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TECHNICAL REPORT

Research Roadmap for Healthful Interior Lighting Applications

CIE 218:2016

UDC: 28.97.972

Descriptor: Interior lighting

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3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen berichtet und überprüft werden, sowie neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 3-46 of Division 3 "Interior Environment and Lighting Design" and has been approved by the Board of Administration as well as by Division 3 of the Commission Internationale de l'Eclairage. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 3-46 de la Division 3 "Environnement intérieur et étude de l'éclairage" et a été approuvé par le Bureau et Division 3 de la Commission Internationale de l'Eclairage. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist vom Technischen Komitee CIE 3-46 der Division 3 "Innenraum und Beleuchtungsentwurf" ausgearbeitet und vom Vorstand sowie Division 3 der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

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RESEARCH ROADMAP FOR HEALTHFUL INTERIOR LIGHTING APPLICATIONS

Summary

Although light is defined as electromagnetic radiation that provides the stimulus for vision, we now know conclusively that ocular detection of this signal also has many other physiological and psychological effects in humans and other organisms. This knowledge has led some to argue for rapid adoption of lighting recommendations that incorporate “lighting for health” elements, whereas others have argued that a more cautious approach would be wiser. CIE created Technical Committee 3-46 to outline a research agenda that could lead to evidence-based recommendations for healthful interior lighting within the context of delivering good lighting quality. The starting point for this work was CIE publication 158:2004/2009 and its five principles for healthy lighting. Although not a comprehensive review of the literature on this vast topic, this report summarizes the state of knowledge at the time of publication and identifies gaps in our understanding that in the view of the committee ought to be filled in order to support safe and beneficial future uses of light. The report delivers a research roadmap of questions in themed groups: Fundamental Processes, Daily Pattern, Longer Patterns, Application, Application – Specific, and Individual Differences. The roadmap indicates the ease with which each question might be answered and its importance to lighting application in the short term. Design considerations and the ethics of using light to influence health also receive attention.

RECHERCHES A MENER POUR UN ECLAIRAGE INTERIEUR RESPECTUEUX DE LA SANTE HUMAINE

Résumé

Bien que la lumière soit définie comme le rayonnement électromagnétique stimulant la vision humaine, nous avons maintenant la preuve que ce rayonnement a également de nombreux autres effets sur l'homme (physiologiques et psychologiques) comme sur d'autres êtres vivants. Cette connaissance a conduit certains à plaider en faveur d'une adoption rapide de recommandations d'éclairage intégrant des aspects « éclairage pour la santé humaine », alors que d'autres ont fait valoir qu'une approche plus prudente serait plus sage. La CIE a créé le Comité Technique 3-46 avec comme objectif de définir un programme de recherches menant à des recommandations basées sur des preuves scientifiques, permettant d'obtenir un éclairage intérieur de qualité respectueux de la santé humaine. Le point de départ de ce travail a été la publication CIE 158:2004/2009 et ses cinq principes pour un éclairage sain. Bien que ne représentant pas une revue exhaustive de la littérature sur ce vaste sujet, le présent rapport résume l'état des connaissances au moment de sa publication et identifie les lacunes des connaissances actuelles qui, de l'avis du comité, devraient être comblées afin de proposer une utilisation sûre et bénéfique de la lumière dans le futur. Le rapport fournit un programme de recherches présenté sous forme de questions rassemblées par thèmes: Processus Fondamentaux, Rythmes Quotidiens, Rythmes à plus Long terme, Applications, Applications plus Spécifiques, et Différences Individuelles. Cette feuille de route indique la facilité avec laquelle chaque question pourrait être traitée et son importance à court terme pour l'éclairage intérieur. Les considérations de conception et d'éthique concernant l'utilisation de la lumière pour influencer la santé sont aussi abordées.

FORSCHUNGS-ROADMAP FÜR GESUNDHEITSFÖRDERNDE BELEUCHTUNGSANWENDUNGEN IN INNENRÄUMEN

Zusammenfassung

Auch wenn Licht als elektromagnetische Strahlung definiert ist, welche den Reiz für das Sehen liefert, ist abschließend bekannt, dass die Wahrnehmung dieses Signals durch das Auge ebenfalls viele andere physiologische und psychologische Effekte beim Menschen und in anderen Organismen mit sich bringt. Diese Kenntnis hat manche dazu gebracht, für eine

schnelle Einführung von Beleuchtungsempfehlungen zu argumentieren, welche “Beleuchtung für Gesundheit” beinhalten, während andere argumentierten, dass ein behutsamerer Ansatz sinnvoller wäre. CIE hat das Technische Komitee 3-46 ins Leben gerufen, um einen Forschungsplan zu entwickeln, der zu nachweisbasierten Empfehlungen für gesundheitsfördernde Innenraumbeleuchtung bei gleichzeitig guter Beleuchtungsqualität führen könnte. Der Startpunkt für diese Arbeit war die Publikation CIE 158:2004/2009 und ihre fünf Prinzipien gesundheitsfördernder Beleuchtung. Auch wenn es sich nicht um eine umfassende Literaturrecherche zu diesem mächtigen Thema handelt, fasst dieser Bericht den Wissensstand zum Zeitpunkt der Publikation zusammen und zeigt Lücken in unserem Verständnis auf, welche aus Sicht des Komitees gefüllt werden müssten, um zukünftige sichere und förderliche Nutzungen des Lichtes zu unterstützen. Der Bericht liefert einen Forschungsfahrplan von Fragen in folgenden Themengruppen: Grundlegende Prozesse, Tägliche Struktur, Längere Strukturen, Anwendung, Anwendung – spezifisch, Individuelle Differenzen. Der Fahrplan zeigt den Aufwand auf, mit welchem jede Frage beantwortet werden könnte, sowie ihre Wichtigkeit hinsichtlich kurzfristiger Lichtanwendung. Designüberlegungen und ethische Fragen hinsichtlich der Verwendung von Licht zur Gesundheitsbeeinflussung werden ebenfalls betrachtet.

1 Introduction

Evidence that a separate photoreceptor detects irradiance and provides the entrainment signal for circadian regulation (Berson et al. 2002; Hattar et al. 2002) has galvanized lighting researchers, manufacturers, and designers (Bommel and Beld 2004; DiLaura 2005). Some have argued that lighting applications should rapidly change to adopt this new information (Bommel 2005; Bommel and Beld 2004; German Institute for Standardization (DIN) 2013), whereas others have called for a more cautious approach (Boyce 2006).

CIE published the first consensus report concerning the ocular effects of light on physiology and behaviour in 2004 (CIE 158:2004/2009), and convened expert symposia on the subject in 2004 (CIE 2004) and 2006 (CIE 2006). The first symposium emphasized the evidence that light has effects on people beyond vision (“light and health”), whereas the second event focused more on the potential applications of this knowledge (“lighting and health”). The emphasis on application continued in 2007 with a workshop at the 26th Session of the CIE in Beijing (Brainard and Veitch 2007). Workshop participants expressed two diverging opinions: “Time to forge ahead” and “Take care to avoid unintended consequences”. CIE Technical Committee 3-46 was formed in response to these competing influences.

The Terms of Reference for TC 3-46 are:

“This TC will review relevant CIE publications (CIE 158:2004 and the two CIE expert symposia on light and lighting and health in 2004 and 2006) and the more recent scientific literature to identify the information that is needed before such lighting application may take place. The output will be a technical report which will describe a research roadmap intended to stimulate fundamental research into questions relevant to lighting applications.”

The World Health Organization definition of health underlies this report: “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). We seek knowledge of the effects of light that will result in positive psychological and physiological states and rhythms in order to support evidence-based lighting recommendations. That said, the committee has focused primarily on the research directions related to the CIE publications referenced in its Terms of Reference. This means, for example, that research related to spatial appearance judgements is not included (but see Veitch and Galasiu (2012) for a consideration of this topic).

Research productivity in all aspects of light, lighting, and health has been prodigious in the years over which this TC has worked; but it remains the considered opinion of the committee members that in many areas we remain in the early days of understanding what will constitute a healthful lighting application in any specific installation. Even in domains where there has been the greatest activity, it can be difficult to derive applications guidance because of limitations of research design or reporting.

This document is not a comprehensive research review; it is not a sequel to publication CIE 158 (CIE 2004/2009). Rather, it sets out the questions for which those who write standards, recommendations, and codes will need answers if these documents are to provide integrated guidance incorporating goals for health and well-being along with visual requirements. The purpose of this document is to clarify the research questions (Clause 2) and to set out some simple guidance for research methods (Clause 3) to speed the work of developing knowledge that can be put into practice. Clause 4 provides insight into the gap between fundamental research and application.

2 Research agenda

The research agenda is based primarily on the five principles of healthy lighting first articulated in CIE publication 158 (CIE 2004/2009), augmented by questions relating to glare

and flicker that many had thought resolved, but that have re-emerged with the advent of solid-state lighting¹. The five principles, as stated in CIE 158, are:

- The daily light dose received by people in Western (industrialized) countries might be too low.
- Healthy light is inextricably linked to healthy darkness.
- Light for biological action should be rich in the regions of the spectrum to which the non-visual system is most sensitive.
- The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces.
- The timing of light exposure influences the effects of the dose.

The challenge in translating these general principles into specific recommendations is in the need for detailed information expressed such that results from different investigations can be directly compared and combined.

2.1 Total light exposure

Since the publication of report CIE 158 (CIE 2004/2009), several additional investigations have added to the evidence that increased daytime light exposures can contribute to better well-being as expressed through various behavioural and physiological measures. For example, women who showed mild seasonal mood variations reported less quarrelsome social interactions immediately following periods of exposure to light greater than 1 000 lx in intensity (aan het Rot et al. 2008). Hubalek et al. (2010) observed that night-time sleep quality varied proportionally to the light dose received at the eye during that day, with better sleep quality following days of greater light exposure. Smolders et al. (2013) found that feelings of vitality increased positively with daily light exposure. These findings are generally consistent with one another, and we are unaware of any investigations showing contrary results, in which (over the range of normally-occurring conditions in present-day environments) increasing light exposure has shown adverse effects on well-being.

Despite this consistency in findings, we do not know what the optimal light exposure ought to be for healthy, day-active adults; and even less so for other populations, such as the elderly or children. The reasons for this are multiple: inconsistency in reporting, experimental investigations that have tested a limited range of exposures, uncertainty concerning the appropriate spectral sensitivity function governing particular biological processes, and measurement errors that are described in more detail below (Clause 3). Consider the variety in light exposure or light dose measurements reported:

- illuminance level (ideally, measured vertically at the eye, in the angle of gaze) (expressed in lx);
- luminous exposure: illuminance level over a specified time span or, whether it is a steady state that is measured, or (if variable), calculated by integrating the illuminance over time (expressed in lx·h);
- photon density (expressed in photons per square centimetre and second), generally used for experimental conditions;
- duration of light exposure above a threshold (commonly expressed either in a unit of time, or as a percentage of a fixed time period, such as "% of waking time above 1 000 lx").

A first step to the development of concrete recommendations would be the establishment of consensus concerning light dose equivalency. For flashing lights, there has long existed a function by which to establish the equivalent intensity (in terms of brightness perception) of

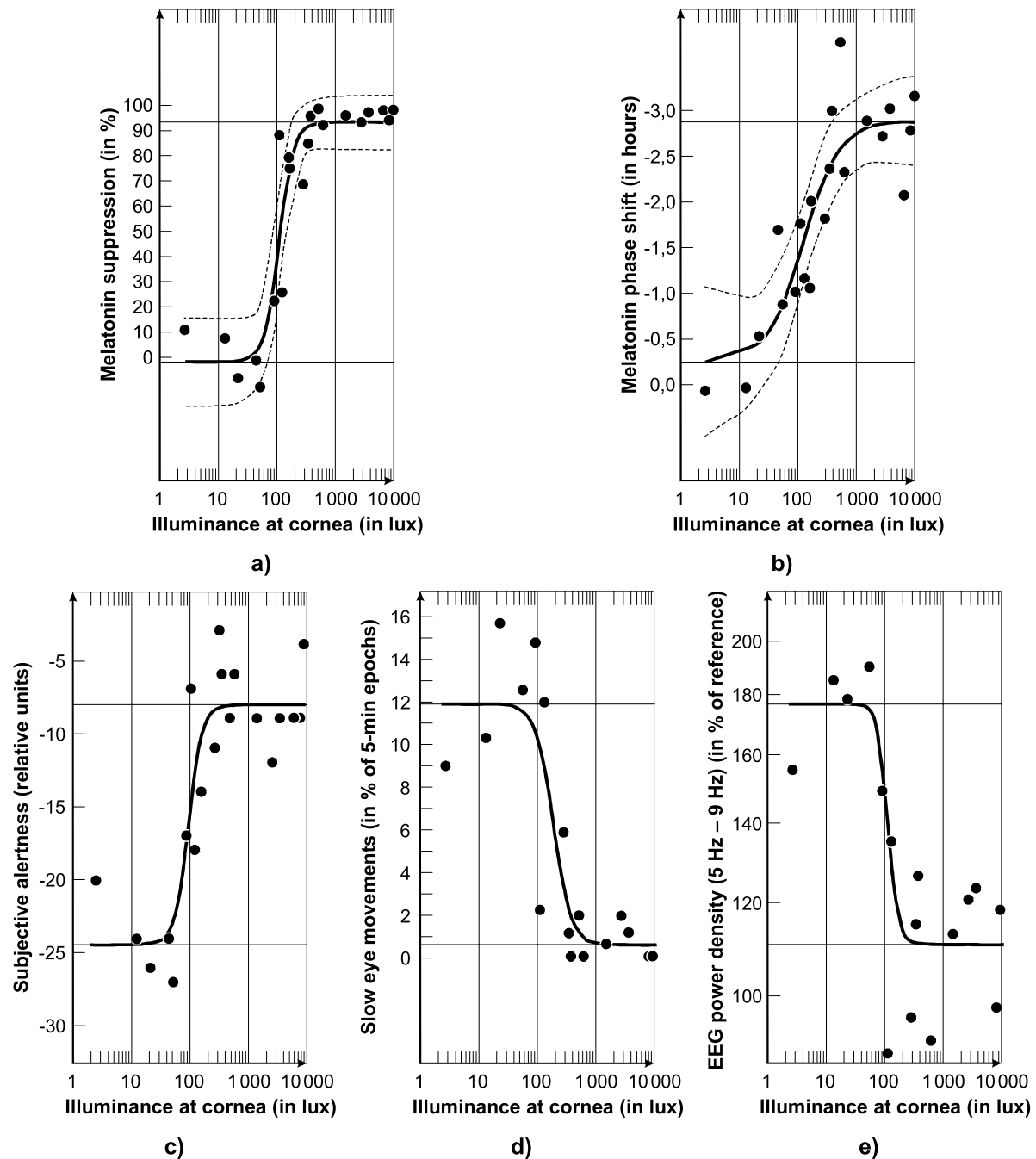
¹ It might be argued that it is time to revisit these principles, given the knowledge acquired since 2004 when they were originally written. It is up to a future committee to deal with this task; it is beyond the scope of this document.

flashes of varying intensity and duration (Blondel and Rey 1912). In the case of light dose, we do not know whether one short pulse of high luminous flux could be biologically equivalent to a longer exposure at a lower level of luminous flux. For light therapy of seasonal mood disorders, the psychiatric community has determined empirically that for therapeutic effect (reduction in depressive symptoms) an exposure to 10 000 lx from a light box for 30 min is equivalent to 2 500 lx of the same white light for 2 h (Lam and Levitt 1998). If such a relationship could be established for other physiological or behavioural effects, it would become feasible to identify a suitable light dose for a given population (e.g. infants; the elderly; working adults) and to provide guidance as to how to deliver that dose in an energy efficient manner suited to a given application.

To achieve this step requires agreement concerning the effects we wish to trigger. For flashing lights, the goal was to achieve equivalent brightness perceptions, a relatively simple observation. For total light dose, the goal is unclear as yet. There is increasing evidence that light exposure influences many physiological processes through at least two non-visual pathways (Cajochen 2007; Veitch and Galasiu 2012). The better-known pathway concerns the regulation of melatonin secretion by the pineal gland (CIE 2004/2009). This pathway controls circadian rhythms; light exposure at night, particularly at short wavelengths, suppresses melatonin and influences subjective sleepiness (Badia et al. 1991). The other pathway leads to acute effects on alertness through an activation mechanism that is separate from melatonin suppression (Cajochen 2007).

When studying the circadian regulation path, researchers demonstrate changes in rhythm principally through physiological measurements such as melatonin secretion and its derivative, the dim light melatonin onset (DLMO); in some investigations, we also see core body temperature, other hormone secretion patterns (e.g. cortisol), sleep-activity patterns (using actigraphs) or electro-encephalograph (EEG) recordings as outcome measurements. The principal publications provide standards for measuring, analysing, and reporting circadian rhythm effects (Portaluppi et al. 2010). The general agreement on what constitutes a marker of circadian entrainment (or its absence) could make it possible to develop a model for dose equivalency based on the literature, provided that researchers reported the experimental conditions with suitable precision (see 3.1.1).

This will not be a simple matter, as different markers thought to reflect the same underlying processes show slightly different dose-response relationships. Consider the results shown graphically in Figure 1. These are dose-response relationships from two experiments (Cajochen et al. 2000; Zeitzer et al. 2000), both conducted in the same institution around the same time. Young male and female volunteers were exposed to a white light of one illuminance level for 6,5 h in the early biological night. No spectral data for the light source are available (one of the papers described it as “cool white fluorescent light”). Zeitzer et al. (2000) observed the 50 % response point to be ~120 lx for both phase shifting and melatonin suppression; however, the saturation point differed, being ~220 lx for melatonin suppression and ~525 lx for phase shifting (Figure 1 a) and b)). Cajochen et al. (2000) found that the inflection point for 50 % response was 90 lx for EEG theta-alpha activity, 180 lx for slow eye movements and 100 lx for subjective alertness (Figure 1 c)–e)). It may be that the 50 % response of the circadian system reliably occurs around 100 lx, but if the maximum response occurs at widely varying exposures for different outcomes it will be difficult to obtain consensus on recommendations.



NOTE The upper graphs a) and b) are re-drawn from Zeitzer et al. (2000).
The lower graphs c), d) and e) show results reported by Cajochen et al. (2000).

Figure 1 – Published dose-response relationships between white fluorescent light of varying illuminances after a 6,5-h exposure period

It is not the purpose of this document to develop such a model, but to point to the value of such a model to support applications. Some work along this line exists (Chang et al. 2012; Dewan et al. 2011), but not in sufficient quantity to establish consensus guidelines, even for the limited case of circadian regulation. Current knowledge suggests that if a model can be developed to relate circadian rhythms to equivalent light doses, it will be non-linear, or will be moderated by other variables. A linear model would exist if there were equivalence between a short high-intensity exposure and a longer low-intensity exposure, each expressed in lx·h. This question has clear implications for practical applications but is not well understood as yet. Rimmer et al. (2000) found that continuous light exposure was most effective at resetting the

circadian phase, but intermittent light was nearly as effective. Gronfier et al. (2004) also observed that intermittent exposures could be as effective as continuous exposure in modifying circadian phase, despite the total dose being considerably lower. They also observed that the response was non-linear, with the first minutes of exposure providing a stronger response than later minutes; Chang et al. (2012) reached the same conclusion. Dewan et al. (2011) found evidence of non-equivalent responses, with a longer duration at lower intensity showing greater effects on circadian phase adjustment than a shorter duration at a higher intensity.

Concerning the acute effects of light exposure, there is even less evidence to support consensus, because it is not yet clear what outcomes we wish to influence with light exposure. Scientists examine many physiological and behavioural outcomes in order to elucidate these processes – for there are probably more than one process involved. This is a very active research area, as evidenced by the following (non-exhaustive) list of findings:

- Bright white light can have an acute activating effect, which is linked to feelings of increased alertness, reduced sleepiness and increased vigilance levels during daytime and night time (Cajochen 2007; Smolders and Kort 2014; Lowden et al. 2004; Daurat et al. 2000; Phipps-Nelson et al. 2003; Rüger et al. 2006; Smolders et al. 2012).
- Participants select more intense light settings when they experienced low levels of alertness and vitality (Smolders 2013).
- During daytime, increased white light exposure can modulate cognitive brain functioning, with generally better cognitive performance, such as logical reasoning and creative thinking (Smolders et al. 2012) and office work performance (Gifford et al. 1997).
- During daytime, periods of bright light exposure ($> 1\,000\text{ lx}$) can lead to better mood and to social interactions that are less quarrelsome and more co-operative than those following lower light exposures (aan het Rot et al. 2008). This might be associated with an acute effect of bright light on serotonin metabolism (aan het Rot et al. 2007).
- Both exposure to bright light and thinking about such exposure are associated with improved self-regulation and self-awareness (Steidle and Werth 2014).

Dose-response and dose-equivalency functions cannot yet be developed because we lack adequate information about the multiple parallel processes affected by light exposure. The list of daytime outcomes above are unlikely to be mediated by the circadian clock mechanisms, because they are immediate effects occurring during the period in which there is little or no circulating melatonin. Feelings of alertness and more positive mood associated with light exposure might be the result of one process, but also might arise from more than one process, these various processes acting in parallel – consider, for example, that the hormone cortisol has a circadian pattern but is also influenced by immediate exposures, not all of them related to light or vision. This means that for the present, researchers need to investigate a wide variety of behavioural and health outcomes that might reasonably be affected by light exposure.

The next step would be to organize the broad set of empirical results to identify the underlying processes that give rise to various observations. For example, Veitch and Galasiu (2012) differentiated visually-mediated processes such as spatial appearance from non-visual processes such as circadian regulation and acute alerting effects. This will be a challenging task because at present there are no generally-accepted markers that identify other processes. In the cases of brightness perception or circadian regulation markers exist that all experts agree upon (e.g. brightness judgements (CIE 2014); dim-light melatonin onset (Benloucif et al. 2008)). These markers provide a relatively straightforward way to establish a dose-equivalency function that predicts the response of the specified process to a given light dose. As this degree of agreement does not yet exist for other aspects of human functioning, we pose very general research questions regarding light dose effects:

1. What fundamental psychological and physiological mechanisms underlie the acute alerting effects of light, by day and by night (noting that these may differ)?
2. It seems that light exposure affects serotonin metabolism, which might explain observed effects on mood and social behaviour. Is this the same mechanism as for acute alerting effects?
3. Given answers to question 1, what is the dose-response relationship between light exposure and daytime effects on alertness, feelings of well-being, subsequent sleep, etc.? Is there a minimum level required; does the shape of the curve show diminishing returns (as in the case of visual performance)? This information would help to determine whether or not daytime illuminance recommendations (currently based on visual requirements) are adequate to support non-visual functions.

This report focuses primarily on psychological and physiological processes arising from light received at the eye. However, healthful lighting applications ought also to consider the possibility of effects arising from tissue exposures rather than retinal photoreception. These effects are very poorly understood as yet, but there is speculation concerning effects that many would consider important. For instance, it has been suggested that the risk of developing severe myopia is higher if children do not receive daily exposure to high-intensity light (Hobday 2015; Mutti et al. 2014). This exposure is believed to trigger dopamine release in the retina and thereby to affect the rate of growth of the eyeball. Light penetrates tissue to varying degrees depending on the tissue type and wavelength (Jacques 2013; Tedford et al. 2015), with various therapeutic applications (e.g. Albarracin et al. 2011; Fitzgerald et al. 2013). We present these concepts with one blanket research question:

4. Does light exposure affect physiological processes through direct absorption (i.e. not retinally mediated mechanisms)? If so, what are the desirable intensities, spectra, etc. for those exposures?

Although both the full suite of processes and their associated light dose-response relationships are yet unknown, it is possible to identify the types of information needed to support lighting recommendations and standards:

- Investigations should include three or more exposure conditions, to enable curve-fitting. These should cover a broad range of exposures expressed either as intensity or duration, or both.
- Investigations should include some short exposures as well as long exposures. Exposure duration will affect energy consumption for lighting; the shorter the exposure to a more intense electric light, in general the lower the energy used to deliver it.
- Individual differences in dose equivalency and dose-response relationships are likely, meaning that investigations must be specific to the age, chronotype, visual health status, and physical health status of the population to which the results are to be generalized.
- Research quality must improve. Clause 3 of this document describes this issue in greater detail.

2.2 Light-dark rhythms

Many physiological functions follow circadian cycles, with some processes being more pronounced during periods of light exposure and others during darkness; for this reason, the principles of healthy lighting promulgated in CIE 158 (CIE 2004/2009) included the requirement for periods of darkness as well as an increase in daily light exposure. Over most of the millennia of human evolution, this was provided by the daily rhythm of the natural day-night cycle, sunlight or daylight followed by moonlight or starlight. Only for a comparatively short period in evolutionary time has humanity been capable of altering this cycle significantly using other light sources.

With the widespread use of easy to control electric light the natural day-night cycle has been disrupted, with the general result that there is less difference between the light and dark

periods than is the case in the absence of electric light. As noted above, daytime light exposures are comparatively low for most people, who spend up to 90 % of their waking time indoors. This level extends into evening and night-time hours, both indoors and outdoors, resulting in what some have called a perpetual exposure to biological twilight. In short, it can be difficult to achieve a large difference in light exposure between daytime and night-time.

Leaving aside for the moment the problems of overnight workers, for which the problems are more complex, it is becoming clear that exposure to light at night has several effects that contribute to chronic problems in humans through a variety of mechanism¹:

- Light exposure at night acutely suppresses melatonin secretion (Brainard et al. 1991; Brown 1994).
- Melatonin provides the signal for night-time states of immune function, digestion, wakefulness, and other biological processes (Arendt and Skene 2005).
- Light at night acutely increases alertness (Badia et al. 1991) and leads to sleep loss (Cajochen et al. 1992).
- Sleep loss reduces subsequent cognitive performance and diminishes immune function (Irwin 2002).
- Disrupted circadian rhythms are implicated in the development of obesity, some cancers, cardiovascular disease, and depression (Stevens and Zhu 2015).
- Independently of sleep loss and circadian disruption, animal tests of light exposure at night have shown adverse effects on mood and cognition that some believe might explain adverse effects in humans (Bedrosian and Nelson 2013; LeGates et al. 2012).

Our exposure to light at night comes about in part from the need to satisfy other lighting needs: the safety and security that come from roadway and street lighting; the aesthetic appeal of building façade lighting; social and task lighting associated with activities in urban spaces. For people who desire or need to be active at night, these are valid lighting needs. However, this results in a considerable exposure to light at night within the urban environment, and where this light trespasses into private homes, and especially into sleeping rooms, this also affects those for whom the light is obtrusive and unwanted. Even through closed eyelids, and when delivered in very short flashes, light at night can shift the circadian rhythm (Zeitzer et al. 2014). Some of our research needs concern how to achieve some of these valid design goals simultaneously with reducing obtrusive light and potential ecological consequences; Clause 4 deals with these application topics.

Although it is clear that healthy functioning requires alternating exposure to light and darkness, there are many questions outstanding that prevent any other than the most general guidelines:

5. How dark does dark need to be? For how long? Is there a spectral dependency, in which low levels of some wavelengths are acceptable but others are not? (This will influence our understanding of the importance of obtrusive light in sleeping rooms, and the use of night lights; it also has implications for night-shift workers.)
6. What are the effects of increasing the amplitude of the light-dark cycle? For example, if one has a long period of exposure during the day to a very high light level, might it be possible to tolerate slightly more light overnight? (See also Clause 2.5.)
7. How long should each phase of the exposure be (whether light or dark)? If higher light levels are needed than are currently recommended, it will be necessary to model the energy use required to deliver that level. The energy requirements will be more easily provided if they are demonstrated to be as low as possible (either by delivering a longer exposure at a lower level, or a shorter exposure at a higher level).
8. How does the requirement for a light-dark cycle vary with age, from infancy to old age?

¹ Outdoor light at night is also implicated as an ecological problem (e.g. Gasont et al. 2015), but the present document is limited to consideration of effects on humans.