IEA 4E SSL ANNEX – 3RD TERM, TASK 1 UPDATE

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2023-10-23 – IEA 4E SSL Annex Experts' Meeting, Toulouse

3rd Term Work Plan – Task 1

Objectives:

To study the health impacts on people of solid-state lighting, considering issues that concern both large fractions and small sensitive groups of the population.

Provide interpretation and guidance to policy-makers on setting appropriate requirements on health-related metrics for all forms of solid-state lighting.

Task 1 Team Members

Canada (NRC-CNRC Ottawa) :
Jennifer Veitch, Ashley Nixon

Jennifer Veitch is known internationally for her work on the human aspects of lighting.
Jennifer is the current president of the CIE.
Ashley Nixon has a PhD from the University of Ottawa and joined the NRC in September 2022. She currently works around the interplay between sleep/circadian rhythms, well-being, and environmental conditions, including light.

Australia (Australian Radiation Protection and Nuclear Safety Agency) :
Sarah Loughran, Lin Shen, Rohan Mate

Sarah Loughran is the Director of Radiation Research and Advice. She has contributed to ICNIRP guidelines on electromagnetic fields.

Lin Shen is a research Fellow at the Sleep and Circadian Medicine Laboratory at Monash University. Her current work includes examining light exposure, biomathematical modelling and personalised interventions for improving performance and wellbeing in shift workers across multiple industries

Rohan Mate is currently a Science Officer at ARPANSA and is also undertaking a PhD at Monash University investigating occupational RF exposures.

France (Centre Scientifique et Technique du Bâtiment) :
Christophe Martinsons

Christophe Martinsons is a lighting researcher studying the lighted environment in buildings and cities to improve people's well-being and health.

Update the 2014 Health Report

Health: broadly defined according to WHO (1948) definition: *Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*. (World Health Organization (WHO) 1948)

Do:

- Identify the psychological and physiological processes that light can affect, based on scientific evidence,
- Focus on areas where regulation or consumer advice might help to prevent adverse effects – identify how to identify products that work for people, or ways to apply them that will be beneficial (or avoid harm)
- Identify areas where metrics and test methods don't exist yet; but

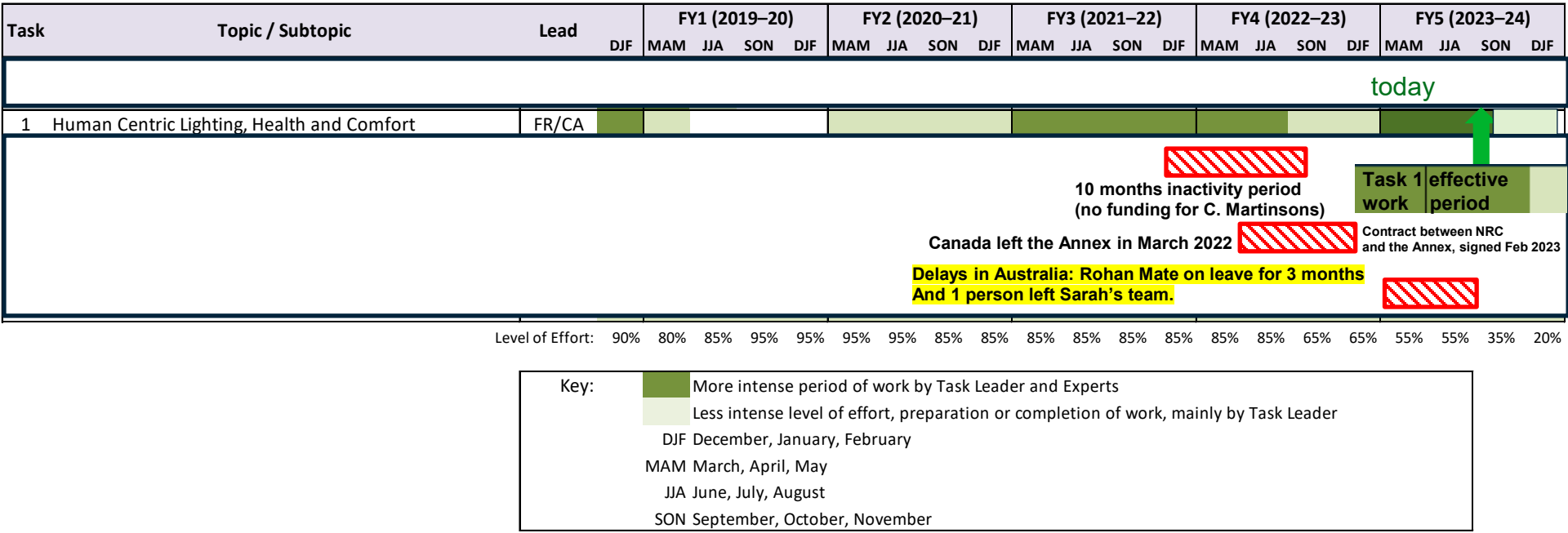
Don't:

- Specify the lighting design choices that deliver the desired conditions. This is a review of the evidence not a guide to how to do lighting correctly.

Revised Report scope

- **Literature search will encompass light effects on health regardless of source (to capture relevant papers).**
- **Conclusions will focus on products: lamps & luminaires (both consumer and commercial) for general interior lighting; street lighting; with the caveat that these are products designed to emit white light.**
  - Focus on emissions (from products), but with commentary on exposures (products in use)
- **Out of scope: automotive, light sources that are not lighting products (e.g., battery powered: toys, portable lamps) and displays**
- **In general, the conclusions will address products in the Task 6 performance tiers,**
  - When used as intended in everyday applications;
  - Highlighting risks that could emerge if used incorrectly by consumers (where engineering controls don't apply);
  - Providing guidance relevant to sensitive populations;
  - Excluding exposures during manufacturing or installation.

“Official” planned schedule



Key:	
	More intense period of work by Task Leader and Experts
	Less intense level of effort, preparation or completion of work, mainly by Task Leader
DJF	December, January, February
MAM	March, April, May
JJA	June, July, August
SON	September, October, November

Work plan

2019

Refine list of review topics, Develop review criteria; Assign topics to leaders.
Done, revised plan shown here.

Jan 2020 to Dec 2021

Literature search, develop databases; Review key papers, inter-compare reviewing results; Refine criteria; Continuous coordination with CIE & ISO committees; continue reviewing & developing recommendations.
Done for some sections, not for others.

Jan 2022 to Feb 2023

Inactivity period due to French agency ADEME's late commitment and Canada leaving the Annex
Contracting completed between NRC and the SSL Annex

Aug 2023 to Sep 2023 Delay from Australia : Rohan has been on 3 months extended leave, and a team member got a promotion to another part of the agency (two people down). Rohan gets back in mid-October, and ARPANSA are finalizing recruitment for the other team member so work can get back on track.

Jan 2023 to Oct 2023 Literature search, reading & analyzing papers and reports

Nov 2023 to Dec 2023 Writing (to be detailed by the team)
Jan 2024 to Feb 2024 Internal review of report by annex members and management committee, rounds of corrections
End of Feb 2024 Publication of report

Updated report chapters

2014 Report	Revision	Responsible team
Electrical safety	Out of scope, covered by existing standards. State this in Introduction	
EMF	Out of scope, covered by existing standards. State this in Introduction. This includes WiFi-enabled devices	
Glare	Yes, especially including new CIE report on UGR adaptation If possible, include subsection on identifying sensitive people & the conditions that cause problems for them	Christophe
Photobiological safety	Yes, but reduced length – no need to describe or derive action spectrum or risk categories (as was previously done) – being concise If possible, include subsection on identifying sensitive people & the conditions that cause problems for them	Christophe
TLM [formerly, flicker]	Yes If possible, include subsection on identifying sensitive people & the conditions that cause problems for them *LiFi / visible light communication?*	Jennifer with Ashley
"Non-visual" effects	Yes **Including discussion of CIE quantities for assessing effects.** **Part 1: circadian regulation; sleep; related medical (cancer, hormone…); physiological (cardiovascular, digestive, etc.)** **Part 2: mood; cognitive (vigilance, attention, etc.); well-being** If possible, include subsections on identifying sensitive people & the conditions that cause problems or that benefit them; Evaluate some product claims	Part 1: Sarah with Lin and Rohan Part 2: Jennifer with Ashley
Ecological effects of exterior lighting	This content has been moved to Task 3, where it fits better. Georges has a graduate student (Mohamed Ridha Kouki) working on the subject.	~~Christophe leads, with support from Jennifer & Sarah~~
Conclusions	Draw the individual issues together to help to identify what a "good" product might be and identify how they might combine	

Draw the individual issues together to help to identify what a “good” product might be and identify how they might combine

Literature Search Strategy

Common general strategy with specific outcome terms for each section

Supplemented with unabstracted papers of which we are aware (e.g., conference papers)

Part 1 – Lighting terms (IV)

Title & abstract: ("Light" OR lighting OR LED OR LEDs OR "solid state lighting" OR "light emitting diode" OR "fluorescent *" OR "incandescent *" OR "optical radiation" OR lamp OR luminaire)

AND

Title & Abstract: Section specific light terms – See TLM for example

Part 2 – Population/ Sample terms

AND

Title & Abstract: TBD

Part 3 – DV terms (by section)

AND

Title & Abstract: TBD

Part 4 – What we don't want to include

AND NOT

Title & Abstract: "colour preference" OR "color preference"

Filters

Scopus

Year (2012 – 2021)

Language (French & English)

Document type (Article, conference proceeding, review)

(**no** option to select human/animal studies as a filter)

Pubmed

Publication date (2012 – 2021)

Language (French & English)

Initial screening procedure

From title and abstract:

- Exclude papers that are out of scope
- List the reasons for being out of scope
- Retain included papers
- Verify that key papers are included

Identify categories of included papers from full text

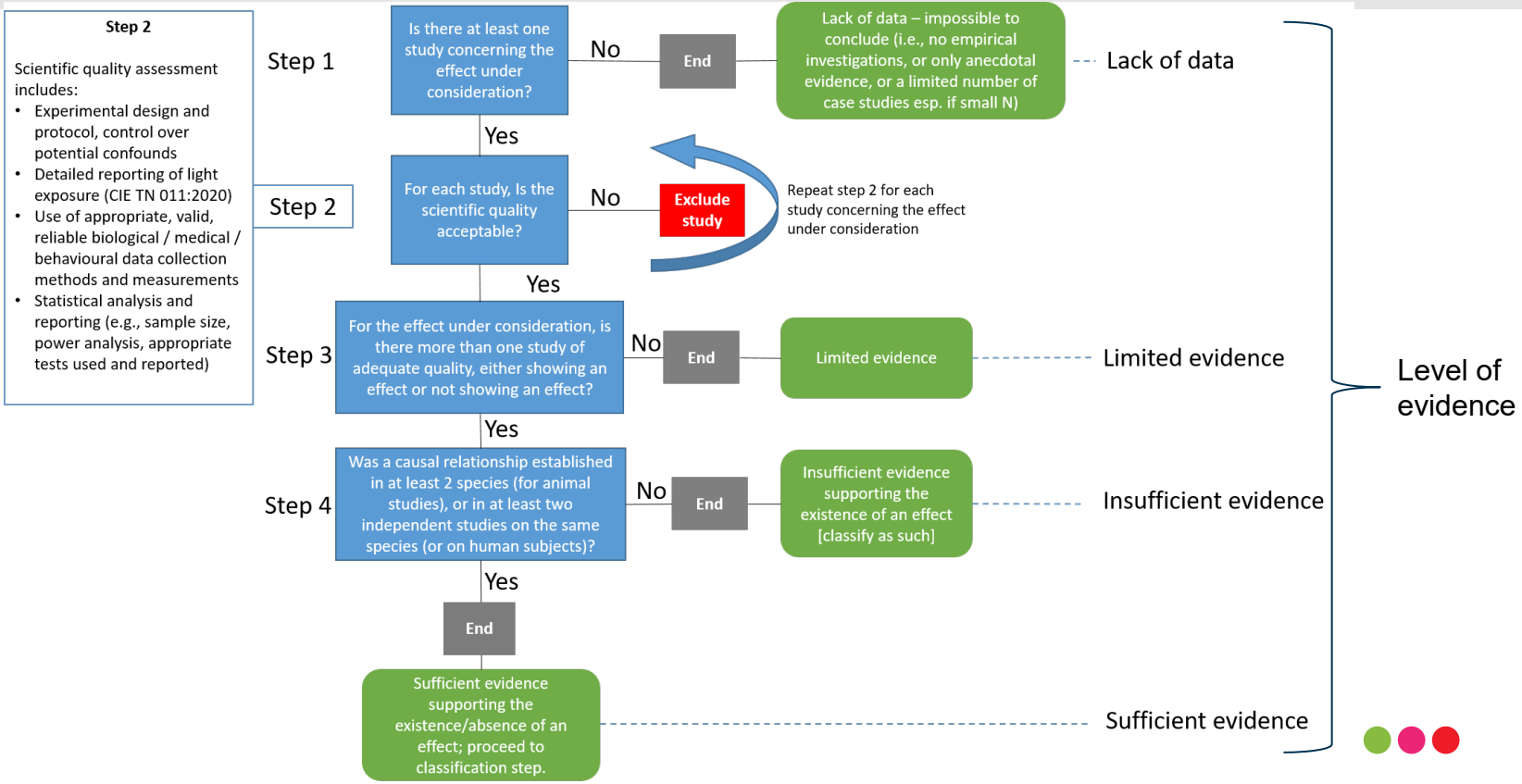
- Identify mutually exclusive categories (if possible)
- Assign each included paper to one category (if possible)

Eligibility screening

Use the following flow chart to :

- Apply quality criteria to include or exclude papers
- Assess the level of evidence brought by each included paper

Eligibility and assessment of level of evidence



Analyse effect(s) in each category

Effect categorization

Use the following charts:

- First chart applies to human impacts
- Second chart applies to animal and in-vitro studies

Effect categorization : Humans only

Procedure applicable to studies involving human subjects.

Examples: glare, headaches, visual performance, asthenopia, fatigue, mood, sleep, etc.

<table>
<tr><td colspan="2"></td><td colspan="5">Method of investigation on humans (adapted from Boyce 2021)</td></tr>
<tr><td colspan="2"></td><td><u>Observation</u>: isolated case reports, anecdotal evidence, very small number of subjects</td><td><u>Basic epidemiology</u>: Descriptive studies, ecological studies</td><td><u>Advanced epidemiology</u>: case-control studies (retrospective), cohort/longitudinal studies (prospective)</td><td><u>Interventional studies:</u> Field trials.</td><td><u>Laboratory or clinical studies:</u> Randomized trials in a controlled environment</td></tr>
<tr><td rowspan="6">Level of evidence on humans</td><td>Sufficient evidence supporting the existence of an effect</td><td colspan="2" rowspan="2">Observation and basic epidemiology cannot provide evidence (causal proofs), only hints or correlations.</td><td>Probable effect</td><td colspan="2">Proven effect</td></tr>
<tr><td>Limited evidence supporting the existence of an effect</td><td>Possible effect</td><td colspan="2">Probable effect</td></tr>
<tr><td>Insufficient evidence supporting the existence of an effect</td><td colspan="5" rowspan="2">The available data do not allow us to conclude whether the effect exists or not.</td></tr>
<tr><td>Lack of data</td></tr>
<tr><td>No effect indicated by the available data</td><td colspan="2">Observation and basic epidemiology cannot provide the evidence of “no effect”</td><td colspan="3">Effect not supported by data</td></tr>
</table>

Effect categorization: Animal models

Procedure applicable to outcomes measured on animal models or in-vitro, and applicable to humans

Examples: retinal damage, sleep disruption, etc.

		Level of evidence on animal models, in-vivo, ex-vivo or in-vitro studies				
		Sufficient evidence supporting the existence of an effect	**Limited** evidence supporting the existence of an effect	**Insufficient** evidence supporting the existence of an effect	**Lack of data**	**No effect** indicated by the available data
Level of evidence on humans (assessed from advanced epidemiological studies, or interventional studies, or controlled clinical/laboratory studies)	**Sufficient** evidence supporting the existence of an effect	**Proven effect**		**Probable effect**		
	Limited evidence supporting the existence of an effect	**Probable effect**	**Possible effect**			
	Insufficient evidence supporting the existence of an effect	**Possible effect**	**The available data do not allow us to conclude whether the effect exists or not**			
	Lack of data					
	No effect indicated by the available data					**Effect not supported by data**

Level of certainty for classification

For each effect under consideration	
CLASSIFICATION	**LEVEL OF CERTAINTY**
Impossible to conclude	
Possible effect	
Probable effect	
Proven effect or Effect not supported by data	

Process

Each team works on its own reviews and classifications.

Teams draw their own tentative conclusions.

We are at this stage now.

Teams review one anothers' conclusions.

Teams draft their chapters and have other teams review them.

Teams integrate content, then add final conclusions.

Full document sent to Annex for review and then revision.

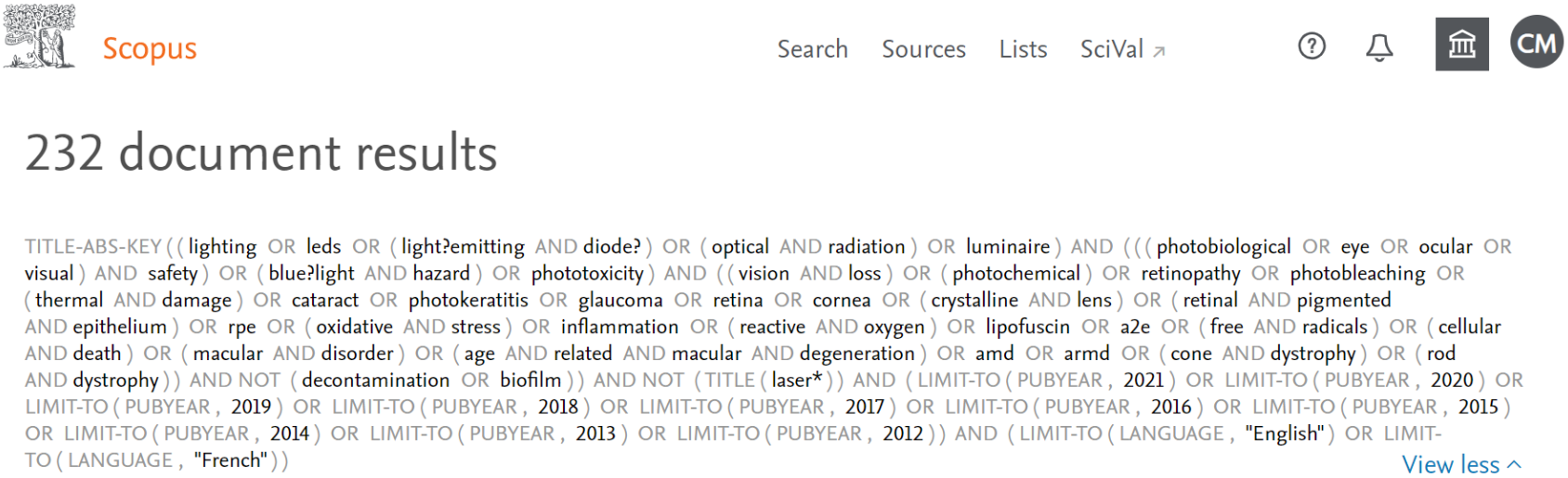
Search equation for Photobiological Safety (PBS) – December 2021

Part 1 – Lighting terms (IV)
Title & abstract: light* OR LED OR (light?emitting AND diode?) OR (solid state lighting) OR (fluorescent light*) OR (incandescent light*) OR (optical radiation) OR lamp OR luminaire
AND
Title & Abstract: ((photobiological OR eye OR ocular OR visual) AND safety) OR (blue?light hazard) OR phototoxicity
Part 2 – Population/ Sample terms
AND
Title & Abstract:

Sensitive populations (better not include them in search strategy)
Pre-existing conditions:
Retinal disease
RPE disease
Macular disorder
Age related macular degeneration (AMD, ARMD)
dystrophy of the photoreceptors, cone dystrophy, rod dystrophy
Aphakic, pseudophakic
lens implant
Age:
Children, Infant, adolescent, Elderly
Part 3 – DV terms (by section)

AND
Title & Abstract :
(vision loss) OR photochemical OR retinopathy OR photobleaching OR (thermal damage) OR cataract OR photokeratitis OR glaucoma OR retina OR cornea OR (crystalline lens) OR (retinal pigmented epithelium) OR RPE OR (oxidative stress) OR inflammation OR (reactive oxygen) OR lipofuscin OR A2E OR (free radicals) OR (cellular death) OR (macular disorder) OR (age related macular degeneration) OR AMD OR ARMD OR (cone dystrophy) OR (rod dystrophy)
Part 4 – What we don't want to include terms
AND NOT
Title & Abstract: decontamination OR biofilm OR laser

Search equation for Photobiological Safety (PBS)



Photobiological Safety (PBS)
Results of initial screening

Database	SCOPUS
Search date	Updated 11 Oct 2021
Time period covered by search	2011 to Sep. 2021
Identified from databases	232
Excluded (not relevant)	174
Identified from other sources	5+12
Relevant	75

Reasons for excluding records:

- Biology, medical and ophthalmology papers on retinal pathologies **unrelated to exposure to LEDs**.
- Articles on **blue light filters** and **intraocular (IOL) implants** with blue light filters.
- **Exposures not reflecting general lighting**: automotive headlights, medical treatments using light (photobiomodulation for instance), displays, screens, billboards, smartphones.
- **Luminaire design**, optical design, electrical engineering aimed to improve PBS.
- **Metrology**, measurement techniques of PBS.

Photobiological Safety (PBS)
Topics and eligibility screening (quality criteria)

Thematic categories	Number of included records	Number of eligible records
Biology, medical and ophthalmology papers on retinal phototoxicity from blue light, LEDs, lamps or luminaires (**blue light hazard**) In-vivo and ex-vivo animal studies (rat, mice, etc.) : 19 papers In-vitro studies (light interactions with retinal cells) : 7 papers	26	
Considerations and critics of animal models used in phototoxicity experiments	2	
Considerations about blue light hazard exposure limit values	2	
Epidemiology / link with age-related macular degeneration (AMD)	**4**	
Blue-light emission or exposure data of LED lamps and luminaires	12	
Myopia	**9**	
Other impacts (dry eye, cataract, skin ageing)	**3**	
Review papers	16	
Collective health appraisal reports	3 reports, 2 papers	

Current knowledge of the PBS of LEDs and SSL products

The blue light hazard is an adverse effect on the eye caused by LEDs used in lighting.

It concerns the retina. With SSL, exposure to IR and UV is dramatically reduced, in comparison with discharge lamps.

The retina can be injured by an intense/accute exposure to blue light through photochemical processes

- Oxidative stress
- Death of photoreceptor cells

Current exposure limit values:

- Defined by ICNIRP, based on work published in 1976 and 1989 (Ham et al.)
- Used to define the risk groups of lighting products in CIE S009 and IEC 62471 for the general adult population only

Sensitive populations:

- Children (transparency of the lens)
- Elderly people (retina is more susceptible to photochemical damage)
- People having a retinal disease
- People having an artificial lens implant

PBS research: new features, new questions

- Use of LEDs as the exposure source in the experiments
- Use of several animal models (not only rats – a nocturnal species)
- Very sensitive techniques to detect cellular death in tissues (TUNEL): new results on rodents
- Consideration of the circadian clock (retina is more sensitive at night)
- Investigations of combined exposure to long wavelengths
- Epidemiology / link with age-related macular degeneration (AMD)
- Myopia progression in children and adolescents
- Other impacts

LED are now used in in-vivo, in vitro and ex-vivo studies

LED lamps and luminaires have been used in all the research papers published in the period

- Exposure conditions are closer to real life scenarios
- Phosphor-converted white LEDs and colored LEDs are used (« real life » spectra)
- Halogen lamps are now seldom used
- Lasers were excluded from the literature search

New animal models are used

- ICNIRP data were based on results obtained on macaques (1976, 1989)
- Rodents are now used but are imperfect models (no macula in the retina, smaller eye, etc.)
- Dosimetry of retinal light exposure is critical. It relies on optical models of the eye. This is an important aspect when assessing the research
- A meta-analysis showed that after correcting for the eye parameters, the retina of rodents was found to be twice as sensitive to blue light damage as the retina of primates

PBS: potential effects to assess

POTENTIAL IMPACT 1 :

Retinal damage happens at lower exposure doses (in comparison with current ICNIRP basic restriction)?

POTENTIAL IMPACT 2 :

Exposure to LEDs during the circadian night can cause more retinal damage than during the day ?

POTENTIAL IMPACT 3 :

Protective effect of near-infrared and red light on the retina ?

POTENTIAL IMPACT 4 :

Lifetime exposure to LEDs is associated with a excess of risk of developing AMD later in life ?

POTENTIAL IMPACT 5 :

Chronic and prolonged exposure to LEDs is associated with the onset of myopia in children ?

OTHER POTENTIAL IMPACTS

POTENTIAL IMPACT 1:
Retinal damage at lower exposure doses?

Using new biological markers (TUNEL), retinal damage was detected at exposure levels below the ICNIRP threshold value:

- Factor of 10, 20 or 50 according to the considered study
- Damage to retinal pigmented epithelium was found in rodents, in addition to photoreceptor cell death

Consequence for SSL products:

- ICNIRP limits might be reduced in the coming years, leading to new definitions of risk groups and more stringent regulations on products emitting cold white light and blue light. [IEC/CIE 62471 is under review right now.]
- PBS standards and regulations are likely to be amended to include **sensitive populations**, which are not currently considered.

POTENTIAL IMPACT 2:
PBS depends on circadian clock?

The retina has its own endogenous biological clock

- The light sensitivity of the retina increases at night
- Many molecular and cellular processes are under the control of the retinal circadian clock

Consequence for SSL products:

- PBS regulations could become more stringent with SSL products used at night (outdoor lighting, nighttime and posted work for instance)
- Future lighting standards could prescribe reduced light levels in nighttime workplaces and for posted workers in general

POTENTIAL IMPACT 3: Protective effect of NIR/red light?

Red light seems to improve healing from photochemical damage induced by UV and blue light.

- Red light modifies mitochondrial activity and reduces the effects of oxidative stress
- Near-infrared (NIR) is also being investigated (1 paper 2023 – also in cognition/well-being review)

Consequence for SSL products:

- The industry might promote the development of LEDs having increased emission in the red part of the spectrum

POTENTIAL IMPACT 4:
Link between lifetime exposure to LEDs and AMD?

Are LEDs and SSL products linked to the earlier onset of age-related macular degeneration (AMD) ?

Conflicting views in the literature :

- The association between sunlight exposure and a higher risk of AMD is currently debated (conflicting studies and meta-analyzes)
- The extra-dose of light exposure due to SSL products is highly dependent on individual lifestyle and local climate (time spent indoors vs outdoors).

Consequence for SSL lamps and luminaires

- More epidemiological studies should be carried out

POTENTIAL IMPACT 5: Myopia progression in children and adolescents exposed to LEDs ?

Melanopsin and neuropsin regulate eye growth and focal length during childhood

- Exposure to **violet light** suppresses myopic elongation of the eye
- Wearing lenses with more violet light transmittance is associated with less myopic progression
- Time spent outdoors is the main determinant of violet light exposure

Consequence for SSL lamps and luminaires

- The lighting industry might promote the development of LEDs enriched in the violet range (380 nm – 410 nm) with the constraint of complying with blue light hazard limits
- Future lighting standard might recommend to use violet-enriched SSL products in schools and nurseries

The glazing/window industry might promote more transparent glasses to increase indoor exposure to short wavelength daylight

The ophthalmic industry might avoid recommending blue light filtering coatings on prescription glasses for children

PBS: other potential impacts?

Blue light and the dry-eye syndrome

- 1 paper

Blue light and the development of cataract

- 1 paper

Blue light and premature ageing of the skin

- 1 paper

Consequence for SSL lamps and luminaires

- More studies are needed…

Search equation for glare

Part 1 – Lighting terms (IV)
Title & abstract: light* OR LED OR (light?emitting AND diode?) OR (solid?state lighting) OR “fluorescent light*” OR “incandescent light*” OR “optical radiation” OR lamp OR luminaire
AND
Title & Abstract: glare
Part 2 – Population/ Sample terms
AND
Title & Abstract:

Sensitive populations (better not include them in search strategy)
Pre-existing conditions:
Age: Children, Infant, adolescent, Elderly

Part 3 – DV terms (by section)
AND
(disability OR discomfort) OR scotoma OR {after-image} OR {post-image} OR dazzle OR {dry?eye} OR accommodation OR migraine OR headache OR paroxysmal)
Title & Abstract :
Part 4 – What we don’t want to include terms
AND NOT
Title & Abstract: photovoltaic OR glazing OR window OR fa?ade OR shading OR laser

Search equation for Glare

Scopus

Search Sources Lists SciVal ↗

192 document results

TITLE-ABS-KEY (({light source} OR lighting OR led OR leds OR {solid state lighting} OR {light emitting diode} OR fluorescent OR incandescent OR {optical radiation} OR lamp OR luminaire) AND glare AND (disability OR discomfort OR scotoma OR {after-image} OR {post-image} OR dazzle OR {dry-eye} OR accommodation OR migraine OR headache OR paroxysmal) AND NOT (laser OR photovoltaic OR glazing OR window OR fa?ade OR shading)) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012)) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "French"))

View less ^

Glare:
Results of search equation and initial screening

Database	SCOPUS
Search date	Updated 11 Oct 2021
Time period covered by search	2011 to Sep. 2021
Identified from databases	192
Excluded (not relevant)	138
Identified from other sources	20
Relevant	74

Reasons for excluding records in initial screening:

- Glare of **image sensors**
- Glare from **daylight**
- **Glare tests** used in optometry
- **Glare filters** / colored glasses / photochromic glasses
- **Luminaire design**, optical design to minimize glare
- **Visual ergonomics**, rating of luminous environments (not about products)
- Glare from **other sources of light**: medical procedures using light, automotive headlights, traffic signals, billboards, computer vision syndrome, etc.
- **Metrology**, measurement methods of glare
- Computation of **glare metrics**, generic models

Glare:
Topics and eligibility screening (quality criteria)

Thematic categories	Number of references	Eligible records
Health effects of glare (muscular troubles, eye symptoms, migraine)	3	
Spectral and color sensitivity	8	
Non-uniform sources, multiple sources, moving sources, small sources	10 + 20	
Discomfort glare with indoor lighting SSL products	4	
Discomfort glare with outdoor lighting SSL products	7	
Age factor in disability and discomfort glare	4	
Glare and timing considerations	4	
Physiological response to glare: pupil size, eye opening, eye movements, bio-signals	9	
Review papers	5	
Collective health appraisal reports	7	

Current knowledge on glare from SSL products

Disability glare is pretty well understood (just a few papers)

- Does not necessarily cause discomfort. No direct health impacts but safety impacts to due temporary decrease in vision performance (falls, trip hazards, vehicle accidents, etc.)
- Veiling luminance due to light scattering in the eye : reduction of perceived contrasts (1 paper investigates basic mechanisms in the eye).
- Well-established empirical models (such as Adrian and Bhanji 1991)
- The age factor is well understood and taken into account in models and metrics such as TI (threshold increment)

Discomfort glare is the subject of most research papers on glare

- Indoor discomfort glare from new area light SSL sources such as OLED and backlit panels has been investigated in 1-2 papers
- Outdoor discomfort glare from road lighting and pedestrian zones
- Psychological outcomes (uneasiness, stress, attention deficit, etc.)
- Age factor is in still under investigation (3-4 papers investigating discomfort glare for age > 50)

Extreme forms of glare

- Temporary scotoma and after-images greatly alter vision, after exposure to very bright SSL source, no paper found with LEDs

Recovery time after disability glare (1 paper)

- Surprisingly, glare from cold-white LEDs would not be associated with a longer recovery time, compared with warm-white LEDs

New methods to investigate glare

Physiological responses to glare are investigated to provide a more objective evaluation and comprehension of discomfort glare

- Eye-tracking parameters (pupil diameter, blinking parameters, saccades parameters, degree of eye opening, squinting).

  Some correlations were found, such as: severe glare discomfort increased the speed of eye movement and cause larger pupil constriction. Larger variations of eye movement were found among seniors.

  Pupil diameter is also controlled by ipRCGs

- Electrocardiography (ECG), electroencephalography (EEG), electromyography (EMG: measurement of the intensity of the electrical activity on facial muscles near the eye)
  - all these methods were not conclusive (but there were only a few studies). More studies needed.
- fMRI was used to investigate correlations of glare with cortical activity. A correlation was found with hyperexcitability or saturation of visual neurons (1 study).

Glare: potential effects to assess

POTENTIAL IMPACT 1 :

Discomfort glare is increased by light emitted at short wavelengths by LEDs?

POTENTIAL IMPACT 2 :

Discomfort glare is increased by the non-uniformity of SSL sources?

POTENTIAL IMPACT 3 :

Increased glare from SSL is associated with migraines, neck pain, eyestrain and photophobia?

POTENTIAL IMPACT 4 :

Sensitivity to glare depends on circadian clock?

POTENTIAL IMPACT 1: Discomfort glare is increased by light emitted at short wavelengths by LEDs?

Current discomfort glare metrics (UGR) do NOT depend on spectrum (of source and background)

Discomfort glare from LEDs is influenced by spectral power distribution:

- Blue LEDs produce higher discomfort than white LEDs
- With increasing short wavelength radiance, discomfort glare ratings increase
- For white light, the CCT is not the proper metric, but high CCT is more glaring than low CCT
- Spectral sensitivity to discomfort glare depends on illuminance level and eccentricity in the field of view
- Conflicting results about the influence of background color

POTENTIAL IMPACT 2: Discomfort glare is increased by the non uniformity of SSL sources?

Non uniformity is a very important feature of LED arrays used in lamps and luminaires

UGR (discomfort glare metrics) underestimate glare from non-uniform sources

- LED linear arrays and matrices are associated by higher discomfort than uniform light sources of the same size and luminance
- Many papers of the subjects (30 papers between 2012 and 2016)
- Consensus was reached within CIE to define a modified UGR index
- CIE 232:2019 « Discomfort caused by glare from luminaires with a non-uniform source luminance »

$UGR' = UGR + 8 \log k^2$ with k being a non-uniformity factor

POTENTIAL IMPACT 3: Increased glare from SSL is associated with migraines, neck pain, eyestrain and photophobia?

Migraines and headaches triggered by glare (3-4 papers)

- Concerns sensitive people including (but not limited to) migrainers
- Influence of the ipRGC retinal cells (melanopic light exposure)
- Green light is a more powerful trigger, compared with other wavelengths

Neck pain (1-2 papers)

- Muscular pains associated with glare experienced during computer work

Eyestrain

- Visual fatigue (asthenopia)

Photophobia (light aversion, fear of light)

- Is mentionned as a possible consequence of migraines and dry-eye symptom triggered by discomfort glare

POTENTIAL IMPACT 4: Sensitivity to glare depends on circadian clock?

Effect of time of the day on glare sensations

- Circadian clock may modulate the glare response
- Other individual factors at play such as caffeine intake and individual chronotype
- A few papers, but only from one team

Not specific to SSL

Results of search equation: Temporal light modulation

Database	SCOPUS
Search date	2022-04-10
Time period covered by search	2014-01-01 to 2021-12-31
Identified from databases	1363
Identified from other sources	30 + 5
Excluded (not relevant)	1356
Relevant	43

Excluded papers and notes:

Flashing lights used for information; Reviews

Scientific quality assessment has not yet been performed.

Additional papers known to the team are added.

Notes:

- Our literature search strategy was imperfect as it failed to find Veitch & Martinsons (2020). However, with our existing knowledge we are confident that we have the key papers.
- We decided to include some papers from prior to 2014 because they appear not to have been cited in that review, and they are very relevant. These are counted in “included from other sources”.
- We will discuss the use of flash, and reviews, if they make useful comments in relation to included studies (including our own).

Topics of included papers
Temporal light modulation

Thematic categories	Number of included references
Flicker	7
Stroboscopic	13
Phantom array (PA)	8
Cognitive	8
Brain activity	3
Eye movements / ocular	6
Comfort/satisfaction/affect	12
Health	1
Predictive quantities	8
Sensitive	3
other	0

A question of relevance…

This review focuses on general lighting, but there is still work ongoing with respect to fundamental perception, particularly of the phantom array, e.g.
Park S, Lee C-S, Kang H, Pak H, Wilkins A. Visibility of the phantom array effect according to luminance, chromaticity and geometry. *Lighting Research & Technology*. 2020;52(3):377-388. https://doi.org/10.1177/1477153519867115

Many of these studies take place at adaptation luminances below general room lighting.

Our original screening criteria would exclude them. We plan to include them because of the importance of the fundamental work being performed.

PA has been shown to occur for non-luminous black-on-white tasks at ordinary room levels, although it is weaker than for the low-luminance, luminous task studies.

Key recent findings

Miller et al. 2023, in press

SVM does not predict PA visibility.

PA visibility peaks between 500 – 1000 Hz but it can be visible up to 6000 Hz.

Visibility of both phenomena is greater for rectangular than sine waves and for duty cycles of 10% and 30% more than 50%.

People with light sensitivities (Leiden Visual Sensitivity Scale) see SVM and PA more strongly.

Kong et al. 2023

Peak frequency 600 Hz. Visibility threshold for pure sine waves: 3% for red, 6-7 % for green and white.

At 80 Hz, visibility threshold for pure sine waves: 12% for red, 30-35% for green and white.

At 1800 Hz, visibility threshold for pure sine waves: 30-35% for red, green and white

Key recent findings

Veitch et al. (2023, in press)

TLM of 100 Hz or 500 Hz increased brain activity and arousal (indexed by pupil size) compared to no-TLM.

Cognitive interference, the difference in average reaction time between the relatively difficult and relatively easy Stroop task questions, was lower for 500 Hz than 100 Hz (i.e., performance was slightly better for the higher frequency).

This is controversial, even among this research team. It doesn't mean that 500 Hz would be good for everyone, because increased arousal does not help performance on complex tasks and because the Stroop task doesn't involve reading lines of text (which would likely trigger PA and for which TLM is known to have ill effects).

Results of search equation
Non-visual Effects Part 1 (Australia)

Database	SCOPUS and PubMed
Search date	Updated February 2023
Time period covered by search	2012 - 2022
Identified from databases	3045
Duplicates removed	1271
Excluded (not relevant)	1226
Relevant	548

Based on initial title and abstract search

Excluded papers

Included Topics
Non-visual Effects (Part 1, Australia)

Thematic categories	Number of references
Human studies with physiological, sleep or circadian rhythm outcomes In-vivo and ex-vivo animal studies (rat, mice, etc.) Review articles on the physiological, sleep or circadian rhythm outcomes	Screening not complete
Sleep	=
Circadian rhythm	=
Immune system	=
Hormonal changes	=
Neuroendocrine function	
Review papers	=

Results of search equation: Non-visual effects, part 2 (Canada)

Database	Scopus + PubMed
Search date	Updated August 8th 2023
Time period covered by search	2011 to Aug. 2023
Identified from databases	1675
Excluded (not relevant)	1624
Identified from other sources	1
Relevant	52

Excluded papers and notes:

- **Outcomes not related to mood, cognition, or well-being (e.g., glare)**
- **Non-polychromatic light sources**
- **Exposures not reflecting general lighting**: automotive headlights, medical treatments using light, displays, screens, billboards, smartphones
- **Metrology or luminaire design/modeling**

Scientific quality assessment has not yet been performed.

Additional papers known to the team are yet to be added.

Non-visual effects, part 2 – notes on categories

There is a fuzzy line between daytime alertness research and sleep/circadian rhythm research – this will need careful coordination with Australia.

There are relevant meta-analyses to be included, especially:

Brown, T. M., Brainard, G. C., Cajochen, C., Czeisler, C. A., Hanifin, J. P., Lockley, S. W., Lucas, R. J., Münch, M., O'Hagan, J. B., Peirson, S. N., Price, L. L. A., Roenneberg, T., Schlangen, L. J. M., Skene, D. J., Spitschan, M., Vetter, C., Zee, P. C., & Wright, K. P., Jr. (2022). Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. *PLoS Biology, 20(3), e3001571. https://doi.org/https://doi.org/10.1371/journal.pbio.3001571*.

They recommend 250 lx melanopic EDI all day, 10 lx mel EDI evening, >1 lx overnight. The daytime level is not achievable with electric lighting within current energy codes and regulations.

Next steps

Jan 2023 to Oct 2023 **Literature search, reading & analyzing papers and reports**

Nov 2023 to Dec 2023 **writing (to be detailed by the team)**

Jan 2024 to Feb. 2024 Internal review of report by annex members and management committee, rounds of corrections

End of Feb 2024 Publication of report