International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

CIE Australia Lighting Research Conference 2025

Abstract Booklet

Tuesday, 4th February 2025
QUT Brisbane
Campus and meeting room TBC
also online via Webex

Version 1.2
Note: The programme is subject to change

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The International Commission on Illumination – also known as the CIE from its French title, the Commission Internationale de l´Eclairage – is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology. For more information see: http://www.cie.co.at/.

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PROGRAMME

All times are Australian Eastern Standard Time (AEST, UTC/GMT +10 hours).

08:30	**Registration**		
08:50	**Webex meeting opens**		
09:00	Steve Coyne	Australia	Welcome, housekeeping
09:05	Jennifer Veitch	Canada	CIE President's welcome
09:15	**Session 1: Photobiology, safety and hazards**		
	Stephen Dain	Australia	Sunlight and macular degeneration: a systematic survey of the epidemiological evidence
	Zora Liu	USA	Impact of narrowband spectra on visual and safety perception under low light levels
	Maitreyee Roy	Australia	Impact of blue-blocking lenses on colour vision in individuals with colour deficiency
	Vineetha Kalavally	Malaysia	Preliminary analysis of relationships between light quantification metrics and sleep-wake cycles
	Stephen Dain	Australia	Eye and face protection against biological hazards: optical radiation issues
	Question and answer session		
10:50	**Morning tea**		
11:10	**Session 2: Products and preference**		
	Andrew Chalmers	New Zealand	Light source colour naturalness
	Reagan Warenda	USA	Effect of colour and abstract images on emotions and heart rate variability
	Madhavi Perera	Sri Lanka	Investigation of relationship of MICI with perceived adequacy of illuminance and spatial brightness
	Crispin Rock	Australia	User preference of dimming controllers
	Dan Croucher	Australia	Net zero - lighting for Australian households and commercial buildings - every watt counts!
	Question and answer session		
12:45	**Lunch**		
13:25	**Session 3: Visual performance**		
	Olivia Knoechel	USA	Effect of melanopic equivalent daylight illuminance on human cognition
	Joanne Wood	Australia	Transition to LED road lighting: impact on visual performance and pedestrian recognition
	Thomas Oram	Australia	Perceiving is believing: observation analysis for social public lighting
	Mark Schier	Australia	Further detection threshold of traffic signal changes
	Hind Alzahrani	Saudi Arabia	How effectively are (PVA/PVP) films filled with AL-doped ZnO@GO shielding UV and blue light?
	Question and answer session		
15:00	**Session 4: Measurement**		
	Lambert Tissot	Australia	Phototherapy meter calibration: a continuous improvement
	Iza Linders	Australia	Measuring patient light exposure in the ICU: methods & implementation
15:30	**Afternoon tea**		
15:50	**Session 4: Measurement (continued)**		
	Guillaume Dotreppe	Belgium	On the difficulty of absolute limiting photometric distance estimations
	Jack Gordon	Australia	Evaluation of crosstalk in cobalt blue glass and Wratten no. 12 gelatine filters for slit lamp biomicroscopy
	Anas Mohamed	Maldives	Overcoming challenges in miniaturizing spectral sensors
	Tony Bergen	Australia	On the challenges of metrological traceability and measurement uncertainty in the age of AI
	Question and answer session		
	Workshop		
17:15	Gillian Isoardi	Australia	Investigations of Unexpected Developments in your Research – Experiences from the IEA SSL Annex Interlaboratory Comparison on Temporal Light Measurement (IC 2023)
17:50	**Voting on "Best Presentation", concluding comments**		
18:00	**Close**		
19:00	**Conference dinner**		

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ABSTRACTS

Session 1

Photobiology, safety and hazards

SUNLIGHT AND MACULAR DEGENERATION: A SYSTEMATIC SURVEY OF THE EPIDEMIOLOGICAL EVIDENCE

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Promotions of blue-blocking lenses as protection for the retina have cited a very selected subset of epidemiological studies and short-term laboratory experiments as evidence.

The initial aim of the study was to assemble all the identifiable primary epidemiological studies on sunlight/blue-light and ARM. From this the prospects of providing evidence-based advice to patients can be assessed.

Medline was searched (most recently September 2024) using the words [Sunlight OR Blue light] AND [Macular degeneration OR Drusen]. A total of 384 papers were found. Web of Science was then searched (most recently September 2024) using the words of [Sunlight OR Blue light] AND [Macular degeneration OR Drusen]. Comments, opinion pieces and editorials were excluded but provided a further 8 references. Two identified meta analyses provided an additional 5 papers and 3 theses In all, 49 papers and 3 theses were identified as primary epidemiological evidence.

The results showed a date range of1983-2024. There were studies from 19 individual countries and 1 from a pair of countries.

There were 9, previously published, methods of classification of the types of ARM referenced, 8 sets of authors described their own method and 9 sets of authors did not set any diagnostic criteria. There were 5 different methods of characterizing the sunlight dose and 12 sets of authors did not specify how they characterized sunlight dose.

There were multiple reports from some studies, the Chesapeake Bay, Beaver Dam and Blue Mountains studies provided 4 papers each. One paper reported on blue, violet and sunlight separately and 1 reported only blue light. The remainder considered daylight as a whole only.

The study types comprised 17 case-control, 28cross-sectional, 3 cohort and 1 cross-sectional follow-up.

The heterogenous collection of classifications and dose characterisations, makes meta-analysis very problematic, but the aim to identify all the evidence as a yardstick against which to measure any claims of previous authors that their survey was "systematic" and the comprehensiveness of the support for the industry claims.

This extent of evidence has never before been fully identified. Subsets of the data will be analysed for specific factors including the age groups at exposure, the use of protective measures and the relationship of occupation and ARM.

At this stage it is possible to say that no study provided the unequivocal evidence that any relationship was with, specifically, blue light. The studies are far from unanimous in reporting statistically significant relationships between sunlight dose and the risk of ARM and the evidence for early life or late life sunlight dose being more of a risk is equivocal.

IMPACT OF NARROWBAND SPECTRA ON VISUAL AND SAFETY PERCEPTION UNDER LOW LIGHT LEVELS

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Light is necessary for human visual perception, but anthropogenic light at night (ALAN) [1] has been associated with negative consequences for the environment and several species, including humans [2-4]. Recently, narrowband spectra (i.e., amber or red LED) and light sources with low correlated colour temperature (CCT) have been proposed as an alternative to reduce the negative effects of ALAN [5,6]. However, the trade-offs between ecological consequences and human perception caused by narrowband spectra light sources have not been systemically investigated [7]. A literature review has been conducted to examine psychophysical studies on colour perception, discrimination, and preference, with a particular focus on the effects of different light spectra—specifically amber and white light—under low lighting conditions. The search was limited to peer-reviewed journal articles with spectra as independent variable and colour, visual, and safety perception as dependent variables. The relationship between light spectra and subjective responses were analysed and significant research gaps were identified to guide future studies.

References

[1] Durmus, D. (2024). Opinion: Embracing 'anthropogenic' over 'artificial' light at night. Lighting Research & Technology, 56(3), 309-310.

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IMPACT OF BLUE-BLOCKING LENSES ON COLOUR VISION IN INDIVIDUALS WITH COLOUR DEFICIENCY

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Purpose: Blue-blocking lenses (BBLs) have become important due to the high levels of short-wavelength light emitted by LED screens and lighting [1]. Blue light is vital for trichromatic vision, as it aligns with the peak sensitivity of the shortwavelength cones in the retina. Although BBLs are designed not to block the transmission of blue light entirely, there is still concern about whether colour vision discrimination may be reduced due to the attenuation of a blue light stimulus [2, 3]. This study investigates the impact of BBLs on colour vision deficient (CVD) individuals, comparing it to those with normal colour vision.

Methods: The colour discrimination ability of eleven participants (aged 21–25 years, mean: 22±1.75) was evaluated using the Cambridge Colour Test. Participants included four with deutan colour deficiencies and six with normal colour vision (control group). Tests were conducted under simulated photopic and mesopic lighting using three BBLs and one untinted control lens fitted in fit-over goggles. Results were categorised into protan, deutan, and tritan thresholds, reflecting the sensitivity of long, medium, and short-wavelength cones. A two-way ANOVA compared the weighted mean differences across BBLs and lighting conditions for each threshold in both groups.

Results: A significant interaction was found between lens type and lighting conditions on the tritan threshold in both the control and CVD groups ($p<0.05$) as shown in Figure 1 and Figure 2. BBLs significantly affected the tritan threshold under both photopic and mesopic conditions ($p<0.05$), with a greater impact observed in mesopic lighting.

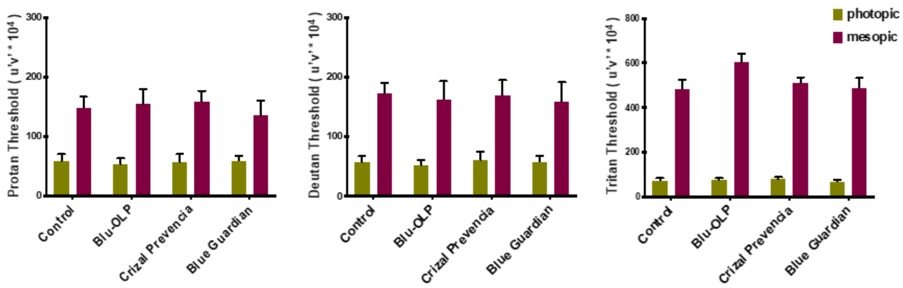

Figure 1: Colour discrimination thresholds of the normal vision group for control and BBL lenses along protan, deutan, and tritan confusion lines under photopic and mesopic lighting, with a larger scale for tritan thresholds

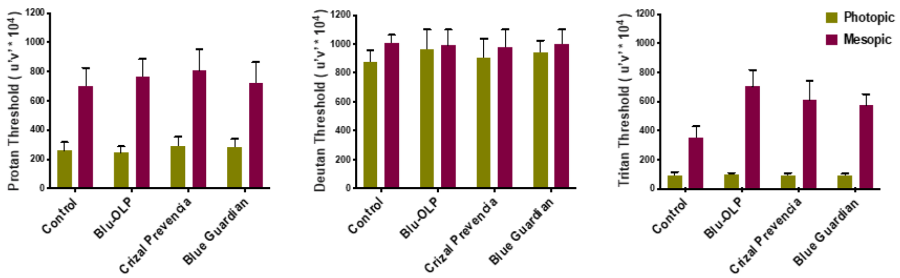

Figure 2: Colour discrimination thresholds for the CVD group for control and BBL lenses along protan, deutan, and tritan confusion lines under photopic and mesopic lighting, with a larger scale for tritan thresholds

Conclusion: BBLs reduced colour discrimination in both normal and CVD individuals, with a greater impact under mesopic conditions.

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PRELIMINARY ANALYSIS OF RELATIONSHIPS BETWEEN LIGHT QUANTIFICATION METRICS AND SLEEP-WAKE CYCLES

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Motivation

The measurement of daily light exposure is a complex process as many aspects such as light quantification metrics need to be considered. This is further complicated by the discovery of melanopsins in intrinsically photosensitive retinal ganglion cells (ipRGCs) and their contributions to entraining human circadian rhythms which motivated the necessity to measure daily light exposure as 5 α-opic illuminances instead of the traditional photopic illuminance only. Hence, there is a need to rectify which light quantification metrics should be considered when relating daily light exposure to human circadian rhythms or sleep-wake cycles.

Methodology

A data collection study was conducted where 20 participants wore SPECCY, an Internet-of-Things (IoT) integrated mini light spectral sensor, and GENEActiv actigraphy watch for a week. SPECCY, worn at chest-level, was configured to log photopic and α-opic illuminance exposures every minute. Using the collected light data, preliminary correlation analysis was carried out on light quantification metrics described in the paper by Hartmeyer et al. [1] with the participants' sleep onset (S_{ON}), wake onset times (W_{ON}), mid-sleep times (MST) and sleep efficiency (SE). The summarized results are shown in Table 1, where each metrics are calculated individually across 5 α-opic and photopic illuminances.

Table 1. Light quantification metrics and their summarized correlations with sleep metrics.

Light Quantification Metric	Description	Threshold/Timespan	Summarized Results
MLiT*(C)*	Mean timing above threshold	*C* = 50 lx, 100 lx, 150 lx, 200 lx, 250 lx, 300 lx, 350 lx, 400 lx, 450 lx, 500 lx, 750 lx, 1000 lx	Positive correlated with MST and W_{ON} from *C* = 100 lx – 500 lx. Positive correlated with SE for C = 50 lx and 100 lx.
TAT*(C)*	Total duration above threshold (TAT)		$p > 0.05$ except for TAT100 and W_{ON} for S-cone illuminance ($r = -0.47$).
M*(n)*m	Mean illuminance of brightest continuous period	n = 1h, 2h, 3h, 4h, 5h, 6h	Positively correlated with SE from n = 3 h – 6 h. Negatively correlated with S_{ON} for n = 1 h and 2h.
M*(n)*on	Brightest continuous period onset		Positively correlated with S_{ON} at n = 3 h.
M*(n)*mid	Brightest continuous period midpoint		
M*(n)*off	Brightest continuous period offset		
T_B, T_D	Max/min threshold where TAT > 6 hours	-	T_B is positively correlated with SE.
M_B, M_D	20% trimmed mean of light above T_B / below T_D	-	M_B is positively correlated with SE.
C_B, C_D	Longest continuous interval above T_B / below T_D	-	$p > 0.05$.
Circadian variation	Average hourly coefficient of variation	-	$p > 0.05$.
$CE_{Midpoint}$	Midpoint of cumulative exposure	-	Positively correlated with MST and S_{ON}.
$LE_{Centroid}$	Centroid of light exposure	-	Positively correlated with S_{ON}.

Results

By having a later MLiT at *C* = 100 lx to 500 lx (highest *r* at *C* = 150 lx), W_{ON} and MST will be delayed. Results imply that SE is improved if MLiT at *C* = 50 lx or 100 lx is higher, which could be caused by MLiT having a higher value if there is no light exposure after midnight. Exposure to higher and longer continuous periods of daylight could also improve SE.

References

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EYE AND FACE PROTECTION AGAINST BIOLOGICAL HAZARDS: OPTICAL RADIATION ISSUES

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At the outbreak of the COVID-19 pandemic there were no eye and face protection standards. ANSI issued a standard and the AS/NZS committee SF-006 and ISO committee TC94 SC6 WG4 started work.

Two optical radiation-related issues emerged. Firstly a need to avoid interfering with colour-contingent clinical judgements. Eye and face protection is required to meet colour limits for the detection of traffic signals. This relate to medical and hospital needs to maintain the visibility of warning lights, but colour-contingent tasks of recognition of cyanosis and jaundice are more critical. ISO 12609-1 includes requirements but the derivation is not identified. Secondly, to provide protection against ultra-violet radiation when working in outdoors. Solar UV protection is only required for eye protectors against sunglare and a specific marking is required for eye protectors with UV protection.

To derive an appropriate metric for coloration, a sample set of 5 yellow tinted eye protectors, 5 "blue-blocking" lenses and 10 Lee® theatrical filters with $\tau_{V,\,D65}$ ≥80% and 19 Lee® filters 80%> $\tau_{V,\,D65}$ ≥70% were used. They were assessed against the PPE requirements and by their effect on an illuminant P4000 (general clinical observation gold standard) in meeting the Duv and colour rendering index required, compliance with the cyanosis observation index, ISO 12609-1 and the CIE Colour Rendering Index and the Crawford Index and the Ferguson-Crawford Sum Deviation (pre-CIE measures derived from lighting and detection of cyanosis and jaundice). The ISO 12609-1 requirement closely predicted performance on D*uv*, ANSI-IES limits (the most stringent) on CCT, a CRI ≥90, Crawford Index and the Ferguson-Crawford Sum Deviation.[1]

To assess the possibility of incorporating UV transmittance requirements as integral rather than optional requirement, 7 faceshields and two goggles, which had been submitted for splash resistance testing, were measured for luminous and UV transmittance. All samples passed the requirements of ISO 12312-1, AS 1067.1 and ANSI Z80.3 (normal use) being the main sunglass standards in use.[2]

AS 16321.4 (INT):2023 Eye and face protection for occupational use Part 4: Protection against biological hazards, incorporates the spectral transmittance limits of ISO 12609-1 and the UV transmittance limits of AS 1067.1. Work on ISO 16321-4 is ongoing.

References

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2 Dain SJ, Cheng BB, Roy M. Ultraviolet protection in eye and face protection against biological hazards. Ophthal Physiol Opt. 2024;44:1142-1147. https://doi.org/10.1111/opo.13342

ABSTRACTS

Session 2

Products and preference

LIGHT SOURCE COLOUR NATURALNESS

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Because of the widespread adoption of LED sources for general lighting, it is important to demonstrate that they can provide good colour quality in the illuminated environment. This has been one of the aims of CIE Division 1 – and technical committee TC 1-91 has been working on "Methods for evaluating the colour quality of white-light sources". Colour Naturalness has been selected here for investigation as the quality aspect of importance in many lighting applications. It can be defined [1] as the "Subjective extent of how natural the colour appearance of an identified object (e.g. a rose) is under the current light source compared to the ideal colour appearance in your memory in the way you remember that object."

Some seventeen publications between about 2008 and 2020 have quantified the colour naturalness of (mainly LED) lighting through the use of observational experiments under various controlled conditions. This paper will compare five selected cases for their relative predictive performance for Naturalness applied to a range of real and simulated sample sources. Each sample is characterized by its normalized SPD (spectral power distribution). To date, 50 sample sources have been studied – 25 simulated LED/laser SPDs and 25 "real" commercial or CIE model spectra.

The majority of the proposed metrics make use of standard colorimetric results as variables in the Naturalness computations. A useful concept to note here is the MCRI (memory colour rendering index) [2]. This is not claimed to be a naturalness metric but it can be argued that memory plays an important part in a person's perception of naturalness; hence we include MCRI here. We note that the Naturalness metrics under discussion are nearly always linked to a specific range of CCTs. These limitations are generally adhered to as nearly as possible in our computations. Table 1 summarizes the naturalness models we have implemented to date, plus their origins. Several were designed to produce an "ideal" maximum of 100 units; others worked on different scales which have been converted to the 0…100 range for ease of comparison.

Table 1. Naturalness models investigated.

Authors	Ref. No.	Formula (Our name)	Scale (nominal)	CCT Range
Dangol, Islam et al	[3]	Nat(1)	0…100	2700 < CCT ≤ 6500 K
Khahn, Bodrogi et al	[4]	Nat(2)	0…100	CCT ≤ 4100
Khahn, Bodrogi et al	[5]	Nat(3)	0…100	CCT used as a variable
Royer et al *	[6]	Nat(4)	8…1 => 0…100	CCT = 3500 K
Esposito, Houser et al	[7]	Nat(5)	0…5 => 0…100	CCT = 3500 K

* Royer developed a metric termed "Normalness" which is interpreted as equivalent to Naturalness.

In addition we calculate Nat(Av), being the arithmetic mean of Nat(1) to Nat(5) inclusive. Some preliminary results for the two groups of sample sources are illustrated in Figure 1. Note that Rm is the symbol for MCRI.

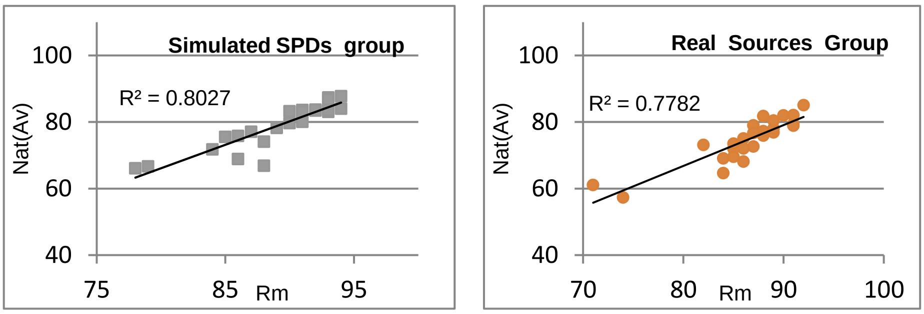

Figure 1: Simple comparison of naturalness performance for the two source groups

References

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EFFECT OF COLOUR AND ABSTRACT IMAGES ON EMOTIONS AND HEART RATE VARIABILITY

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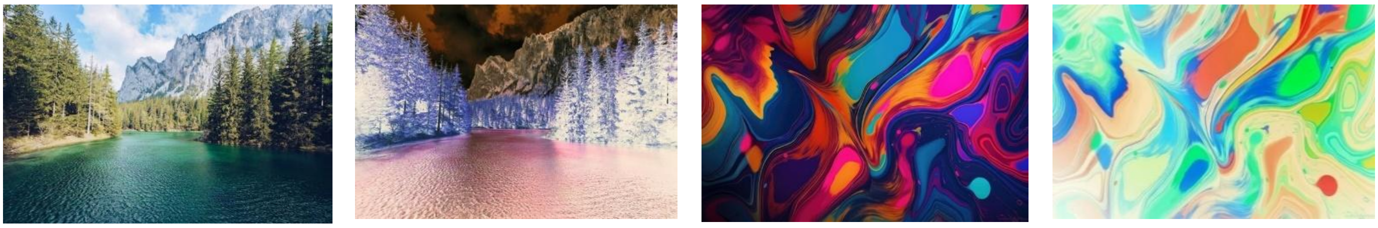
Previous research has shown that colour can influence both emotional responses and physiological metrics, such as heart rate variability (HRV) [1-3]. However, the specific effects of abstract images, as opposed to realistic scenes, remain underexplored. While colours are known to evoke certain moods, the combined impact of colour and image abstraction on emotional state and autonomic responses, such as HRV, is not well understood. This study addresses this gap by examining how variations in colour and abstraction in visual images affect emotional perception and physiological arousal.



(a) (b) (c) (d)

Figure 1. Stimuli included (a) natural scene with normal colours, (b) natural scene with inverted colours, (c) abstract scene with normal colours, and (d) abstract scene with inverted colours.

Participants were exposed to four stimuli shown in Fig. 1—natural scenes and abstract art, each presented in normal and inverted color schemes— using an augmented reality projector [4]. Participants completed a pre-experiment (for baseline) and post-viewing questionnaire to assess their emotional reactions to the images and colour schemes. Participants' alertness levels were quantified using Karolinska sleepiness scale [5], and emotional responses were quantified using arousal and valence grid [6]. The results were analysed to identify correlations between physiological responses and subjective emotional reactions. The findings from this experiment may have implications for real-world applications, such as in healthcare settings, where colour choices can influence patients' stress levels or mood.

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INVESTIGATION OF RELATIONSHIP OF MICI WITH PERCEIVED ADEQUACY OF ILLUMINANCE AND SPATIAL BRIGHTNESS

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Cuttle [1] introduced the concept of MRSE (Mean Room Surface Exitance) as a measurement of PAI (Perceived Adequacy of Illumination) and spatial brightness (SB). Duff et al.[2] discussed that MRSE has a strong relationship with PAI and spatial brightness (SB). Measuring MRSE is complicated and Cuttle [3] proposes a measurement method to measure Mean Indirect Cubic Illuminance (MICI) and Raynham et al.[4] suggests that average MICI is nearly equal to the MRSE for small rooms.

This study investigate the relationship of average MICI with PAI and SB. A classroom with zero daylight and illuminated by with fluorescent luminaires was selected. Six lighting scenes were created by selectively switching off luminaires and the MICI was measured according to Cuttle [3]. A survey was conducted among 35 students and they were asked to about PAI (Yes/ No) and SB. The SB was rated using 5 point Likert scale and mean spatial brightness (MSB) for each lighting scene was calculated. PAI was calculated by percentage of respondents responding "Yes". The obtained results are indicated in table 1

Table 1. MICI vs MSB and PAI.

MICI	MSB	PAI (% of Yes)
143.6	4.01	76%
125.13	3.83	72%
88.6	3.5	66%
73.3	3.4	50%
65.4	3.1	43%
52.2	2.81	40%

For the considered case, linear regression indicated a strong relationship with MSB and PAI which further strengthens the argument made by and Raynham et al. [4] that MICI can be used in place of MRSE since it is easier to measure. However this results need to be further investigated with large number of rooms.

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USER PREFERENCE OF DIMMING CONTROLLERS

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An experiment investigating preferred correlated colour temperature (CCT) of dimmed lighting was carried out and initial results were previously reported. Thirty participants were recruited from the staff and student body at the School of Architecture, Design and Planning at the University of Sydney. A series of dynamically dimming lighting conditions with variable CCTs were rated for preference using a Likert scale. Analysis of the data showed that in a work or office scenario, consistent CCT was preferable to any change in CCT when lighting was dimmed. In a home or social scenario no change or a small shift in CCT towards red up to a $\Delta\ u'v'$ of about 0.04 was found to be preferable than a larger shift in CCT or any shift towards blue.

These results were broadly consistent across the booth and immersed setups, as well as between the automatic and manual dimming tests. However, further analysis has revealed a statistically significant difference in preference for manual control of dimming compared to automatic dimming, but only when the participant was rating a condition with no change in CCT and only when situated in the immersed setting. The significant difference in preference applied to both the home and work scenarios.

A follow-up experiment has been re-designed to further investigate this pattern in the data to identify and isolate which independent variables have affected the result. Complexity will be added to the manual dimming task, the automatic dimming curve will be varied, and the participants will complete a questionnaire to compare the two experimental setups for preference, ease of rating the conditions and how realistic each setup feels. The extra data are expected to improve the experimental design for future research.

NET ZERO: LIGHTING FOR AUSTRALIAN HOUSEHOLDS AND COMMERCIAL BUILDINGS – *EVERY WATT COUNTS!*

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Using the umbrella of the E3 Program and the objectives of the Greenhouse and Energy Minimum Standards Act 2012, significant decisions were taken by Australian and New Zealand Energy Ministers during 2024 which will lead to the improved quality and energy performance of lighting products available for Australian consumers from 2025 while contributing to Australia's Net Zero energy transformation ambitions. On 19 July 2024, Energy Ministers agreed to the determination for incandescent and halogen lamps (Australia only) to effectively continue the phase out of these inefficient lighting technologies (where an equivalent LED lamp is available), while in December 2024 agreement was reached on the introduction of minimum energy efficiency performance standards for a range of light emitting diode (LED) lamps for the first time in Australia.

This presentation covers the challenging regulatory journey, including working with stakeholders and navigating cross jurisdictional boundaries to ensure that Australian consumers can confidently purchase the most energy efficient lighting available - in the case of LED lamps, this also heralds for the first time, the use of improved packaging information for LED lamps and compliance to international photobiological safety requirements. It also allows the Australian lighting industry to lock in their contribution towards Australia's target of reducing greenhouse emission by 43% by 2030 and net zero by 2050.

ABSTRACTS

Session 3

Visual performance

EFFECT OF MELANOPIC EQUIVALENT DAYLIGHT ILLUMINANCE ON HUMAN COGNITION

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In recent years, a great deal of attention has been paid to the physiological and psychological effects of blue light on humans. Many studies aimed to quantify the effects of melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs) on humans due the influence of light on non-image forming functions, such as sleep, mood, alertness [1]. While past studies explored cognitive functions [2,3], they have not systematically controlled illuminance or melanopic contribution of a light source. Here, a psychophysical study was conducted to investigate the correlation between the melanopic equivalent daylight illuminance ($E_{v,\alpha}^{D65}$; mel-EDI) [1] of a light source and cognitive performance.

For the study, participants are exposed to three different lighting conditions (Table 1) in a randomised order and are tested on various cognitive tasks. After a 4-minute initial adaptation period under each lighting condition, participants completed several cognitive tasks aimed to test their verbal memory, processing speed, and cognitive flexibility. The Rey Auditory Verbal Test (RAVLT), Trail Making Test (TMT-A and TMT-B), Controlled Word Order Association Test (COWAT), and other transitionary tests are completed in a 10-minute period per lighting condition. The results indicate the extent of mel-EDI and its correlation with human cognitive function.

Table 1. Summary of Lighting Conditions

	Condition 1	**Condition 2**	**Condition 3**
Nominal Colour	White	White	Blue
Illuminance (lux)	196	191	165
CCT (K)	3776	9268	N/A
$E_{v,\alpha}^{D65}$ (lux)	14459	21335	24827

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TRANSITION TO LED ROAD LIGHTING: IMPACT ON VISUAL PERFORMANCE AND PEDESTRIAN RECOGNITION

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Background: Light Emitting Diode (LED) road lighting and the impact of correlated colour temperature (CCT) variations on driving-related human factors was the focus of this research. This work is highly relevant for road authorities, transitioning from traditional High Intensity Discharge (HID) to LED road lighting, as they make many choices including which CCT types to select based on community preferences, environmental factors and maintaining safety.

Methods: This night-time field-based study measured visual performance and pedestrian recognition under three road lights: LEDs (3000K, 4000K) and High Pressure Sodium (HPS), for 20 young participants with normal vision (M=25.1±3.2 years). Field-based vision measures included ability to discriminate fine detail (visual acuity) and detect faint objects (contrast sensitivity), using customised chart-based targets. A peripheral pedestrian recognition task measured the time that participants (seated in a stationary vehicle) could first recognise pedestrians wearing non-reflective clothing walking towards the centre of the road at two different distances.

Results: There were no significant differences in visual acuity or contrast sensitivity between the three road lighting conditions ($p>0.07$). However, pedestrians were recognised significantly sooner under HPS compared to 3000K or 4000K LED road lighting (15.4s vs 17.6s vs 19.0s respectively), where overall, pedestrian recognition was 3.6s sooner under HPS compared to 4000K LED, translating to a difference of 5 m, likely resulting from the characteristically greater lateral light distribution from HPS.

Conclusions: Road lighting design using LED luminaires needs to consider the impact of their potentially sharper luminous cut-offs and provide designs with appropriate characteristics and dimensions.

PERCEIVING IS BELIEVING: OBSERVATION ANALYSIS FOR SOCIAL PUBLIC LIGHTING

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Understanding site context is a critical step for public space lighting design projects. Knowing how and by whom a space will be used helps determine technically suitable lighting conditions. While context for utilitarian public spaces like motorways can be simple to understand, social spaces require deeper contextual analysis.

For public spaces to support night-time social activity, they require affective atmospheres that meet user needs and desires. Lighting greatly influences how public spaces are used and perceived, helping to define their atmosphere. Because atmospheres are informed by perception and use, analysis that ignores these factors will struggle to achieve contextually sensitive outcomes. While some lighting designers are exploring social research methods like observation to analyse site context, their processes for data collection and analysis remain under-documented. For widespread adoption, an accessible resource for public lighting observation is required.

This research aims to demonstrate that site analysis emphasising perception and social activity is needed for lighting designers to understand social context. Methods and findings from observational studies across two Brisbane university campuses will be presented. Observations focused on typical use of six pre-determined campus spaces, selected for their programming as social spaces and proximity to interior third spaces like libraries. Collected observation data will be grouped into themes of basic user demographics like approximate age and gender, observed activities and their location, lighting conditions and weather conditions. This work represents the first phase of a larger PhD project developing a preliminary co-design framework for public space lighting that invites night-time social activity for inclusive, equitable communities.

FURTHER DETECTION THRESHOLD OF TRAFFIC SIGNAL CHANGES

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Traffic signals using incandescent lamps have been replaced by LED signals in recent times, largely because of their costs both capital and running. Although LEDs can effectively switch on or off instantaneously, the LED drivers can sometimes take several power line cycles to activate before the LEDs emit light. This can cause a time gap between one signal switching off and another signal switching on.

One aspect of the Australian standard for traffic signals, AS 2144 [1], is the affordance of a gradual activation time for the lamps. This was largely due to the inertia of the incandescent lamp filament warming up and is potentially largely redundant with the LEDs. The changeover time inherent in the standard could create some perceived gaps in the change from red-green or from green-yellow-red.

In our presentation at CALReCo 2024 [2], we described a preliminary experiment, using PsychoPy software [3], to explore the perception of gaps in a computer simulated traffic signal presentation. Here we found when signals changed from red to green there was a significantly longer time when being *concerned* about a gap compared to just *detecting* a gap. In those presented data, we posited that the detection of the gap may have been accentuated (i.e., shortened) by the presence of a spatial gap (top of signal lantern—red moving to bottom—green) and presented a single result where the red and green appeared at the same spatial location, supporting this hypothesis.

In this follow-up presentation, we have repeated the experiment with ten participants (at the time of writing) comparing the effects with and without the spatial displacement and initial data suggests that when there is no spatial separation between the red and green lights, a shorter gap was more readily detectable. We will present the results of these experiments, including with results from additional participants and with more repeats from the existing participants.

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HOW EFFECTIVELY ARE (PVA/PVP) FILMS FILLED WITH AL-DOPED ZNO@GO SHIELDING UV AND BLUE LIGHT?

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Purpose. The creation of anti-blue light films with high transparency, low haze, and made entirely of nontoxic, affordable, abundant, and environmentally friendly materials, is becoming increasingly popular, with rising demand anticipated in the near future. Previous research explored polymer nanocomposites made from poly(vinyl alcohol) (PVA) and poly(vinyl pyrrolidone) (PVP) incorporated with various concentrations of the nanocomposite (ZALGO)x, where x = 0 (PP), 1 (ZPP1), 3 (ZPP3), 5 (ZPP5), and 7 (ZPP7) wt%, to promote human health by preventing eye damage [1]. This study focuses on assessing the UV and blue light shielding capabilities of these materials.

Methods: All unfilled PVA /PVP (PP) film, and composite films (ZPP1, ZPP3, ZPP5 and ZPP7) were evaluated. The protective qualities of these films and their effect on blue perception were assessed based on their spectral transmittance, which was measured with a Hopoocolor OHSP350S spectrometer.

Results. Compared to the unfilled (PP) film, the composite films displayed high anti-UV capacity, with UVA and UV-B blocking ratios of 84.11 %-99.93 % and 86.26–99.98 %, respectively as shown in Figure 1. These composite films could block 78.18–99.43 % of blue light in the 400- 500 nm region. They offer low transparency (37.46–13.56 %) while reducing blue light retinal irradiance (2.14–0.06) as shown in Figure 2.

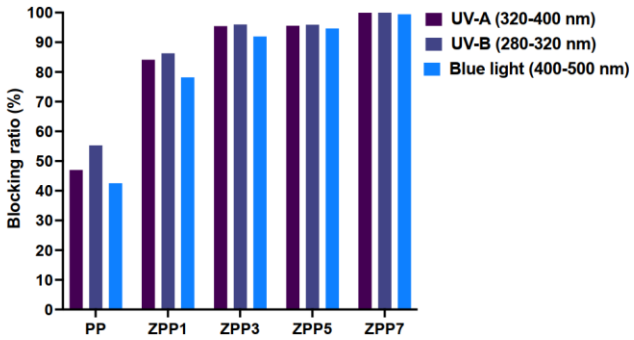

Figure 1: Shielding ratios of PP, ZPP1, ZPP3, ZPP5 and ZPP7 to UV-A, UV-B, and blue light.

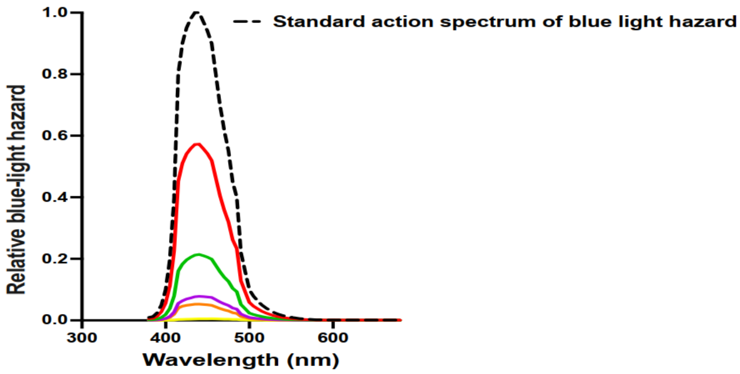

Figure 2. The relative hazard of transmitted light through each PVP/PVA film.

Conclusion. Composite films can shield the human eye from photochemical retinal damage by lowering a component of blue light that may impair blue vision.

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ABSTRACTS

Session 4

Measurement

PHOTOTHERAPY METER CALIBRATION: A CONTINUOUS IMPROVEMENT

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Jaundice (hyperbilirubinaemia) is a condition in which the skin turns a yellowish colour due to the presence of high levels of bilirubin in the blood, and it is common in prematurely-born infants. Treatment is usually by phototherapy: exposing the skin to blue-coloured light with a peak wavelength range of 450 nm to 460 nm, and the recommended irradiance should be of a minimum of 0.05 $W.m^{-2}$ [1]. Meters called phototherapy or "bilirubin" meters have been developed to control the exposure levels.

Calibrating those devices is complicated [2] and has been challenges such as low output, action spectrum, units, new lighting technology.

Before the emergence of high-powered LED chips widely available at specific wavelengths, a Xenon or cool white LED source combined with an interference filter was widely use. This setup, though functional, brought a lot of issues, including a lack of uniformity, and a limited output.

In recent years, new development of LED sources with peaks in the 450 nm region have sensibly helped laboratories creating setups that offers a great uniformity and a very well matching spectrum. However, most "bilirubin" meters on the market have a scale of about 0-20,000 $\mu W.cm^{-2}$, but our setup only managed to test up to 1,000 $\mu W.cm^{-2}$.

Some hospitals have taken action and required testing the meters across the full scale of the instrument. We created a new dimmable LED source based on high powered 450 nm LED chips arranged in an arch, in a similar pattern as the actual phototherapy bed. This allows us to test the full scale of the meter. Such levels could be dangerous for our retina (blue light hazard), so our setup is fully enclosed, and the test meter display is read through a digital camera.

Figure 1 shows the action spectrum recommended by DIN 5031 along with our source spectrum:

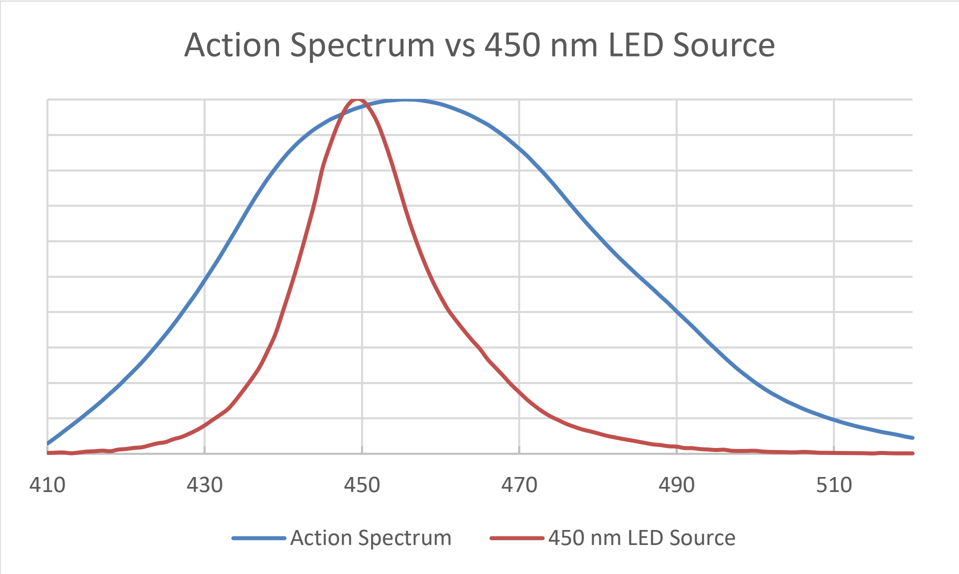

Figure 2: Action Spectrum VS Our Source Spectrum [1]

Reference

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MEASURING PATIENT LIGHT EXPOSURE IN THE ICU: METHODS & IMPLEMENTATION

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Measuring patient light exposure and impact on patient recovery in intensive care units (ICUs) presents unique challenges due to the complexity of the clinical environment and limited research on optimal lighting measurement methodologies within these settings. However, accurately measuring light exposure is crucial for optimising ICU environments, informing evidence-based lighting recommendations, and ultimately improving patient outcomes in critical care settings.

This presentation introduces an approach for continuous lighting measurement in ICUs, addressing measurement challenges such as sensor placement, while ensuring data reliability. Our methodology involves positioning the Mini Spectral Sensor (MSS) 'Speccy' as close to the patient's eye level as possible, to capture light exposure across different spectral qualities. The sensor remains attached throughout the patient's stay, enabling uninterrupted measurements of ICU lighting. The methodology accounts for the need for accuracy while accommodating clinical care activities, patient comfort, and positioning changes, as well as the practical limitations of the ICU environment, such as space constraints.

We will demonstrate the feasibility of our approach and highlight key considerations for future studies. By providing practical guidance on light measurement in ICU environments, we aim to enable further research into optimal light exposure in the ICU and its impact on patient outcomes. Our work contributes to the development of evidence-based lighting standards for critical care environments, with the potential to significantly improve patient care and recovery.

ON THE DIFFICULTY OF ABSOLUTE LIMITING PHOTOMETRIC DISTANCE ESTIMATIONS

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The limiting photometric distance (LPD) defines the minimum measurement distance for far-field goniophotometry based on the photometric inverse square law (ISL) [1]. CIE standards propose various distances depending on luminaire characteristics (beam pattern and luminous extent) [2,3]. Recent studies show substantial angular variation in LPD based on illuminance computations, with off-axis LPD values exceeding those along the optical axis [4]. This discrepancy suggests that current standards, which define measurement distances solely along the optical axis, may be inadequate.

To validate these findings, experimental assessments of the LPD for a narrow-beam device under test (DUT) were conducted at the Physikalisch-Technische Bundesanstalt (PTB) and the Australian Photometry and Radiometry Laboratory (APRLab). Figure 1 shows results from distance-dependent illuminance measurements on an array of two narrow-beam LEDs using two distinct photometric benches, and a far-field goniophotometer installed in a 16m tunnel. An expanded view of the region of interest is shown for a better comparison between the results obtained through the different measurement installations.

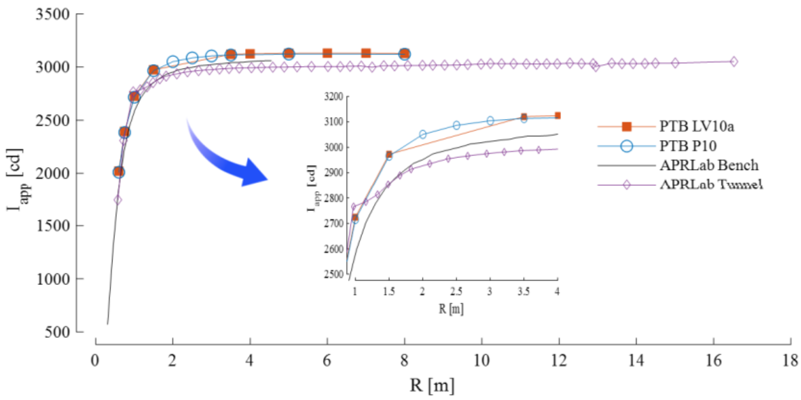

Figure 3: Intensity evolution with the measurement distance as captured on three different photometric installations. The on-axis measurement of an array of two 18° beam width narrow-beam LEDs is shown.

Table 1: LPD comparison through various measurement setups.

	PTB	APRLab Bench	APRLab Tunnel
LPD	$\sim 3\,m$	$\sim 3.1\,m$	$\sim 9.4\,m$

Although similar intensity profiles are observed in Figure 1, the slight differences in intensity trend and absolute value result in varying absolute LPD estimates depending on the measurement setup and reference intensity. Table 1 presents the LPD values on different measurement setups as the distance for which the ISL is verified at 1% or better. The tunnel measurements suggest an LPD value nearly 3 times larger than the measurements performed at the PTB and on the photometric bench at the APRLab. Even larger discrepancies are observed in off-axis directions. Hence, for precise LPD assessment, a specialised setup ensuring accurate alignment across distances and angles and precise elimination of stray light is recommended. Alternatively, numerical models can simulate ideal conditions, eliminating errors due to measurement and manufacturing variances.

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EVALUATION OF CROSSTALK IN COBALT BLUE GLASS AND WRATTEN NO. 12 GELATINE FILTERS FOR SLIT LAMP BIOMICROSCOPY

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Introduction: Anterior eye assessment and contact lens fitting services are enhanced when a slit-lamp biomicroscope can produce high-quality images of sodium fluorescein dye, which is instilled onto the surface of the eye. The contrast in these images is degraded when the emission and excitation filters are not properly matched. Direct measurement of faint crosstalk between gold standard cobalt blue filters and genuine Wratten No. 12 filters has not been directly measured in prior work [1].

Methods: Halogen light was directed through the Haag-Streit BQ900 (1958) slit lamp's cobalt blue filter and Wratten No. 12 gelatine filter (Edmund Optics, Singapore), onto the detector node of a USB4000 Spectrophotometer (Ocean Optics, USA). The calibrated absolute irradiance in photopic conditions was captured over 10 seconds, averaging 5 scans.

Results: Qualitative measurements of the overlap between the cobalt blue filter and the Wratten 12 Kodak gelatine filter show that it occurs at two distinct peaks at 520 nm and 560 nm.

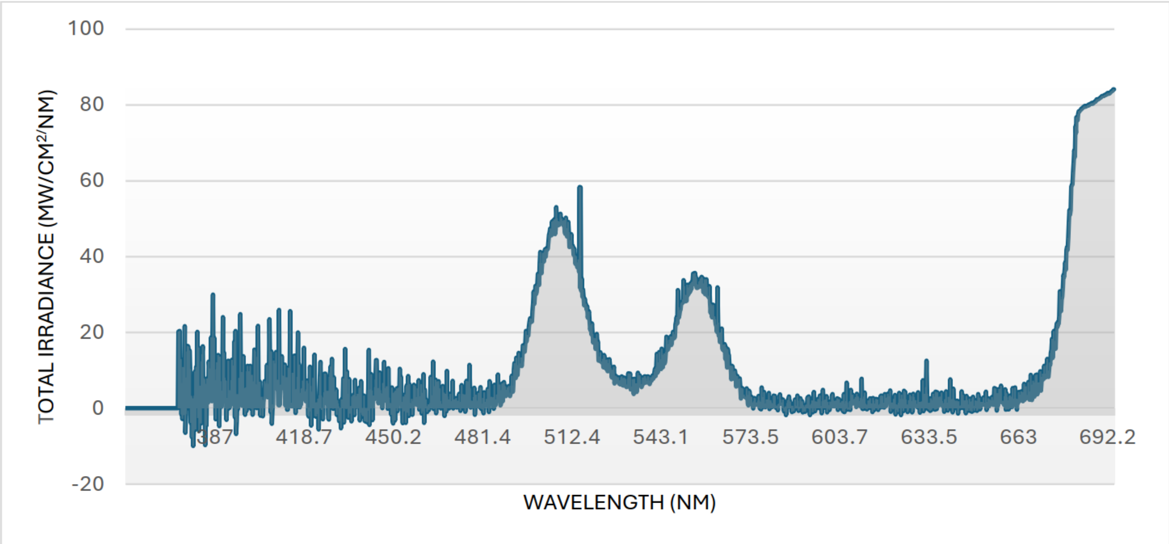

Figure 1: Crosstalk between HaagStreit BQ900 (1958) cobalt blue glass and Wratten No. 12 gelatine filter

Discussion: Recently, manufacturers of ophthalmic slit lamps have increasingly opted for expensive interference filters over traditional cobalt blue glass absorption filters. Enhancing cobalt blue glass with additional metal oxides could potentially reduce crosstalk, offering a more affordable solution for universal eye care.

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OVERCOMING CHALLENGES IN MINIATURIZING SPECTRAL SENSORS

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Miniaturized spectral sensors are essential for portable and unobtrusive measurement applications, including environmental monitoring, industrial analysis, and human light exposure monitoring. However, compact designs present challenges in ensuring the spectral measurement accuracy, power efficiency, battery life, and adaptability. This work focuses on developing a miniature spectral sensor system that meets strict dimensional limits (50 mm x 25 mm x 15 mm), lasts a week on a single charge of the battery, and is suitable in a variety of settings, such as a wearable or as a sensing device in a built environment.

The design process began by selecting a battery to fit the size and power constraints. This was then followed by optimizing component layout for the remaining space. The selected spectral sensor balanced power efficiency, size, and spectral resolution, while other components like flash storage and a temperature sensor were chosen to maximize functionality (within limitations). A microprocessor with Bluetooth low energy (BLE) and USB capabilities was chosen to meet data transfer and communication requirements. Mechanical robustness and waterproofing were ensured with a 3D-printed resin casing and careful component selection, particularly for the USB port. A layered diffusing film setup and the placement choice of the spectral sensing component optimized the directional response. An equally important design consideration was the firmware of the device, which was optimized for power saving by using low-power modes and managing sensor activation periods effectively.

The final design achieved compactness, power efficiency, and robustness. Calibration and machine learning techniques addressed the limitations of a low-resolution sensor by synthesizing a high-resolution spectrum from a low-resolution sample. Although this approach introduces challenges in traceability and complicates measurement uncertainty, it significantly improves the accuracy and quality of the spectral output. These solutions together culminated in a robust and a versatile miniaturized spectral sensor, supporting a broad range of portable sensing applications.

ON THE CHALLENGES OF METROLOGICAL TRACEABILITY AND MEASUREMENT UNCERTAINTY IN THE AGE OF AI

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Metrological traceability is the "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty" [1]. Traceability of a measurement made by an instrument therefore relies on that instrument being calibrated by an accredited laboratory, which can assign an uncertainty to the calibration and which can be traced through the calibration of reference equipment back to the SI.

Until now, instruments have normally operated in a more or less predictable way. A photometer's reading can be compared with a corresponding reading made by a calibrated reference instrument. The calibration results can then usually be interpolated with a reasonable degree of confidence—for example, if an illuminance meter has calibration points at 100 lx, 200 lx, 300 lx and 400 lx, and each has a correction factor of 1.02, then a measurement made at 250 lx could reasonably be assumed to also have a correction factor of 1.02.

However, instruments are now available on the market which produce a synthesised measurement result. An instrument may have limited performance but use a lookup table of measurements made on higher-quality equipment and machine learning to make an educated guess at a measurement outcome. While there are clearly applications where such a process can be beneficial, such as for miniaturised sensors, this does raise a number of questions regarding the use of the instrument, the calibration protocol, and how the calibration of the instrument is traceable to the SI.

This presentation will explore the issues raised above, and highlight the complications in relation to metrological traceability and evaluation of the measurement uncertainty of the calibration.

References

[1] Joint Committee for Guides in Metrology, International vocabulary of metrology – Basic and general concepts and associated terms (VIM), 3rd edition, JCGM, 2012 DOI: https://doi.org/10.59161/JCGM200-2012 (2012)

ABSTRACTS

Workshop

Investigations of Unexpected Developments in your Research – Experiences from the IEA SSL Annex Interlaboratory Comparison on Temporal Light Measurement (IC 2023)

INVESTIGATIONS OF UNEXPECTED DEVELOPMENTS IN YOUR RESEARCH – EXPERIENCES FROM THE INTERLABORATORY COMPARISON ON TEMPORAL LIGHT MODULATION MEASUREMENT (IC 2023)

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In recent years lighting market regulations (initiated in 2021 with the European Commission's updated Ecodesign Directive) have expanded to include limits on Temporal Light Modulation (TLM) from Solid State Lighting (SSL) products. In particular, for the TLM quantities of short-term flicker index, P_{st}^{LM}, and stroboscopic effect visibility measure, M_{vs}, upper limits have been defined for a range of LED products to ensure product quality and protect the health and safety of users.

Measurement of these specific limits for TLM relies on methodologies set out in International Electrotechnical Commission (IEC) Technical Reports - IEC TR 61547-1 and IEC TR 63158. At this time, the member governments of the International Energy Agency (IEA) 4E SSL Annex identified the urgent need for TLM accreditation for laboratories providing these required testing services.

They also noted that TLM proficiency test reporting from an international inter-laboratory comparison (IC) compliant with ISO/IEC 17043 [1] was needed to gain such status from the relevant accreditation bodies. To address this gap in the market, the IEA 4E SSL Annex developed and conducted an Interlaboratory Comparison on TLM Measurement (IC 2023).

IC 2023 compared measured TLM waveform data and the calculated quantities of short-term flicker index, P_{st}^{LM}, and stroboscopic effect visibility measure, M_{vs}, for four comparison artefacts - LED lamps. Deviations from reference values are shown in Figure 1.

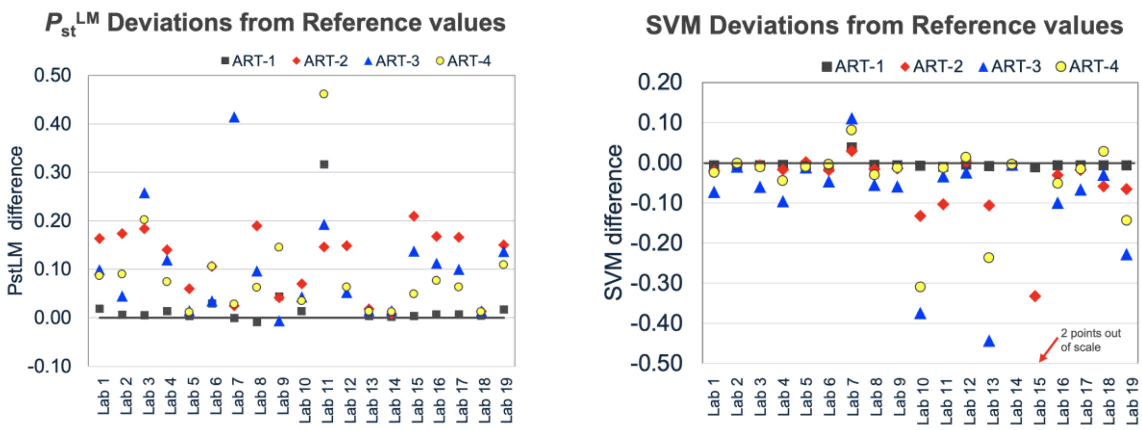

Figure 1 – Deviations of the participant labs' results from Reference values for P_{st}^{LM} (left) and *M*vs (right).

The large deviations in P_{st}^{LM} initiated a technical study on the influence of AC power supplies on measurement using halogen lamps with some of the IC 2023 participants, covering 27 different models of AC power supplies from 18 manufacturers.

This workshop will present the key findings and outcomes from IC 2023. This will include:

- Analysis of the results, which identify the need for more robust test methods – with improvement in required performance specifications for TLM instruments, test equipment, and guidance on determining measurement uncertainties. This workshop will highlight and discuss the results of IC 2023 in terms of recommended improvements to test methods.

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- Measurements from the technical study revealed variations of significance in M_{vs}, likely attributable to anti-aliasing filter performances in the low-pass frequency region.
- Measurements from the technical study also revealed large variations (more than one order of magnitude) in P_{st}^{LM}, depending on the laboratory-grade AC power supplies used. From the results of IC 2023, a method is proposed by which a laboratory can estimate the quality and subsequent measurement uncertainty of P_{st}^{LM} when using their specific AC power supply.
- The workshop will address how the IC 2023 results highlight the shortcomings of P_{st}^{LM} as a critical measure of TLM performance, and how the assessment and measurement of visible flicker might be improved through use of the Flicker Perception, M_{p}, metric.

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