Considerations on how to light the night-shift

A Lowden PhD and G Kecklund PhD
Department of Psychology, Stress Research Institute, Stockholm University, Stockholm, Sweden

Received 8 January 2021; Revised 23 March 2021; Accepted 27 March 2021

Electric lighting has decreased dependence on natural light to illuminate the workplace. Humans are genetically predisposed to be day-oriented (diurnal) and depend on daylight to regulate circadian rhythms. Shift work will force workers to sleep and work at non-biological times, inducing circadian disruption with implications for workers’ safety and health. The scientific literature may be used in practice in shift work settings to improve safety, performance and health in the workplace by reducing circadian misalignment. Alertness profiles at work and degree of melatonin suppression may indicate degree of circadian disruption among workers. However, when considering lighting solutions at night, there are several factors that need consideration. Light measures based on biological effectiveness should be used rather than room illuminance giving better predictions of performance and long-term health among workers. Also, large individual differences in light sensitivity and preferences suggest not only to rely on common lighting alone but also to implement complementary individual lighting solutions at work. Lighting advice should consider shift scheduling characteristics such as speed of turnover and shift timing to guide decisions of preferred circadian phase influence. Lighting should also include the flexibility to be fit for morning, afternoon and evening work.

1. Introduction

In a 24-hour society, there is a need to plan lighting for groups that work atypical hours. Shift workers and especially night workers are required to function during the night when they are biologically programmed to sleep. They need to sleep in daytime and to follow daily rhythms that challenge their biology and therefore are subjected to circadian disruption that often includes sleep problems and fatigue. Since modern society is highly dependent on work being performed at night, it is of importance to consider actions to prevent threats to safety and health. Lighting is one of the most fundamental aspects since it affects work performance, mental state, circadian regulation and long-term health. In the following, we try to give advice on lighting at night and to stress the important factors that in practice will help make correct decisions concerning lighting based on light intervention trials.

It is estimated that 84% of the working population in industrialised societies spend more than 90% of the day indoors. Some chronobiologists would argue that our dependence on artificial lighting could be harmful for health. Such arguments are based on the view of the closeness of evolutionary development to contact with outdoor light/dark changes. But still, also for indoor workers, daylight is the strongest
environmental factor affecting circadian regulation, wakefulness, sleep, mood, neuroendocrine and cognitive performance.4,5

The extent of night work in society has been estimated. In 27 European countries, 19% of the work force work at night at least once a month.6 Similar data in Turkey reach 16%, 13% in the Republic of Korea, 11% in Argentina and 30% in the United States. Most shift workers (about half) have work hours that have alternating/rotating work schedules involving also working during days, early mornings and evenings. Common jobs that include night-shifts are found within the health care sector (doctors, nurses, assistants and other healthcare support staff). Another large group is active in the protective service sector (fire fighters, police officers and security guards) and in manufacturing and production (bakers, machinists, assembly workers, energy production including workers engaged in installation, repair and maintenance). Also, the transportation sector holds many night workers (e.g., drivers, traffic controllers).

Several factors relating to lighting contribute to the health, performance and safety issues in night work. One factor is the mismatch of circadian alignment of the internal circadian clock of the worker and work hours. A second factor is the chronic or partial sleep deprivation that is associated with night work and thirdly, the melatonin suppression and alerting effect from illumination at night.7 These factors will be given additional attention below since they have to be considered when designing illumination at work with the aim to improve health and to acknowledge the concept of human-centric lighting (HCL).8

1.1. Circadian alignment

The circadian system is primarily regulated by light influences and is partially also influenced by time cues like sleep timing, food intake and social interaction (so called Zeitgebers). It has been estimated that around 19% of metabolites found in blood show strong circadian fluctuations.9 The circadian system aligns with the dark/light cycle by light signals given to light receptors in the retina and especially to the intrinsic photosensitive retinal ganglion cells (ipRGCs) that directly project to the brain and central clock. The central clock, located in the hypothalamic suprachiasmatic nuclei (SCN), needs to synchronise body cells driven by peripheral clocks within organs to entrain the biological system to the light/dark cycle as well as to prepare the body for forthcoming activity and rest periods. If the body is not synchronised to work hours, there will be signs of circadian disruption that include fatigue and decreased cognitive performance, short-term or chronic sleep problems, metabolic disturbances and other health threats. Most people travelling across time zones will experience similar circadian disruption (jetlag), and in working life any person who needs to be awakened by an alarm clock risks showing circadian disruption (social jetlag) where timing of sleep during workdays differs from sleep timing on days off.4

Changes in alertness provide a useful indicator highlighting safety risks associated with circadian disruption. Essentially, performance and metabolism follow a similar pattern as alertness.10 Fatigue management is often a prime reason to change illumination in shift work settings since the adaptation process is influenced by light exposure (also timing of sleep patterns will affect alertness levels). Figure 1 demonstrates modelled alertness levels in three workers in connection to five successive night-shifts. The day worker maintains a diurnal (day-oriented) phase position and is here used as a reference. Observe that all workers have a diurnal rhythm during the first night-shift. (If in darkness and without time cues a normal worker would follow a rhythm close to 24.2 hours but daytime lighting will normally entrain the rhythm to
24.0 hours, the normal scenario for a day worker.) This will enable an early rise and promote focus and performance in connection to day work. If the day worker would work at night sleepiness will occur especially by the end of the night-shift and increase the risk of falling asleep. A few hours later the rise of alertness will interfere with sleep and possibly cause sleep problems.  

Shift worker 1 is semi-adapted to night work. By the end of five days, the circadian rhythm is delayed by 4 hours being a typical feature in shift work since light influences during both day and at night will partially delay the rhythm. The semi-adapted shift worker is likely exposed to moderate bright lighting at work. A normal light level measured horizontally at desk level would be 500 lx. This will resemble 150 lx–200 lx (at 2700K: 61–82 equivalent daylight illuminance) measured vertically at eye level. This level likely does not have the circadian strength to fully shift the phase of the alertness curve to adjust to night work.

Shift worker 2 has, by the fifth night, shifted phase position by more than 8 hours and is close to being fully adopted to focus well at night and to sleep satisfactorily during daytime. This faster adaptation is obtained when there is a lack of conflicting exposure to daytime light and the nighttime worker having a strongly illuminated work environment, being observed for example among oil platform workers in the North Sea or in simulated nightwork.

1.2. Sleep deprivation

Epidemiological studies have demonstrated that a short sleep (being defined as having a length of 4 hours–7 hours) is linked to shift and night work as well as negative health outcomes. In particular, short sleep has been associated with coronary heart disease, stroke, type 2 diabetes, obesity and workplace accidents and early morning work and night work have been identified as a cause of sleep deprivation. For early morning work, the sleep period ends close to the circadian nadir and is then perceived as being too short and non-refreshing. Sleep after a night-shift is often rather undisturbed but terminates prematurely after 4 to 6 hours. These phenomena could add to a vicious circle that increases problems with health. A scenario providing a strong light level at night will entrain a worker to delay the circadian rhythm and align the rhythm to night work. This has, in many studies, been shown to improve sleep during daytime.

1.3. Melatonin suppression and direct alerting effects

The past 30 years in research have deepened our understanding of the importance of light exposure for circadian patterns and arousal. The degree of influence depends on
light level, time of light administration and spectral distribution. Measuring the degree of melatonin suppression has often captured the effectiveness of light exposure. Melatonin is a robust hormone, produced by the pineal gland but only during dark hours. This hormone is a central player in the regulation of circadian rhythms and is viewed as a main actor of the central clock in the brain in order to synchronise brain structures, peripheral organs and cellular activity. Melatonin signals night to the body and thus mostly during sleep in diurnal species. The retinal ganglion cells peak in sensitivity to the range of 450 nm to 490 nm in the light spectrum that is perceived as blue by the brain and is included in daylight and monochromatic blue light. The influence of blue wavelengths supresses melatonin production. The degree of suppression of melatonin has in research represented the objective strength of a particular light source to induce phase change to a circadian rhythm.

Unfortunately, the photopic luminous measures, which are available in commercially illuminance meters (luxmeters), do not represent the spectral response of the human circadian system. It is now well accepted that the photopic luminous efficiency function does not represent the spectral response of the human circadian system. But recently, a Commission Internationale de l’Eclairage (CIE) international standard has defined some metrics to assess responses of the human non-visual system to ocular light and particular the effect on melanopsin contained in the ipRGCs. The melanopic equivalent daylight illuminance (MEDI) measured at the eye of users complements the photopic illuminance measured at the desk. And the melanopic equivalent daylight luminance is corresponding to the visible luminance of a surface but weighted for its melanopic effects.

Different outcome measures have been suggested: irradiance or melanopic lux or a daylight (D65) equivalent quantity where (D65) represents average daylight with a correlated colour temperature (CCT) of approximately 6500 K. The metric is based on the calculated ratio of melanopic irradiance from a D65 source and a target source which forms the melanopic daylight efficiency ratio at the same photopic illuminance. The photoreceptor sensitivity in the human eye may also be described by MEDI that matches the illuminance of the standard D65 daylight photon density. In daytime, a recommended minimal MEDI level throughout the day would be 250 lx at the eye measured on the vertical plane about 1.2 m above floor level (eye when seated). In this paper, we follow the recommendations of CIE S 026 and present measured MEDI or estimated (≈MEDI) based on reported illuminances at eye level and light source information.

Light at night and especially light rich in blue wavelengths has been shown to reduce sleepiness (fatigue, tiredness) at night and also improve night time performance. The direct alerting response has been investigated by several research teams. Cajochen et al. have demonstrated that an alertness response is related to dosage of light with the strongest effects generated by a light > 1000 lx (fluorescent room lighting 4000K, ≈>760 MEDI). On the other hand, in an environment with very little light in the evening (< 1 lx, ≈<0.76 MEDI) at a lower level than typical indoor lighting, a 50% suppression of melatonin levels has been observed at <30 lx (≈<23 MEDI). In this study, individual differences were huge, the sensitivity to evening light ranged from 6 lx to 350 lx (≈4.6–266 MEDI). Low light levels are common in the field, for example, a nurse’s light levels rarely exceeded 38 lx (≈29 MEDI) at night. Others only reached 72.5 ± 54.9 lx during a night-shift. Levels around 80 lx has in earlier work been considered as a threshold for the start of suppression of melatonin production.

It is natural to suggest light as a countermeasure during nightwork since alertness
Levels then normally are low (see Figure 1). Circulating melatonin at night promotes sleepiness but light at night will suppress melatonin and therefore alerting effects have been reported. But interestingly as discussed by Cajochen et al., it seems the alerting effect occurs independently of the circadian system, for example, it also occurs during daytime when there are non-detectable levels of melatonin. It seems the direct and indirect light pathways (via the SCN) projections by light to the brain give an alerting effect that trigger the arousal system and cortical activation. Direct alerting effects occur within minutes after exposure whereas the circadian stimulus generates slow reactions.

Figueiro et al. have investigated how the use of a red saturated light with a peak wavelength of about 630 nm would affect performance and alertness at night. These gives improved performance responses as compared to dim light with minimal suppression on melatonin levels. The red light strategy at night is promising, but there is a need for further studies on effects on alertness, melatonin and sleep.

1.4. Light at night

The International Agency for Cancer (IARC) has identified groups subjected to chronic circadian disruption to be more vulnerable to cancer. One possible pathway to this disease could be light exposure at night. Previous epidemiological studies have indicated elevated risk of breast cancer in groups exposed to night work. One suggested explanation would be that light suppresses melatonin at night and that would decrease oestrogen levels thereby increasing the risk of breast cancer cell development and being cancerous. But several recent meta studies have put into question this health risk, instead showing that night-shift work, which includes long-term shift work, has little or no effect on breast cancer incidence. However, in seven meta-analyses, fairly consistent evidence for a positive association between ever versus never night-shift work and breast cancer risk has been found. More recently, a working group at IARC have questioned the specific role of light at night but rather highlighted the general circadian misalignment in the life of the shift worker as compared to a diurnal lifestyle. All authors agree that there is a need for future studies using improved methodology and field studies that will hopefully resolve the yet unclear relation of light at night, circadian disruption and disease. Outcome of further studies will influence future lighting strategies at night.

1.5. Different shift schedules

When we in general terms discuss shift work, we have to realise it is an ambiguous term that includes a wide range of work hour arrangements that involve two or more teams (shifts) that differ in terms of the starting and finishing times. Night work is normally defined as any work with the length of 4 hours between the hours 24:00 to 06:00. Workers may be assigned to only night hours and would then be considered to be permanent night workers. In industry settings with round the clock production a regular three-shift system is most common where workers are assigned night, morning and afternoon type hours in a regular pattern that is repeated, for example, every 6 weeks. The shift length is often close to 8 hours. In this case, the common character is to either have a rapidly rotating system with a maximum of three 8 hours night-shifts in a row followed by days off or other shift types. The slowly rotating systems include more than three nights in a sequence, mostly found within industrial settings. The irregular three-shift, common in the health care and transport sector, has no repetition or structure, scheduled work hours may change every month as may work period lengths. Instead of having 8 hours of work, a common practice is to use 12 hour shifts in 24-hour operation.
settings; it is then referred to as two-shift work and will include night work. In the public and health care sector, it is common to use self-selected work hours where workers have influence on the sequence of shifts. In this sector, a two-shift system may involve 12 hours shifts (including night work), three-shift, or two-shift 8 hours that only include morning and afternoon shifts. The distinction between different shift systems is important and will influence how lighting may be used to support circadian adaptation to work hours.

1.6. HCL in shift work

HCL concepts are in most cases oriented on the natural course of daylight and therefore they need special adaptation to be used also for night-shift work. The idea of HCL is to reduce the stimulus to the non-visual system as far as possible in the evening before habitual bed time. As night-shift does not foresee a bed time, HCL concepts for night-shift lighting need to be adapted. Light is still needed for sufficient vision and workplace standards have to be obeyed. In Figure 2, the 24-hour period is expressed by the progression of core body temperature (dotted line) and melatonin excretion (black line). Body temperature shows a sinusoidal pattern peaking in the afternoon and showing a minimum ($T_{\text{min}}$) at early morning. Melatonin onset starts at around 20:00 and peaks at night and is lowered during early morning hours. We can roughly divide the 24 hours period into three periods. The biological effect of light administered in period A will phase delay circadian rhythms. Observe that period A is defined by the onset of melatonin production and ends at $T_{\text{min}}$. Light during period B will influence the circadian rhythm to be phase advanced and coincides with the rise of body temperature. Exposure during period C will maintain the current phase of the rhythm and may also counteract phase delaying effects of blue light in the evening demonstrating that light history also will play a role in the effectiveness of lighting. Basically, exposure to bright light at any hours of the day will signal to the arousal system and increase alertness. When bright light is received in the wrong circadian phase, adaptation to night work is impeded.

The outline in Figure 2 emphasises the time of day effects of light exposure, but we also have to consider duration of exposure, light

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure2.png}
\caption{Circadian rhythm of melatonin = fat line and core body temperature ($T$) = dotted line. Light given after $T_{\text{min}}$ (period B) promote a phase advance of the rhythm (when $T$ increases). Light given before $T_{\text{min}}$ of the T rhythm (period A) promotes a phase delay (when $T$ decreases). Little effect on phase occurs at other times (period C). Modified from Lowden et al.\cite{16}}
\end{figure}
intensity, exposure levels prior to present influence (light history) and individual differences in sensitivity to light exposure. Alertness levels in general follow the circadian temperature rhythm modelled in Figure 2.

1.7. Dependence on daylight

Figure 3 gives an example of the impact of seasonal changes in daylight exposure. In a study undertaken north of the Arctic circle, we observed an increase of sleepiness in winter compared to summer among a group of 32 office day workers studied across a work week.48 We found a general elevated level of sleepiness most of the day in winter; the studied group was totally dependent on electric lighting during their workdays. Other signs of circadian disruption in winter were increased sleep problems and symptoms of depression. The seasonal difference for sleep onset amounted to a delay of 30 minutes on workdays in winter and 62 minutes on days off. A corresponding effect was found for sleep offset, which was delayed by 27 minutes in winter. In summary, our data and data from others49,50 indicate that the risk of circadian misalignment increases as dependence on electric light increases, suggesting not only shift workers would be benefitted by HCL. We may thus expect that seasonal periods with little daylight have the strongest effect in psychobiological outcomes (of any light regiment).

1.8. Individual preferences

A light intervention study was performed among train traffic controllers (dispatchers) working in a control room environment. The aim was to help the circadian adjustment of controllers assigned to irregular, rapidly rotating, three-shift work. Common static lighting was replaced by a dynamic tunable system (CRI Ra = 94). The workers had the opportunity to turn off the common lighting system and instead use individual lights at the desk according to their own preference. In Figure 4, the individual light profiles in connection to the night-shift are plotted. Data were derived from light meters worn at the wrist (Actiwatch Spectrum, Philips Respironics). In general, the controllers followed the advice from the research team to start the shift at a high light level that is lowered towards the end of the shift. However, we also observed that quite a large proportion of workers preferred an almost dark environment at night. Such large individual differences might need to be considered when

![Figure 3](image-url)  
**Figure 3** Mean (and standard error) sleepiness (KSS) during workdays in winter (grey line) and summer (black line) with asterisks marking the statistical significance of seasonal differences (* = p < 0.05; ** = p < 0.01). KSS: Karolinska Sleepiness Scale

![Figure 4](image-url)  
**Figure 4** Individual light profiles during night-shift
planning lighting at night. Some causes of the difference in preferences are likely related to selection processes into night work.

1.9. Selection into nightwork

In shift work, it is likely that selection processes are active, deciding if a worker will conduct shift work. For example, one selection process points towards the fact that permanent night workers show an over-representation of diurnal types towards eveningness and tolerance to shift work. In line with this reasoning, it is quite possible that also lighting aspects could contribute to selection processes. Groups with various forms of functional neurological disorder (FND) show more problems with retinal function than other groups in ability for depth perception, peripheral vision, colour perception and visual ability. These groups show avoidance behaviours (higher degree of photophobia) and more problems with circadian alignment resulting in, for example, a delayed sleep phase that suits night work. According to the theory of reduced inhibition, decision making and concentration abilities may be disturbed if negative factors in the environment are difficult to delimit but instead amplify lack of motivation, pessimism, impulsivity and anxiety. It is thus likely that among shift workers (especially permanent night workers), the proportion with photosensitivity is relatively high if light levels are kept low at night. Former research has paid attention to negative (and positive) consequences in the introduction of LED lighting. We have in our studies observed photosensitive night workers who find it impossible to cope with a bright light strategy at night due to bad quality lighting regarding flicker, glare and uncomfortable spectral distribution. The recommendation to lighting designers is to find lighting solutions that do not exclude FND or photosensitive workers.

1.10. Ageing

The relative effectiveness of photo-reception is reduced by ageing, the effectiveness of the retinal system is reduced (0.52) at midlife compared to that of a 14-year old’s individual sensitivity to daylight. It is estimated that for indoor work, a 65-year worker needs three times as much light compared to the 25-year worker to reach similar photo-reception and circadian effects. In the CIE S 026 standard MEDI and other illumination quantities may be age-corrected, 32 years old is used as reference. At 50 years, the correction is 0.835 and at 75 it is 0.589 for a CIE standard illumination D65. These ageing effects are more pronounced with low intensity lighting that is found indoors and during the dark season. Also, in ageing, short spectral wavelengths have a reduced capacity as compared to long spectral wavelengths to reach the retina that further lowers the circadian efficacy of light exposure. The main factors explaining ageing effects are related to the decreased pupil area and the light transmitting property of the lens.

2. Lighting advice

It is possible to find lighting advice within the scientific literature to be used in practice in shift work settings, but there are also other pathways for planning countermeasures to fatigue management at night. Such common strategies involve caffeine, naps, melatonin medication (to promote sleep) but also educational programs about circadian physiology and sleep. But basically, the problem in night work centres on circadian misalignment. At night, the inherent biological clock is not synchronised with the need to work efficiently. In recurrent night work, the other problem is the negative effect on sleep quality and length that causes workers to be chronically sleep deprived at work. Light at work will either maintain or adopt circadian
rhythms to night work through the power of suppressing melatonin and could be part of a fatigue-management plan. In the following section, we will discuss how a lighting regimen may be designed in practice.

Data from light studies have generated guidelines for treatment with light to improve adaptation of the circadian rhythm to night work. Light studies have most frequently been performed in simulated shift work, but field studies have also been reported. The effects of light depend on the timing of light. If light is given before T_{min} of the circadian rhythm, a phase advance on the circadian rhythm is expected and if light is given after T_{min}, an expected advance of the rhythm will occur. T_{min} of the rhythm may differ between individuals, it coincides with the core body temperature low and usually occurs 1 to 2 hours before a habitual time of waking. Depending on the shift characteristic, the lighting planner may predict the position of the T_{min}.

2.1. Rapidly rotating night work to slow partial night adaptation

The rationale of giving low MEDI light levels at night is to reduce adaption to night work and to avoid a phase delay of the circadian rhythm. This is preferable in rapidly rotating shift systems with no more than three night-shifts in a row.

Simulated night work studies have demonstrated that a full spectrum light will maximally suppress melatonin at night but also that light that has filtered out blue wavelengths gives less melatonin suppression. The former study found a marginal suppression of 6.4% by using a polychromatic light (>530 nm, 193 lx at eye level). A similar filtered light (>520 nm, 317 lx) did not affect melatonin differently than dim light but improved performance. When using an even longer wavelength, a red saturated red light peaking at 627 nm to 630 nm also showed little influence on melatonin suppression.

Later simulated studies have tried more realistic scenarios and demonstrated that also ceiling mounted LED-luminaires using full-night, short-wavelength, narrow-bandwidth light could reduce sleepiness and improve task performance during the night-shift, compared to long-wavelength light and also phase delay the circadian rhythm. And it seems that either blue or red light promote better performance compared to a dim light option.

In rapidly rotating schedules, a minimal suppression of melatonin is preferable as well as an alerting lighting. Therefore, a close to long wave-length light is recommended. If possible, computer screens should use blue filtering. The light level should keep MEDI low but allow for the individual at the work desk to use high MEDI lighting to prevent somnolence and to allow readability and visual requirements. This would be a complementary solution to let workers with a special need of an alerting response or visual performance to use individual lighting devices at their work stations. Such arrangements are also more considerate to selected photosensitive workers. The acute alerting response should, shortly after exposure, be expected to be similar to the effect of a cup of coffee. A possible negative effect is that a short-wavelength environment could be rated as having a better light comfort than a comparable long-wavelength environment.

Figure 5 gives an example of how 24-hour lighting could be designed in an 8-hour shift work arrangement consisting of a dynamic tunable illumination system (ceiling mounted LED-panels, 35 W, CRI Ra = 94, 3000–5200 K). The programming of lighting is adapted to the changing times of teams at 06:30–13:30–21:30. At the beginning and end of each shift, the light level is lowered to help eye adaptation when passing into or out of work. This adjustment was designed to apply
to a work place with in general low CCT illumination in the building and with very little daylight exposure. During the morning shift, the illumination level reaches 260 MEDI. This vertical illumination at eye level when seated, 1.2 m height is slightly higher than the recommended lowest recommended daytime light level of 250 MEDI as stated by Brown et al. and a consensus group of chronobiologists. In practice, an illumination system is often designed providing a stronger effect than in use to account for environmental differences in illumination of light sources and to improve sustainability. The 100% level in Figure 5 corresponds to about 900 lx measured horizontally at the work desk, reaching about 430 lx at eye level (MEDI ≈ 310).

At night, the light level is kept low at 15% of maximum corresponding to 70 MEDI and CCT is held as low as possible, in this case 3000K. According to the German Committee for Workplaces (ASTA), a workplace is recommended to provide a night time CCT of less than 4100 K. One problem in this example is that the common lights could not be set at a lower illumination and CCT level. Thus, an even more effective circadian strategy could be to turn off the common illumination and instead use beams of amber LED lamps to reach a recommended level of 10 MEDI during the night as stated by the Brown et al. and the consensus paper. Today, many workstations are based on computer work, a bright computer screen will complement common light with about 40 MEDI. However, even if a low MEDI is to be recommended at night, it is important to take into account task-related visual requirements and how fatigue management could handle the increased risk of inducing sleepiness. For example, workers having monotonous tasks and working alone will be subjected to greater risk of human error at a low MEDI level.

Light administration with high CCT during the morning shift starts at 08:00 hours and is prolonged to promote alertness and to exert circadian phase-resetting. Some workers on the morning shift may have a history of night work and might then have a phase advanced $T_{\text{min}}$ and the strong light influence should be presented after $T_{\text{min}}$ for all. Light on afternoon shifts is designed to resemble a slow natural outdoor decrease of light between 18:00 hours and 21:00 hours with a decrease of short wavelengths. The light for evening

---

**Figure 5** An example of a dynamic tunable light profile in shift work settings across 24 hours. The design included ceiling mounted LED panels (35W, CRI Ra = 94) and the effect was chosen to reach at least 250 lx MEDI at 90% of the maximum. Maximum effect illumination (100 %, CCT = 5200K) represents reaching 910 lx on the table (horizontal) and the chosen 90 % daytime level reaching 793 lx (CCT = 5200K, MEDI = 260 lx). The 70 % level (CCT = 4000K, MEDI = 100 lx) is used during the team changing time at 13:30 hours and during the first part of the evening shift. At night the 15% of the maximum reaches 240 lx on the work area (CCT = 3000K, MEDI = 70 lx). MEDI: melanopic equivalent daylight illuminance

---

Lighting Res. Technol. 2021; 53: 437–452
shifts aims to facilitate sleep after work by using light that has shown less blocking effects on the melatonin rhythm and that gives less phase advance of the circadian rhythm.

Possible challenges when using high light levels in lighting are unwanted side effects such as glare, reflections in computer screens, unwanted contrast effects, flicker and uncomfortable spectral distributions. Side effects have to be carefully monitored and a dynamic system often has to be partly modified. Lighting installations should be set in collaboration with experienced lighting designers and would benefit also by collaboration with experts on non-visual effects.

This section has discussed lighting in rapidly rotating shift systems. Lighting at night is then more difficult to handle as compared to other shift systems and many considerations have to be thought about. Basically, the low light level recommendations are to improve diurnal circadian patterns for shift workers that support adaptation to morning work and health. In shift scheduling, a reduced number of night-shifts with a sleep-friendly system that minimises circadian disruption is to be recommended. But such effects are modest and sleepiness is still high by the end of a night-shift. The light level at night could be increased to promote alertness when need of diurnal orientation is less crucial, especially if night-shifts are rare or if night-shifts are followed by days off and with separation to the next morning shift. But also, additional individual-based countermeasures for alertness could be considered and have been proven to be effective. These countermeasures include alerting lighting, coffee and napping strategies.

2.2. Lighting for permanent nightwork/slow rotation to promote quick night adaptation

Most recent recommendations to guide lighting for night work have emphasised that caution should be applied due to the unknown long-term effects that could be negative for health. But there is currently little doubt that a more brightly lit night-shift will increase alertness and performance as well as promote adaptation to night work, although results will depend on MEDI values (high MEDI supports night adaptation), length of exposure (long duration supports night adaptation) and spectral distribution (high CCT achieves stronger circadian effects). Even though light affects the circadian phase at all times of day, during the night sensitivity to light changes dramatically close to T_{min} (peaking 2 hours before T_{min}), light before T_{min} delays the rhythm and light given after T_{min} advances the rhythm. A phase-response curve to light has been modelled based on laboratory data emphasising how timing of light exposure affects phase change. During restricted laboratory conditions a bright light pulse may phase delay the circadian rhythm reaching almost 12 hours across three days if given a 5 hours light pulse just before T_{min}. Such adaptation to night work is rarely seen in the field due to conflicting light influences by, that is, daylight. Earlier field studies that have supported adaptation to nightwork have therefore recommended the use of coloured lenses to block blue wavelengths especially while travelling home from work (e.g., dark or orange lenses).

If visual requirements are crucial at the work place, it is quite possible to maintain requirements but choose a different melanopic efficiency depending on the chosen circadian strategy. Brown et al. give an example that a maintained light level of 300 lx may vary in spectral distribution producing a range of MEDI values for LED-based applications (172 lx–248 lx).

A blue-enriched light (17 000 K) has, in daytime field studies, been proven to increase alertness and performance and similar effects are shown at night. In one study, a 17 000 K
(350 lx at eye level, \(\approx 390\) MEDI) for night workers was tested in control rooms in a petrochemical plant with significant improvements in alertness and performance.\(^7\) \(^4\) Similar but slightly less significant improvements in performance at the same plant were observed when using 6500K (\(\approx 361\) MEDI) as compared to 3000–4000K (\(\approx 158\) MEDI) solutions.

At times, intermittent short light exposure could be an option in real life settings. Bjorvatn et al. gave oil platform workers individually based intermittent 30 minutes of bright light (10 000 lx at eye level, 5377 lx MEDI) treatment according to circadian phase estimations before T\(_{\text{min}}\), during the first four night-shifts. The treatment modestly increased subjective night time adaptation. Lowden et al.\(^2\) administered bright light (2500 lx at eye level, \(\approx 1700\) MEDI) only during breaks in a truck factory. The regimen reduced sleepiness, suppressed melatonin at night and lengthened day sleep.

In summary, we have seen that time spent indoors has increased in industrial societies which has reduced the biological influence of daylight and caused deviations from diurnal circadian rhythms. A work organisation that includes shift work also includes workers that show among the strongest deviations found in society. Electric lighting at work has traditionally partly reinforced such deviations. But as the understanding of light influences increase, lighting technology has also changed and supported new advice for shift work lighting. In this paper, we have emphasised some considerations that could be useful when implementing lighting in shift work settings. Especially, shift characteristics and adaptation of lighting to 24-hour operations, concerns about individual differences or preferences regarding the sensitivity to light, and maintained dependence on natural daylight influences have been highlighted.

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by NordForsk, Nordic Program on Health and Welfare (grant no 74809) and Bertil och Britts Stiftelse för Belysningsteknik.

**ORCID iD**

A Lowden PhD ⓜ https://orcid.org/0000-0002-6980-2971

**References**

1. Vetter C. Circadian disruption: What do we actually mean? European Journal of Neuroscience 2018; 51: 1–20.
2. Schweizer C, David R, Bayer-Oglesby L, Gauderman W, Ilaicqua V, Juhani M, et al. Indoor time – microenvironment – activity patterns in seven regions of Europe. Journal of Exposure Science and Environmental Epidemiology 2007; 17: 170–181.
3. De la Iglesia H, Moreno C, Lowden A, Louzada F, Marqueze E, Levandovski R, et al. Ancestral sleep. Current Biology 2016; 26: R271–R272.
4. Roenneberg T, Merrow M. The circadian clock and human health. Current Biology 2016; 26: 432–443.
5. Potter G, Skene D, Arendt J, Cade J, Grant P, Hardie L. Circadian rhythm and sleep disruption: Causes, metabolic consequences and countermeasures. Endocrine Reviews 2016; 37: 584–608.
6. International Labour Organization. Working Conditions in a Global Perspective. Geneva: ILO, 2019.
7 Smith MR, Eastman CI. Shift work: Health, performance and safety problems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment. Nature and Science of Sleep 2012; 4: 111–132.
8 Boyce P. Exploring human-centric lighting. Lighting Research and Technology 2016; 48: 101.
9 Ang J, Revell V, Mann A, Mäntele S, Otway D, Johnston J, et al. Identification of human plasma metabolites exhibiting time-of-day variation using an untargeted liquid chromatography-mass spectrometry metabolomic approach. Chronobiology International 2012; 29: 868–881.
10 Åkerstedt T. Shift work and disturbed sleep/wakefulness. Occupational Medicine 2003; 53: 89–94.
11 Lee C, Smith MR, Eastman CI. A compromise phase position for permanent night shift workers: Circadian phase after two night shifts with scheduled sleep and light/dark exposure. Chronobiology International 2006; 23: 859–875.
12 van Bommel W. Interior Lighting – Fundamentals, Technology and Application. Cham: Springer Nature Switzerland AG, 2019.
13 Bjorvatn B, Lowden A. Use of light therapies to support alertness and recovery. In Härmä M, Kärhula K, editors. Working Hours, Health, Well-being and Participation in Working Life. Helsinki: Finnish Institute of Occupational Health, 2020; 62–64.
14 Bjorvatn B, Kecklund G, Åkerstedt T. Bright light treatment used for adaptation to night work and re-adaptation back to day life. A field study at an oil platform in the North Sea. Journal of Sleep Research 1999; 8: 105–112.
15 Czeisler C, Johnson M, Duffy J, Brown E, Ronda J, Kronauer R. Exposure to bright light and darkness to treat physiologic maladaptation to night work. New England Journal of Medicine 1990; 322: 1860–1866.
16 Lowden A, Öztürk G, Reynolds A, Bjorvatn B. Working time society consensus statements: Evidence based interventions using light to improve circadian adaptation to working hours. Industrial Health 2019; 57: 213–227.
17 Kecklund G, Axelsson J. Health consequences of shift work and insufficient sleep. British Medical Journal (Online) 2016; 355: 1–13.
18 Dawson D, Campbell SS. Timed exposure to bright light improves simulated night shifts. Sleep 1991; 14: 511–516.
19 Dawson D, Encel N, Lushington K. Improving adaptation to simulated night shift: Timed exposure to bright light versus daytime melatonin administration. Sleep 1995; 18: 11–21.
20 Baehr EK, Fogg LF, Eastman CI. Intermittent bright light and exercise to entrain human circadian rhythms to night work. American Physiological Society 1999; 277: 1598–1604.
21 Lowden A, Åkerstedt T, Wibom R. Suppression of sleepiness and melatonin by bright light exposure during breaks in night work. Journal of Sleep Research 2004; 13: 37–43.
22 Boivin DB, James FO. Light treatment and circadian adaptation to shift work. Industrial Health 2005; 43: 34–48.
23 Boivin D, Boudreau P, James F, Kin N. Photic resetting in night-shift work: Impact on nurses’ sleep. Chronobiology International 2012; 29: 619–628.
24 Brainerd G, Hannifin J, Gleseson J, Byrne B, Glickman G, Garner E, Rolla M. Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. The Journal of Neuroscience 2001; 21: 6405–6412.
25 Tappan K, Arendt J, Skene DJ. An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. Journal of Physiology 2001; 535: 261–267.
26 Lucas R, Pierson S, Bergson D, Brown T, Cooper H, Czeisler C, et al. Measuring and using light in the melanopsin age. Trends in Neurosciences 2014; 37: 1–9.
27 Commission Internationale de l’Eclairage. CIE System of Metrology of Optical Radiation for ipRGC-influenced responses to light. Vienna: CIE, 2018.
28 Brown T, Brainard G, Cajochen C, Czeisler C, Hanifin J, Lockley S et al. Recommendations for healthy daytime, evening, and night-time indoor light exposure. Preprints 2020. DOI: 10.20944/preprints202012.0037.v1.
29 Figueiro M, Sahin L, Wood B, Plitnick B. Light at night and measures of alertness and
performance: Implications for shift workers. Biological Research for Nursing 2016; 18: 90–100.

30 Phipps-Nelson J, Redman J, Dijk D, Rajaratnam S. Daytime exposure to bright light, as compared to dim light, decreases sleepiness and improves psychomotor vigilance performance. Sleep 2003; 26: 695–700.

31 Vandewalle G, Balteau E, Phillips C, Degueldré C, Moreau V, Sterpenich V, et al. Daytime light exposure dynamically enhances brain responses. Current Biology 2006; 16: 1616–1621.

32 Cajochen C, Zeitzer J, Czeisler C, Dijk D. Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. Behavioral Brain Research 2000; 115: 75–83.

33 Phillips A, Vidafar P, Burns A, McGlashan E, Anderson C, Rajaratnam S, et al. High sensitivity and inter-individual variability in the response of the human circadian system to evening light. Proceedings of the National Academy of Sciences of the United States of America 2019; 116: 12019–12024.

34 Figueiro MG, Rea MS, Bullough JD. Circadian effectiveness of two polychromatic lights in suppressing human nocturnal melatonin. Neuroscience Letters 2006; 406: 293–297.

35 Dumont M, Lanctôt V, Cadieux-Viau R, Paquet J, Dumont M, Lanctôt V, et al. Melatonin production and light exposure of rotating night workers. Chronobiology International 2012; 29: 203–210.

36 Gooley J, Chamberlain K, Smith K, Khalsa S, Rajaratnam S, Van Reen E, et al. Exposure to room light before bedtime suppresses melatonin onset and shortens melatonin duration in humans. Journal of Clinical Endocrinology and Metabolism 2011; 96: 463–472.

37 Figueiro MG, Pedler D. Red light: A novel, non-pharmacological intervention to promote alertness in shift workers. Journal of Safety Research 2020; 74: 169–177.

38 Stevens R, Hansen J, Costa G, Haus E, Kauppinen T, Aronson K, et al. Considerations of circadian impact for defining “shift work” in cancer studier: IARC Working Group Report. British Medical Journal 2015; 68: 154–162.

39 Stevens RG, Rea MS. Light in the built environment: Potential role of circadian disruption in endocrine disruption and breast cancer. Cancer Causes and Control 2001; 12: 279–287.

40 Haus EL, Smolensky MH. Shift work and cancer risk: Potential mechanistic roles of circadian disruption, light at night, and sleep deprivation. Sleep Medicine Reviews 2013; 17: 273–284.

41 Travis R, Balkwill A, Fensom G, Appleby P, Reeves G, Wang X, et al. Night shift work and breast cancer incidence: Three prospective studies and meta-analysis of published studies. Journal of the National Cancer Institute 2016; 108: 1–9.

42 Erren T, Morfeld P, Groß J, Wild U, Lewis P. IARC 2019: “Night shift work” is probably carcinogenic: What about disturbed chronobiology in all walks of life? Journal of Occupational Medicine and Toxicology 2019; 14: 10–12.

43 Hunter CM, Figueiro MG. Measuring light at night and melatonin levels in shift workers: A review of the literature. Biological Research for Nursing 2018; 19: 365–374.

44 Sallinen M, Kecklund G. Shift work, sleep, and sleepiness – Differences between shift schedules and systems. Scandinavian Journal of Work, Environment and Health 2010; 36: 121–133.

45 Mardaljevic J, Christoffersen, Raynham P. A proposal for a European standard for daylight in buildings: Lux Europa 2013 12th European Lighting Conference, Krakow, Poland, 17–19 September, 2013: pp. 1–14.

46 Rångtell F, Ekstrand E, Rapp L, Lagermalm A, Liethof L, Olaya M, et al. Two hours of evening reading on a self-luminous tablet vs reading a physical book does not alter sleep after daytime bright light exposure. Sleep Medicine 2016; 23: 111–118.

47 Mitchell P, Hoese E, Liu L, Fogg L, Eastman C. Conflicting bright light exposure during night shifts impedes circadian adaptation. Journal of Biological Rhythms 1997; 12: 5–15.
48 Lowden A, Lemos N, Gonçalves B, Öztürk G, Louzada F, Pedrazzoli M, et al. Delayed sleep in winter related to natural daylight exposure among Arctic day workers. *Clocks and Sleep* 2018; 1: 105–116.

49 Wright K, Mchill A, Birks B, Griffin B, Rusterholz T, Chinoy E. Entrainment of the human circadian clock to the natural light-dark cycle. *Current Biology* 2013; 23: 1554–1558.

50 Moreno C, Vasconcelos S, Marqueze E, Lowden A, Middleton B, Fischer F, et al. Sleep patterns in Amazon rubber tappers with and without electric light at home. *Scientific Reports* 2015; 5: 1–11.

51 Saksvik I, Bjorvatn B, Hetland H, Sandal G, Pallesen S. Individual differences in tolerance to shift work – A systematic review. *Sleep Medicine Reviews* 2011; 15: 221–235.

52 Vetter C, Fischer D, Matera J, Roenneberg T. Aligning work and circadian time in shift workers improves sleep and reduces circadian disruption. *Current Biology* 2015; 25: 907–911.

53 Kooij JJS, Bijlenga D. High prevalence of self-reported photophobia in adult ADHD. *Frontiers in Neurology* 2014; 5: 1–4.

54 Sonuga-Barke E, Cortese S, Fairchild G, Stringaris A. Annual research review: Transdiagnostic neuroscience of child and adolescent mental disorders – Differentiating decision making in attention-deficit/hyperactivity disorder, conduct disorder, depression, and anxiety. *Journal of Child Psychology and Psychiatry* 2016; 57: 321–349.

55 Wang Y, Alonso JM, Ruan X. A review of LED drivers and related technologies. *IEEE Transactions on Industrial Electronics* 2017; 64: 5754–5765.

56 Wilkins A, Veitch J, Lehman B. LED lighting flicker and potential health concerns: IEEE standard PAR1789 update. In: *2010 IEEE Energy Conversion Congress and Exposition, ECCE 2010 – Proceedings*. 2010: 171–178.

57 Turner PL, Mainster MA. Circadian photo-reception: ageing and the eye’s important role in systemic health. *British Journal of Ophthalmology* 2008; 92: 1439–1444.

58 Charnan WN. Age, lens transmittance, and the possible effects of light on melatonin suppression. *Ophthalmic and Physiological Optics* 2003; 23: 181–187.

59 Smith MR, Fogg LF, Eastman CI. Practical interventions to promote circadian adaptation to permanent night shift work: Study 4. *Journal of Biological Rhythms* 2009; 24: 161–172.

60 Bjorvatn B, Pallesen S. A practical approach to circadian rhythm sleep disorders. *Sleep Medicine Reviews* 2009; 13: 47–60.

61 Dijk D, Eastman C, Boulouz Z, Alfred J, Terman M, Campbell S. Light treatment for sleep disorders: Consensus report. *Journal of Biological Rhythms* 1995; 10: 113–125.

62 Van De Werken M, Giménez M, De Vries B, Beersma D, Gordijn M. Short-wavelength attenuated polychromatic white light during work at night: Limited melatonin suppression without substantial decline of alertness. *Chronobiology International* 2013; 30: 843–854.

63 Regente J, de Zeeuw J, Bes F, Nowozin C, Appelhoff S, Wahnschaffe A, et al. Can short-wavelength depleted bright light during single simulated night shifts prevent circadian phase shifts? *Applied Ergonomics* 2017; 61: 22–30.

64 Sahin L, Figueiro MG. Alerting effects of short-wavelength (blue) and long-wavelength (red) lights in the afternoon. *Physiology and Behavior* 2013; 116-117: 1–7.

65 Papamichael C, Skene DJ, Revell VL. Human nonvisual responses to simultaneous presentation of blue and red monochromatic light. *Journal of Biological Rhythms* 2012; 27: 70–78.

66 Sunde E, Pedersen T, Mrdalj J, Thun E, Grønli J, Harris A, et al. Alerting and circadian effects of short-wavelength vs. long-wavelength narrow-bandwidth light during a simulated night shift. *Clocks and Sleep* 2020; 2: 502–522.

67 ASTA C. Empfehlung des Ausschusses für Arbeitsstätten (ASTA) Künstliche biologische wirksame Beleuchtung in Arbeitsstätten. Retrieved 13 April 2021, from https://www.baua.de/DE/Aufgaben/Geschaeftsuehrung-von-Ausschuessen/ASTA/pdf/Beleuchtung.pdf?__blob=publicationFile&v=2.

68 Pallesen S, Bjorvatn B, Mageryi N, Saksvik I, Waage S, Moen B. Measures to counteract the negative effects of night work.
69 Khalsa S, Jewett M, Cajochen C, Czeisler C. A phase response curve to single bright light pulses in human subjects. *Journal of Physiology* 2003; 549: 945–952.

70 Boivin DB, James FO. Circadian adaptation to night-shift work by judicious light and darkness exposure. *Journal of Biological Rhythms* 2002; 17: 556–567.

71 Crowley S, Lee C, Tseng C, Fogg L, Eastman C. Combinations of bright light, scheduled dark, sunglasses, and melatonin to facilitate circadian entrainment to night shift work. *Journal of Biological Rhythms* 2003; 18: 513–523.

72 Hébert M, Martin S, Lee C, Eastman C. The effects of prior light history on the suppression of melatonin by light in humans. *Journal of Pineal Research* 2002; 33: 198-203.

73 Sasseville A, Benhaberou-brun D, Fontaine C, Charon C, Hébert M. Wearing blue-blockers in the morning could improve sleep of workers on a permanent night schedule: A pilot study. *Chronobiology International* 2009; 26: 913–925.

74 Motamedzadeh M, Golmohammadi R, Kazemi R, Heidarimoghadam R. The effect of blue-enriched white light on cognitive performances and sleepiness of night-shift workers: A field study. *Physiology and Behavior* 2017; 177: 208–214.