Institution: The University of Manchester

Unit of Assessment: 5 (Biological Sciences)

Title of case study: A new international lighting standard that meets our biological needs

Period when the underpinning research was undertaken: 2003 - 2014

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Robert Lucas	GSK Chair in Neuroscience	2003 - present
Timothy Brown	Professor Senior Lecturer Research Fellow Research Associate	2020 - present 2017 - 2020 2012 - 2017 2004 - 2012
Annette Allen	Research Fellow Research Associate	2017 - present 2011 - 2017
Helena Bailes	Research Associate	2006 - 2013

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Inappropriate light exposure can compromise health, wellbeing, and performance by disrupting biological rhythms and patterns of sleep. Determining the extent to which artificial light sources and architectural environments induce such 'non-image-forming' effects requires a suitable measure of light intensity. University of Manchester research led by Lucas has developed and validated a measure that predicts light's non-image-forming capacity. This has been standardised in an SI-anchored metric for light, which forms the basis of lighting design guidelines that specifically address non-image-forming effects, and has allowed lighting manufacturers and engineers to develop products and systems which, while maintaining illumination, avoid the disruptive effects of artificial light.

2. Underpinning research

Research at the University of Manchester (UoM) has established ways of measuring light that predict its effect on newly discovered receptors. Quite apart from allowing vision, light has diverse impacts on mammalian behaviour and physiology, including: setting the phase of circadian clocks; adjusting pupil size; regulating alertness; and altering hormone release. These diverse responses rely upon assessments of ambient light intensity rather than generation of visual images. Such 'non-image-forming' responses derive from a new sort of photoreceptor cell in the mammalian inner retina. In 2005 Lucas established that a protein found in these inner retinal photoreceptors called melanopsin (that is distantly related to the rod and cone opsins responsible for conventional vision), provides their light detection mechanism [1].

The realisation that non-image-forming responses originate with a distinct photoreceptor has led to the widespread appreciation that light in the 'blue' part of the spectrum (to which melanopsin is most responsive) can have an impact on human physiological and behavioural state that is quite separate from its contribution to visual appearance. Turning such qualitative assessments into quantitative design guidelines however requires an internationally accepted method of measuring light that is relevant for melanopsin photoreceptors. Light energy comes

at different wavelengths and any attempt to describe light intensity in terms of a single number must address the problem of how to sum energy across different wavelengths. In the case of biological systems, this must take into account the fact that photoreceptors are not equally sensitive to all wavelengths. The SI base unit for visible light (the candela), and derived units such as lumen and lux, overcome this problem by applying a wavelength correction when measuring light that matches the relative sensitivity of cone-based vision across the spectrum. At the time of this research there was no equivalent method of measuring light for melanopsin, meaning that there was no way of comparing the non-image-forming impact of different light sources or lighting designs.

Lucas' group (funded by Wellcome Trust, BBSRC, Philips Lighting, and ERC Advanced Grant) set out to produce a light-measurement system suitable for melanopsin [2-4]. Lucas and colleagues at UoM used a cell-based assay to provide the first description of human melanopsin's spectral sensitivity, and showed that it peaked around 480nm [4]. They proposed that the 480nm spectral sensitivity of melanopsin could be employed as a wavelength normalisation function in a new photometric measure of light intensity (which they termed "melanopic") relevant for melanopsin photoreception [2]. They further showed that measuring light in these terms predicts the melanopsin response to light of divergent spectral composition [2 and 3].

The strategy for measuring light proposed by Lucas and colleagues was considered alongside alternatives by an international expert panel, and adopted as the basis of a new light-measurement strategy suitable for melanopsin photoreceptors [5]. This allowed, for the first time, the efficiency of light environments and lighting products for eliciting non-image forming responses to be quantified and compared. This is a critical step in optimising design and introducing regulatory standards for the built environment in order to maximise alertness and performance, improve mood and enhance general wellbeing.

3. References to the research

1. Melyan Z, Tarttelin EE, Bellingham J, **Lucas RJ**, Hankins MW (2005). Addition of human melanopsin renders mammalian cells photoresponsive. Nature 433:741-5. DOI: 10.1038/nature03344
2. al-Enezi J, Revell V, **Brown TM**, Wynne J, Schlangen L, **Lucas RJ** (2011). A 'melanopic' spectral efficiency function predicts the sensitivity of melanopsin photoreceptors to polychromatic lights. J Biol Rhythms 26(4):314-23. DOI: 10.1177/0748730411409719
3. **Brown TM**, Tsujimura S, **Allen AE**, Wynne J, Bedford R, Vickery G, Vugler A, **Lucas RJ** (2012). Melanopsin-based brightness discrimination in mice and humans. Curr Biol 22(12):1134-41. DOI: 10.1016/j.cub.2012.04.039.
4. **Bailes HB, Lucas RJ** (2013). Human melanopsin forms a pigment maximally sensitive to blue light (lmax≈479nm) supporting activation of Gq/11 and Gi/o signaling cascades. Proc Roy Soc B 280:20122987. DOI: 10.1098/rspb.2012.2987
5. **Lucas RJ**, Peirson SN, Berson DM, **Brown TM**, Cooper HM, Czeisler CA, Figueiro MG, Gamlin PD, Lockley SW, O'Hagan JB, Price LL, Provencio I, Skene DJ, Brainard GC (2014). Measuring and using light in the melanopsin age. Trends Neurosci. 37(1):1-9. DOI: 10.1016/j.tins.2013.10.004

4. Details of the impact

Context

Inappropriate levels of light can compromise health and wellbeing by disrupting biological rhythms and patterns of sleep (with associated impacts on alertness, performance and mood, and enhanced risk of chronic illness). Light's ability to disrupt rhythms and sleep should therefore be accounted for in the design of lighting products and built environments. Lucas' group at UoM has developed a method of measuring light that can quantify its ability to elicit

such non-image-forming responses. This method has obtained approval by scientific consensus and been developed as a new SI-compliant international standard for measuring light. It allows regulators, engineers and designers for the first time to quantitatively compare the potential of lighting products and light environments to induce these subconscious light responses. The new 'melanopic' measurement system is being applied in guidelines for healthy lighting design and informing the wavelength composition of lighting products.

Pathways to Impact

The pathway to impact encompassed establishing a scientific consensus on the best method of measuring light, and then working closely with Public Health England (PHE), international standards bodies and the lighting industry to establish it as an international standard metric.

January 2013: Lucas initiated and chaired the First International Workshop on Circadian and Neurophysiological Photometry in Manchester, funded by the lighting industry (through the ZVEI, the German Electrical and Electronic Manufacturers' Association) and supported by PHE and the relevant European and worldwide standards body (the European Committee for Standardisation (CEN) and the International Committee for Illumination (CIE)). The group approved the new approach for light measurement for non-image-forming responses incorporating the 'melanopic' metric developed by Lucas and colleagues at UoM, which was published in Lucas *et al*. 2014 [5].

2014-2018: Lucas served on CEN and CIE committees for devising new metrics for light measurement (CIE JTC-9 and CENTC169WG13).

August 2019: A follow-up international workshop was held at UoM, established and chaired by Brown, funded by the BBSRC and UoM's Centre for Biological Timing and supported by regulatory bodies and policy makers (CIE, PHE), which agreed quantitative guidelines for healthy light exposure based upon the melanopic measurement system.

2011-present: Lucas, Brown and Allen present their work to industry (including Philips Lighting, Apple, Samsung); at events targeting lighting engineering and design communities (including Smart Buildings (>33,000 attendees); Professional Lighting Design Convention (>1,000); Light and Building (>200,000)); and to general and technical media (including BBC TV Breakfast/World News; Electronics weekly (circulation approximately 41,000); The Lighting Journal (circulation approximately 2,000).

Reach and significance of the impact

Policy impact – new international standard for measuring light

Lucas's method of quantifying light (proposed in [5]) resulted in a new SI-compliant system of light measurement [A]. His method was adapted by a committee set up by the CIE and accepted by international ballot in 2018. The standard - CIE S 026/E:2018 'International Standard – CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light' [A] - based entirely on Lucas *et al*., 2014 [5] and citing references [2, 4 and 5], establishes the appropriate method for measuring light when considering non-image-forming effects. The CIE full international standard supersedes earlier guidance on light measurement published in draft standards (*i.e*. to function until the international standard was agreed) from German and European standards agencies, also based directly on Lucas' research and recommendations [B].

Guidance for design/application of artificial and architectural lighting released by influential third parties

Sleep disturbance is estimated to cost approximately 2% of gross domestic product across OECD (Organisation for Economic Co-operation and Development) nations (GBP50,000,000,000 annually in UK alone). The method for measuring light arising from UoM work and now codified in CIE standard CIE S026 is applied by government and non-governmental organisations around the world as the basis for guidance on healthy lighting design. These policies apply to a wide range of domestic, public, and industrial settings,

aiming to reduce the harmful effects of artificial light and disrupted lighting schedules by adjusting light exposure as quantified by the standard. Specifically they all recommend the use of high melanopic light during the day and/or low melanopic light during the night. Examples include:

- **International Well Building Institute (IWBI)**: administers the WELL Building Standard – a performance-based system for measuring, certifying, and monitoring features of buildings that impact the health and wellbeing of the people who live, work, and learn in them, currently being applied to projects encompassing 669,000,000 ft^2 across 64 countries. Lucas *et al.*, 2014 [5] informed v1 of the WELL Building Standard [C] (launched October 2014), the first standard of its kind that focuses solely on the health and wellness of building occupants.
- **US Department of Energy**: produced fact sheets in 2014 aimed at anyone considering LED lights – as used by local government in terms of road lighting, but also all other branches of government and industry and the general public [D].
- **The Building Research Establishment:** a non-profit UK-based organisation supporting research and education to provide a better built environment. Released a fact sheet 'Lighting for Circadian Rhythms' [E] based on Lucas at al. 2014 [5] and codified in CIE S026.
- **The CIE:** the organisation responsible for maintaining SI metrics for light has released its own guidance on artificial lighting based upon CIE standard CIE S026 [F].

Product design

The lighting device and measurement industries are increasingly adapting their products to account for non-image-forming effects of light. In the case of lighting design, this involves modulation of output in the 'blue' part of the spectrum, the most obvious current examples being the computer, tablet and smartphone screen yellowing apps widely applied to minimise sleep disruption, *e.g.* f.lux [G]. Numerous 'healthy lighting' products are now being sold, based on CIE S026 or previous drafts of the standard (*e.g.* [H]), and the market for such products is predicted to reach USD3,500,000,000 by 2024. Instruments for measuring light in melanopic units are also appearing (*e.g.* [I]).

5. Sources to corroborate the impact

A. Published international standard on light measurement from the CIE (CIE S 026/E:2018) (2018): 'International Standard – CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light' – *based entirely on the metric for measuring light in melanopic units proposed by Lucas et al. 2014 [5] and a direct application of the principle established in al Enezi et al. 2011 [2].*

B. Draft versions of the standard and initial technical reports which preceded the international standard CIE S 026/E:2018, *all based entirely on Lucas et al. 2014 [5]*:

(i) Draft standard DIN SPEC 5031-100:2015-08 (2015, in German): 'Optical radiation physics and illuminating engineering - Part 100: Melanopic effects of ocular light on human beings - Quantities, symbols and action spectra'.

(ii) CIE Draft International Standard DIS 017/E:2016 ILV (2016): 'International Lighting Vocabulary, 2nd Edition'.

(iii) CEN Technical Report PD CEN/TR 16791:2017 (2017): 'Quantifying irradiance for eye-mediated non-image-forming effects of light in humans'.

C. The WELL Building Standard (v1 with May 2016 addenda) - *advice on the non-visual impact of light is based upon Lucas et al., 2014 [5].*

D. US Department of Energy fact sheet: PNNL-SA-102586 Solid-State Lighting Technology Fact Sheet: 'Lighting for Health: LEDs in the New Age of Illumination' (May 2014) – *based entirely on Lucas et al. 2014 [5].*

E. Building Research Establishment fact sheet "Lighting for Circadian Rhythms" (October 2019) – *based on Lucas et al. 2014 [5].*

F. Letter from CIE (1 December 2020) confirming Lucas and Brown's pivotal roles in establishing expert-scientific consensus lighting recommendations based on the new light measurement standard, including CIE guidance on artificial lighting ('Recommending Proper Light at the Proper Time', 2nd Edition, 3 October 2019) - *based upon CIE standard CIE S026 and cites Lucas et al. 2014 [5]*.

G. f.lux screen yellowing app - *cites Lucas et al. 2014 [5] and CIE S 026/E:2018*.

H. 'Healthy lighting' products that reference the International Standard CIE S 026:2018 or previous drafts of the standard:
- Seoul Semiconductor's SunLike Series Natural Spectrum LEDs – *cites the International Standard CIE S 026/E:2018.*
- Light Design for WELL with BIOS SkyBlue – *references the WELL building standard and "melanopic lux" proposed by al Enezi et al. 2011 [2] and Lucas et al. 2014 [5].*
- Zumtobel Human Centric Lighting with tunableWhite - *cites CIE S 026/E:2018, DIN SPEC 5031-100 and the WELL Building Standard.*
- Samsung Human Centric Lighting Solutions (Optimized Light for Circadian Rhythm Synchronization) - *based upon 'melanopic ratio', a direct application of Lucas et al.'s melanopsin metric [5] standardised in CIE S 026/E:2018.*
- Osram LED Components for Circadian-friendly Lighting - *cites the draft standard DIN Spec 5031-100*.

I. Light measurement systems and devices for measuring light in melanopic units *(proposed by Lucas et al. 2014 [5])*:
- Gigahertz-Optik GmbH Spectral light meter with flicker measurement function – *cites the International Standard CIE S 026:2018.*
- Solemma Adaptive Lighting for Alertness (ALFA) - A new circadian lighting design software - *based entirely on the melanopic lux metric proposed by Lucas et al. 2014 [5].*
- JETI LiVal Radiometric Software – *cites the draft standard DIN SPEC 5031-100:2015-08.*