Institution: University of Essex

Unit of Assessment: 4- Psychology, Psychiatry and Neuroscience

Title of case study: New LED flicker parameters change industry standards, improve lighting design and safeguard health and wellbeing.

Period when the underpinning research was undertaken: 2000-2018

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:
Arnold Wilkins	Professor	1997- 30th September 2014
Tom Foulsham	Reader	2011-present

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

Most electric lighting fluctuates rapidly in brightness, generating "flicker" which is not always seen but has negative effects on health including headache and fatigue. Essex research transformed understanding of these effects by determining how fast flicker must be to prevent harm, and was foundational to the development of a **global industry standard for mitigating health risks from LED lighting**: Institute of Electrical and Electronic Engineers (IEEE)1789™ (2015) that became an Approved American National Standard in 2016. This standard has motivated **regulatory practices**, and driven **innovation in lighting design**. As a result, companies trading in more than 100 countries are now using safer technologies to supply and sell billions of compliant LED products worldwide, reducing health risks, mitigating lower economic productivity due to ill health, and accelerating global adoption of energy efficient LED lighting.

2. Underpinning research

"**Flicker**" here refers to the rapid and repeated variation in brightness of a light source over time due to changes in power supply voltage. This may be visible as a change in the intensity of the light source but even when it is so fast as to be invisible, it can still provoke a biological neuronal response [**R1**].

Essex research determined: **(i) the levels of flicker which have adverse effects on health, causing headaches, fatigue, eyestrain [R1], and epileptic seizures [R2] that in turn contribute to economic costs such as absenteeism and reduced productivity; and (ii) the speed and amount of flicker that must be avoided in order to prevent harm.**

Figure 1. Temporal light artefact: car dashboard and street view. (Source: A Wilkins).

Prior to Wilkins' research it was thought that the effect of light fluctuation on health was restricted to flicker that could be seen, particularly at a frequency of ~200Hz, on the basis of observable electrical activity of the retina. Research at Essex provided the important insight that awareness of flicker per se is not necessary for flicker to be harmful, and showed that the upper frequency limit for harmful effects is substantially higher than previously thought [**R1**].

Wilkins demonstrated that even variation in the brightness of a light that is so fast you are unaware of it as flicker, nevertheless creates a *spatial* pattern that can sometimes be seen during a rapid eye movement. This is known as a temporal light artefact [**R3**, **R4**]. When a visual scene is intermittently illuminated, the

contours in the scene appear at a succession of locations in the eye, forming a pattern that can sometimes be seen. For instance, lamps changing rapidly between light and dark can result in people seeing a trail of images of the lamp. Such patterns are particularly noticeable with the LED taillights of cars at night.

*Figure 2. Another temporal light artefact example: tail lights. (*Source: *https://sudonull.com/post/18780-Brightness-pulsations-facts-mechanisms-and-norms*

Research at Essex determined how fast flicker must be in order to avoid these detectible patterns and potential harm. The pattern is most visible when a lamp fluctuates at around 600 - 1000 Hz. However, Roberts and Wilkins [**R4**] showed that the pattern can be seen at frequencies above 1000 Hz. These data were used to produce a function linking health risk to both flicker frequency and extent of the fluctuation (modulation depth). These upper frequency limits of temporal light artefacts are as high as 11,000 Hz (11kHz) in some individuals [**R3**], particularly those who suffer visual discomfort, suggesting that even very high frequency fluctuation may be detrimental to health [**R5**].

LED lighting is controlled by circuitry that provides a low-voltage DC electrical supply from the AC mains. Due to this aspect of circuit design, some LEDs fluctuate at high frequencies and some do not [**R6**]. Wilkins' evidence-based theory of visual discomfort and his demonstrations that poor design will create hyperexcitation of the visual cortex has been recognised in lighting design [**R5**]. The importance of his research demonstrating the impacts of spatial arrangement of lights and acceptable ranges of flicker was recognised by a 2016 Walsh-Weston Award from the Society of Light and Lighting for best paper focusing on fundamental lighting matters [**R5**].

Lights can be designed so that fluctuation is too fast for detectible patterns to occur, without incurring additional costs. Wilkins' research laid the foundation for creating design specifications for LED lights that do not represent a health risk or cause discomfort.

3. References to the research

Research Quality: The research has been supported by competitive grant funding and published in peer-reviewed journals. Impact factors (IF) taken from Web of Science. PDFs of R1- R6 are available from the HEI on request.

R1 Wilkins, A.J., Veitch, J. and Lehman, B. (2010), LED lighting flicker and potential health concerns: IEEE standard PAR1789 update. *IEEE ECCE*, 171-178. DOI:10.1109/ECCE.2010.5618050

R2 Fisher, RS., Harding, G., Erba, G., Barkley, GL. and Wilkins, A., (2005). Photic- and Pattern-induced Seizures: A Review for the Epilepsy Foundation of America Working Group. *Epilepsia,* 46 (9), 1426-1441. IF = 6.0 DOI: 10.1111/j.1528-1167.2005.31405.x

R3 Brown, E., Foulsham, T., Lee, C-s, Wilkins A.J. (2019). Visibility of temporal light artifact at 11kHz. *Lighting Research and Technology*, *52*, 371-376. IF = 2.3 DOI: 10.1177/1477153519852391.

R4 Roberts J.E. and Wilkins, A.J. (2013). Flicker can be perceived during saccades at frequencies in excess of 1kHz. *Lighting Research and Technology*, *45*, 124-132. IF = 2.3. DOI: 10.1177/1477153512436367

R5 Wilkins, A.J. (2016). A physiological basis for visual discomfort: application in lighting design. *Lighting Research and Technology*, *48*, 44-54. [This paper was awarded the 2016 Walsh-Weston Award by the Society of Light and Lighting for 'best paper focusing on fundamental lighting matters' https://journals.sagepub.com/page/lrt/collections/awardwinners]. IF = 2.3 DOI: 10.1177/1477153515612526

R6 Lehman, B. and Wilkins A.J. (2014). Designing to mitigate the effects of flicker in LED lighting. *IEEE Power Electronics Magazine*, Vol. 1, (3), 18-26. DOI: 10.1109/MPEL.2014.2330442.

Competitively Awarded Research Grants

G1 Wilkins, A. *Tests of a theory of visual discomfort*. Medical Research Council. £424,011. Dates: 01.12.1997-30.09.2000. G9715885/1

4. Details of the impact

Summary LED lighting is energy efficient but potential flicker and associated discomfort and health risks may deter or slow its adoption. Essex research determined parameters for the speed and amount of flicker in lighting that is required to prevent harmful effects on health. Wilkins' function was the foundation for the development of a global industry standard for mitigating health risks from LED lighting developed by the Institute of Electrical and Electronic Engineers (IEEE) in 2015 (IEEE1789™[**S1**]). The standard subsequently became an Approved American National Standard (ANS) in 2016. The standard drove innovation in the design of lighting and electrical components that enable flicker frequency and depth to be set to safe and comfortable limits. With companies trading in over 100 countries applying safer technologies and billions of compliant LED products now sold worldwide, IEEE 1789 has significantly mitigated individual ill health and consequent reduced economic productivity, and accelerated worldwide adoption of energy efficient LED lighting.

Development of IEEE Standard 1789™ [S1]

In 2008, Wilkins was invited as a recognised expert in visual stress from flicker [**R1- R6**], to join an international working group established by the IEEE, a worldwide technical professional organisation based in the USA, to consider the impact of flicker in LEDs. The working group comprised of visual scientists, lighting experts, environmental psychologists, lamp designers, LED driver designers, medical experts, and LED lamp users, and developed **IEEE Standard 1789: *"Recommended Practices for Modulating Current in High Brightness LEDs for Mitigating Health Risks to Viewers"*** [**S1**]. Essex research [**R4**] produced the function linking risk to both flicker frequency and modulation depth, which forms the core of IEEE 1789. Wilkins was co-editor of Clauses 6 and 8 of IEEE 1789 [**S1**]. Essex research [**R1**, **R2**, **R4**, **R6**] is listed in the bibliography. The report was approved by the IEEE Standards Board on 26 March 2015 [**S1**].

A testimonial from the founder and chair of the IEEE Standards Group, IEEE PAR 1789, emphasises the importance of Wilkins's work in defining this standard [**S2**]: "***Professor Wilkins's research was a foundation for the recommended practices that were contained in the IEEE PAR 1789 document****. The standard relied heavily on his published work that explained the levels of flicker that can lead to fatigue and headaches. This led to the IEEE standards group creating low risk regions for flicker. From these regions, it is not too difficult for a power electronics designer to create an electronic driver to keep the flicker below the risk regions. However****, these safe operating regions were unknown prior to Professor Wilkins's work****.*"

Adoption of IEEE 1789 Recommendations Internationally

IEEE 1789 has been embedded in regulatory frameworks worldwide. For example, The American National Standards Institute (ANSI), which coordinates the US voluntary standardization system, accepts IEEE 1789 as satisfying ANSI requirements for openness, committee balance, public review and appeals process; **IEEE 1789 became an approved 'American National Standard'** on September 7, 2016 [**S3**, p. 517]. The ANSI/IEEE1789 Standard has enabled regulatory bodies to promote the adoption of energy efficient LED lighting by ensuring that it is also safe and comfortable:

The **USA Environmental Protection Agency (EPA)** has a mission to protect human health and the environment. The EPA promotes 'greener' product choice by endorsing a product label known as '**Energy Star'** [**S4a, b**] with which manufacturers certify that their electrical products, including light bulbs and fixtures, conform to established standards. In 2018, Energy Star updated their lighting (luminaires) specification (V2.1 **[S4c]**, updated from v2 effective 2016) to include a section on flicker that requires compliance with product testing and metrics described by IEEE Recommended Practices [**S1**]. Compliance with ANSI/IEEE 1789 is required in order for the product label 'Energy Star' to be used [**S4c**, section 7, p.11; section 11.6, p. 21 and section 11.7, p.22] ensuring safe and comfortable green product choice.

The State of California USA has an Energy Commission whose code is to reduce wasteful energy

consumption. ANSI/IEEE 1789 formed part of the evidence presented during the three-yearly open stakeholder consultation on the State of **California's "Building Energy Efficiency Standards** for Residential and Non-residential Building (Title 24)" [**S5a**]. California now has established standards regarding product testing for flicker, and mandatory reporting of test results to the California Energy Commission. The California Title 24 2019 [**S5b**] mandated requirement that "light output has an amplitude modulation of less than 30 percent for frequencies less than 200Hz" (**S5b**, p. 125) conforms to the ANSI/IEEE 1789 standard. Specifically, the identified limit is below the threshold specified by the IEEE 1789 Recommended Practice (**S1**, p.44 and Figure 20), so as to limit the adverse biological effects of flicker.

Industry and governmental agencies worldwide recommend compliance with IEEE 1789 to minimise risks to health and promote energy efficiency [**S1**]. For example, the International Energy Agency (IEA), a consortium of 13 countries whose aim is to reduce electricity consumption via energy efficient products, specifies criteria for flicker modulation to protect health based upon [**S1**] (p. 6 footnote 6 [**S6a**]). The Alliance for Solid State Illumination Systems and Technologies (ASSIST) [**S6b**] recommendations cite [**R4** and **R6**]. The Design Lights Consortium [**S6c**] is dedicated to accelerating the widespread adoption of high-performing commercial lighting solutions and in 2018 adopted the requirement to test in accordance with IEEE Recommended Practices (**S6c** p.8 refers to [**S1**]). The International WELL Building Institute (IWBI) sets standards for buildings, interior spaces and communities seeking to support health and wellness. The IWBI [**S6d**] electric light quality part 2 requires that electric lighting in regularly occupied spaces conforms to low risk LED as defined by IEEE standard 1789 [**S1**].

Driving Innovation in Lighting Design and LED Products

The testimonial from the IEEE 1789 Chair [**S2**] notes the extensive impact of the IEEE Standard resulting from Wilkins' research on the LED industry worldwide: "*companies have made a decision to add the extra components to the power electronic drivers to minimize flicker".* He further states that "***the research Professor Wilkins has performed at Essex has strongly influenced the design specifications of widespread LED lighting technologies*** *(probably millions of bulbs) on the commercial market today. Because of this, there will be fewer negative biological effects upon photosensitive populations".* [**S2**]

Evidence of lighting design innovation driven by IEEE 1789 is provided by **USA patents** for driver design (e.g. 2017, **[S7]** citing [**R1**] and [**R6**], and evidence that companies trading in over 100 countries worldwide have changed their product design to conform to IEEE 1789, to mitigate health risks. For example, **Signify** (formerly **Philips Lighting**), a global leader in lighting, trading commercially in more than 70 countries, created their *EyeComfort* trademark [**S8**] based on research presented in [**R1**] and the IEEE Recommended Practices [**S1**]. **Dyson** [**S9**], a global consumer technology company trading in more than 100 countries worldwide has developed a trademarked task light *CSYS*, that is described as a "*powerful light (over 1000 lux) with glare protection and low optical flicker*" (in [**S9**, footnote 3] refers to [**S1**], asserting that the product has been "*tested according to IEEE 1789 - 2015*)". Manufacturers of LED drivers [**S10a-f:** Xicato, Helvar, EldoLED, Unios, Optoga, New Horizon] for use in public and industrial spaces worldwide have developed drivers that conform to IEEE 1789 [**S1**] to avoid the temporal light artefacts that lead to poor photographic images and negative impacts on human health and productivity from 'invisible flicker'.

Improving Public Health

IEEE 1789 recommended practices underpin public health guidelines; for example, the conclusions and recommendations of a policy report (CRCE-RDD 01-2016) published by Public Health England [**S11**] - ' Human responses to lighting based on LED lighting solutions', part of the series 'Protecting and Improving the Nation's Health' – drew heavily upon IEEE 1789, citing [**S1 and R5**] on p.42 references: "*Following IEEE [**S1**], this report highlights the need for a practical flicker metric*" (p. 13). The report concludes on p.41 that "*flicker may be a risk factor for some adverse health effects*" and recommends limiting flicker to avoid such effects.

In the USA, IEEE 1789 has driven major programmes of retrofitting of LED lighting in public

contexts such as education and health facilities, in recognition of the health and economic benefits of flicker-free lighting; by 2019 more than 230 school districts, and leading universities had been retrofitted (**S12a**) and by 2020 more than 60 health facilities had been retrofitted [**S12b**].

5. Sources to corroborate the impact (all available from HEI)

S1 IEEE Standard 1789 ™ *Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers, 2015*. Wilkins listed as a member of the working group on p.vi. Available at: http://www.bio-licht.org/02_resources/info_ieee_2015_standards-1789.pdf. IEEE Website: https://standards.ieee.org/standard/1789-2015.html Accessed Feb 2021.
S2 Testimonial from Chair of the IEEE1789 Working Group, dated 2019.
S3 Link to website from which the list of ANSI Approved Standards can be downloaded. https://www.ansi.org/resource-center/standards-action. Full list of standards downloaded on 18.02.2021, document dated Feb 16th 2021, IEEE1789 listed on page 517, showing it was approved by ANSI on September 7th 2016.
S4a-c. a: US Environmental Protection Agency (EPA) website showing Energy Star. **b:** Energy Star website. **c:** ENERGY STAR Program Requirements for Luminaires Eligibility Criteria (introduced into 2018 partnership agreement v.2.1, effective September 1st , 2018, p.11, 21, 22 and retained in the 2019 partnership agreement v.2.2, p. 11, p.22, p. 23).
S5ab. a: The California Energy Commission Building Energy Efficiency Standards (Title 24) consultation (JA10. p.18) 2014 Stakeholder Consultation, **b:** Title 24 2019
S6a-d. Collation of independent organizations and regulatory bodies recommending IEEE compliance: **a:** International Energy Agency (IEA), Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E): **[S1** p.6, 9**]. b:** The Alliance for Solid-State Illumination Systems and Technologies (ASSIST)**:** [**R4, R6**]. **c:** Design Lights Consortium (DLC): p.8 refers to [**S1**]. **d:** The International WELL Building Institute (IWBI): Have updated standards for electric lights based on IEEE Recommended Practices [**S1**].
S7 Patents. **USA Patents for Driver Design.** Patent No. 9,584,704 B2, and Patent No. 9,655,174 B2, 2017. Citing Wilkins' research.
S8. Signify (formerly **Philips Lighting**): As a global leader in lighting, present in over 70 countries, Signify (Philips) created their *EyeComfort* trademark based on [**R1, S1**] https://www.lighting.philips.co.uk/consumer/led-lights/eyecomfort Accessed Feb 2021. EyeComfort Whitepaper Accessed Feb 2021.
S9. **Dyson:** A global consumer technology company sold in over 100 countries, IEEE Recommended Practices have influenced the design and testing standards of Dyson products including the trademarked task light CSYS (p.3 footnote 3 refers to [**S1**]) CSYS Desk Light Accessed Feb 2021.
S10a-f Collated list of manufacturers of IEEE1789 conforming LED drivers.
S11 Public Health England, Centre for Radiation, Chemical and Environmental Hazards (CRCE): '*Human Responses to Lighting Based on LED Lighting Solutions'* which was commissioned by the Chartered Institution of Building Services Engineers (CIBSE) and the Society of Light and Lighting. The 2016 report references IEEE Recommended Practices [**S1**]. Evidenced by: a) CRCE-RDD 01-2016, p.13, p. 42. Accessed Feb 2021.
S12ab Evidence of IEEE1789 informed changes to lighting to in education **a:** http://schoolconstructionnews.com/2019/12/05/the-health-and-cost-benefits-of-flicker-free-lighting; and health care **b:** https://energyfocus.com/wp-content/uploads/2020/03/The-Benefits-of-LED-Lighting-for-Healthcare-Facilities-HCO-News.pdf Accessed Feb 2021.