TECHNICAL REPORT

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# Light and lighting — Integrative lighting — Non-visual effects

*Lumière et éclairage — Éclairage intégratif — Effets non visuels*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by ISO/TC 274, Light and lighting in cooperation with the International Commission on Illumination (CIE).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

The content of this document represents the state of the art at the date of publication and it is not necessarily complete.

At present ipRGC-influenced responses to light (IIL responses) are often referred to as non-image-forming (NIF) or non-visual (NV) responses to reflect their distinction from perceptual vision. This document reflects that interest while allowing for the possibility for the accepted range of light responses driven by ipRGCs to expand as we gain more knowledge.

The light patterns of exposure can be beneficial or non-beneficial for humans depending on the setting, relating to spectrum, intensity, duration, and timing of the resulting light exposure.



# Light and lighting — Integrative lighting — Non-visual effects

## 1 Scope

This document provides an analysis and evaluation of the current state of the art with regard to ipRGC-influenced responses to light in applying this knowledge in the context of identified topics to be considered for use in lighting applications. This analysis has taken into consideration published scientific papers, use cases, reports, best-practice guidelines and recommendations, see Annex A. However, evaluation of the results will be based on scientifically validated findings.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE S 017:2020, *ILV: International Lighting Vocabulary*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

CIE maintains a terminology database for use in standardization at the following address:

— e-ILV: available at https://cie.co.at/e-ilv

**3.1**
**integrative lighting**
lighting integrating both visual and non-visual effects, and producing physiological and/or psychological benefits upon humans

Note 1 to entry: The term "integrative lighting" applies only to humans.

Note 2 to entry: Lighting primarily for therapeutic purposes (light therapy) is not included.

Note 3 to entry: The term "human centric lighting" is used with a similar meaning.

[SOURCE: CIE S 017:2020, entry 17-29-028]

**3.2**
**ipRGCs**
**intrinsically-photosensitive retinal ganglion cells**
retinal ganglion cells that are photosensitive by means of the photopigment melanopsin

[SOURCE: CIE S 026:2018, entry 3.11, modified — notes to entry omitted]

**3.3**
**ipRGC-influenced responses to light**
**ipRGC-influenced light (IIL) responses**
light-induced responses or effects that can be elicited by ipRGCs

Note 1 to entry: ipRGCs can play a role in both visual and non-visual responses to ocular light exposure. At present ipRGC-influenced responses to light are often referred to as non-image-forming (NIF) or non-visual (NV) responses to reflect their distinction from perceptual vision.

Note 2 to entry: ipRGC-influenced responses to light can be influenced by rod, cone and melanopsin inputs.

[SOURCE: CIE S 026:2018, entry 3.12, modified — notes 1 and 2 to entry revised]

**3.4**
**spectrum**
display or specification of the monochromatic components of the radiation considered

[SOURCE: CIE S 017:2020, entry 17-21-015, modified — notes to entry omitted]

**3.5**
**illuminance**
density of incident luminous flux with respect to area at a point on a real or imaginary surface

$$E_\mathrm{v} = \frac{\mathrm{d}\Phi_\mathrm{v}}{\mathrm{d}A}$$

where

$\Phi_\mathrm{v}$ is luminous flux;

$A$ is the area on which the luminous flux is incident.

Note 1 to entry: The illuminance is expressed in lux ($\mathrm{lx} = \mathrm{lm \cdot m^{-2}}$).

[SOURCE: CIE S 017:2020, entry 17-21-060, modified — notes 1 and 2 to entry omitted]

**3.6**
**electric lighting**
lighting by electric light sources

[SOURCE: CIE S 017:2020, entry 17-29-025, modified — notes to entry omitted]

**3.7**
**daylighting**
lighting for which daylight is the light source

[SOURCE: CIE S 017:2020, entry 17-29-031, modified — notes to entry omitted]



# 4 Practical implementation

## 4.1 General

Daylighting and electric lighting can affect psychological and biological functioning via image-forming and non-image-forming pathways.[1] Due to benefits and risks that relate to both pathways, experience has shown that both ought to be considered in the lighting design process. Knowledge about both image-forming and non-image-forming effects of lighting enables a better evaluation of the effects of daylighting and electric lighting on the human body.

In particular, the processing of information contained in the light beyond the forming of images plays a crucial role. Among other things, this additional information can influence the human internal clock and circadian rhythm. Besides the quantitative properties of light in the space as defined in CIE S 026:2018,[64] their temporal course is also of central importance. In practice, this means that a given lighting installation, which will always have non-image-forming effects (positive or negative), is managed in a suitable way in order to make positive use of the lighting.

All lighting installations will have effects on visual and physiological systems and can be intentionally designed for these effects. Best results will occur when the lighting designer works with a multidisciplinary team that includes occupational health experts, psychologists and others.

## 4.2 Beneficial aims

### 4.2.1 General

Considerations with regard to beneficial effects of light on humans focus on criteria for daylighting and electric lighting. These considerations can be identified in addition to the classic visual criteria as listed in ISO 8995-1 [65] and are not meant to affect the visibility and quality of vision. The considerations are grouped based on the strength of the scientific evidence at the time of writing. *Well-established* effects have a strong body of scientific literature to support them. *Moderate evidence* effects have a smaller scientific literature basis, but the evidence is consistent across studies. *Insufficient evidence* effects are emerging areas with less consistent effects and low consensus. This classification into levels of evidence only represents the status as at the end of 2019. Future research and publications might provide new insights resulting in a different level of evidence.

For the individual planning and implementation of integrative lighting, it is important to determine the desired outcomes and to prioritize their importance. This requires an understanding of the conditions to which users can be exposed over the entire day and night (e.g. during working hours, while at home or in transition). The effects of any light exposure also depend on the state of the individual, including their prior light history and their internal states (e.g. groups of individuals in an airport could have differing states of jet lag or circadian disruption).

Therefore, an informed design choice taking into account at least the following considerations is advisable:

— probability of achieving the desired outcome;

— net benefits of the desired outcome.

**IMPORTANT — The beneficial results of integrative lighting can only be achieved if it is planned and applied correctly by qualified specialists. Equally important is the correct operation of the lighting system by the actors/users involved.**

The scientific background to the conclusions below is presented in Annex A.

### 4.2.2 Well established

The following are well established:

Integrative lighting can synchronize and support the human circadian system. To achieve this goal, it is necessary to establish a strong daily light-dark pattern when planning and implementing daylighting and electric lighting.

Integrative lighting can be beneficial for both acute and long-term effects on well-being and mood states.

### 4.2.3 Moderate evidence

There is moderate evidence for the following:

Integrative lighting can have positive effects on sleep quality, sleep onset and performance on the subsequent days. This is partly based on avoiding a possible negative influence on the circadian system by the non-visual effects of the electric lighting.

Integrative lighting can activate, increase cognitive performance and reduce sleepiness during evening/night-time, which might be desirable for night work. These influences can also be sought in the short term, without taking into account a daily course.

Integrative lighting might benefit some individuals with medical conditions such as dementia[2,3].

#### 4.2.4 Insufficient evidence

There is insufficient evidence for the following:

Integrative lighting can activate, increase cognitive performance and reduce sleepiness during daytime. These influences can also be sought in the short term, without taking into account a daily course.

Integrative lighting could increase academic performance and concentration. There is some evidence from animal models, but limited evidence in human populations and none published showing longer-term benefits.

### 4.3 Avoidance of risks

#### 4.3.1 General

As already mentioned, the consideration of benefits and risks is an important task in the planning and commissioning of a lighting installation. In particular, risk prevention measures can be recommended for some specific applications and lighting situations.

#### 4.3.2 Well established

The following are well established:

Light exposures below established exposure limits published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) will avoid any risk of injury to the visual system.

Exposure to light during night shifts can reduce melatonin secretion and affect the timing of sleep. This is one possible contributing factor in the aetiology of some adverse health effects of night shift work.

If night-shift work cannot be avoided, lighting patterns need to be planned to take into account the shift schedule, and users need to maintain 24-hour patterns of light and dark exposure to achieve the intended results. Darkness during sleeping hours would be good practice. The negative health impacts of most night-shift schedules cannot be fully mitigated by integrative lighting.

For many people insufficient levels of lighting during the daytime can have negative physiological effects. Too much light at the wrong time for the wrong activity and person can be detrimental to well-being. The challenge is to understand the user group and needs well in order to avoid mismatches.

#### 4.3.3 Moderate evidence

There is moderate evidence for the following:

High light exposure in the evening hours can cause sleep disturbances.

Interactions between the circadian system and safety at work have to be taken into account (e.g. the need to maintain alertness in night-shift medical staff throughout the shift and on the travel home).

Different light exposures might be needed for different age groups to account for changes in short-wavelength transmission in the eye. Young children are more sensitive to short-wavelength optical radiation than adults, because of higher transmission of the lens of the eye at these wavelengths.

#### 4.3.4 Insufficient evidence

There is insufficient evidence for the following:

If night-shift work cannot be avoided, filtering out short wavelengths during night work could maintain alertness with less circadian disruption.

Very high intensity "blue enriched light" can compete with natural light as a zeitgeber. This can counteract seasonal adaptation of the biological clock. Thus, dynamics of lighting aimed at biological effects have to consider seasonal changes in natural light exposure.

### 4.4 Implementation Considerations

In planning an integrative lighting installation, it is important that the aims above be achieved in concert with the established aims of a high-quality lighting installation, such as providing positive and avoiding negative physiological effects, supporting visual tasks, providing good colour rendering and spatial brightness. This requires a careful consideration of several factors, including:

— occupant profile (e.g. age distribution, visual conditions, state of health) of the expected users of the space;

— activity profile: predominantly transitory, predominantly sedentary, predominantly active but at a fixed position, etc.; and

— predominantly controlled (e.g. institutionalized) or predominantly uncontrolled population.

These factors can be reviewed to produce an assessment of:

— potential health conditions expected to be encountered;

— generalized expectations of sleep patterns (e.g. it can be reasonably expected that teenagers will generally have different sleep routines compared to elderly occupants);

— the quantity of light required at the eye to achieve a defined circadian stimulation, which will differ between individuals.

NOTE These lists are not exhaustive.

Achieving the aims will not depend on light sources and lighting installations alone, but requires consideration of control systems, training on their appropriate use, and user understanding and acceptance. Considerations include:

— Interindividual differences (e.g. chronotypes, sensitivity to light) cannot fully be considered in a fixed design, but could be managed using controls and local modifications.

— Conflicts of priorities between different needs (of the same or different users in one space) can occur. This has to be solved by the designer in a way that does not compromise lighting quality.

— Problems can occur when individuals have control over the lighting but inadequate instructions on how to use it in a beneficial way. Provision of detailed and easy to understand instructions is likely to mitigate this problem.

— The power of building operators (such as employers) to decide on the time and duration of activation can result in problems of acceptance of lighting. This needs to be properly addressed when a lighting installation is introduced, see last point above. This problem could be mitigated by clearly informing occupants about the functioning and objectives of this lighting installation.

### 4.5 Conclusion

Besides visual and psychological effects, every form of lighting affects the human body via the ipRGC-influenced pathway. The light patterns of exposure can be beneficial or non-beneficial for humans depending on the setting relating to spectrum, intensity, duration, and timing of the resulting light exposure. At the same time, all existing visual and psychological aspects of lighting design remain completely valid. Lighting schemes designed to achieve ipRGC-influenced effects by following the course of daylight and that also follow existing guidance for lighting quality are likely to achieve beneficial integrative lighting objectives. The many factors to be considered make this a challenging task. Thus, the involvement of professional lighting designers who are familiar with the opportunities and risks that are associated with ipRGC-influenced responses to light can lead to the best outcomes.

# Annex A
(informative)

# Scientific background

## A.1 General

### A.1.1 Photodetection

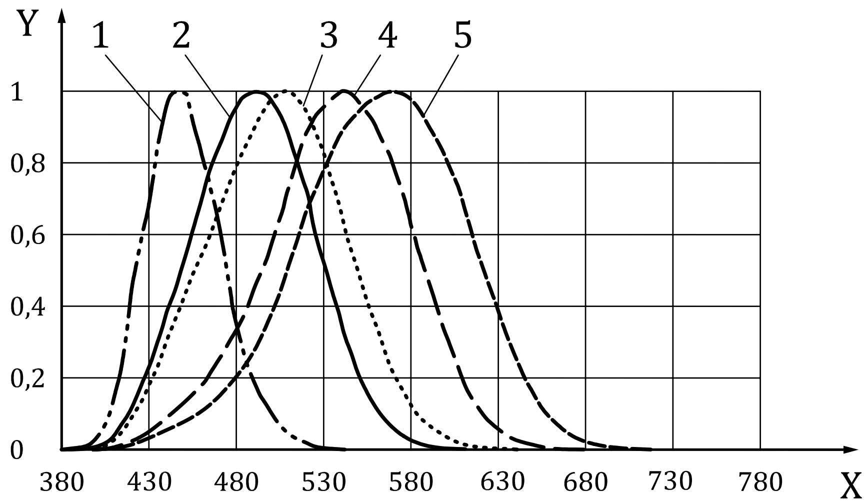
Optical radiation that reaches the retina stimulates responses from at least five photoreceptive cell types:

— The rods respond at low ambient light levels (as low as approximately 0,005 cd $m^{-2}$) and saturate at the levels typical of daytime. They are spread across the entire retina but are less numerous in the fovea. They have low spatial resolution and do not detect colour; thus they are primarily responsible for scotopic vision.

— Long-, medium-, and short-wavelength sensitive cones predominate in the fovea and are responsible for resolution of fine details and colour vision. They are the primary photoreceptors responsible for photopic vision (>5 cd $m^{-2}$).

— Intrinsically-photosensitive retinal ganglion cells (ipRGCs)[4];[5];[6];[7];[8] are irradiance detectors, detecting the presence of light but not resolution of image details. As compared to the rods and cones, the response threshold is higher and the temporal resolution is lower. The ipRGCs were identified from a long line of research that focused mostly on the effects of night-time light exposure on the suppression of the hormone melatonin, for which reason the active photoreceptive molecule in these cells was named melanopsin. There are at least five subtypes of ipRGC, but the precise response characteristics and projections of each is not yet known [9];[10];[11];[12].

Each photoreceptor has a characteristic spectral efficiency function, or action spectrum. CIE S 026:2018[64] defined the action spectra for the five cell types, illustrated in Figure A.1 below. The action spectrum for the ipRGCs, known as the melanopic spectrum, peaks at 490 nm.




**Key**

X $\lambda$ in nm

Y relative spectral sensitivity

1 $s_{sc}(\lambda)$

2 $s_{mel}(\lambda)$

3 $s_{rh}(\lambda)$

4 $s_{mc}(\lambda)$

5 $s_{lc}(\lambda)$

SOURCE: CIE S 026:2018[64]

**Figure A.1 — Relative action spectra for the short (sc), medium, (mc) and long (lc) type cones, the rods (rh) and ipRGCs (mel)**

When the ipRGCs were identified in the early 2000s, it was thought that there were two separate retina-brain systems, one for visual perception mediated by rods and cones, and one for so-called “non-visual” effects. This is now known not to be the case, as evidence mounts for complex interconnections between the cell types. For instance, the ipRGCs contribute to the regulation of pupil size[13] as well as to the regulation of circadian rhythms[5];[7]. For this reason, it is incorrect to use the phrases “circadian lighting” or “non-image-forming effects” or similar phrases to describe integrative lighting responses. If one wishes to refer specifically to effects involving the ipRGCs, then the phrase “ipRGC-influenced light (IIL)” responses is preferred [as specified in CIE S 026:2018[64]].

### A.1.2 Parameters influencing ipRGC light responses

Five parameters are known to affect IIL responses to light exposure: the spectrum, intensity, duration, timing, and daily pattern of exposure. Integrative lighting recommendations will need to consider all of these parameters simultaneously.

The melanopic action spectrum standardized in CIE S 026:2018[64] was, as noted above, derived largely from investigations in which the usual night-time release of melatonin during darkness was suppressed by exposure to light to varying degrees depending on the wavelength of the exposure.[14] At any given wavelength, the intensity of the light exposure also influenced the response. This dose-response function was an essential element in demonstrating the existence of ipRGCs. Thus, to increase IIL responses one might increase the intensity of exposure to the wavelengths to which the ipRGCs are most responsive (as recommended in CIE 158:2009); however, this does not imply that one must also reduce the intensity of exposure to other wavelengths, which support responses by the other photoreceptors.

As noted by Lucas et al.[13] for pupil size and seen by Gooley et al.[16] for melatonin suppression and circadian phase resetting, the role of ipRGCs and other photoreceptors changes over the duration of light exposure and in different ways depending on the intensity of the exposure. For instance, Gooley et al.[16] found that cone photoreceptors contribute to circadian phase resetting at low irradiances and early in an exposure, but ipRGCs dominate at high irradiances and over longer exposures. However, exposures need not be continuous to be effective at eliciting IIL responses, at least for overnight circadian phase resetting[17].

It has long been known that light responses vary depending on the time of the exposure,[18] with the system sensitivity depending on when the exposure occurs. Circadian phase resetting is the clearest example of this. Light exposure before the nadir of the daily rhythm of core body temperature (i.e. in the late evening or overnight) will delay the circadian rhythm, so that the nadir will occur later. Light exposure immediately after the nadir of core body temperature (i.e. early morning) will advance the circadian rhythm, so that the nadir on the following night will occur earlier.

The pattern of light exposure over the day has been known as an influence on subsequent IIL responses for some time[19];[20];[21]. Nonetheless, it remains unclear how to use this knowledge for lighting applications, because the daily pattern of light exposure can vary widely from one individual to another and the possible combinations of light exposure patterns are infinite. Except for individuals who remain in one environment for nearly all of the time (e.g. in patients in hospitals or care homes; those in custody), daily patterns of light and dark exposure are mostly determined by individual behaviours, creating a concept of “light hygiene” under personal responsibility. Much remains to be known about the desirable “spectral diet” for well-being [22].

## A.2 Scientific background for implementation guidance

### A.2.1 Beneficial effects

#### A.2.1.1 Well established

Integrative lighting can synchronize and support the human circadian system. In order to achieve this goal, it is necessary to establish a strong daily light-dark pattern when planning and implementing daylighting and electric lighting.

The human circadian clock oscillates independently with a frequency slightly longer than 24 hours, but exterior signals maintain the 24-hour daily rhythm. The strongest of these signals, or *zeitgebers*, is the pattern of light and dark exposure[15];[23]. Regulation of daily rhythms of sleeping and waking, immune system functioning, digestion, and other physiological processes, requires a period of exposure each day to both bright light and darkness[15].

Integrative lighting can be beneficial for well-being and mood states, both acute and longer-term.

There is good evidence from several field investigations that people who receive a higher light exposure each day experience more positive moods and report better overall vitality[15];[24] than those who do not. Social interactions immediately following a period of bright light exposure have been shown to be more co-operative and less quarrelsome.[25] The precise mechanisms for these effects are not known. The CIE concluded in 2004 on the basis of these results that most people appear likely to benefit from higher light exposures than those to which they are currently exposed.[15] It is not yet known exactly what light exposure is desirable (see A.2.1.2 and A.2.1.3).

#### A.2.1.2 Moderate evidence

Integrative lighting can have positive effects on sleep quality, sleep onset and performance on the subsequent days. This is partly based on avoiding a possible negative influence of the circadian system by the non-visual effects of the electric lighting.

When the circadian system is well regulated by a daily pattern of light and dark exposures, sleep quality and quantity are greater[26];[27];[28]. There is some evidence from field investigations that a higher light exposure during the day results in better sleep on the following night[27];[29];[30];[31]. The present data do not identify the best specific intensity, spectrum, or duration of this light exposure, although they do suggest that higher light exposures in the morning are generally more efficacious than those later in the day.



Integrative lighting can activate, increase cognitive performance and reduce sleepiness during evening/night-time. These influences can also be sought in the short term, without taking into account a daily course.

There is broad agreement that light exposure at night can increase alertness, reduce sleepiness, and improve cognitive performance[32];[33]. This is thought to be related to the immediate suppression of nocturnal melatonin secretion. This can be considered a benefit for those working night or evening shifts, but see A.2.2 for related risks to be avoided.

Integrative lighting might benefit some patients with conditions such as dementia.

A rigorous Cochrane Review of this literature concluded in 2014 that light therapy does not show benefits for patients with dementia,[3] but this review protocol included only randomized controlled trials of light therapy. A broader inclusion of research designs, including studies that combined non-pharmacological treatments, found that sleep efficiency improved in multi-modal treatments that included light exposures.[34] Several investigations that have used architectural lighting changes to increase light exposure by day, both in residential care homes and private homes, have reported improved sleep and reduced restlessness following increased light exposure[35];[36];[37]. Each study increased light exposure in a different way, some with the specific intent to increase IIL by targeting the ipRGCs; nonetheless, it is not clear what combination of spectrum, intensity, and duration can be best for this purpose beyond an increase in total light exposure, preferably early in the day.

### A.2.1.3 Insufficient evidence

Integrative lighting can activate, increase cognitive performance and reduce sleepiness during daytime. These influences can also be sought in the short term, without taking into account a daily course.

Many investigators have tested the hypothesis that increased daytime light exposures in controlled laboratory experiments can cause immediate changes in cognitive performance. Two systematic reviews have recently examined the cumulative evidence for such effects[38];[39]. Both concluded that there is only weak evidence for effects on objective measures of performance. Most of the papers they reviewed found weak or inconsistent results. Lok et al.[38] found that only three of 17 papers with performance measures showed positive effects of light exposure on performance; for Souman et al.,[39] only two of 12 papers showed positive effects on performance. The two reviews concurred in finding that papers with self-reported measures of alertness were more consistent in demonstrating higher self-reported alertness in response to higher light exposures. However, even these results were not consistent in showing dose-response relationships. Lok et al.[38] also reviewed the literature on objective physiological measures of alertness, and there too revealed that the results are inconsistent. Both review teams concluded that the quality of many of the studies was poor, with low statistical power resulting from small sample sizes being a frequently cited problem. The fact that it is generally impossible to keep participants from being aware of the light manipulation if they experience more than one experimental condition makes expectancy biases or a placebo effect more likely sources of false conclusions.

Pachito and colleagues[40] examined field investigations that tested the effects of light exposure on alertness and mood in daytime workers, using the rigorous Cochrane Review methodology. Their review began with 2 844 possible references but winnowed this to five papers by excluding work that did not meet the Cochrane criteria for research quality. The result of this review was the conclusion that, based on low-quality evidence, light of a higher correlated colour temperature (CCT >5 000 K was the cut-off) might increase alertness, but not improve mood, among daytime workers. The field studies, like the laboratory studies, suffered from small sample sizes, possible bias in the data, and inadequate reporting of research method details. These reduce confidence in the conclusions.

Integrative lighting could increase academic performance and concentration. There is some evidence from animal models, but limited evidence in human populations and none published showing longer-term benefits.

A series of field intervention tests of a variable-lighting system that implemented specific settings for teachers to use during different teaching periods (high illuminance, high CCT for concentration;



low illuminance, lower CCT for periods when calm was wanted) showed some effects of greater attention during the high illuminance, high-CCT setting in comparison to conventional classroom lighting[41];[42];[43], but not in all classrooms nor on all tests. Moreover, none of the investigations used the correct research design (a nested design with students in classrooms, for which classrooms are the unit of analysis), nor was there any attempt to control for pre-existing differences between the classes (e.g. in ability or socio-economic status). Furthermore, the only lighting setting labelled as being for concentrated work was the high illuminance, high CCT condition; it is possible that that the effect on attention was the result of the association between that setting and focused work, rather than being an IIL response.

One study controlled the vertical photopic illuminance but increased the melanopic irradiance by adding indirect high-CCT fluorescent lamps to the lighting system in three experimental classrooms[44] compared to one classroom with standard lighting. The lighting systems were static throughout the school days (unlike the studies described above). Post-tests after five weeks of the lighting intervention were designed to differentiate between the long-term effect of the intervention and the acute effect of the enriched lighting. Both processes appeared to operate, such that students tested under the intervention lighting showed improved concentration whether or not they had experienced the intervention during the preceding weeks, but those who had experienced the intervention also showed a greater reduction in errors. One weakness of this study design, however, is the fact that it did not use the nested research design, meaning that although the lighting condition varied between the classrooms, there could have been other differences between the classrooms that would have explained these effects. Moreover, the four classrooms were in two different schools, and differed in the age groups and in the class start times.

Fisk and colleagues[45] reviewed both the human and animal research concerning the effects of light exposure on cognitive performance and learning. Cognitive processes also show circadian rhythms, making it difficult to differentiate between light exposures that cause direct effects on cognitive processes and indirect effects that result from changes in circadian rhythms. Fisk et al.[45] proposed that light affects cognitive processes indirectly through parallel influences on sleep, circadian rhythms, and acute alertness, and argued for stronger research designs that would clarify the contributions of the various processes.

### A.2.2 Risk avoidance

#### A.2.2.1 Well established

> Light exposures below established exposure limits published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) will avoid any risk of injury to the visual system.

The IEC and the CIE jointly published a risk assessment system for establishing the photobiological safety of lamps and lighting systems.[46] Sliney, Bergman, and O'Hagan[47] described the development of this standard and its scientific basis. There is no evidence that white light sources used for general lighting pose any risk to health, regardless of their spectral power distribution. Media suggestions that LED lighting with relatively high short-wavelength emissions (e.g. phosphor-converted blue LEDs) pose a risk to eye health have been shown to be unsubstantiated, as even long-duration exposures to such sources do not approach the exposure limits and remain considerably lower than exposures received from viewing the sky on a clear day[48].

> Exposure to light during night shifts can reduce melatonin secretion and affect the timing of sleep. This is one factor in the aetiology of some adverse health effects.

Most of our knowledge of ipRGCs derives from studies in which light exposure at night suppressed melatonin. As noted above, the effect of light exposure on subsequent sleep depends on its timing in relation to the circadian rhythm, a fact that has been recognized for decades. If the light exposure is irregularly scheduled, then melatonin secretion and other circadian rhythms that depend upon it (including the sleep-wake cycle) will be disrupted. These disruptions are among the factors that contribute to adverse health consequences associated with prolonged night-shift work[49];[50];[51], including obesity, cardiovascular problems, and cancer. Melatonin disruption associated with exposure to light at night was among the factors that led to the classification of night-shift work as a potential carcinogen by the International Agency for Research on Cancer in 2007 [52].

> If night-shift work cannot be avoided, lighting patterns need to be planned to take into account the shift schedule, and users need to maintain 24-hour patterns of light and dark exposure to achieve the intended results. Adequate exposure to dark during non-work hours is critical.

The need for a regular daily pattern of light and dark exposure to maintain regular circadian rhythms is undisputed, and was identified by the CIE as among the principles of healthy lighting in 2004.[15] Work schedule solutions combined with employee habits have been proposed, based on empirical guidance, that are designed to aid in the maintenance of proper circadian regulation using timed 24-hour patterns of light and dark exposure for those who must work shifts[53];[54].

> Too much light at the wrong time for the wrong activity and person can be detrimental. The challenge is to understand the user group and needs well in order to avoid mismatches.

As noted above, the effect of light exposure on the circadian system depends on when the exposure occurs in the circadian cycle[18];[54]. Bright light exposure at night for a person whose intended activity is sleep will interrupt melatonin secretion and reduce sleep quality; whereas the same light exposure at night for a night-shift worker might improve alertness and facilitate necessary work performance. Lighting installations must begin from an understanding of the user group and its needs, paying particular attention when there are multiple user groups with differing needs in the same space (e.g. in health-care settings).

#### A.2.2.2 Moderate evidence

> High light exposure to the ipRGCs in the evening hours can cause sleep disturbances.

The effect of evening light exposure on circadian regulation was discussed above. Regularly extending the apparent day length by remaining exposed to high illuminance in the evening will delay the circadian phase. Here, we consider the effects on acute melatonin secretion and sleep on the same night. There are several laboratory studies that demonstrate these effects in adults. For example, Chellappa et al.[55] found that a 2-hour evening exposure to 40 lx (photopic illuminance) from a 6 500 K compact fluorescent lamp (CFL) reduced melatonin secretion in comparison to 40 lx from a 3 000 K CFL or an incandescent lamp, and it also led to reduced subjective sleepiness in the late evening. However, there was no measurement of the subsequent sleep quality. Similarly, Chang et al.[56] reported that four hours of reading a self-luminous electronic book, versus reading a printed book under the same low ambient lighting, reduced pre-bedtime sleepiness, reduced melatonin secretion, delayed sleep onset, and reduced morning feelings of alertness. A systematic review of the literature on the effects of screen time on sleep among children under five years of age found an association between greater daytime or evening screen use and poorer night-time sleep.[57] However, the evidence is not sufficient to set light exposure criteria to limit these effects.

> Interactions between the circadian system and safety at work have to be taken into account (e.g. the need to maintain alertness in night-shift medical staff throughout the shift and on the travel home).

As noted above, individuals bear responsibility for their personal light hygiene. It can be desirable to use bright light exposure to maintain night-time alertness during shift work, and there are recommendations for the scheduling of such exposures in relation to circadian rhythms[53];[54]. Continuous exposures appear not to be necessary,[58] although precise guidance remains lacking. Blue-filtering glasses have been recommended for use on the drive home, to maintain alertness while promoting readiness for sleep after the shift[53];[54].

> Different light exposures might be needed for different age groups to account for changes in short-wavelength transmission in the eye.

> Young children are more sensitive to high short-wavelength content than adults.



Age-related changes in vision are fairly well understood, for instance it is well known that the lens yellows with age and transmits less short-wavelength radiation[59];[60]. CIE S 026:2018[64] includes possible correction functions that can be applied to calculate the relevant α-opic exposures for viewers of various ages. These functions are averages, whereas the individual differences in transmission changes are large.[60] Moreover, the use of intraocular lenses to treat cataracts adds to the variability in spectral transmission among older adults. CIE 227:2017[61] provides guidance on lighting needs for older people and those with visual impairments.

### A.2.2.3 Insufficient evidence

> If night-shift work cannot be avoided, filtering out short wavelengths during night work could maintain alertness with less circadian disruption.

Knowing that disrupted circadian rhythms are detrimental to health, some investigators have sought to create light interventions for night shift workers that will maintain alertness at work while not suppressing night-time melatonin secretion. This is particularly relevant when the work schedule changes frequently enough that a complete circadian adjustment to the new schedule is impossible. One proposed technique is to reduce short-wavelength exposures (e.g. by using blue-filtering glasses) while maintaining or increasing longer-wavelength exposures[50];[54]. Those who have recommended this approach note that it lacks a robust research foundation. Effectively, this technique decreases melanopic irradiance while increasing m-cone-opic and l-cone-opic irradiance.

> Very high intensity "blue enriched light" can compete with natural light as zeitgeber. This can counteract seasonal adaptation of the biological clock. Thus, dynamics of lighting aiming at biological effects have to consider seasonal changes in natural light exposure.

One investigation has followed groups of people over a seasonal change (January – February in the northern hemisphere) during which time one group experienced a lighting intervention during their working days to increase melanopic irradiance (office lighting using an 8 000 K fluorescent lamp), whereas the other group continued with the conventional 4 000 K lamp.[62] The conventional group´s participants showed a seasonal shift in waking times that responded to the advancing dawn, but the intervention group did not show this change. The implications of this finding for overall health and well-being are unclear.

Survey data show that the timing of dawn entrains sleep-wake cycles,[63] but that this entrainment is lower for people who live in larger cities. The use of electric lighting and social demands (e.g. work and school schedules) make annual patterns imperceptible to many people.[64] Any implications for lighting practice are unclear.