metre

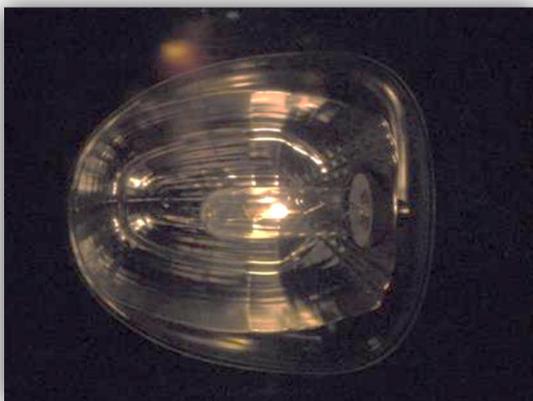
1m	250W						
Lamp Number	17	19	20	21	28	29	30
Total UVA, W/m ²	0.51	0.43	0.48	0.48	0.17	0.17	0.17
Total BL, W/m ²	1.00	0.88	0.99	0.99	0.87	0.88	0.84
Total U _{veff} , W/m ²	2.1E-04	3.6E-04	1.2E-04	2.7E-04	7.4E-05	1.0E-04	1.0E-06
illuminance, lx	2428	2211	2510	2499	2325	2361	2250
UVA hazard ratio, W/lm	2.1E-04	1.9E-04	1.9E-04	1.9E-04	7.3E-05	7.4E-05	7.6E-05
BL hazard ratio, W/lm	4.1E-04	4.0E-04	4.0E-04	4.0E-04	3.8E-04	3.7E-04	3.7E-04
U _{veff} hazard ratio, W/lm	8.6E-08	1.6E-07	4.7E-08	1.1E-07	3.2E-08	4.3E-08	-3.9E-08
	Philips				Osram		

Table 7 – Results of 315w bare lamp measured at a distance of 1 metre

1m	315W		
Lamp Number	46	47	48
Total UVA, W/m2	1.01	1.01	0.94
Total BL, W/m2	1.72	1.71	1.68
Total UVeff, W/m2	4.1E-04	4.6E-04	2.4E-04
illuminance, lx	2778	2837	2830
UVA hazard ratio, W/lm	3.6E-04	3.6E-04	3.3E-04
BL hazard ratio, W/lm	6.2E-04	6.0E-04	5.9E-04
UVeff hazard ratio, W/lm	1.5E-07	1.6E-07	8.5E-08
	Philips		

Results – Blue Light

Majority of the emission is from 10-20mm or emitter/arc tube. Refer to **Pictures 1 & 2** below showing area of emission when lamp is at full operational temperature captured using exceptionally high strength light filters.



Pictures 1 & 2 – Examples of arc tube at full operational temperature

Table 8 – Results of 250w bare lamp measured at a distance of 1 metre

MPE time, min	BL											
		100W			140W	150W			210W	250W		315W
Lamp Number	3	22	32	38	6	27	41	12	21	29	47	
BL irradiance, W/m2, 1m												
bare lamp	0.31	0.39	0.32	0.46	0.43	0.48	0.51	1.20	0.99	0.88	1.71	
SGS 253	0.72	0.71	0.65	0.92	0.92	0.94	1.05					
SGS 254					0.66	0.71	0.76	2.21	1.74	1.51	3.30	
BL radiance, W/m2.sr, 1m												
bare lamp	987	1242	1019	1465	1369	1529	1624	3822	3153	2803	5446	
SGS 253	2281	2277	2084	2942	2915	3003	3343					
SGS 254					2112	2251	2435	7037	5549	4796	10510	
BL radiance, W/m2.sr averaged over 100mrad, 1m												
bare lamp	31	39	32	46	43	48	51	120	99	88	171	
SGS 253	72	71	65	92	92	94	105					
SGS 254					66	71	76	221	174	151	330	
MPE time, min												
bare lamp	17	13	16	11	12	11	10	4	5	6	3	
SGS 253	7	7	8	6	6	6	5					
SGS 254					8	7	7	2	3	3	2	
MPE time, min (based on averaged over 100 mrad)												
bare lamp	538	427	521	362	388	347	327	139	168	189	97	
SGS 253	233	233	255	180	182	177	159					
SGS 254					251	236	218	75	96	111	51	

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4 WP2000 – RATIONALISATION OF BS EN62471

Key Points	
1.	Workers should not be exposed to levels of optical radiation that exceed the exposure limit values. It is an offence to expose workers to levels that exceed the exposure limit values.
2.	Some light sources, such as highway lighting, are safe when people are at “normal” distances from the lamp. However, there is a risk of exceeding the exposure limits during maintenance or servicing when workers are likely to get close to the lamp.
3.	Lamps and lamp systems should be assigned to a risk group by the manufacturer under a British Standard, BS EN 62471. Work close to Risk Group 3 lamps and lamps systems should be assessed to ensure that workers do not exceed the exposure limit value.
4.	The most effective safety measure is to ensure that lamps are switched off before work is carried out in close proximity to the lamp.

Introduction

In 2010, specific legislation (Control of Artificial Optical Radiation at Work Regulations) was introduced to restrict worker exposure to harmful levels of optical radiation, including light and ultraviolet radiation (UVR). However, this legislation generally placed no greater burden on employers than was already required under the Management of Health and Safety at Work Regulations 1999.

Lamps and lamp products should meet the requirements of BS EN 62471 “Photobiological Safety of Lamps and Lamp Systems”. EN 62471 is harmonised under the Low Voltage Directive and therefore BS EN 62471 can be used to demonstrate compliance with some of the essential health and safety requirements of the UK implementation of the Directive (The Electrical Equipment (Safety) Regulations 1994). The term “lamps and lamps systems” should also be interpreted to include light emitting diode (LED) sources.

This guide provides an outline of the legislation, the Health and Safety Executive’s guidance to the legislation and BS EN 62471 (which is identical to EN 62471).

Legislation

Regulations covering health and safety at work in the UK are made under the Health and Safety at Work etc Act 1974. That Act requires employers to assess the risk from work activities to both employees and others (including members of the public). The Management of Health and Safety at Work Regulations were first introduced in 1992 and then updated in 1999. There was no specific reference to any limitation of worker exposure to intense sources of light or UVR. However, regulatory authorities have used the exposure limit values (ELVs) published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) as levels below which people could be safely exposed without harm. The ICNIRP ELVs have been incorporated into BS EN 62471 and form the basis for the risk groups (see below).

The Control of Artificial Optical Radiation at Work Regulations (the Regulations) builds on the requirements of the Management of Health and Safety at Work Regulations (Management Regulations), but places no additional burden on employers if they had already assessed the risks of carrying out the work under the Management Regulations and had implemented appropriate control measures. The exposure limits are not included in the Regulations, but reference is made to the parent Artificial Optical Radiation Directive, published by the European Union and Council. These exposure limits are the same as the exposure limit values published by ICNIRP.

For clarity, the Regulations only apply to people at work, although the Management Regulations will still apply to those who are not. People at work will include anyone who is carrying out an activity as part of their employment or as a self-employed person. This wide definition means that it is important for any assessment of optical radiation exposures by workers from one employer will need to additionally consider any other workers who may be exposed. On a roadway, this would be interpreted to include anyone driving as part of their work.

The Regulations only cover artificial sources, so exposure to optical radiation from the sun or moonlight is not included. Again, the Management Regulations will apply to workers' exposure to sunlight (including UVR exposure) during daylight hours.

There are a few specific requirements of the Regulations that employers may not have been aware of when carrying out general risk assessments:

1. People who are particularly at risk of adverse health effects following exposure to optical radiation; and
2. Adverse reactions with photosensitising chemicals.

These are similar in that some workers may be react to light or UVR because of medical conditions and some because of chemicals they are working with or drugs they are taking. In terms of chemicals that may get onto the skin, it is important that the employer identifies any potential photosensitivity. There are a wide range of substances, which produce photosensitive reactions when eaten. These include a number of alternative medicines. It may be difficult for the employer to take this into account when carrying out the risk assessment unless employees raise concerns, such as skin rashes.

The Regulations give guidance on sources that may present a particular risk and therefore specifically need a risk assessment. For lasers, this is clearly stated as Class 3B and Class 4 laser products. However, at the time that the parent Directive was being drafted, there was no equivalent safety classification scheme for lamps. Therefore, the Regulations state that specific risk assessments are required for non-laser sources that present a hazard equivalent to Class 3B and Class 4 lasers. These would only be Risk Group 3 lamps and lamp products (see description of risk groups under BS EN 62471).

It is important to consider multiple sources of exposure, where relevant, and repeated exposures. Multiple sources could include a lamp system with a number of lamps, or it would include a situation where a worker could be exposed to more than one lamp system at the same time. However, in most situations, the exposure from one lamp system will dominate. Repeated exposures are likely to be more important, especially since some of the risks presented by repeated exposure are cumulative over a working day – considered to be an 8-hour shift.

The risk assessment should identify the likelihood that a worker will be exposed to levels of optical radiation that may result in the exposure limit value being exceeded. Based on this risk assessment, control measures should be implemented.

The control measures required to reduce the risk of exceeding the exposure limits in the Regulations are similar to those required by the Management Regulations. Therefore, the first thing to consider is whether the work can be carried out with the source switched off and therefore exposure to the hazard eliminated. If this is not possible, then some form of engineering control measure should be

considered. Only then should procedures be used and, as a final resort, personal protective equipment.

Personal protective equipment, such as UVR protective eyewear, should not be used as the first level of protection to avoid turning the power to the lamp off. Indeed, eyewear that provides protection from the blue light may impede visibility, especially at night. However, protection both for the eyes and hands are reasonable to avoid the risk of injury should the lamp shatter. Appropriate hand protection is also sensible when handling lamps that may be hot.

If exposures above the exposure limits are likely then it would be appropriate to consider arrangements for health surveillance should a worker exceed the exposure limit value. Routine health surveillance is not required under the Regulations where the risk of exceeding the exposure limits is adequately managed.

HSE Guidance

The guidance from the Health and Safety Executive (Guidance for Employers on the Control of Artificial Optical Radiation at Work Regulations (AOR) 2010) provides a flow chart to assist employers determine the effort required to comply with the Regulations.

Work involving lamp replacement on roadway lighting with power on to the lamp is not specifically covered by the Guidance. Therefore, unless appropriate information is available, for example from the lamp manufacturer, it is necessary to undertake a risk assessment to determine if employees will be exposed to levels of optical radiation in excess of the exposure limit values referenced in the Regulations.

Institution of Lighting Professionals Guidance

The Institution of Lighting Professionals (ILP) (nee the Institution of Lighting Engineers ILE) General Publication 03 'Electrical safety, Code of practice for electrical safety in highway electrical operations' section 21.3.3 Lamp changing, and luminaire cleaning provides some guidance on lamp change operations.

Section 21.3.3 advises (appropriate tasks only noted):

While carrying out lamp changing the following work routine is typical:

- Isolate the luminaire electrically
- Remove the dust and dirt from the top of the luminaire
- (additional steps deleted for clarity)
- Energise circuit and test the lamp operation by shielding the PECU if necessary.

Under this guidance whilst hot / live lamp changes are not prohibited it is acceptable for the operative to ascend to or descend from a luminaire whilst it is operational and as such have sight of the working lamp during these operations.

It should also be noted that BS 7671 (the Wiring Regulations) would also prohibit a live lamp change.

BS EN 62471

Optical radiation is divided into named groups depending on wavelength. Ultraviolet radiation covers the wavelength range from 100 nm to 400 nm, with some overlap with the part of the optical radiation spectrum that we can see (380 nm to 780 nm). Infrared radiation is from 780 nm to 1,000,000 nm (1 mm). Ultraviolet radiation is additionally split into UV-A (315 to 400 nm), UV-B (280 nm to 315 nm) and UV-C (100 nm to 280 nm). The possible adverse health effects on the eye and skin if the exposure limit values for ultraviolet radiation are exceeded are presented in the table below.

CIE spectral region	Effects on the Eye	Effects on the Skin
Ultra-violet C (UV-C) (180 nm to 280 nm)	Photokeratitis	Erythema (sunburn) Accelerated skin ageing process Increased pigmentation
Ultra-violet B (UV-B) (280 nm to 315 nm)		
Ultra-violet A (UV-A) (315 nm to 400 nm)	Photochemical cataract	Pigment darkening Photosensitive reactions Skin burn

BS EN 62471 (Photobiological Safety of Lamps and Lamp Systems) introduces risk group classification to assist employers and others with the measures that may be required to protect people from optical radiation. It is important to recognise that the test methods used in the Standard are intended to assure a common approach to assessing lamps and lamps systems. Depending on the application, the assessment may or may not represent worst-case exposure conditions. It is also important to recognise that the assumptions used in determining the risk groups may not be relevant for specific work activities.

The risk groups are defined as follows:

Risk Group	Assumptions – for exposure at 200 mm from the lamp or lamp system (ELV = Exposure Limit Value)
Exempt (RG0) – trivial risk Considered not to be hazardous unless specific and prolonged exposure takes place – usually through deliberate action.	<ul style="list-style-type: none"> The erythemally-weighted ultraviolet radiation (UVR) will not exceed the ELV within 8 hours Exposure to UV-A will not exceed the ELV within 1000 s The blue-light ELV will not be exceeded within 10,000 s The retinal thermal hazard ELV will not be exceeded within 10 s The infrared radiation ELV will not be exceeded within 1000 s
RG1 – very low risk Normal behaviour, such as not being in exactly the same location for extended periods of time, tends to limit exposures. Assumed that “normal behavioural limitations” mean that RG1 lamps and lamp systems are unlikely to be hazardous.	<ul style="list-style-type: none"> The erythemally-weighted UVR will not exceed the ELV within 10,000 s Exposure to UV-A will not exceed the ELV within 300 s The blue-light ELV will not be exceeded within 100 s The retinal thermal hazard ELV will not be exceeded within 10 s The infrared radiation ELV will not be exceeded within 100 s

<p>RG2 – low risk</p> <p>Aversion responses, such as averting exposure to very bright light, are assumed to protect individuals. Anyone overcoming aversion responses may increase the exposure duration and therefore exceed the ELVs.</p>	<ul style="list-style-type: none"> • The erythemally-weighted UVR will not exceed the ELV within 1,000 s • Exposure to UV-A will not exceed the ELV within 100 s • The blue-light ELV will not be exceeded within 0.25 s • The retinal thermal hazard ELV will not be exceeded within 0.25 s • The infrared radiation ELV will not be exceeded within 10 s
<p>RG3 – high risk</p> <p>Even momentary exposure to the optical radiation from the lamp or lamp system may result in the ELV being exceeded</p>	<p>Any lamp or lamp system that exceeds the ELVs within the time periods given above is assigned to RG3.</p>

Note 1 – the risk group risk categories are different to those given in BS EN 62471, but represent the current views of the experts within the International Commission on Illumination and the International Electrotechnical Commission.

The assignment of a lamp or lamp system to a specific risk group generally assumes exposure to that single lamp or lamp system. Therefore, the information contributes to the risk assessment, but further analysis may be required under specific circumstances. For example, exposure to multiple RG1 or RG2 lamps or lamp systems during a working shift may need to be taken into account. However, this is only likely to be relevant for situations where the erythemally-weighted UVR, UV-A and blue light ELVs are likely to be exceeded during repeat exposures. The other ELVs relate to instantaneous exposure and are not cumulative.

BS EN 62471 does not specify any control measures, such as lamp or lamp system labelling. PD IEC/TR 62471-2 (Guidance on manufacturing requirements relating to non-laser optical radiation safety) was intended to guide product-specific standards' committees on labelling that may be applied for products. This has not been adopted as such by committees such as IEC TC34 and therefore labelling and information to the user depends on the diligence of the manufacturer or supplier. For this reason, it is likely that many lamps and lamp systems will not be marked with the risk group.

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GP03: Code of Practice for Electrical Safety in Highway Electrical Operations. Institution of Lighting Professionals. (<https://www.theilp.org.uk/resources/ilp-general-reports/gp03/>).

Standards

BS EN 62471: 2008. Photobiological safety of lamps and lamp systems. (Identical to EN 62471. Technically the same as IEC 62471, but formatted differently).

BS 7671:2008+A1:2011. Requirements for electrical installations. IET Wiring Regulations. Seventeenth edition.

PD IEC/TR 62471-2: 2009. Photobiological safety of lamps and lamp systems. Guidance on manufacturing requirements relating to non-laser optical radiation safety.

Glossary

Blue-light – a term used for the wavelength range 400 to about 500 nm which is particularly effective at causing photochemical effects in the eye. The physical amount of visible radiation from 400 to 700 nm is adjusted for its effectiveness, with a maximum at 435-440 nm.

CIE – International Illumination Commission (from its French name).

Erythema - reddening of the skin caused (usually) by the ultraviolet radiation

Erythemally-weighted ultraviolet radiation – a modification of the physical amount of ultraviolet radiation to adjust for the different effectiveness of different ultraviolet radiation wavelengths to cause erythema. 270 nm ultraviolet radiation is the most effective wavelength at causing erythema

Exposure Limit Value (ELV) – Legally-binding limits of optical radiation that a person can be exposed to. The ELV depends on the wavelength of the optical radiation, the duration of exposure and, in some cases, the dimensions of the source.

IEC – International Electrotechnical Commission. Technical Committees 76 “Optical radiation safety and laser equipment” and 34 “Lamps and related equipment” are relevant.

Lamp – the device that emits optical radiation. Includes light emitting diodes.

Lamp system – the combination of the lamp and the luminaire.

Optical radiation – ultraviolet radiation, light and infrared radiation. Covers the wavelength range 100 nm to 3000 nm in this document.

Photochemical – a process which results from the conversion of optical radiation into a chemical effect.

Photokeratitis – inflammation of the front surface of the eye. Known as “arc-eye”. Appears about 24 hours after exposure and symptoms (extreme pain and feeling of sand in the eye) last for about 24 hours.

Retinal thermal hazard – relative effectiveness of wavelength of optical radiation between 380 nm and 1400 nm to cause harm to the retina (region at the back of the eye).

Ultraviolet radiation (UVR) – optical radiation between 100 nm and 400 nm, subdivided into ultraviolet A, B and C.

5 WP3000 – ESTIMATION OF A WORKER’S EXPOSURE TO OPTICAL RADIATION WHEN “HOT” CHANGING LAMPS

Introduction

To assess how much optical radiation a worker might receive when "Hot" changing a lamp it is necessary to both know how much radiation is generated by the lamp and how long the worker is exposed to its radiation and at what distance. To assess amount of time a worker spends at a given distance from the lamp the following steps were taken:

- Video a worker changing a lamp;
- Extract a still image every second from the video;
- On each still assess the distance between the worker's eye and the light source; and
- Assess the dose of radiation received from a range of lamps of known output.

Taking the Video

The video was recorded in the early hours of 6th March 2014 from a bridge over the M4 close to Junction 7. The location is shown on the map below.



Figure 1 - Map showing the location of the site

The image below shows the position that the video was taken from and the lantern that had its lamp changed



Image 1 - showing the locations of the camera and the lantern

The camera position was selected so that as far as possible the movement of the worker would be in a plane parallel to the image plane.

During the observation of the lamp changing the crew turned off the power before ascending to change the lamp.

Extraction of the Still Images

Using video editing software 90 images were extracted, one for every second from the point where the worker started to ascend towards the lantern to the point where the lamp had been unscrewed. The figure below shows a typical image. Note as the lantern was switched out it is difficult to see so it has been marked out for clarity in the figure.

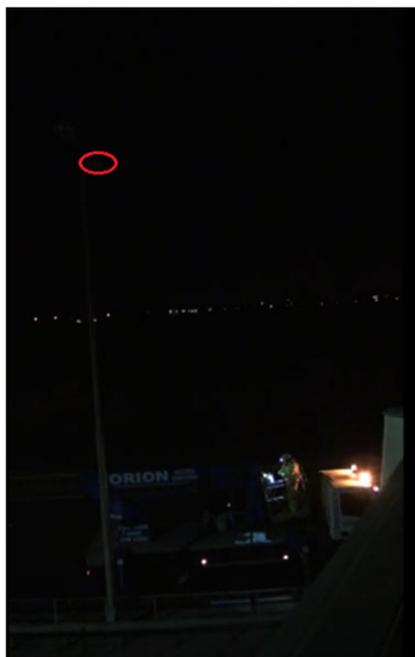


Image 2 - Typical image of the lamp changing operation

Assessment of Distance between Worker's Head and Lantern

To assess the distance between the workers head and lantern in each image the pixel co-ordinates of the head and lantern were found in the image and the pixel distance between the two was calculated. It was known that the column was exactly 12m high so by measuring the height in pixels on one image it was possible to convert the pixel values into metres.

The movement of the worker was split into three phases:

- Assent towards the lantern;
- Above the cut off of the lantern where the worker did not receive any radiation from the lantern; and
- Lantern open, where the worker could view the lamp directly.

The chart below plots the second by second distances from the lantern.

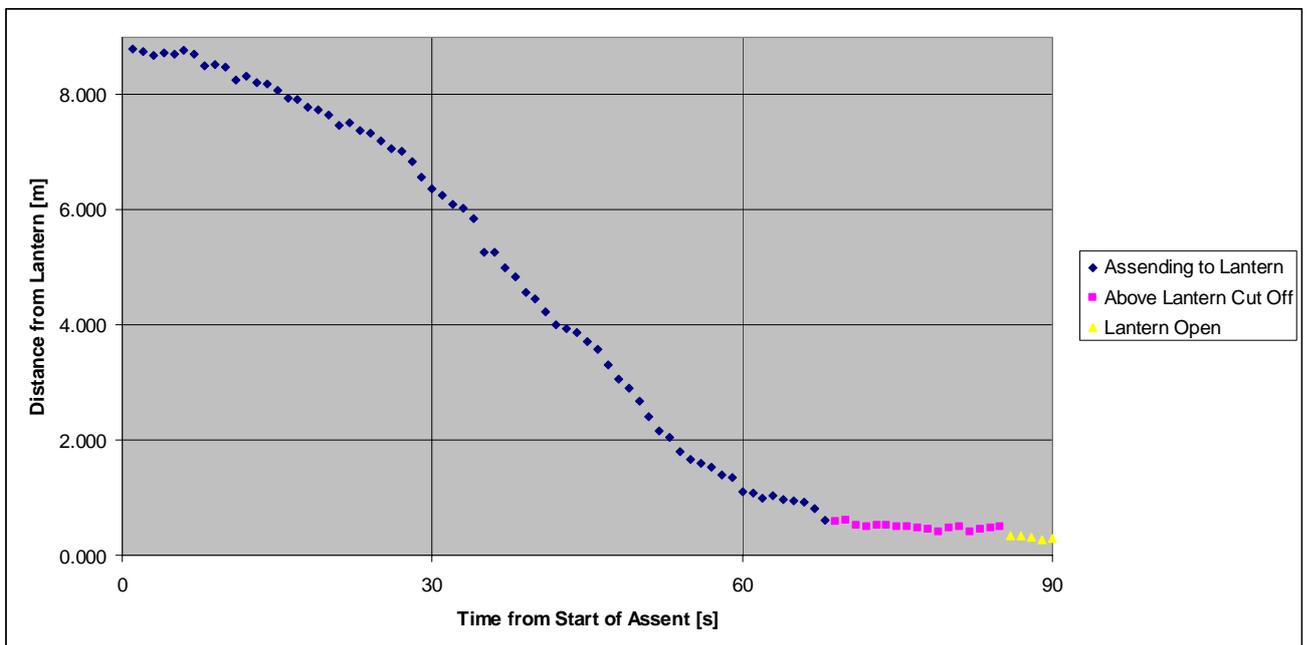


Figure 2 - Plot of distance of the worker from the lantern with time

Dose Assessment – UV-A Hazard

For the UV-A hazard the cumulative dose was calculated by dividing the effective irradiance at 1 meter for each source and dividing it by the distance between the worker and source squared. The irradiance for the assent phase from the luminaire measurement was used and that bare lamp data was used when the luminaire was open. By summing the second by second values it is possible to calculate the total dose received for one lamp change operation. By comparing the dose per operation with the maximum permitted dose $10,000 \text{ Jm}^{-2}$, it was possible to calculate the maximum number of operations that could take place in any 8 hour period. The Table 9 below gives the results of the calculations.

Table 9 – UV-A dose calculation results

Lamp Wattage	100w	140w	150w	210w	250w	315w
Overall Dose [Jm^{-2}] per operation	18.51	27.07	24.40	77.65	40.51	84.07
Max Operations for Limit $10,000 \text{ Jm}^{-2}$	540	369	410	129	247	119

For the blue light hazard the limit relates to the radiance received at the worker's eye, if the source is small (subtending a solid angle of less than 0.01sr) then it is assumed that due to eye movements the radiation is spread out over the retina in an area equivalent to solid angle of 0.01 sr. In such conditions, the dose received by the worker is a function of the irradiance at the eye divided by the notional solid angle of 0.1 sr. When the worker is close to the source then it is the source radiance that contributes to the dose.

While the worker was ascending to the lantern the radiation from the lantern was used to calculate the irradiance at the workers eyes. The solid angle subtended by the flashed area of the lantern at the worker's eye was calculated by taking the optical dimensions of a typical lantern (0.42 by 0.33 m for a Philips SGS 254 flat glass) assuming that for any locations the actual flashed area may as little as a quarter of the total possible optical area giving a notional area of 0.03465 m^2 this was multiplied by the cosine of the angle from the lantern to the worker and divided by the distance squared to give the solid angle. It was found that the solid angle was less than 0.01 sr till the worker was within 1.52 m of the lantern at an angle of 48° . The radiance of the lamp was used directly in the calculations as when the lantern was open the worker was close to the source.

Dose Assessment – Blue Light Hazard

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Table 10 below gives the results of the calculations.

Table 10 – Blue light hazard dose calculation results

Lamp Wattage	100w	140w	150w	210w	250w	315w
Overall Dose [$\text{Jm}^{-2}\text{sr}^{-1}$] per operation	7554	9254	10337	23407	19524	33654
Max Operations for Limit $1,000,000 \text{ Jm}^{-2}\text{sr}^{-1}$	132	108	97	43	51	30

Photobiological Risks Associated with Hot Changing Metal Halide Lamps

There are a number of risks associated with hot lamp changing lamps in general. These include:

- **Thermal Risks:** the outer of most HID lamps operates at high temperature and may easily cause burns;
- **Mechanical Risks:** handling hot lamps may cause thermal stresses in the outer glass that may shatter, and the flying broken glass may then cause injuries; and
- **Electrical Risks:** if the lamp outer breaks then support wires inside the lamp become exposed, these wires are connected to the supply voltage and so may pose a serious hazard. To make matters worse it is possible that if the arc in the lamp is extinguished that the lamp ignitor may try to restart the lamp, sending pulses of several kilo volts to the lamp.

Note: there are ways of mitigating the above risks, for example the electrical risks could be reduced by ensuring that the luminaire is isolated before it is opened.

To these risks must be added the risk of damage to the eyes of the operator due to optical radiation. There are two principal risks:

- **Cataractogenesis:** damage to the lens of the eye due to radiation in the range 315 - 400nm this is often described as the UV-A hazard; and
- **Photoreinitis:** damage to the retina of the eye due to radiation in the range 300 - 700nm this is often described as the blue light hazard.

To ensure the safety of workers there is legislation in place that gives exposure limits for radiation associated with both risks. The law associated with the control of optical radiation starts with the European Directive 2006/25/EC; this has been implemented into UK Law as statutory instrument 2010 No. 1140 *The Control of Artificial Optical Radiation at Work Regulations*.

The limits for exposure to optical radiation are based upon the radiant exposure, or dose, of radiation received. Thus, to assess any potential risk it is necessary to know both how much radiation is present and the time for which a worker may be exposed. To assess the risks involved in hot lamp changing the radiation output of a series of lamps and luminaires was measured and the process of lamp changing observed. From this information it was possible to calculate on a second by second basis how much radiation a worker would receive, it was thus possible to assess how many hot lamp changes it would take for a worker to receive the maximum permitted dose for any

given 8 hour period. The table below shows the results for the six types of metal halide lamps that were tested.

Table 11 – Number of lamp changes per wattage per 8 hour shift

	Lamp Type (Metal Halide)					
	100W	140W	150W	210W	250W	315W
540	369	410	129	247	119	
Blue Light	132	108	97	42	51	30
Number of hot lamp changes for the maximum dose to be reached						

Green in the above table indicates that it is unlikely that any given worker will change that number of lamps in a given 8 hour period. Yellow in the above table indicates that it is possible that a worker may change that number of lamps in any given 8 hour period. Red in the above table indicates that it is likely that a worker will change that number of lamps in any given 8 hour period and therefore potentially exceed the maximum permitted dose. The photobiological risks may be reduced significantly if the lamp is turned off before the lantern is opened.

6 A3 HINDHEAD & A27 SOUTHWICK TUNNEL VISIT SUMMARY

Site visits to observe tunnel maintenance activities were undertaken on two separate occasions as follows:

- A3 Hindhead Tunnel – 20th February 2018; and
- A27 Southwick Tunnel 5th December 2019.

A3 Hindhead Tunnel

The A3 Hindhead tunnel visit was attended by Paul Batchelor and Hiren Patel of WSP with tunnel maintenance activities being observed between the hours of 23:00 and 03:00.

The types of maintenance activities being undertaken were as follows:

- VMS and lane drop matrix sign routing inspections (at height);
- Fan replacement at the southern end of the tunnel (at height); and
- Electrical panel inspections (ground level).

All activities were observed in the south bound bore.

Unfortunately, no tunnel lighting maintenance work was being undertaken directly on or in the vicinity of the luminaires during this closure.



Image 2 & 3- Maintenance work to VMS and replacement fan

It was noted that full operational and boost (live traffic) lighting was not in use on the evening of the works. Due to the nature of the activities being undertaken, none of the operatives working at height were in direct view of the tunnel lighting itself. When activities required operatives to be in proximity to tunnel lighting units, their backs were generally turned to the tunnel lighting and when ascending to the infrastructure, focus was always on the piece of equipment to which they were attending.

As a result, the data captured was not suitable for assessment purposes but enabled the survey team to get a better understanding of the activities being undertaken, how they are carried out in a controlled safe manner and how tunnel lighting units are or are not interacted with.

A27 Southwick Tunnel

The A27 Southwick tunnel visit was attended by Paul Batchelor and Hiren Patel of WSP; and Professor Peter Raynham of UCL, with tunnel maintenance activities being observed between the hours of 22:30 and 03:00.

The types of maintenance activities being undertaken were as follows:

- Principal inspection of roof mounted tunnel lighting (at height);
- Fan inspection and test (at height);
- Electrical panel inspections (ground level); and
- Photometric survey undertaken by TRT Lighting (not observed).

All activities were observed in the east bound bore.

A full Principal Inspection of the tunnel lighting system was being conducted during the course of the closure and the full activity and process was able to be observed and recorded.



Image 4 & 5- Tunnel lighting Principal Inspection activity

Both stills and video images were taken of the operatives whilst working in proximity, inspecting the luminaires, which were later analysed by Professor Peter Raynham to determine the duration of potential exposure to AOR whilst in the vicinity of the luminaire. The methodology and results of the analysis are outlined in section 7.

The lighting installation is consisting of the following light sources:

- Twin T8 36 Watt PL (Permanently on and burnt to destruction, approximately 40,000 hours)
- High Pressure Sodium lamped luminaires with a mix of 250 and 400 Watt lamps (located the length of the tunnel and used as part of the boost lighting system for the portals and daytime running levels of illumination).

The approximate layout of the tunnel is as indicated in image 6 below.

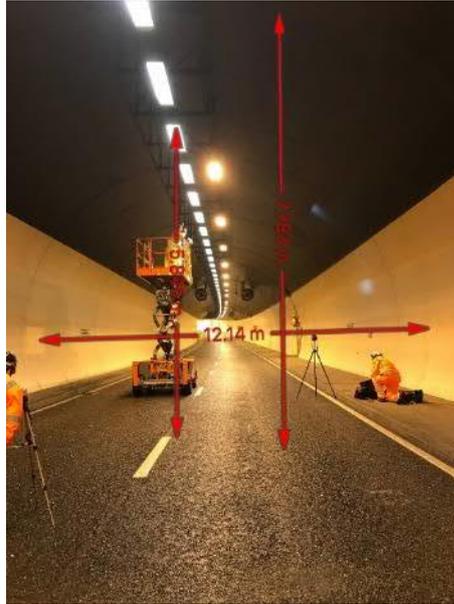


Image 6 - Tunnel dimensions as measured on site

General Observations

The following general observations were noted in relation to the Principal Inspection activity:

- Ascending to the centrally mounted luminaires was only undertaken once in each bore. Once inspection height had been reached, platform stayed at this height throughout the length of the bore, with occasional minor adjustments to height.
- Only one of the operatives was inspecting the luminaires, cabling and mounting structure. The second operative was in control of operating the platform, although was on occasions observed to be looking in the general direction of the tunnel lighting.
- In general, the main inspectors eyeline was above the light source level of the luminaire, as indicated in image 7, but would on occasions be required to be below the light source level to inspect certain aspects of the installation, as indicated by image 8.

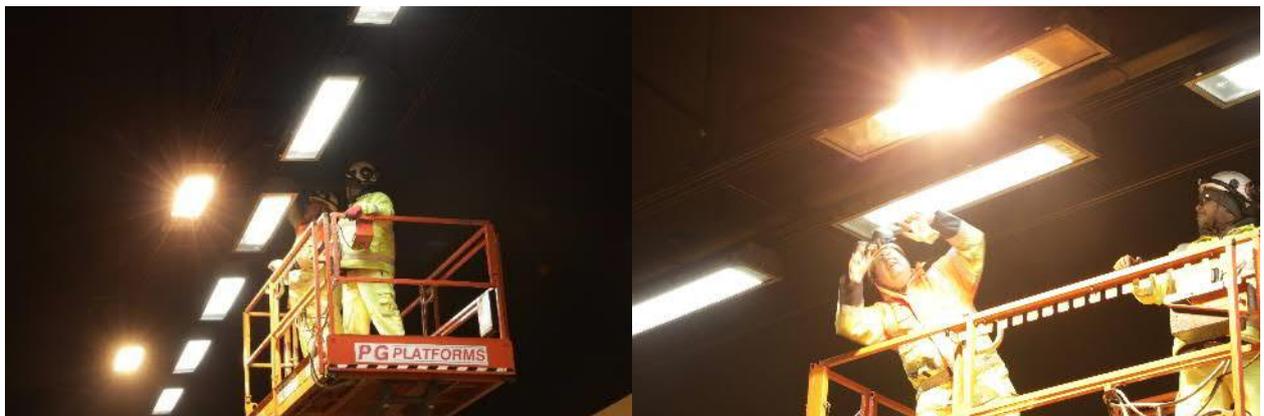


Image 7 & 8 - Tunnel dimensions as measured on site

7 ESTIMATION OF AN OPERATIVES EXPOSURE TO OPTICAL RADIATION WHEN UNDERTAKING A PRINCIPAL INSPECTION IN A TUNNEL

In order to assess how much optical radiation a worker might receive when working in the proximity to a tunnel light fitting, it is necessary to both know how much radiation is generated by the lamp and how long the worker is exposed to its radiation and at what distance. To assess amount of time a worker spends at a given distance from the lamp the methodology outlined in section 5 of this report was applied to the footage captured at A27 Southwick tunnel.

For the purposes of this part of the report data associated with an LED lamped tunnel fitting was utilised for consideration within the overall assessment. Although the light sources observed in both Hindhead and Southwick were a combination of Fluorescent and High Pressure Sodium, the future of tunnel lighting technology is rapidly shifting to LED, therefore deemed to be more future ready in terms of this assessment.

Signify provided a sample Flow Star LED tunnel fitting (BGB301 30K 740 DTS) and associated photometric data, which was subsequently tested by LIA laboratory to verify colorimetry and photometric measurements. Refer to Appendix B for LIA test laboratory reports.



Image 9 – Signify Flow Star LED tunnel luminaire

The Flow-Star luminaire is a di-symmetric road lantern distribution, see polar (Figure 3) and conical curves (Figure 4) below. Thus an analysis of what happens in the quadrant 0 to 90° is sufficient as all other quadrants will be the same by symmetry.

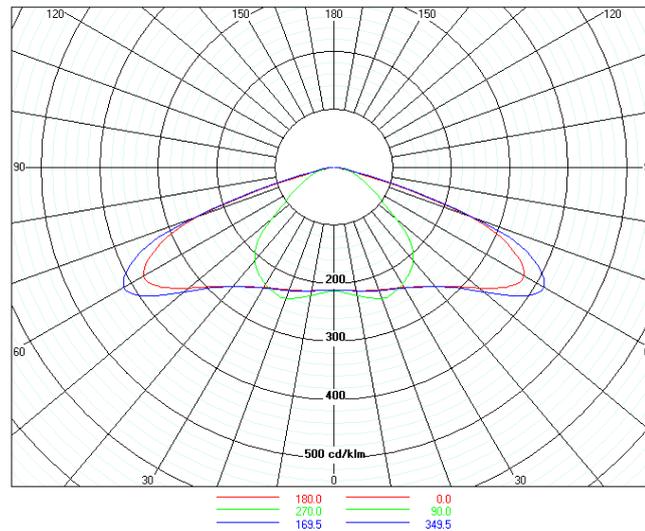


Figure 3 – Signify Flow Star polar curve diagram

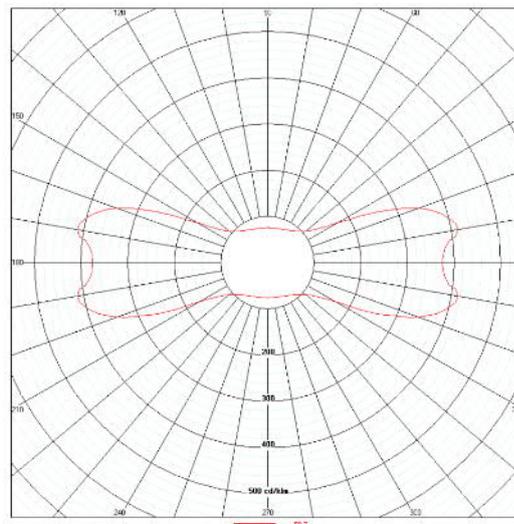


Figure 4 – Signify Flow Star conical curve diagram

It would be normal to arrange the luminaires so that 0 - 180° plane is aligned with the axis of the tunnel.

In the observed tunnel, the inspector was looking from the side of the luminaires, the viewing point was mostly from points at the same level as the luminaire, and above, on a few occasions the inspector's eye was slightly below the luminaire. Appendix C contains a series of 60 images, taken at second intervals from a short video of the inspector working. The images show that inspector was only below the luminaires for 6 of the images, i.e. about 10% of the time and even then, his eyes were only just below the luminaires.

Given the inspector's height and location at the side of the lanterns the view of the lanterns was from a gamma angle close to 90° in the 90° c-plane.

The luminance of a Flow Star luminaire (based on the data proved in file *BGB301 30K 740 DTS.LDT*) was calculated and is presented in table 12 below.

Table 12 – Number of lamp changes per wattage per 8 hour shift

Luminance [cdm ⁻²]		C Planes						
		0	15	30	45	60	75	90
Gamma angles	60	18092	18978	7960	4596	3892	3642	3605
	65	13733	14075	4137	2911	2460	2291	2279
	70	8096	7199	2465	1757	1463	1371	1370
	75	1794	1839	1080	849	779	735	735
	80	197	297	239	224	267	255	254
	85	28	33	26	18	26	17	18

In document ‘*Assessment of personal exposures to non-laser optical radiation in entertainment*’ by John O’Hagan and Marina Khazova they reference (p20) the ICNIRP luminance limit which states that it is not necessary to carry out a full assessment of retinal hazards for white light sources with a luminance below 10,000 cdm⁻².

The inspector was looking at the luminaires from the side at high angles thus gamma of at least 75° and C planes in the range 60° to 90°. This area is shaded light green in table 12. It is clear that the inspection that was observed there was no potential hazard to the inspector.

From certain directions of view the light source may prove to be hazardous, however, it is not likely that a maintenance operative in a tunnel would look at the luminaires from these lower angles for any length of time as glare from the luminaire will be make any tasks hard to see and viewing uncomfortable. The natural reaction of a human to light sources of high intensities and brightness, is to avert its gaze or close its eyes. It is highly unlikely that an operative would be able to intentionally maintain visual contact with such light sources by overriding the eye and brains involuntary and natural reaction to prevent damage.

8 SUMMARY / CONCLUSIONS

As can be seen from the collated data associated with WP1000 and the finalised version of the metal halide Ready Reckoner (WP3000), there is a cumulative risk to Highways England workforce over a prolonged period of time and exposure from the photobiological effects of such lamps. This risk can be effectively mitigated by ensuring that, where practicable, no 'hot change' operations are undertaken and that the luminaire and associated lamp are isolated prior to and during the lamp change operation, defined as from the operative ascending from carriageway level to descending back to carriageway level.

Protective eyewear with appropriate UV filters should be issued and worn only as a last resort where all other means of undertaking a lamp change without isolating the luminaire have been exhausted. It should be noted that eye protection forms part of the basic requirements of PPE for all operatives undertaking any form of onsite work on behalf of Highways England.

The Ready Reckoner should be utilised as part of regular toolbox talks to ensure that all risks associated with such light sources have been identified and understood and that the recommended number of safe changes that can be carried out within an eight-hour shift are not exceeded.

It should also be noted that the RG (Risk Group) rating was not present on the packaging or the actual lamps themselves of any of the lamps utilised for the testing associated with WP1000. The Health and Safety at Work Act 1974 (HSWA) Section 6 Part 6.1 Items C states 'to take such steps as are necessary to secure that persons supplied by that person with the article are provided with adequate information about the use for which the article is designed or has been tested and about any conditions necessary to ensure that it will be safe and without risks to health at all such times as are mentioned in paragraph (a) above and when it is being dismantled or disposed of'. This item places a direct obligation on manufacturers to provide information pertaining to their products within the literature associated with the product. As previously stated, none was present with those provided for testing and is unlikely to be provided for those that are sold wholesale. Such information would have to be sought from the direct from the manufacturer or other information sources such as product related websites. Therefore, it is likely that not all manufacturers are meeting their obligations in accordance with the HSWA in respect to the provision of adequate health and safety information associated with Metal Halide light sources. It should be noted that GE does make reference to UVC filters on both lamp and packaging associated with Metal Halide light sources.

As previously stated, the hazards associated with metal halide lamps in the form of photobiological effects are significantly reduced and effectively mitigated should the lamp remain isolated during the lamp change or inspection operation.

The Task has raised a number of questions with respect to other highway maintenance operations where operatives may be exposed to sources of optical radiation as follows:

1. The Task has only related to metal halide light sources and the industry and Highways Authority are now seeing the introduction of LED technologies which may carry a different risk.
2. Tunnel maintenance has been identified as an area where maintenance operatives are required to work at height adjacent to the operation tunnel lighting fixtures when carrying out maintenance checks on other roof mounted equipment as well as the luminaires. In these cases, the lights remain operational and the operatives are in close proximity to them for the duration of their shifts.



Based upon the findings of this Task it is recommended that the above aspects are considered and investigated, a consideration paper has been submitted.

Appendix A

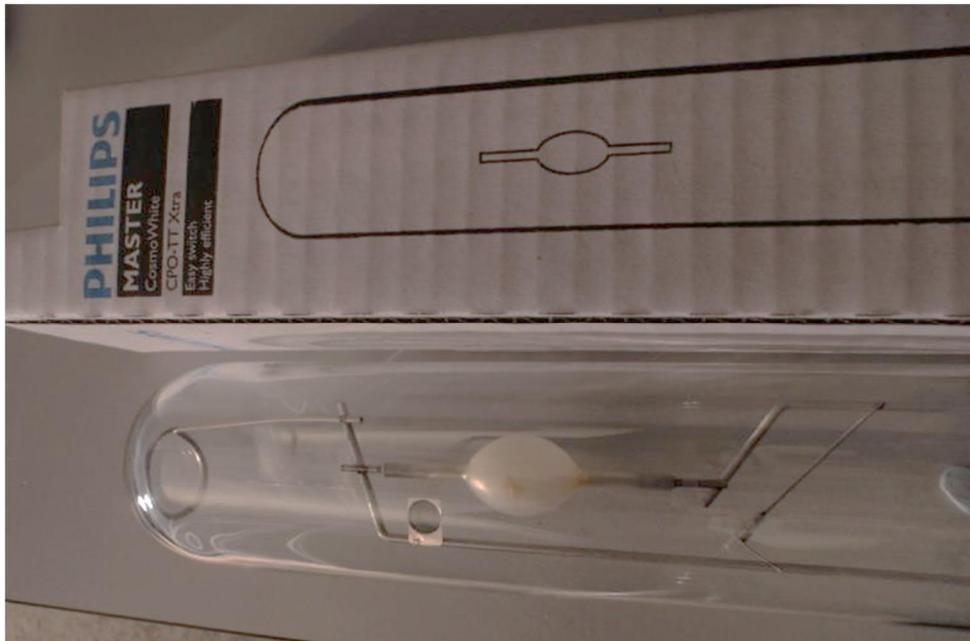
LIST OF LAMPS

List of lamps

ID	Manufacturer	Model	wattage, W	UV label	
1	GE	ConstantColor CMH StreetWise	100	UVC	CMH100/TT/UVC/730/E 40
2	GE	ConstantColor CMH StreetWise	100	UVC	CMH100/TT/UVC/730/E 40
3	GE	ConstantColor CMH StreetWise	100	UVC	CMH100/TT/UVC/730/E 40
4	GE	ConstantColor CMH StreetWise	150	UVC	CMH150/TT/UVC/730/E 40
5	GE	ConstantColor CMH StreetWise	150	UVC	CMH150/TT/UVC/730/E 40
6	GE	ConstantColor CMH StreetWise	150	UVC	CMH150/TT/UVC/730/E 40
7	GE	ConstantColor CMH StreetWise	100	UVC	CMH100/TT/UVC/730/E 40
8	GE	ConstantColor CMH StreetWise	100	UVC	CMH100/TT/UVC/730/E 40
9	GE	ConstantColor CMH StreetWise	150	UVC	CMH150/TT/UVC/730/E 40
10	GE	ConstantColor CMH StreetWise	150	UVC	CMH150/TT/UVC/730/E 40
11	Philips	Master SON-T PIA Plus	150		1922295XX



ID	Manufacturer	Model	wattage, W	UV label
12	Philips	Master CosmoWhite CPO-TT Xtra	210	210W/942 E40
13	Philips	Master CosmoWhite CPO-TT Xtra	210	210W/942 E40
14	Philips	Master CosmoWhite CPO-TT Xtra	210	210W/942 E40
15	Philips	Master CosmoWhite CPO-TT Xtra	210	210W/942 E40
16	Philips	Master CosmoWhite CPO-TT Xtra	210	210W/942 E40



17	Philips	Master CityWhite CDO-TT Plus	250	250W 830 E40
18	Philips	Master CityWhite CDO-TT Plus	250	250W 830 E40
19	Philips	Master CityWhite CDO-TT Plus	250	250W 830 E40
20	Philips	Master CityWhite CDO-TT Plus	250	250W 830 E40
21	Philips	Master CityWhite CDO-TT Plus	250	250W 830 E40

ID	Manufacturer	Model	wattage, W	UV label	
<p>The photograph shows two types of compact fluorescent lamps (CFLs). The top lamp is a Philips Master CityWhite CDO-TT Plus, which is a warm white light bulb with a blue and white label. The bottom lamp is an Osram Powerball HCI-TT, which is a clear glass bulb with a yellowish internal coating and a metal base.</p>					
22	Osram	Powerball HCI-TT	100	UV filter, >300C	100W/830 WDL
23	Osram	Powerball HCI-TT	100	UV filter, >300C	100W/830 WDL
24	Osram	Powerball HCI-TT	100	UV filter, >300C	100W/830 WDL
25	Osram	Powerball HCI-TT	150	UV filter, >300C	150W/830 WDL
26	Osram	Powerball HCI-TT	150	UV filter, >300C	150W/830 WDL
27	Osram	Powerball HCI-TT	150	UV filter, >300C	150W/830 WDL
28	Osram	Powerball HCI-TT	250	UV filter, >300C	250W/830 WDL
29	Osram	Powerball HCI-TT	250	UV filter, >300C	250W/830 WDL
30	Osram	Powerball HCI-TT	250	UV filter, >300C	250W/830 WDL

ID	Manufacturer	Model	wattage, W	UV label	
31	Philips	Master CityWhite CDO-TT Plus	100		100W/828 E40
32	Philips	Master CityWhite CDO-TT Plus	100		100W/828 E40
33	Philips	Master CityWhite CDO-TT Plus	100		100W/828 E40
34	Philips	Master CityWhite CDO-TT Plus	100		100W/828 E40
35	Philips	Master CityWhite CDO-TT Plus	100		100W/828 E40
36	Philips	Master CosmoWhite CPO-TT Xtra	140		140W/628 E40
37	Philips	Master CosmoWhite CPO-TT Xtra	140		140W/628 E40
38	Philips	Master CosmoWhite CPO-TT Xtra	140		140W/628 E40
39	Philips	Master CosmoWhite CPO-TT Xtra	140		140W/628 E40
40	Philips	Master CosmoWhite CPO-TT Xtra	140		140W/628 E40

ID	Manufacturer	Model	wattage, W	UV label	
41	Philips	Master CityWhite CDO-TT Plus	150		150W/828 E40
42	Philips	Master CityWhite CDO-TT Plus	150		150W/828 E40
43	Philips	Master CityWhite CDO-TT Plus	150		150W/828 E40
44	Philips	Master CityWhite CDO-TT Plus	150		150W/828 E40
45	Philips	Master CityWhite CDO-TT Plus	150		150W/828 E40
46	Philips	Master CosmoWhite CPO-TT Xtra	315		315W/942 E40
47	Philips	Master CosmoWhite CPO-TT Xtra	315		315W/942 E40
48	Philips	Master CosmoWhite CPO-TT Xtra	315		315W/942 E40

Appendix B

LIA LABORATORY REPORTS

T e s t R e p o r t

Report No : L18167A
Client: : WSP Group
Unit 9
The Chase
John Tate Road
Foxholes Business Park
Hertford
SG13 7NN
Description : Flow Star BGB300 Luminaire LED Module
Manufacturer : Philips
Type/Models : BGB301 30K/NW SH | DTS D9 FU MDD
Test Specification : BS EN 13032-4:2015 Clause 4.5.3
Dates of Testing : 26/03/2019
Conclusion : Refer to body of report
Date of Issue : 16/04/2019
Date of Expiry : 15/04/2024

Tested by: **D.CHAMBERS**
Position: Laboratory Engineer



Approved by: **N.GABIR**
Position: Technical Lead -
Photometry



INTRODUCTION

WSP Group have supplied the product identified in Table 1. for evaluation in accordance with the specification detailed on page one of this report.

PRODUCT DETAILS

Table 1. *Product Details*

Product Description	Flow Star BGB300 Luminaire LED Module
Model No.	BGB301 30K/NW SH DTS D9 FU MDD
Number of Samples	One
Date of Receipt	27/03/2019
Condition on Receipt	Good
Nominal Dimensions	L-450,W-420,H-69
Product Supply Requirement	230-240V AC 50/60Hz
Lamp Type and Power	LED,249W

Continued on following page

TEST SETUP

Table 2. Test Procedure and Equipment Used

Test Standard	BS EN 13032-4:2015 Clause 4.5.3
Equipment Used	2.0m diameter 4 π sphere-spectroradiometer (462)
Standard Lamp Used	SCL-600-F149
Standard Lamp Traceability	NIST-RF1476
Power Supply	KIKUSUI PCR 1000M AC Power Supply (262)
Power Measurement	N4L single phase power analyser (394)
Temperature Measurement	Thermometer (142)

Table 3. Lamp Conditioning

Sample ID	L18167
Lamp ageing Time (Mins)	0
Stabilisation Time (Mins)	60
Total Operating Time (Mins)	82
Support Structure	Suspended
Orientation in Test	Lamp Cap Horizontal

Continued on following page

RESULTS

Table 4. Colorimetry Results

Sample ID		L18167
COLORIMETRY	x coordinate	0.3770
	y coordinate	0.3782
	u coordinate	0.2222
	v coordinate	0.3345
	u' coordinate	0.2222
	v' coordinate	0.5017
	Dominant Wavelength (nm)	577.7
	Purity (%)	26.7
	Colour Temperature (K)	4103
	Ra (%)	75.4
	R1 (%)	72.4
	R2 (%)	80.9
	R3 (%)	87.7
	R4 (%)	74.9
	R5 (%)	72.6
	R6 (%)	73.2
	R7 (%)	83.1
	R8 (%)	58.4
	R9 (%)	-13.8
	R10 (%)	54.9
	R11 (%)	71.4
	R12 (%)	51.4
	R13 (%)	73.6
R14 (%)	93.0	
Lumen Output (lm)	26250	
Efficacy (lm/W)	100	
OPERATING CONDITIONS	Ambient Temperature (°C)	24.8
	Voltage (V)	239.1
	Current (mA)	1128.80
	Power (W)	262.49
	Power Factor	0.97

Continued on following page

▼ Chromaticity

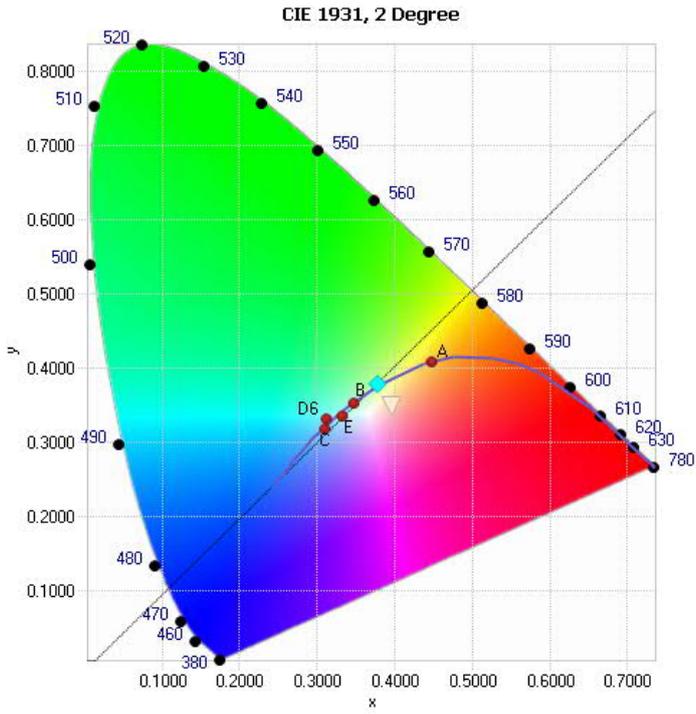


Figure 1. CIE 1931 diagram for sample L18167

▼ SPECTRAL FLUX GRAPH:

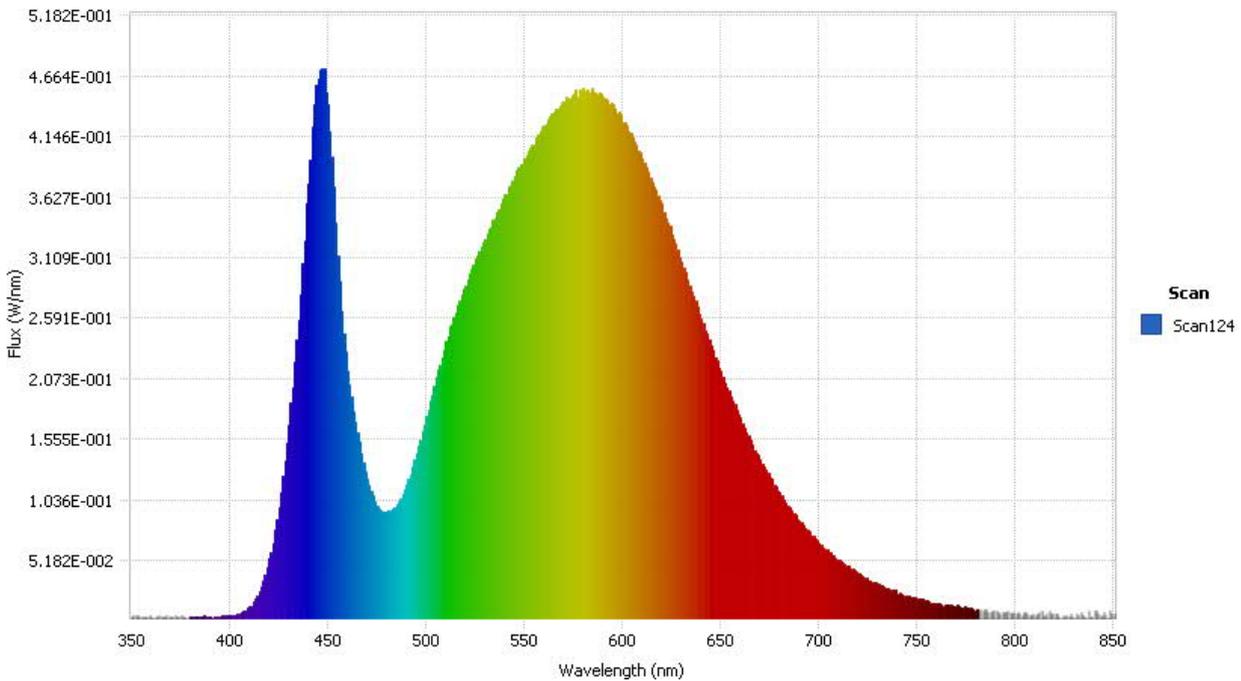


Figure 2. Total spectral flux for sample L18167

Continued on following page

DEVIATION(S) FROM TEST STANDARD

No reported deviations from test standard.

MEASUREMENT UNCERTAINTY

The following expanded uncertainties apply to the measurements shown in the results;

Chromaticity x coordinate (x): $\pm 6.83\%$
Chromaticity y coordinate (y): $\pm 6.83\%$
Chromaticity u' coordinate (u'): $\pm 6.82\%$
Chromaticity v' coordinate (v'): $\pm 6.82\%$
Colour Temperature (K): $\pm 9.00\%$
Colour Rendering Index (%): $\pm 8.31\%$
Luminous Flux (lm): $\pm 11.34\%$

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

Continued on following page

SCHEMATIC DIAGRAM & IDENTIFICATION OF PHOTOMETRIC CENTRE

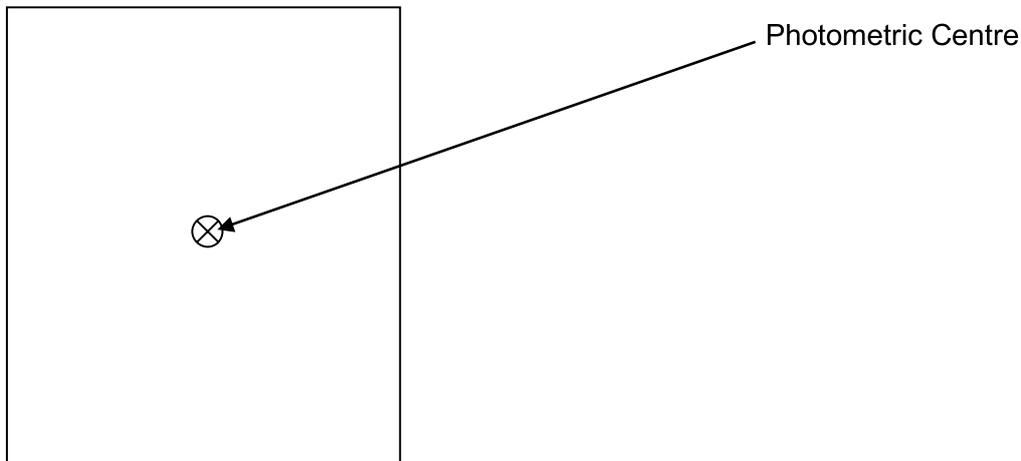


Figure 3. *Product dimensions and photometric centre*

ILLUSTRATION



Figure 4. *Product image*

End

T e s t R e p o r t

Report No : L18167B

Client: : WSP Group
Unit 9
The Chase
John Tate Road
Foxholes Business Park
Hertford
SG13 7NN

Description : Flow Star BGB300 Luminaire LED Module

Manufacturer : Philips

Type/Model : BGB301 30K/NW SH | DTS D9 FU MDD

Test Specification : BS EN 13032-4:2015 Clause 4.5.5

Date Testing Started : 21/03/2019

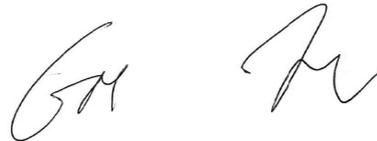
Conclusion : Refer to body of report

Date of Issue : 16/04/2019

Date of Expiry : 15/04/2024

Tested by: **G.JOHN**

Position: Technical Manager-
Photometry



Approved by: **N.GABIR**

Position: Technical Lead -
Photometry



INTRODUCTION

WSP Group have supplied the product identified in page one for determination of light output distribution.

PRODUCT DETAILS

Table 1. Test Sample Details

Product Description	Flow Star BGB300 Luminaire LED Module
Model No.	BGB301 30K/NW SH DTS D9 FU MDD
Number of Samples	One
Condition on Receipt	Good
Nominal Dimensions (mm)	L-450,W-420,H-69
Product Supply Requirement	230-240V AC 50/60Hz
Lamp Type and Power	LED,249W
Sampling Method: Test samples selected and supplied by client, no sampling method specified by client.	

Continued on following page

PROCEDURE

Table 2. Test Procedure and Equipment Used for Photometric Measurements

Test Standard	BS EN 13032-4:2015 Clause 4.5.5
Equipment Used	Radiant PM1200 Near field goniophotometer (459)
Calibration Spectrometer Used	JETI Specbos 1211UV
Calibration Spectrometer Traceability	Calibration certificate number 3740 WK-L Calibrated 19-04-2018
Scan Setup	Elevation: 0°- 90°, step size: 3° Azimuth: 0°- 360°, step size: Various
Power Supply	KIKUSUI PCR 1000M AC Power Supply (262)
Power Measurement	N4L Single phase power analyser (394)
Temperature Measurement	Testo 925 Handheld Thermometer (142)
Airflow Measurement	Testo 405i Thermal Anemometer (419)

Table 3. Lamp Conditioning and Setup

Lamp ageing Time (Mins)	0
Stabilisation Time (Mins)	60
Total Operating Time (Mins)	135
Support Structure	NFMS Turning Frame

Continued on following page

TEST RESULTS

Table 4. Test Environmental and Operating Conditions

Ambient Temperature (°C)	25.1
Voltage (V)	240.1
Current (mA)	1125.80
Power (W)	262.51
Power Factor	0.97

Table 5. Beam Angle Results

Luminous Flux of Luminaire (lm)	Luminous Efficacy (lm/W)
26250	100

Continued on following page

Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
0	0	84,497.00	9	330	82,265.00	15	315	84,623.00	21	200	90,548.00
3	0	84,770.00	12	0	82,336.00	15	337.5	82,912.00	21	220	93,023.00
3	51.43	85,484.00	12	25.71	84,308.00	18	0	83,240.00	21	240	95,677.00
3	102.86	86,324.00	12	51.43	86,917.00	18	21.18	85,831.00	21	260	95,139.00
3	154.29	85,260.00	12	77.14	86,419.00	18	42.35	88,878.00	21	280	95,537.00
3	205.71	84,657.00	12	102.86	89,817.00	18	63.53	91,461.00	21	300	93,682.00
3	257.14	84,665.00	12	128.57	89,944.00	18	84.71	93,434.00	21	320	88,150.00
3	308.57	84,077.00	12	154.29	88,336.00	18	105.88	93,532.00	21	340	84,239.00
6	0	82,535.00	12	180	86,978.00	18	127.06	93,499.00	24	0	84,137.00
6	36	85,327.00	12	205.71	87,160.00	18	148.24	91,892.00	24	18	86,910.00
6	72	86,496.00	12	231.43	86,799.00	18	169.41	89,958.00	24	36	91,848.00
6	108	86,716.00	12	257.14	87,405.00	18	190.59	87,920.00	24	54	94,702.00
6	144	86,204.00	12	282.86	86,505.00	18	211.76	89,401.00	24	72	95,266.00
6	180	85,713.00	12	308.57	84,258.00	18	232.94	92,025.00	24	90	95,987.00
6	216	84,715.00	12	334.29	82,188.00	18	254.12	91,658.00	24	108	97,381.00
6	252	84,948.00	15	0	82,409.00	18	275.29	93,638.00	24	126	98,509.00
6	288	84,947.00	15	22.5	84,855.00	18	296.47	89,000.00	24	144	98,656.00
6	324	84,666.00	15	45	87,472.00	18	317.65	86,674.00	24	162	95,154.30
9	0	82,343.00	15	67.5	90,241.00	18	338.82	83,841.00	24	180	91,890.00
9	30	83,765.00	15	90	91,917.00	21	0	84,042.00	24	198	91,384.00
9	60	87,675.00	15	112.5	92,158.00	21	20	86,972.00	24	216	95,204.00
9	90	87,446.00	15	135	90,927.00	21	40	90,663.00	24	234	98,617.00
9	120	88,527.00	15	157.5	88,871.00	21	60	93,623.00	24	252	99,911.00
9	150	86,906.00	15	180	87,544.00	21	80	94,976.00	24	270	98,160.00
9	180	86,165.00	15	202.5	87,054.00	21	100	95,502.00	24	288	97,847.00
9	210	85,737.00	15	225	88,281.00	21	120	96,147.00	24	306	93,590.00
9	240	85,815.00	15	247.5	90,009.00	21	140	94,689.00	24	324	89,230.00
9	270	85,375.00	15	270	89,658.00	21	160	93,430.00	24	342	85,300.00
9	300	85,018.00	15	292.5	87,604.00	21	180	91,724.00	27	0	84,532.00

Continued on following page

This page is to be read in conjunction with the first page of this report

Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
27	17.14	88,192.00	30	147.27	102,288.00	33	250.43	92,594.30	36	344.35	85,377.00
27	34.29	93,065.00	30	163.64	96,484.00	33	266.09	91,817.00	39	0	84,803.00
27	51.43	96,196.00	30	180	93,755.00	33	281.74	96,689.00	39	15	88,243.00
27	68.57	93,930.00	30	196.36	93,456.00	33	297.39	100,955.00	39	30	92,494.00
27	85.71	93,458.00	30	212.73	98,698.00	33	313.04	102,295.00	39	45	90,578.00
27	102.86	95,058.00	30	229.09	102,687.00	33	328.7	94,216.00	39	60	82,408.00
27	120	99,864.00	30	245.45	96,645.00	33	344.35	84,639.00	39	75	78,709.00
27	137.14	102,300.00	30	261.82	95,421.00	36	0	84,044.00	39	90	78,770.00
27	154.29	97,962.00	30	278.18	92,189.00	36	15.65	86,918.00	39	105	81,062.00
27	171.43	94,408.00	30	294.55	101,268.00	36	31.3	92,420.00	39	120	85,652.00
27	188.57	92,957.00	30	310.91	99,221.00	36	46.96	92,970.00	39	135	100,195.00
27	205.71	94,595.00	30	327.27	93,043.00	36	62.61	87,251.00	39	150	105,514.00
27	222.86	99,999.00	30	343.64	86,305.00	36	78.26	84,076.00	39	165	99,302.00
27	240	103,489.00	33	0	84,748.00	36	93.91	84,881.00	39	180	96,314.00
27	257.14	96,981.00	33	15.65	86,005.00	36	109.57	87,914.00	39	195	101,666.00
27	274.29	97,244.00	33	31.3	94,808.00	36	125.22	96,139.00	39	210	109,527.00
27	291.43	97,099.00	33	46.96	95,212.00	36	140.87	103,102.00	39	225	106,401.00
27	308.57	98,412.00	33	62.61	88,528.00	36	156.52	100,008.00	39	240	98,039.00
27	325.71	92,084.00	33	78.26	88,965.00	36	172.17	94,552.00	39	255	85,096.00
27	342.86	86,187.00	33	93.91	86,942.00	36	187.83	93,933.00	39	270	86,926.00
30	0	84,722.00	33	109.57	90,205.00	36	203.48	98,801.00	39	285	85,554.00
30	16.36	89,205.00	33	125.22	96,587.00	36	219.13	105,057.00	39	300	97,484.00
30	32.73	95,340.00	33	140.87	101,918.00	36	234.78	105,368.00	39	315	102,651.00
30	49.09	97,430.00	33	156.52	98,046.00	36	250.43	91,487.00	39	330	96,337.00
30	65.45	94,275.00	33	172.17	94,581.00	36	266.09	86,202.00	39	345	87,633.00
30	81.82	91,862.00	33	187.83	92,720.00	36	281.74	87,686.00	42	0	113,607.00
30	98.18	93,340.00	33	203.48	95,905.00	36	297.39	93,732.00	42	14.4	114,261.00
30	114.55	97,744.00	33	219.13	103,149.00	36	313.04	103,653.00	42	28.8	100,768.00
30	130.91	103,361.00	33	234.78	102,056.00	36	328.7	92,824.00	42	43.2	94,423.00

Continued on following page

This page is to be read in conjunction with the first page of this report

Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
42	57.6	85,597.00	45	110.77	85,915.00	48	152.31	177,536.00	51	186.67	214,797.00
42	72	85,037.00	45	124.62	96,818.00	48	166.15	174,567.00	51	200	245,669.00
42	86.4	87,876.00	45	138.46	107,742.00	48	180	171,150.00	51	213.33	161,868.00
42	100.8	89,054.00	45	152.31	133,134.00	48	193.85	203,391.00	51	226.67	103,629.00
42	115.2	93,884.00	45	166.15	138,233.00	48	207.69	196,135.00	51	240	77,142.00
42	129.6	104,763.00	45	180	142,661.00	48	221.54	129,456.00	51	253.33	61,772.00
42	144	112,680.00	45	193.85	143,180.00	48	235.38	97,553.00	51	266.67	56,626.00
42	158.4	123,488.00	45	207.69	138,146.00	48	249.23	82,867.00	51	280	57,308.00
42	172.8	110,380.00	45	221.54	106,139.00	48	263.08	75,539.00	51	293.33	70,270.00
42	187.2	118,886.00	45	235.38	87,136.00	48	276.92	73,032.00	51	306.67	85,145.00
42	201.6	128,682.00	45	249.23	75,055.00	48	290.77	78,966.00	51	320	118,823.00
42	216	125,622.00	45	263.08	79,583.00	48	304.62	93,952.00	51	333.33	188,560.00
42	230.4	104,759.00	45	276.92	80,526.00	48	318.46	125,609.00	51	346.67	193,738.00
42	244.8	93,929.00	45	290.77	81,336.00	48	332.31	172,347.00	54	0	208,514.00
42	259.2	92,431.00	45	304.62	83,988.00	48	346.15	163,579.00	54	13.33	209,609.00
42	273.6	93,241.00	45	318.46	96,482.00	51	0	174,673.00	54	26.67	169,975.00
42	288	94,684.00	45	332.31	115,401.00	51	13.33	176,234.00	54	40	103,178.00
42	302.4	97,441.00	45	346.15	102,858.00	51	26.67	166,173.00	54	53.33	71,628.00
42	316.8	104,237.00	48	0	128,280.00	51	40	113,335.00	54	66.67	61,355.00
42	331.2	101,575.00	48	13.85	130,008.00	51	53.33	88,468.00	54	80	53,263.00
42	345.6	99,062.00	48	27.69	103,733.00	51	66.67	77,640.00	54	93.33	50,459.00
45	0	122,297.00	48	41.54	112,928.00	51	80	65,122.00	54	106.67	55,432.00
45	13.85	123,323.00	48	55.38	91,602.00	51	93.33	63,787.00	54	120	70,459.00
45	27.69	111,599.00	48	69.23	82,573.00	51	106.67	72,492.00	54	133.33	96,230.00
45	41.54	90,076.00	48	83.08	72,219.00	51	120	85,810.00	54	146.67	162,212.00
45	55.38	82,813.00	48	96.92	73,674.00	51	133.33	107,360.00	54	160	258,332.00
45	69.23	78,140.00	48	110.77	82,728.00	51	146.67	159,678.00	54	173.33	240,045.00
45	83.08	76,121.00	48	124.62	94,982.00	51	160	217,376.00	54	186.67	269,361.00
45	96.92	81,529.00	48	138.46	128,178.00	51	173.33	210,419.00	54	200	272,206.00

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This page is to be read in conjunction with the first page of this report

Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
54	213.33	145,385.00	57	231.43	49,101.30	60	244.29	36,963.00	63	248.28	32,626.00
54	226.67	81,560.00	57	244.29	42,273.00	60	257.14	32,681.00	63	260.69	27786
54	240	59,314.00	57	257.14	40,662.00	60	270	34,222.00	63	273.1	27991
54	253.33	48,831.00	57	270	39,592.00	60	282.86	35,656.00	63	285.52	29,972.00
54	266.67	45,860.00	57	282.86	39,806.00	60	295.71	39,541.00	63	297.93	35,390.00
54	280	45,989.00	57	295.71	43,010.00	60	308.57	44,584.00	63	310.34	41,973.00
54	293.33	52,800.00	57	308.57	51,156.00	60	321.43	64,490.00	63	322.76	54,965.00
54	306.67	73,696.00	57	321.43	85,174.00	60	334.29	212,922.00	63	335.17	197,166.00
54	320	97,882.00	57	334.29	214,053.00	60	347.14	292,209.00	63	347.59	319,288.00
54	333.33	190,343.00	57	347.14	274,654.00	63	0	237,838.00	66	0	239,480.00
54	346.67	228,495.00	60	0	243,648.00	63	12.41	247,975.00	66	12.41	268,765.00
57	0	246,760.00	60	12.86	259,381.00	63	24.83	134,194.00	66	24.83	100,598.00
57	12.86	241,772.00	60	25.71	161,050.00	63	37.24	54,524.00	66	37.24	48,266.00
57	25.71	185,133.00	60	38.57	64,492.00	63	49.66	42,966.00	66	49.66	38,777.00
57	38.57	82,315.00	60	51.43	47,229.00	63	62.07	39,587.00	66	62.07	33,089.00
57	51.43	56,543.00	60	64.29	43,850.00	63	74.48	38,065.00	66	74.48	29,529.00
57	64.29	49,885.00	60	77.14	44,087.00	63	86.9	37,541.00	66	86.9	29,217.00
57	77.14	44,997.00	60	90	38,057.00	63	99.31	39,427.00	66	99.31	31,038.00
57	90	47,720.00	60	102.86	43,908.00	63	111.72	39,730.00	66	111.72	32,349.00
57	102.86	47,467.00	60	115.71	45,104.00	63	124.14	43,234.00	66	124.14	39,995.00
57	115.71	50,986.00	60	128.57	54,637.00	63	136.55	54,205.00	66	136.55	50,292.00
57	128.57	67,024.00	60	141.43	74,908.00	63	148.97	97,909.00	66	148.97	69,592.00
57	141.43	103,559.00	60	154.29	210,624.00	63	161.38	315,791.00	66	161.38	234,478.00
57	154.29	226,978.00	60	167.14	349,639.00	63	173.79	324,378.00	66	173.79	248,207.00
57	167.14	297,103.00	60	180	310,174.00	63	186.21	348,878.00	66	186.21	298,354.00
57	180	274,969.00	60	192.86	358,882.00	63	198.62	297,218.00	66	198.62	266,597.00
57	192.86	325,256.00	60	205.71	191,181.00	63	211.03	69,759.00	66	211.03	58,897.00
57	205.71	222,187.00	60	218.57	59,830.00	63	223.45	44,984.00	66	223.45	37,160.00
57	218.57	79,249.00	60	231.43	41,798.00	63	235.86	36,804.00	66	235.86	28673

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This page is to be read in conjunction with the first page of this report

Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
66	248.28	25711	69	248.28	20550	72	240	18320	75	228	18746
66	260.69	23210	69	260.69	21103	72	252	16867	75	240	17666
66	273.1	22149	69	273.1	19526	72	264	15620	75	252	15966
66	285.52	23601	69	285.52	21153	72	276	17680	75	264	17920
66	297.93	28187	69	297.93	24377	72	288	17511	75	276	15888
66	310.34	35,406	69	310.34	28438	72	300	22537	75	288	16218
66	322.76	45,450	69	322.76	39,399.00	72	312	25893	75	300	16846
66	335.17	157,340	69	335.17	99,059.00	72	324	33,507.00	75	312	18461
66	347.59	275,868	69	347.59	249,646.00	72	336	69,821.00	75	324	23547
69	0	194,513	72	0	170,585.00	72	348	190,047.00	75	336	31,628.00
69	12.41	198,543	72	12	164,821.00	75	0	65,271.00	75	348	43,885.00
69	24.83	83,415	72	24	66,025.00	75	12	70,589.00	78	0	81061
69	37.24	45,092	72	36	34,707.00	75	24	46,421.00	78	12	22294
69	49.66	33,002	72	48	28346	75	36	24020	78	24	28840
69	62.07	29354	72	60	28564	75	48	25409	78	36	17894
69	74.48	27583	72	72	25347	75	60	23154	78	48	17408
69	86.9	28776	72	84	25162	75	72	24680	78	60	19485
69	99.31	26448	72	96	23899	75	84	23692	78	72	27044
69	111.72	26321	72	108	24067	75	96	21945	78	84	19025
69	124.14	32,184.00	72	120	25786	75	108	23315	78	96	16677
69	136.55	42,461.00	72	132	32,142.00	75	120	27995	78	108	20004
69	148.97	66,918.00	72	144	44,681.00	75	132	31904	78	120	15950
69	161.38	197,830.00	72	156	89,467.00	75	144	34451	78	132	15124
69	173.79	246,256.00	72	168	170,685.00	75	156	46,909.00	78	144	19084
69	186.21	266,829.00	72	180	151,687.00	75	168	58,489.00	78	156	20156
69	198.62	168,068.00	72	192	187,806.00	75	180	59,157.00	78	168	28698
69	211.03	45,702.00	72	204	61,680.00	75	192	84,202.00	78	180	26119
69	223.45	30,680.00	72	216	31243	75	204	39247	78	192	10613
69	235.86	24803	72	228	20627	75	216	22892	78	204	31089

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Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)	Inclination	Azimuth	Luminance (Cd/m ²)
78	216	16301	81	204	3936	84	192	0	87	180	0
78	228	14553	81	216	6093	84	204	0	87	192	0
78	240	11584	81	228	4161	84	216	0	87	204	0
78	252	15412	81	240	15836	84	228	0	87	216	0
78	264	14543	81	252	11930	84	240	3073	87	228	0
78	276	16147	81	264	796	84	252	0	87	240	0
78	288	11183	81	276	1206	84	264	0	87	252	0
78	300	12557	81	288	10844	84	276	0	87	264	0
78	312	15577	81	300	14837	84	288	1412	87	276	0
78	324	18009	81	312	7996	84	300	3753	87	288	0
78	336	18089	81	324	14524	84	312	5318	87	300	0
78	348	29194	81	336	15333	84	324	1862	87	312	0
81	0	40178	81	348	10678	84	336	3601	87	324	0
81	12	5748	84	0	2922	84	348	3227	87	336	0
81	24	6680	84	12	2844	87	0	0	87	348	0
81	36	6434	84	24	1049	87	12	0	90	0	0
81	48	5247	84	36	123.2	87	24	0	90	12	0
81	60	4034	84	48	0	87	36	0	90	24	0
81	72	13750	84	60	1963	87	48	0	90	36	0
81	84	4358	84	72	0	87	60	0	90	48	0
81	96	1023	84	84	0	87	72	0	90	60	0
81	108	12287	84	96	0	87	84	0	90	72	0
81	120	17432	84	108	0	87	96	0	90	84	0
81	132	2620	84	120	1783	87	108	0	90	96	0
81	144	9007	84	132	0	87	120	0	90	108	0
81	156	8093	84	144	0	87	132	0	90	120	0
81	168	7955	84	156	0	87	144	0	90	132	0
81	180	1703	84	168	678	87	156	0	90	144	0
81	192	5219	84	180	11045	87	168	0	90	156	0

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Table 6. Luminance (cd/m²)

Inclination	Azimuth	Luminance (Cd/m ²)									
90	168	0									
90	180	0									
90	192	0									
90	204	0									
90	216	0									
90	228	0									
90	240	0									
90	252	0									
90	264	0									
90	276	0									
90	288	0									
90	300	0									
90	312	0									
90	324	0									
90	336	0									
90	348	0									

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DEVIATION(S) FROM TEST STANDARD

No reported deviations from test standard.

Continued on following page

IDENTIFICATION OF PHOTOMETRIC CENTRE

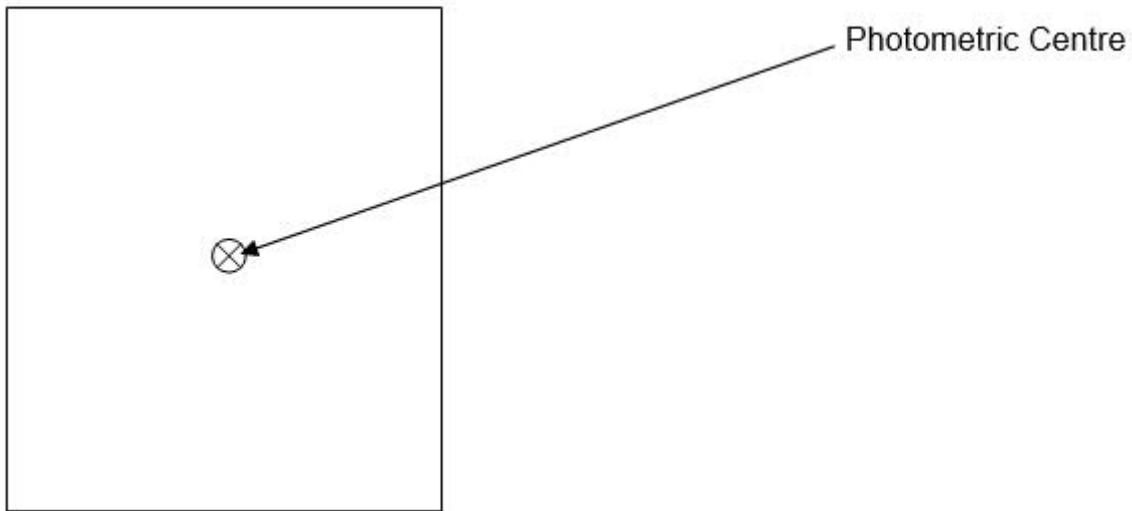


Figure 1. *Product photometric centre*

ILLUSTRATION



Figure 2. *Product image*

End

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Appendix C

VIDEO FOOTAGE STILL IMAGES



0.49 m



0.53 m



0.47 m



0.43 m



0.48 m



0.56 m



0.67 m



0.59 m



0.53 m



0.59 m



0.69 m



0.62 m



0.59 m



0.56 m



0.52 m



0.48 m



0.50 m



0.47 m



0.47 m



0.49 m



0.59 m



0.66 m



0.68 m



0.65 m



0.68 m



0.63 m



0.67 m



0.63 m



0.58 m



0.60 m



0.59 m



0.57 m



0.58 m



0.57 m





0.60 m



0.60 m



0.61 m



0.49 m



0.68 m



0.5 m



0.54 m



0.48 m



0.53 m



0.61 m

211

212



0.67 m



0.70 m



0.63 m



0.55 m



0.43 m



0.52 m



0.49 m



0.43 m



0.40 m



0.39 m



0.38 m



0.48 m



0.54 m



0.59 m



0.47 m



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