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D3.1 Introductory report and web material on lighting for health and well-being in education, work places, nursing homes, domestic applications

D3.3 Introductory report and presentation on Lighting in Smart Cities

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Summary

This report constitutes the deliverables D3.1 and D3.3, **Introductory report and web material on** lighting for health and well-being in education, work places, nursing homes, domestic applications **respectively** lighting for smart cities.

The report provides the initial, baseline information and preliminary conclusions on data reviewed regarding: health and wellbeing at workplaces, health and wellbeing in education, health and wellbeing in domestic applications, health and wellbeing in healthcare (D3.1), and health and wellbeing in Smart Cities (D3.3). The deliverable reports have been combined because the associated data review, processing and presentation of the results was carried out in an identical way.

Light enables sight, safety and orientation, but can do more than this. Light has the power to energize, relax, enhance alertness, cognitive performance and mood. Light also adjusts and stabilizes the duration, and timing, of our sleep-wake cycle. Light is a powerful biological stimuls, and its ability to achieve the above mentioned effects makes lighting strategies a very useful instrument to influence human health, well-being and performance in our 24 hour economy.

The conclusions and information presented here will also be available on the lightingforpeople.eu platform and used to make dedicated presentations and information material for use for SSL-erate workshops and seminars and to reach out to specific stakeholder groups.

1 Introduction

Light has been known for a long time to enable sight, safety and orientation. But light can do more than enabling vision. Light has the power to energize, relax, increase alertness, cognitive performance and mood. Light is the most powerful regulator of the day-night-rhythm of people. Every day again, light exposure adjusts and stabilizes the duration, and timing, of our sleep-wake cycle. Moreover, light is known to be an effective treatment for a variety of conditions that include mental disturbances such as Seasonal Affective Disorder (SAD) and certain kinds of sleep disorders.

The ability of light to achieve these various non-visual effects depends on the spectrum, intensity, and temporal pattern of the light, as well as the light-exposure history and preceding sleep behavior of the individual. Therefore, the optimization of a Human Centric Lighting solution for a given non-visual effect is only possible when this user context is accounted for. This requires a dedicated and tailor-made design, based on a profound understanding of the personal and environmental conditions of the use-case(s). A “one size fits all” Human Centric Lighting solution does not exist, and one may even do more harm than good when applying a solution beyond the context and scope it was designed for.

A review of published data has been started to gather per application field validated knowledge on Human Centric Lighting, in order to provide recommendations to foster implementation. These fields are: workplaces, education, domestic applications, healthcare, and Smart Cities. This introductory report presents the first, preliminary, conclusions and observations from this inventory. Section 2 summarizes these per application field. Section 3 presents the conclusions and observations more in detail. The reviewed literature is listed in Section 4.

2 Summary of Human Centric Lighting Effects per Application

2.1 Health and Wellbeing at Workplaces

The effect of light on employees' mental wellbeing, performance and health is dependent on the intensity level experienced during the workday. Research has shown that exposure to more intense light may boost employees' feelings of alertness and vitality. Moreover, the light intensity may influence individuals' ability to sustain attention and cognitive performance. In addition to the potential beneficial effects of light on mental wellbeing and performance during working hours at night, nighttime exposure to light can reduce melatonin secretion and affect the timing of sleep. There are also some indications that the experienced light levels during daytime working hours can influence sleep during the subsequent night. The light level may also affect working environment appraisal, but individuals' preferred light settings showed some substantial variations.

2.2 Health and Wellbeing in Education

Positive effects of artificial light in classrooms on physical and mental health are achievable. This is especially feasible in classrooms with a low level of natural light or during days with a low level of natural light. Especially lighting in morning hours with higher illumination levels and higher color temperature can have positive effects on academic performance, social behavior, and also on physical and mental health. The absence of light having blue spectral proportions in the morning can delay the circadian clock. Finally, light is a modulator on physical parameters such as blood pressure and body growth and humoral circadian rhythms.

2.3 Health and Wellbeing in Domestic Applications

The most consistent outcome of the studies examined is that light at "room light" or "moderate" or "domestic" intensity levels (40 to 250 lux) has significant effects on alertness, well-being, cognitive performance in the attentional and executive domain, melatonin, EEG during wakefulness and sleep, particularly in the late evening/early night (21:00 to 2:00). The direction of these effects hint to an acute and short term effect of light (i.e. alerting response, longer sleep latencies, less slow-wave sleep, melatonin suppression) when compared to a dim light control or to non-blue-enriched light. More recent studies also indicate that insomnia in older residents is positively correlated with light levels in the evening and at night in the bedroom.

2.4 Health and Wellbeing in Healthcare

Natural and electrical light influences human physiology and behavior, most importantly vision and biological timing. Daily cycles in all body functions, e.g. sleep-wake, core body temperature, are not passively following the day-night cycle, instead, a body clock/circadian clock, located in the anterior hypothalamus, generates an endogenous rhythm that is oscillating with a period slightly longer than 24 hours in isolation from external environment. This pacemaker provides the main signal for internal synchrony of the numerous physiological functions expressing circadian patterns, e.g. core body temperature or the body's synthesis and release of melatonin, a hormone with marked circadian rhythm, normally high at night and suppressed by bright light. The body clock's period need to be adjusted to local time every day to keep in phase with the day-night cycle. The main synchronizer is light, detected through photoreceptor systems in the eyes, to which the body clock has direct neural connections. The ability of humans to manipulate their light exposure has an immanent potential to inflict problems with human physiology (as in shift workers) or to augment the ability of synchronization (as in age-related impaired lens transmission).

How the brain integrates light information is not well understood despite great advances in our knowledge about properties and functions of photoreceptor systems, biological timing, performance and emotions of humans in relation to light exposure. Better understanding of the contributions of photic history, varying intensities, durations and wavelengths of light on physiology implies exact measurements, which is lacking in many areas of current published research. Here we summarize results from meta-analyses and systematic reviews of clinical trials in individuals in psychiatric care and nursing home environments regarding the response in human physiology and behavior to natural light, electrical light and interior lighting systems.

In conclusion, daylight exposure of sufficient intensity has the potential to enhance the adaptation of circadian system to the day-night cycle, while imposed electrical light in the evening overrides this adaptation, suppresses melatonin synthesis and induces circadian rhythms to shift. There is evidence that the effect sizes for light therapy in non-seasonal depression are equivalent to those in antidepressant pharmacotherapy trials. However, there is limited evidence that light treatment may be effective in delaying deterioration and improving neuropsychiatric behavior in demented patients. Architectural designs for healthcare buildings need to increase the area of natural light coming in and integrate programmable interior lighting systems in all indoor areas where residents and staff spend time to allow optimizing exposure of light and darkness according to human biology.

2.5 Health and Wellbeing in Smart Cities

The effect of light on wellbeing, performance and health in urban environments is dependent both on the objective lighting environment and how it is perceived and interpreted in a given context. Research has shown that exposure to light at night has numerous harmful effects on the biological well-being of humans and animals. These biological effects depend on lighting intensity, exposure duration and spectra. However, urban lighting at night has also positive side. It enables safe passage on the routes by ensuring sufficient visibility. There is mounting evidence connecting lighting to higher perceived safety and pedestrian and cyclist outdoor activity. Lighting may also reduce criminal activity. Lighting environment may thus encourage physical outdoor activity, social life and recreation and promote the well-being in cities.

3 General Conclusions and Observations per Application

3.1 Health and Wellbeing at Workplaces

3.1.1 Exposure to more intense light may boost employees' feelings of alertness and vitality

Exposure to more light can counteract feelings of sleepiness and lack of energy during the day [1-7] as well as at night [4,8-11]. These effects are sometimes dependent on the duration and/or timing of the light exposure [6,9,11,12]. In addition, there are indications that daytime exposure to higher intensity levels induces stronger subjective experiences of alertness when persons feel more sleepy and less vital [5,6,13]. The minimal as well as the optimal intensity level to induce alertness and vitality in workplaces are, however, yet unknown.

3.1.2 Light intensity may influence individuals' ability to sustain attention and cognitive performance

The intensity of the lighting in the workplace may affect employees' level of alertness, resulting in, for example, faster responses to stimuli. Research has shown that exposure to higher light levels can support persons' ability to stay alert during the day [1,3,5,7] and at night [9,10,14-16]. The effects sometimes occurred with a delay (~30 minutes or more) [5,7,9,14]. Moreover, exposure to very high intensity levels (>2000 lx at the eye) during daytime not always resulted in significant improvements in alertness [10,14,16].

The light level employed in workplaces can also affect individuals' cognitive task performance. Exposure to bright light (>2000 lx at the eye) during daytime may result in better performance on tasks requiring visual search and working memory or arithmetic ability [16,17]. Similar results were also shown at night, with better performance on tasks requiring recall, visual search, logical reasoning and/or arithmetic ability under very high intensity levels [10,14-16]. However, exposure to bright light (1000 lx at the eye) as compared to a level commonly experienced in offices (200 lx at the eye) during daytime revealed no clear improvements - and even some performance-undermining effects - on tasks requiring visual scanning, inhibitory control and/or working memory [5,7]. This suggests that some tasks may benefit more from daytime bright light exposure than others. More research is needed to determine the optimal light level for different types of activities during daytime working hours as well as during the night shift. It should be noted, however, that in addition to the potential beneficial effects on alertness and performance at night, nighttime exposure to light has also been linked to increased health risks in the long term by several researchers (see also section 1.2.2.3).

3.1.3 Exposure to light at night can reduce melatonin secretion and affect the timing of sleep

A major output of the biological clock system is the production of the hormone melatonin. This production in the pineal gland shows systematic variations with time of day and is under the control of the biological clock. Melatonin is secreted at night and has minimal levels during daytime, even if persons during one day are not exposed to light. Research has shown that exposure to light at night can suppress the secretion of melatonin, with larger suppression under more intense light during the biological night [9,18,19]. This often coincides with increased feelings of alertness and higher sustained attention (see also sections 1.2.2.1 and 1.2.2.2). However, there are also indications that circadian disruptions and melatonin suppression at night can have adverse health effects in the long term [20-28].

In addition to the acute effects of light intensity on the secretion of melatonin, exposure to light at night can also shift the timing of melatonin onset after the light exposure, which can be accompanied by changes in the timing of sleep and wakefulness during the next day. Exposure to higher light levels during the night shift can results in larger phase-shifts [29]. The direction of such phase-shift is dependent on the timing of the light exposure. Exposure to bright light in the early night can delay the timing of sleep onset and awakening [12,30-36], while exposure to bright light in the late night can advance the sleep-wake cycle and result in an earlier timing of sleep and wakefulness [30,33-38]. Although exposure to bright light at night can induce larger phase-shifts with increasing exposure durations [12,31], several studies have provided indications that persons are particularly sensitive to light in the first part of the light exposure [12,32,36,38]. Moreover, research has suggested that, at least under very controlled conditions, relatively low illuminance levels (~150 lx at the eye) are sufficient to suppress melatonin and shift the sleep-wake cycle [9,29,37]. It is thus important to not only consider the effects of the intensity of workplace lighting on employees' state of alertness and performance during the night shift, but also its potential disturbing effect on their sleep-wake cycle and long-term health when designing lighting scenarios for night-shift workers.

3.1.4 Light levels during daytime working hours may influence sleep during the subsequent night

Research has provided some indications that employees' experienced light patterns during the daytime shift may affect the timing and/or quality of their sleep during the following night [17,39,40]. Exposure to more intense light during the day may result in a better sleep quality during the following night among office employees [39], and workers who are exposed to low intensity levels during their work shift (due to a lack of daylight exposure) may experience more complaints of poor sleep [40]. A recent study revealed that exposure to additional bright light exposure among office employees with limited or no access to daylight during the dark winter months enabled them to wake-up earlier. These earlier wake-up times were accompanied with shorter sleep duration, without reductions in sleep quality or increased feelings of sleepiness in the morning [17].

3.1.5 The light intensity can influence employees' appraisals of the lighting and working environment. Which light levels are preferred may vary substantially between persons, type of work-related tasks and with time of day.

Research has shown that lighting in a room with a higher illuminance is generally evaluated as brighter [5,7,40-44]. Bright light settings may be experienced as more activating than commonly experienced intensity levels in indoor workplaces [5,7]. In addition, the atmosphere of a space with a higher intensity level may be perceived as more lively, less tense and more formal [44]. Exposure to a higher intensity level at the work plane may be experienced as more pleasant [41], although exposure to very high intensity levels (>1000 lx at eye, provided by artificial lighting only) may be evaluated as less pleasant [5,7,43] and potentially cause glare. Moreover, multiple studies have revealed substantial inter-individual and intra-individual differences in preferred intensity levels in work-related settings [45-50], suggesting that whether a certain intensity level is experienced as pleasant or attractive may also vary as a function of person characteristics, time of day and/or context. These results highlight the challenge to provide activating and pleasant lighting settings in the workplace, and motivate the development of person-centered lighting scenarios to optimally tune the light to users' preferences.

3.1.6 Exposure to bright light may help to counteract sleepiness in the afternoon after a short night of sleep

Phipps-Nelson and colleagues (2003) [52] tested the effect of exposure to bright light on individuals' feelings of alertness and ability to sustain attention during daytime among persons suffering from sleep loss. In this laboratory study, persons were exposed to either bright light (1000 lx at the eye) or dim light (<5 lx) in the afternoon, after two nights of sleep restriction and exposure to very low intensity levels (<5 lx) in the morning. During the day, subjects' ability to sustain attention was measured every hour with a 10-minute performance task in which they had to respond as fast as possible to auditory stimuli. Moreover, subjects indicated how alert or sleepy they felt at that moment on an hourly basis. The results showed that individuals' feelings of alertness increased in the bright light condition compared to their experienced levels of alertness in the morning, while sleepiness increased when subjects remained exposed to very dim light. Subjects also responded faster in the sustained attention task when exposed to bright light in the afternoon, while they showed decrements in performance compared to the morning measurements in the dim light condition. These results suggest that exposure to bright light in the afternoon may counteract sleepiness among individuals under high sleep pressure due to sleep loss.

3.1.7 Exposure to bright light may increase alertness during daytime office hours

A relatively recent study by Smolders and colleagues (2012) [53] investigated effects of bright light exposure on alertness during regular office hours, in the absence of prior sleep and light deprivation. In this experiment, effects of bright light (1000 lx at the eye) were compared to an intensity level which is commonly experienced in indoor work environments during daytime (i.e., 200 lx at the eye; see e.g., Smolders et al., 2013). In the laboratory, subjects were exposed to one of these lighting conditions for one hour in the morning or in the afternoon. Apart from the visits to the laboratory, subjects lived their daily routine. During the light treatment, subjects engaged in performance tasks and reported on their feelings of alertness and vitality by means of questionnaires every 15 minutes. Results showed that subjects felt more alert and energetic when they were exposed to 1000 lx as compared to 200 lx at the eye. Moreover, they responded faster to auditory stimuli in the bright light condition. These results suggest that exposure to a higher intensity level can benefit employees' experiences of alertness and vitality and their ability to keep focused during daytime office hours, even when they had no disturbed sleep during the previous night or when they had already experienced some daylight or artificial lighting.

3.2 Health and Wellbeing in Education

3.2.1 In educational environments optimized lighting can have positive effects on performance, social behavior, and also on physical health and wellbeing

While several studies have shown that with higher illuminance levels and higher color temperatures, pupils' and students' academic performance (for example the level of concentration) increased compared to standard lighting[1, 2, 5, 9, 11-13, 16], few studies also report that with a reduction of light levels and lower color temperature a decrease in agitation and disturbance during lessons can be achieved[6, 15, 16]. It also seems that light can affect the social behavior of children in a positive way[4, 5, 15, 16] and light might have an effect on physical health (studies have indicated that light might have an influence on parameters like blood pressure or body growth[7] or even be able to shift the circadian rhythm[3]). It is also noteworthy, that there is a connection between academic performance and sleep and sleepiness during school[17]. There is a good chance that optimized lighting environments help to improve sleepiness or sleep at night.

3.2.2 The effects of optimized light environments on concentration

In a summary of three Dutch studies[12], the findings about the effect of light demonstrate beneficial effects of optimized light settings in educational environment. All three studies used the same light system for their experimental groups, which consisted of 1000lx illuminance level and 6500K (cold white) color temperature. For the study controls there had been (1) 600lx and 4000K, (2) 380lx and 3000K, and (3) 300lx and 3000K to 4000K. In total 197 (98, 44, and 55) pupil participated in these studies. While the second and third study report better performance in concentration or at least a positive trend for concentration and fewer errors compared to their controls, findings of the first study report a better performance in concentration test of the control group, nevertheless, the first study also reports an increased performance growth in the experimental group compared to the control group.

3.2.3 Lighting with higher illumination levels and higher color temperature shows positive effects on the level of concentration and/or oral reading fluency (ORF).

In a study[9] with 84 pupils (grade 3, age 7 to 8) separated to four classrooms, the oral reading fluency was measured for two kinds of light conditions. Standard lighting which consisted of 500lx illuminance level and 3500K (warm white) color temperature compared to an lighting optimized for focus tasks which consisted of 1000lx illuminance level and 6500K (cold white) color temperature. The influence of daylight was reduced due to small or blocked windows and drawn blinds. The score for ORF was assessed at the beginning (September), the middle (January) and the completion (May) of the study. The intervention in the experimental groups took place during all focus tasks where the pupil had to read something. Children in the experimental group, the optimized lighting, started with a lower score (assessed before the intervention) and ended with a significant higher score (assessed after the intervention) in ORF compared to the children within the control group. The assessment itself took place under standard lighting for all children. Furthermore, the motivation was evaluated. Even though, there have been no significant findings for motivation, there is a positive upwards trend for motivation under the optimized lighting, while the trend for motivation under standard lighting declined during the school year.

3.2.4 Insufficient blue light in the morning can delay the circadian clock and delayed clock can lead to health and performance problems.

Beside the effects on performance, the lack of light with short wavelength guide to a delay in the circadian system.
The findings of this field study[3] have investigated the effect of light on the circadian rhythmicity. In this study eleven adolescent teenagers (grade 8, age 13 to 14) have been examined on their change in dim light melatonin onset (DLMO) during a five-day school week. For this purpose, students had to wear orange glasses during this period of time in school to filter all blue spectral components from the environmental light. DLMO was examined before and after the intervention. To determine DLMO, a number of saliva samples were taken in the evening between 07:30 pm and 11:00 pm every 30 minutes. A significant delay in DLMO of about 30 minutes occurred in the participants after wearing the orange glasses which indicates that a lack of short-wavelength light may lead to a change in circadian rhythmicity. These findings correlate with other findings from laboratory settings[14].
A delayed circadian clock (eveningness) can lead to disadvantages in exams and poorer academic performance. A study with 132 university students graded from 20 to 22 years, showed a highly significant positive correlation between early chronotype and better grades[14]. Even further, recent studies showed that eveningness could be a risk factor for mental health (higher possibility of depression) and physical health or health-impairing behaviors[8, 10].

3.3 Health and wellbeing in Domestic Applications

A total of 181 studies have been controlled, most of them retrieved from PubMed. Since “domestic light” or “home light” are not a well-defined terms, we decided to include “light-studies”, which aimed at investigating the non-image forming/non-visual impact of light modalities (i.e. exposure duration, intensity, wavelength, lamp types) that can potentially be used in a domestic environment. We excluded studies on the therapeutic effects of bright (>500 lux) and moderate light levels (100-250 lux).

3.3.1 Type of studies

Most of the studies were controlled laboratory or “half-ambulatory” studies- a few were ambulatory and a very few were actually conducted in a domestic environment. We have also added some reviews. The number of investigated people ranged from 1 to 970 per study; however, most of the studies comprised less than 30 people for hypothesis testing.

3.3.2 Type of endpoints

Classical output measures included: temporal profiles of endocrinological markers of the circadian system such as melatonin and cortisol, core body temperature, heart rate, alertness, mood, well- being and performance for different cognitive domains. Less frequently, the EEG during wakefulness and sleep, actigraphy and fMRI was added to the endpoints. Single studies also measured lactate, smoking behavior, visual comfort, plasma thyroid stimulating hormone, blood pressure, event related brain responses (ERPs), oxgen intake, electroretinogram (ERG), hydrogen concentration, digestion, driving performance, blood metabolites and proteins, clock gene expression etc.

3.3.3 The most important results

The most consistent outcome of these studies is that light at “room light” or “moderate” or “domestic” intensity levels (40 to 250 lux) has significant effects on alertness, well-being, cognitive performance in the attentional and executive domain, melatonin, EEG during wakefulness and sleep, particularly in the late evening/early night (21:00 to 2:00). The direction of these effects hint to an acute and short term effect of light (i.e. alerting response, longer sleep latencies, less slow-wave sleep, melatonin suppression) when compared to a dim light control or to non-blue-enriched light. More recent studies also indicate that insomnia in older residents is positively correlated with light levels in the evening and at night in the bedroom.

The long-term (i.e. circadian effects) are less clear, since many studies did no evaluate them. Thus, it is still not clear whether current domestic light settings have synchronizing effects on circadian rhythms humans. However, there are a few studies that indicate that even moderate light levels in the evening can phase delay circadian rhythms. The result outcomes are less clear for moderate light exposure during daytime and in the early morning hours, since fewer studies were conducted during these time windows and potential negative results have been most likely not published.

Important modulators of the effects of light at moderate levels in domestic settings are: age, gender and probably a clock gene polymorphism. In addition, there is emerging evidence that prior light-dark history substantially influences non-visual responses to light. It is rather the relative than the absolute light level in comparison to prior light exposure and/or the concurrent ambient light that determines the extent of nonvisual effects. In other words, it is the ‘‘extra light’’ that makes the difference. Thus, some of the reported effects in the controlled laboratory experiments may have been “favored” by prior dark adaptation.

3.3.4 Outlook

There is a clear lack of a comprehensive dose-response relationship studies for the alerting response to light at different times of day, which should also include light's wavelength aspects. Temporal 24-h hour aspects of light's action are very relevant for its domestic use in order to design appropriate dynamic light settings for at home. Such studies are very demanding and can only be successfully achieved via a multicenter approach, ideally with partners within the SSL-erate project.

Thus there is still a considerable lack on the dose, duration and wavelength of light exposure in domestic setting before comprehensive recommendations can be made for its use in human centric lighting propositions.

3.4 Health and Wellbeing in Healthcare

3.4.1 Daylight and electrical light exposure in relation to biological rhythms and sleep

In healthy young people, a recent cross-over study comparing people when exposed to natural daylight only with exposure to electrical and day-light in constructed building has shown that the latter environment imposed less sun-light to people and more electrical light after sunset, which correlated with delayed timing of the biological clock (1). In addition, late chronotypes advanced their biological timing in response to the natural light-dark cycle only. This implies that evening electrical light exposure shifts sleep, suppresses melatonin and thereby adapting the circadian clock to this artificial light-dark cycle.

In elderly people, increased exposure to natural daylight correlates with an increase in nocturnal melatonin secretion (2). Increasing the time from 37 to 124 min in natural daylight (N=192, mean age=69.9 yrs) increased nigh-time urinary 6-sulfatoxymelatonin excretion by 13.0% (6.8 to 7.7 µg), suggesting a strengthened of the biological timing signal.

In depressed patients, sunlight was observed to act as an antidepressant as reported from hospitals in Canada and Italy (3, 4). Those inpatients, who stayed in rooms with windows facing east with exposure to direct morning sunlight had a shorter hospitalisation by 2.6 (Canada) or 3.7 (Italy) days than patients in west-facing rooms. In Italy the effect was season-dependent with maximum effect in summer/autumn and no difference in winter. Access to day-light has also been associated with additional therapeutic effects beyond regulation of biological rhythms, which is that windows provide outdoor views for temporal information and contact with nature, which should not be underestimated for feeling of well-being (5, 6).

In conclusion, day-light exposure of sufficient intensity during the day will enhance adaptation to the natural day-night cycle, while imposed electrical light in the evening overrides this adaptation and induces the circadian system to shift. It is not clear, whether exposure to electrical light is disrupting internal phase-relationships since none of the studies looked into the internal synchrony of clock-dependent physiological functions before and after exposure to the different light exposure regimes.

3.4.2 Dose-response relationship of light therapy for the treatment of mood disturbances

Daily rhythms in physiology are co-ordinated by a hypothalamic pacemaker, the 24-hour body clock/circadian clock that is synchronized (entrained) to the external world via light/dark cycles by direct retinal afferent neurons. The body clock controls metabolic rhythms via connections to centres controlling sleep and wakefulness, thereby determining the timing of sleep and sleep-related processes such as nocturnal secretion of growth hormones. It also drives hormonal rhythms, e.g. melatonin, cortisol, independently of sleep via connections to the autonomic system. Sleep is a highly complex behavior arising from interactions between multiple brain regions, neurotransmitter pathways and hormones, none of which are exclusive to the generation of sleep. Abnormalities in any key neurotransmitter system will impinge upon sleep and circadian rhythms but also many of the pathologies caused by sleep/circadian rhythm disruption are reported routinely as co-morbid with neuropsychiatric illness but are rarely linked to the disruption of sleep. Disruption of sleep/circadian rhythms and subsequent atypical patterns of social behavior will lead to abnormal light exposure, which in the end has direct effects on overall emotional well-being and cognitive performance as well as the course of chronic mental illnesses, in particular cycles of relapse, recovery and remission.

A number of reports on the efficacy of light therapy were not based on rigorous study designs and have not been included. Those, which met criteria of randomization and control condition showed a dose-response relationship for morning light in patients with seasonal affective disorder (SAD) for typical but not atypical symptoms, with strong light (6000 lux and more) being more effective than medium light (1700-3500 lux) or dim light (600 lux and less) (7). Time of day evaluation of bright light therapy for non-seasonal depression showed that morning exposure was more effective than at any other time of day, and this was equal between groups with and without concomitant drug therapy (8). This indicates that light intensity applied in the morning has different therapeutic effects on typical mood symptoms. Bright light therapy (10 000 lux) in comparison to medium (4000 lux) or dim light (50 lux), applied in the morning as adjunct treatment, increases the antidepressant effects of SSRIs such as sertraline and citalopram in patients treated for depression (9, 10). Light therapy in form of a dawn simulation in non-seasonal depression showed similar effect sizes but here no dose-response relationship was carried out (11). The effect sizes for light therapy are equivalent to those in antidepressant pharmacotherapy trials. What has not been considered is that the requirements for light therapy dosing may differ for young and old individuals due to age-related reduction in lens light transmission and pupil adaptation.

3.4.3 Light levels may influence neuropsychiatric behaviours in people with dementia

The effectiveness of enhanced indoor light intensity in care homes as a treatment for neuropsychiatric behaviours, including agitation/aggression, depression/dysphoria, irritability/lability or apathy/indifference is not conclusive. The magnitude of change is often small, opposite to what is expected, e.g. increase in agitation (12), clinically not relevant and not decreasing caregiver burden (13). A recent meta-analysis evaluating light therapy reported no evidence that light therapy decreases the decline in cognition or decreases agitation and psychiatric symptoms, including depression (14). The trials varied in the modalities of the light therapy and numbers were too small to allow for subgroup analyses that would determine, which modality, (type, intensity, duration, time-of-day) might be beneficial for specific types and severity of dementia.

In conclusion, there is limited evidence that light treatment may be effective in delaying deterioration in cognition and improving neuropsychiatric behaviour. Outdoor studies need to be considered as the sun's light intensity is much stronger (100,000 lux) but the outdoor environment has also the natural component that is potentially very beneficial.

3.4.4 Light levels may influence sleep in nursing home elderly

The effectiveness of enhanced indoor light intensity in care homes as a treatment for sleep problems, including sleep onset latency, sleep efficiency and night-time awakenings is ambiguous with the magnitude of change varying considerably between studies. Forbes et al. (2014) (14) evaluated bright light intervention in a meta-analysis and reported no evidence that bright light reduces sleep onset latency, increases total night-sleep duration (neither after six weeks nor after two years) or improved sleep efficiency and decreased night-time activity. However, quantitative and qualitative evidence from a broader spectrum of studies, e.g. comparative studies, clinical trials, case reports and combined treatments, shows a trend towards improved quality and duration of night-time sleep and reduced day-time sleepiness (15).

In conclusion, there is weak evidence that light therapy alone may be effective in improving night-time sleep quality, which may be related to the considerable heterogeneity between treatment approaches (dawn simulation, visor, and ambient light), light intensities as well as type and severity of dementias of participants.

3.4.5 Interior lighting design identified as part of care programme for residents of long-term care facilities

Interior lighting design in care homes has to fulfil two major roles – providing optimal illumination for visual comfort and for circadian physiology. In order to obtain proper visual sharpness, the average 60-year-old person needs two to three times the light of a 20-year-old, and an 86-year-old person may require five times the lighting levels. These lighting level differences are due to age clouding the lens, creating a decline in retinal illumination, which makes the effective adaptation luminance lower for older adults (6). Therefore, older adults generally require better contrast and higher task luminance to obtain the same visibility level as a younger person. For someone with failing vision, lighting is important for raising confidence in many simple activities, like walking down a hallway.

All day exposure to indoor bright artificial light of 2500 lux for an extended period using an architectural lighting system with programmable lighting control resulted in staff complaining about visual discomfort. Lower light levels (1250 lux) showed not the expected improvement in depression and sleep, nor a decrease in agitation (16). Newer designs of light sources with programmable spectral content to deliver narrow band light targeting the peak response of the circadian system allows to determine a clinically effective dose without excessive brightness (17). This design induced significant reduction in cognitive decline compared to red light control, but no dose-response has been done. However, a walk in sunlight before light therapy affects sensitivity of the circadian system more than the artificial light source and will override the intervention. Light exposure history must be monitored not only during the day but at night since light can disrupt sleep and the circadian rhythms.

In conclusion, design considerations for circadian light include intensity, spectrum, duration, time of day (clock time as well as individual circadian time), and photic history. An architectural lighting design, which is integrated into the interior environment and flexible (programmable) in tuning light by demand are the preferred option for future interventions. A programmable system would include all indoor areas where residents and staff spend time and would allow optimising exposure to light and exposure to darkness. Furthermore, architecture of buildings must increase the areas for natural daylight to come in – e.g. roofs and walls with glass structures. Innovative designs such as dynamic shading of glass, for example when needed to reduce glare and shadows, and new properties of glazing allow huge glass windows, 'sky-frame' doors as well as glass roofs and floors to be built for plenty of natural daylight exposure.

3.5 Health and Wellbeing in Smart Cities

3.5.1 Lighting encouraging physical activity, social life and recreation

Lighting has positive impact on pedestrian and cyclist outdoor activity [1-3]. Appropriate brightness and good color quality have been connected with favorable responses [4-12]. Especially near field lighting has been reported to be important [13-15]. There are some indications that lighting may have even restorative qualities [16-18]. The effect of lighting on crime varies [19-20]. Besides the lighting strategy aiming to improve visual performance also the strategy aiming to improve positive appearance may be effective in crime reduction [20]. There is extensive evidence supporting the effect of lighting on fear of crime. Perceptions of brightness, evenness, extensiveness, spectral quality, pleasantness and focus of light may affect safety perceptions [5,7,10,12].

3.5.2 Light as pollution

Studies have presented that light exposure at night has numerous harmful effects including, for example, cancer and lower cognitive performance [21-22]. Nocturnal light also harms the well-being of other animals causing difficulties in reproduction, orientation and predation [22]. Most potent wavelength region causing circadian effects is in the blue region [23-24]. Thus, light sources limiting blue emission have been developed [25-26]. In addition to the health effects light pollution prevents the observation of stars thus reducing the extra-terrestrial nocturnal landscape of human beings into a near field spatial experience.

3.5.3 Lighting enhancing safe passage

The safety effect of road lighting is highest with pedestrian, cyclist and moped accidents [27]. Along with intensity also the spectral quality affects safety by improving brightness, facial recognition and response time [9,28]. Pedestrians prefer walking in light making them clearly visible to other road users [29] and benefitting their reassurance [30]. Visibility of pedestrians is also important for drivers [31]. Although road lighting improves visual conditions of drivers [27] and it is generally expected to decrease accidents [27,32], it may also result in increased driving confidence, lower performance [33], higher speed [34] and higher traffic noise level. The safety effect of road lighting with automobile accidents may decrease further in the future along with the emergence of automatic detection and response technologies. Technological advances would also enable more altruistic approach to vehicle lighting; not blinding the other road users but providing assisting light.

3.5.4 Highlights

Lighting control aims to reduce energy consumption and light pollution. But what is the best way to control lighting? Haans & de Kort (2012) studied pedestrian responses to dynamically controlled street lighting environment. They found that people prefer to walk in a spotlight than between spotlights or towards a spotlight. Thus having light in immediate surroundings is important for perceived personal safety. Later research has ended similar conclusions.

The need for **restoration** from attentional fatigue or stress may be considerable after the mental effort needed during the work day. Urban planning should ensure that people may satisfy their restoration needs also during the hours of darkness. Nikunen & Korpela (2012) studied how focus of light affected perceptions of restorativenss, preference and fear in simulated urban nightscapes. They found that focusing light on urban greenery resulted in higher restorativeness and preference ratings and lower fear ratings than focusing light on roads and parking lots. The study indicates that the perceived lighting environment may have restorative qualities affecting cognitive performance and recovery from stress via visual system.

The Navara & Nelson (2007) review addresses the complicated web of potential behavioral and physiological consequences resulting from exposure to light at night, as well as the large-scale medical and ecological implications that may result. It is now becoming apparent that lighting may also be considered as **pollution** and actions should be taken to protect the natural light cycle. These actions could include limitations in intensity, blue emission and exposure time.

4 References and Literature Overview

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