PHILIPS

Circle of light

White paper

The effect of light on our sleep/wake cycle

by Luc Schlangen, principal scientist at Philips

Executive summary

Evolution has shaped us to live in much more light than our modern indoor life gives us. We generally need most light in the morning and during the day, less in the evening, and the least possible at night. Ideally, this implies getting outside as much as possible during daytime, along with improved (24-hour) control of indoor lighting systems, so that we sleep better and wake up refreshed.

In our modern society, many of us are sleep deprived. Instead of the eight hours a night that a lot of us need, we now get an average of around six and a half. That is just not enough. Tiredness is linked to a huge number of psychological effects: stress and mistakes as well as poor judgment, memory, concentration, attention and creativity. There are also links with medical effects: excessive use of drugs and stimulants, obesity, lower immunity and even increased rates of type-2 diabetes, cardiovascular disease and cancer.

One of the most exciting areas of current scientific research on the human body concerns the effect of light on our circadian (daily) cycles. Progress accelerated since 2000, when researchers discovered a new type of photoreceptor in the eyes[63,64,65], one which powerfully regulates our sleep/wake cycle. Via this photoreceptor, light resets our body clock, which prompts our body and organs to carry out their required functions at any time of day. Light, health and well-being are all strongly linked to a good sleep/wake cycle, and a disrupted sleep/wake rhythm can have huge impact on our functioning and health. There appears to be a strong relation between compromised sleep and mental illnesses like depression, schizophrenia and bipolar disorder.

The following research findings on the influence of light on our sleep/wake cycle are particularly noteworthy:

1. Production of melatonin, the hormone that helps to induce sleepiness and that regulates our sleep/wake cycle, is directly impacted by light[1,2,3,4]. Not only natural light but also artificial light.
2. By itself, our natural body clock typically runs with an average period of 24 hours and 15 to 30 minutes[5,6,7,8] so somewhat longer than our artificial 24-hour clocks. Unless reset, this will make us want to go to bed later causing us to be more dependent on our alarm clocks in the morning.
3. Light with the right quality and timing can reset the half-hour lag and re-synchronize our body clock with our artificial 24-hour clocks[9,10,11,12].
4. Morning light is very powerful in adjusting our body clock[13,14,15,16] and artificial light that mimics bright daylight is highly effective at regulating and synchronizing our sleep/wake cycle.
5. Light is key to overcoming both jet lag[17] and “social jet lag” (the “Monday morning blues” feeling).
6. Light influences our mood[18,19,20,21,22,23] and reinforces a good sleep/wake cycle, thus contributing to our overall health and well-being.

This White paper highlights some of the research from Philips and others on circadian cycles, and in blue text boxes gives some practical guidance to light, health and well-being.

1. Melatonin helps to regulate our sleep/wake cycle

Evolution has adapted us to outdoor light, and natural outdoor light levels are far above our normal indoor light conditions (Figure 1). Even though a sunny day outdoors gives 100,000 lux, a very dull, cloudy and rainy day still gives 2,000 lux. Indoors, though, light levels are generally a quarter of that or less. Besides affecting how well we can see, lighting levels have a fundamental effect on our sleep/wake cycles.

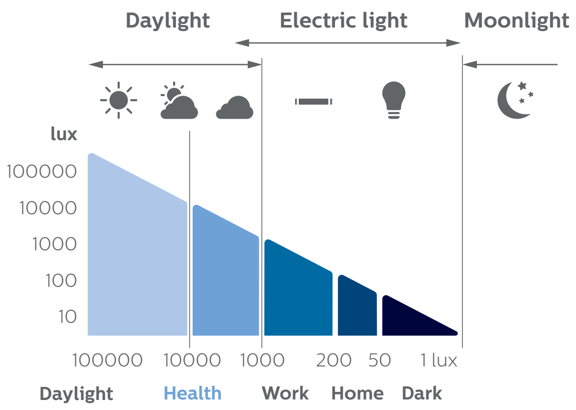

Figure 1: We have evolved outdoors where there is a huge amount of light – there is much less indoors.

Critical to our sleep/wake cycle is melatonin, a hormone that promotes sleep. Normally, we only produce melatonin at night, in the dark, and it tells our body that now is the best time to sleep. During melatonin secretion we feel sleepy, fall asleep quickly, wake least, and get uninterrupted sleep[24]. Exactly how long we sleep depends on the circumstances: it may be eight hours, and sometimes more or less.

When your habitual sleep is at night, daytime melatonin levels are below the detection threshold: when you are active there is normally no melatonin and you feel less sleepy. You can feel sleepy in the daytime too, of course, and so melatonin is not the only thing regulating alertness – how long you've been awake also matters. However, without melatonin in daytime, it is hard to sleep through and get back to sleep after waking[24].

Our melatonin hormone level also regulates our body temperature. High levels of melatonin cause a drop in the core body temperature – the temperature of our internal organs. This change in body temperature is relatively small, only a few tenths of a degree C, but it is very well defined. It oscillates once every 24 hours with a minimum at night (Figure 2).

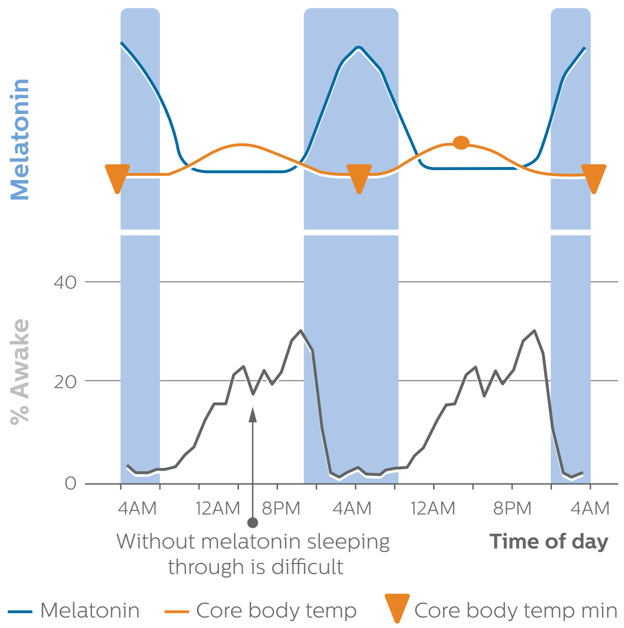

Figure 2: Our body produces melatonin only at night during our regular sleep period. During melatonin production the core body temperature drops. This facilitates deep sleep. During the day, sleeping for more than three to four hours is difficult because we are not producing melatonin. (Diagram derived from Dijk et al[24])

The red triangle in Figure 2 shows the minimum core body temperature, when melatonin secretion is as its peak – typically about two hours before your regular rise time. This minimum core body temperature signals the state of the body clock. It is also the point where we have the least ability to perform well, and the point of our lowest alertness, cognitive performance and motivation[25]. Our performance is also compromised just after we rise in the morning, until we get rid of our sleep inertia and are fully ready for action. We are of course able to overrule feelings of sleepiness – here and elsewhere we can overrule what the body is telling us.

2. The body's internal clock

If people are left in an environment where there is no external light (during the polar winter, or in a cave underground for example) and allowed to get up and go to bed when they want, their sleep-wake cycle runs autonomously with a period that, in most individuals, lasts slightly longer than 24 hours. Our internal clock and so our sleep period, left to itself without any external time cues, rotates clockwise each day by about ¼ to ½ hour (Figure 3)[5,6,7,8,26]. How much actually depends on the individual, and for some it can even rotate counterclockwise.

After spending 24 days in darkness, a clockwise rotation of ½ hour per day results in a schedule that is reversed, so we would be asleep during the day and awake at night. How bad are the effects of this? It depends what we want to do. Some people do actually prefer to live at night, but with families and other social obligations it is then not easy to live a normal life.

Thrown back into the normal world again after these 24 days, we would experience the equivalent of a 12-hour jet lag. We would generally feel dizzy with impaired functioning, sleep problems, nausea and fatigue. However, if the dark conditions would continue for another 24-day period, by day 49 the cycle would be aligned again – we're ready to sleep at night and be awake in daytime.

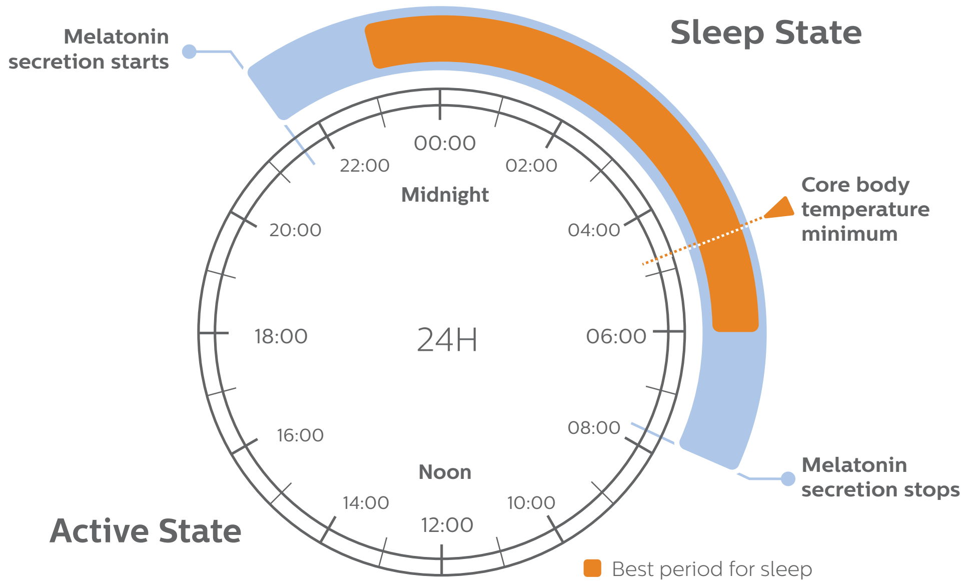

Figure 3: Schematic representation of our body clock cycle. Melatonin is produced during the period that we habitually sleep, usually throughout the night. The hormone melatonin helps regulate our body temperature and body clock. The end of melatonin secretion marks the beginning of the regular wake period. During this period we do not produce melatonin. Melatonin production only resumes one to two hours before the time that we habitually go to sleep, provided the light exposure during these hours remains sufficiently low. The best period for sleep is during melatonin secretion. Light in the hours before the core body temperature minimum moves the best period for sleep to a later timing (i.e., clockwise). Light in the hours after the core body temperature minimum moves the best period for sleep to an earlier timing (i.e., counter clockwise). The closer the light exposure is to the core body temperature, the stronger the shifting action on our body clock. Light exposure can only shift our body clock by about 1-1½ hour a day, at most.

3. Light and the sleep/wake cycle

Normally, light comes in every day to adjust our melatonin secretion and so reset our sleep/wake clock. The circle of Figure 3 helps to show when to time our light exposure and what sort of light is best.

Morning light is very effective at resetting the clock. It shifts the sleep period earlier (so rotating it anti-clockwise in Figure 3), by a maximum of about an hour a day. What is morning light? It is any light that is received during the first hours after the minimum core body temperature. Morning light makes waking up easier so that we become more of a "morning person". Light that is bright and strong in blue wavelengths is most effective for regulating our sleep/wake cycle[9,10]. One study has shown that even short pulses of light can be very effective to reset our body clock[11].

Philips' EnergyLight devices provide bright white or intense blue light potent in influencing the body clock and reinforcing regular sleep patterns when used at the right time. A recent study by the University of Groningen demonstrated that the goLITE blu device can support a sleep advancing protocol in home situations for extreme "evening people" who have difficulty functioning in the morning[27]. Blue light was better than the amber light used in the control group in advancing the phase of the body clock as measured by dim-light melatonin onset time in the evening. Subjects in the blue light group were less sleepy during the day, and, unlike the subjects in the amber group, their cognitive performance did not deteriorate because of the fast advancing sleep protocol. In the follow-up period without morning light exposure, both groups tended to return to the late routine and circadian phase (amber more than blue), indicating the importance of getting strong blue rich light early in the morning every day to stay in tune with the timing of daily obligations.

Many of us – and not just “evening people” – need to use alarm clocks to wake up in the morning and meet our daily responsibilities. As we wake up, our cortisol levels (a stress hormone) rise naturally. Cortisol helps us wake in the morning and get ready for action. Philips produces a wake-up light that simulates sunrise by gradually increasing light levels before the alarm goes off. Philips and the University of Basel collaborated on a study into the use of this light, adjusting brightness in the morning to see the effect on cortisol levels[28]. The study showed that light exposure before the alarm goes off raises the cortisol level directly after waking compared to waking up in darkness[29]. The study also showed that exposure to artificial morning dawn simulation light improved subjective well-being, mood, and cognitive performance even much later during the day. The activating effects of gradually increasing light prior to wake-up were not related to a shift of the clock and were already measurable at first use of the device.

Another study at the University of Groningen has shown that a wake-up light has positive impact on subjective measures of mood, energy levels upon waking, performance, and well-being. This applies to a home setting used in a home setting with habitual sleep and wake times. In addition, it significantly reduces sleep inertia duration, without shifting the body clock[30].

Yet another study at the University of Groningen explored the effects of a wake-up light in a sleep laboratory. This has shown that reduction of subjective sleepiness after being woken up by light was accompanied by a reduction of distal skin temperature, which is associated with a more alert state[31]. Warm hands and feet help us fall asleep quickly, while cold hands and feet signal increased alertness (so the reverse of the core body temperature, where the minimum shows deepest sleep).

Insufficient daytime light exposure can disrupt our sleep. Extra light during the **daytime** can raise nocturnal melatonin levels and enhance circadian amplitude, particularly for the elderly[32] and people who receive very little light during the day.

During the daytime, again especially in the morning, it’s best to be outdoors for a time – take your child out if you can, or take your dog for a walk. Light enhances alertness at all times of the day and night. During daytime alertness is usually appreciated, but at night time it may be less desirable. This applies especially to people who hardly go outside and depend on indoor environments for their light exposure: e.g. workers and school children who spend most of their day indoors, and the elderly who can’t go outside because of physical limitations. Bright or blue rich light during the day is also known to have a positive effect on mood[18-23].

Extra light during the daytime helps people to get better sleep at night. This is yet another argument for get a better outside – particularly for older people. This also increases physical activity.

If we have lots of daytime light exposure, then our sensitivity to light is believed to be lower. A farmer who has been outside all day is less likely to have his sleep disrupted by evening or night-time light exposure than that of a school pupil who has been indoors all day (we don’t know this for sure yet, but it is a hypothesis that scientists are investigating). For some people there can be concerns about excessive light exposure[33]. People who have a very vulnerable retina need to shield it from light as much as possible because it can harm their retina (there are also maximum sunlight recommendations to avoid an increased risk of skin cancer).

Evening light, as long as it is dim and low in blue (short wavelength) content, can help us relax and prepare for sleep. Bright evening light, though, makes us stay up later and can delay sleep – again by up to around an hour a day (so, rotating the sleep period in Figure 3 clockwise). That makes it more difficult to get up early the next morning. What is evening light? It is light that hits our retina in the hours just before the minimum core body temperature. The closer the light is to the moment we reach our minimum core body temperature, the stronger the shifting action on our body clock.

The major difference between a late and early riser is the moment when they are exposed to light. Scientists have not yet found one to be ‘better’ than the other for our bodies and our moods, as long as we don’t change them around too much. There are even indications that when exposed to only natural light (for example while camping in summer time), late risers show larger circadian advances than early risers, and most people become morning people with the end of their internal biological night occurring before wake time just after sunrise[34].

Avoiding bright and blue lights in the evening allows us to stay up enjoying activities without disrupting our circadian rhythm. The latest generation of LED lights is particularly useful since some can be tuned to give off different light frequencies.

For a good night’s sleep, make your bedroom sufficiently dark. Try to keep regular bedtimes. Avoid bright lights (particularly blue lights) in the last one to two hours before bedtime, and instead use warm lights (strong in red and yellow). Relax an hour or so before you go to bed and don’t use computers, mobile phones or anything that overstimulates you. Then, in the mornings, try to make sure you get enough light, and preferably bright light in the first one to two hours after waking.

If we stay up late using (for example) computers, e-readers or tablets then studies have shown that we can become more of an “evening person”. Studies on the consequences of the evening use of (for example) computers should be examined carefully for relevance, though, since many of them put people in darkness before the light or tablet exposure. That alone makes people more sensitive to light – and rarely happens in life. Apps adjusting the light from tablets (bluer/brighter in day, redder/dimmer at night) can be useful when used in a generally dimly lit environment. They may however make less of a difference when used in well lit places, and by people that have had lots of daytime light exposure.

Light **at night** suppresses melatonin[3,4] and makes it more difficult to get to sleep[1], and so harder to get up early next morning. It does this within minutes of our eyes receiving the light, and even a few minutes’ light pulse can be enough to suppress melatonin. That is true for some blind people too[3], who have no vision but whose melanopsin[35] receptors (which affect melatonin secretion) work. One study[3] gave subjects a light pulse at night, which resulted in a brief but dramatic drop in melatonin. When back in darkness, melatonin levels rose quickly – within about 30 to 90 minutes – to enable sleep again.

Because of our sensitivity to even relatively short bursts of light, night guide lights for bathroom visits should be dim (and avoid blue light), but should give out enough light to see safely without stumbling.

It is still best to use as little light as possible at night, though. At night, light disturbs our sleep patterns, and it is best not to disturb them too frequently. Police, doctors and other night workers often have irregular sleep-wake patterns. For their jobs, they often need to be alert at night, but for their health it is not good when their sleep schedules shift frequently. We've evolved to sleep at night and that's what we should do. Whether we go to bed early or late is less important than keeping regular times.

The message from nature is clear: **a regular sleep/wake rhythm is best for our performance and health**. But within this, our bodies have evolved a kind of steering wheel, constantly adjusting the sleep/wake cycle, driven by light and melatonin (see Figure 3). The day(light) length enables the steering wheel to adapt our behavior and physiology to the different seasons. For animals, it can affect migration and reproduction.

So, the timing of light exposure lets us control the sleep/wake cycle. The closer the light exposure occurs to the minimum core body temperature (CBT_{min}), the more strongly the light can shift the rhythm. Light before CBT_{min} makes us sleep later, light after CBT_{min} makes us sleep earlier[13,14,15,16]. In this way, well-timed light exposure can help people with extreme evening or morning preference to regulate their sleep times (light hitting our retina at noon, far from CBT_{min}, hardly shifts our clock at all).

People who go to bed early can often wake up as early as 5 o'clock in the morning and then not get to sleep again. Giving additional evening light can help to delay bed time and sleep onset.

The amount we can shift per day is much longer than the increase or decrease in day length across the seasons (even at the equinox that is typically only a couple of minutes a day). Evolution seems to have developed this so we can shift our routines to get up early to (for example) catch fish that arrive early in the morning, or hunt nocturnal prey.

4. Night shifts, (social) jet lag and the Monday-morning blues

Almost one fifth of the workforce in Europe and North America does **night shift** work (mostly in health-care, industrial, transportation, communications and hospitality sectors)[36]. In principle – like regular jet lag – this is not good for health[37,38,39].

The science surrounding night-shift work is still evolving and it is difficult to set hard-and-fast rules. The exact effects depend on many factors in a complex way, probably including the individual's predisposition, lifestyle and irregularity of the sleep-wake patterns of a (rotating) night shift. Often, melatonin is still produced at night while the workers are on night shift (melatonin rhythms can alternatively be shifted or even abolished). Since night workers haven't slept at night, they feel tired during the day. This is even worse when shift workers have to move their shift by eight hours every few days as happens in fast forward or backward rotating shift schedules. Eight hours is far too much to shift our internal sleep/wake clock (i.e., our melatonin secretion period) within a day –light can only shift our body clock by about one hour a day or two hours in two days, and so on.

Jet lag has similar consequences to night shift work, and here again our body cannot cope with the large disruptions to our sleep/wake cycle.

So, how do we recover from jet lag? We want to reset the body clock, which means receiving light at the right time. Putting on sunglasses and sitting quietly in the day during the recovery period can help. Here too it's a complicated situation, though, and minimizing adjustment times needs light and dark exposures to be well timed. Light at the wrong time can make things worse. It all depends on when our minimum core body temperature occurs, (as explained in the discussion of morning and evening light in section 3), and that can differ by several hours from person to person. Taking melatonin (which in some countries needs a prescription) can help to shift the sleep-wake cycle more rapidly[40,41] but we can still only shift our body clock by a limited number of hours/day.

We are meant to live regularly, and not swing our sleep patterns around. In evolution, there were no airplanes and few night shifts.

We often subject ourselves to **social jet lag**[42,43] which can lead to feeling bad on Monday morning (and beyond). During the working week, many people wake themselves early with an alarm clock, so sleeping less than they need to and hoping to make up for this sleep deficit during the weekend. Going out on Friday evening with lots of bright-light exposure can set the body clock a bit later. Saturday and Sunday are free days that often make us even later. Especially when we (again) have more activities and bright light in the evening, while also having a lack of morning light due to sleeping in and rising late. This can delay the sleep window (the best period for sleep, see Figure 3) by as much as four hours over the weekend.

By Monday morning the sleep window has moved later into the morning, and we struggle to wake. This gives rise to the 'Monday morning blues'. We may get lots of light on our way to work on Monday morning – bright light in the morning would normally help us to recover – but here there can be unpleasant surprises. Our body can perceive this morning light as evening light when it comes before our minimum core body temperature (the temperature minimum has been pushed to a later moment over the weekend, and at worst into the first working hours of the morning). If this happens, that morning light will even push our sleep window forward to a later timing (clockwise in Figure 3), aggravating our social jet lag. When we work indoors, there is then often not enough light during the rest of the day to push our sleep window back.

Office lighting with an extra injection of light in the morning helps to reset peoples' body clocks and keeps people in tune with the timing of their daily obligations. On Monday mornings this is especially relevant for those who have been subjected to bright lights during a hard weekend's partying.

On Monday night it can again be very difficult to sleep early and we often won't sleep very well. If we aren't ready to sleep by midnight and instead switch on our light to read, that can actually make things worse (see Section 3). Luckily, most people suffer from only a moderate social jet lag and can safely seek bright light directly after waking up.

5. Sleep/wake cycles and health

People suffering from jet lag, night shift workers, teenagers and the elderly can all have issues with their circadian rhythm. By the age of 20 we are the most evening oriented ever in our lives[44]. We become more of a morning person as we get older (although we don't know whether this is inbuilt, or whether we just tend to go out less late, or less frequently, in the evening as we get older).

People in intensive care units (ICUs) can have very low circadian amplitude and scientists are exploring whether this plays a role in the development of delirium[45]. Delirium is a major cause of death in ICUs. It also extends the time people need to stay in the ICU, and increases the cost of health care tremendously. Anesthesia may also disturb circadian rhythms – operations seem able to induce circadian delays[46] – these disturbances, like jet-lag, can have a negative influence on recovery.

In ICUs and neonatal ICUs, lights are often on 24 hours a day. One very interesting and important study in a Mexican neonatal unit reduced the length of stay of babies by 30% – simply through decreasing the light at night by shading the infants' eyes. This very easy, low-tech solution had an amazing effect, allowing children to go home 15 to 20 days earlier[47].

There are many indications that sleep and circadian rhythms are critical to wellbeing and health but also to our proper functioning[66]. The severity of psychiatric symptoms is often associated with circadian rhythm disturbances[48,49] – again we don't know which comes first: do mental issues arise before the sleep disturbances, or do sleep issues arise first?

Because of our sensitivity to light, creating sufficient darkness at night is one of the easiest and most important things we can do throughout our lives. We not only need good light during daytime, we need an absence of disturbing light at night.

We do however know that they influence each other. A group of leading scientists has summarized the impact of sleep and circadian rhythm disturbances on our emotional and physical responses[48]. Effects include increased depression, psychosis, risk taking and stimulant intake; impaired cognitive responses, cognitive performance, memory, communication and decision making; lower creativity/productivity and worse motor performance. We can also get somatic responses, increased drowsiness, feel pain more strongly, run increased risk of cancer and metabolic syndrome (a combination of diabetes, high blood pressure and obesity), and compromised immune function.

6. Different applications, different types of light

Our response to light depends on several factors: the internal time of our biological clock, the light spectrum, intensity, preceding light exposure (we respond more if coming from darkness or dim light), but also our preceding sleep behavior. There are lessons in all this for lighting at home, and in offices, schools and hospitals.

During the day, blue-rich light is good for us. A joint study of office lighting in 2008 by Philips and the University of Surrey looked at Philips ActiViva lights (17000K), which are white lights that are very rich in blue, biologically efficient wavelengths. The study used normal office lighting levels (about 370 lux illuminance). People rated their alertness and performance as being higher with ActiViva, they were less troubled by evening fatigue and reported improved sleep quality. All these parameters showed significant improvements, around 10 to 20% better than the control condition with standard white lighting (4000K)[50]. This clearly shows that enhancing daytime light exposure can help us to get better sleep at night. The study was done in winter in the UK, so there was very little daytime light exposure outdoors (it may well be that these effects are very much reduced in summertime, when lack of daylight is less frequent).

When companies design new offices, they pay a lot of attention to factors like air conditioning, infrastructure and ICT, but they rarely consider light at all. Doing so could, however, bring real benefits for sleep, health and well-being, thus improving productivity and creativity. Adaptations of office lighting norms and codes are being discussed to incorporate recent insights[35,51,52].

Light's effect on alertness also has important implications for schools and other educational settings. Philips has developed a SchoolVision lighting system that varies the light intensity and spectrum depending on specific requirements of the school day. This can improve concentration and the speed of completing specific tasks. It can also decrease the number of errors made in tests of attention[53,54].

Light also influences all kinds of clinical outcomes. Many papers show the benefits, which include improved sleep[55], faster recovery times[56], improved sleep and weight gain for preterm infants[57], reduced incidence of delirium[58], and reduced stress and pain medication usage[59].

These and other scientific papers have inspired Philips to develop a hospital lighting system which increases light exposure during parts of the day. A study of hospital patients[60] using this system took place using intervention rooms with much brighter light during the day and lower night-time light (Figure 4). The lights in the intervention room were also designed to create a pleasant controllable atmosphere by means of colored accent lighting. Intervention room patients were much more able to regulate and dim their light exposure at night time, and also to adjust the atmosphere to help them feel more at home.

Like conventional hospital rooms, both the control and intervention rooms had a window. Even without sunblinds, though, the amount of daylight reaching the beds was relatively low – in this study it gave an illuminance of 300 lux. Reading lights were dimmable in the intervention rooms but not in the control rooms. At night the electrical light in the intervention room was restricted to an illuminance of 50 lux, when activated (100 lux in the control rooms).

Room assignments were made according to routine hospital procedures, and conducted by staff that acted fully independently and had no relation to the study. We found significantly higher satisfaction in the intervention rooms among both patients and staff. The patients in the control and intervention rooms were interviewed separately.

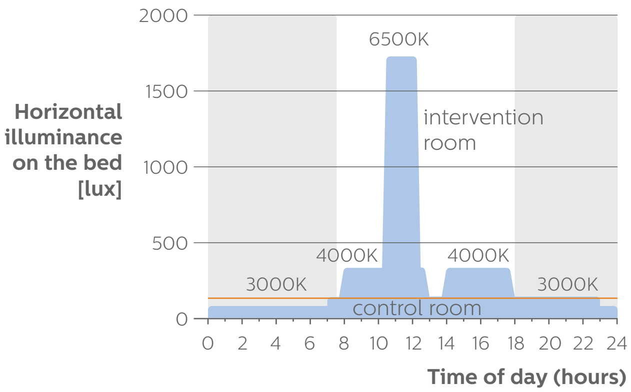

Figure 4: General lighting levels in the intervention rooms were higher than the control rooms during the day, and much higher for a couple of hours around noon. Intervention-room general lighting levels, when activated, are also lower during night time (23.00-7.00).

Sleep duration (measured via actigraphy) lengthened by 6 minutes for every day that a patient was in an intervention room, as compared to being in a control room. This effect was additive, so 12 minutes by the second night, and so on until up to around nearly half an hour longer sleep duration after 5 days, the median length of stay. In the control rooms the sleep duration even reduced slightly (although not significantly) during their stay: patients in general tend to sleep less after a week of hospitalization in the control room.

Light is of course not the only factor in producing a comfortable atmosphere. Noisy environments like open-plan spaces can be distracting. Philips has developed a Soundlight Comfort Ceiling that mimics the rhythm of daylight while absorbing sound for better acoustics. It has been installed at Karolinska, Sweden's largest university hospital, where it was studied by the Stress Research Institute at Stockholm University. Individual patients in the study reported a more comfortable atmosphere and some staff reported greater alertness.

At home, we should take care to have the proper quality of light in the evening and at night. This was clearly demonstrated by one study, in which people were exposed to different kinds of light to test which evening light is least disruptive to sleep. Darkness had least effect, then yellow light and normal room light. Blue enriched white light (very rich in short wavelengths) had more effect, with bright blue enriched light being most disturbing of all[1]. So, minimizing the disruption of sleep and circadian rhythms by late evening (or nocturnal) light means reducing both the amount and the blue-content of the light exposure.

Avoid children's night lights with high blue light content. Preferably also reduce the nocturnal light intensity as much as possible.

7. To summarize

We need greater awareness of the influence of light on our bodies and behavior. Society today largely neglects the regulation of our body clock, and it's circadian rhythmicity, by light in our living environment. Yet, the body clock affects general health and well-being, mental healthcare, metabolic syndrome and other conditions. By regulating the circadian rhythmicity of our body clock, light influences all kinds of health risks and can reduce or even prevent health and sleep disturbances.

These findings need to be applied in all kinds of settings – particularly schools, offices, homes and healthcare establishments. Applying the discoveries should be done with care, since the wrong light recipe can actually make things worse, especially in the evening and at night. The exact recommendations on how much light we need and when are still not fully ready. There is, though, an understanding in the scientific world that we need light to regulate and stabilize our rhythms and that daytime exposure to relatively bright and blue rich light is beneficial - especially after waking up in the morning.

Our circadian cycle has developed over more than a million years to help us survive (Figure 5). Daytime light enhances the strength of the circadian cycle. Evening light pushes the sleep/wake rhythm later, while morning light makes the rhythm earlier (see Figure 3). Nocturnal light compromises sleep and so needs considerable care. Our typical indoor environments often result in irregular and low amplitude light/dark cycles and allow us little control. Healthy and stable sleep-wake rhythms are however essential to health, and that needs a strong and regular light/dark cycle (so high intensity during the daytime and very little or no nocturnal light). You can track and explore the stability of your sleep/wake cycle for a week using a sleep diary[61] like the one shown in Figure 6.

We should be designing lighting systems with more light in the daytime – especially in the mornings – and be very careful with light at night. It is therefore not only about having more light but also about better quality of light: better spectral composition, spatial distribution (whether diffuse or concentrated, etc.), better dynamics and timing.

All this requires greater control and brighter light systems – however full brightness is only needed for part of the day, preferably during the early morning hours after we wake up. Lighting systems with controllable, enhanced daytime light can bring major benefits. Of course we must consider ocular safety and the new lighting systems all comply with laws and regulations[33]. There are energy efficiency and vision aspects of light, too. We need to start balancing energy efficiency (less light) against enhanced daytime brightness for better health[62]. That generally means using LED lights, and making them brighter during only part of the day.

Thorough research is a slow process. Field studies require a tremendous amount of time and money. It can even take as much as a decade from study definition to the actual publication of the study findings. However, indoor spaces affect a huge part of the population and the return on investment can be high – many benefits can already be realized by improvements in intelligent and connected lighting systems that need not be complicated. Results can occasionally be spectacular: the Mexican study mentioned in this paper[47] for example brought huge benefits from simply giving newborn infants an eye mask to put on at night.

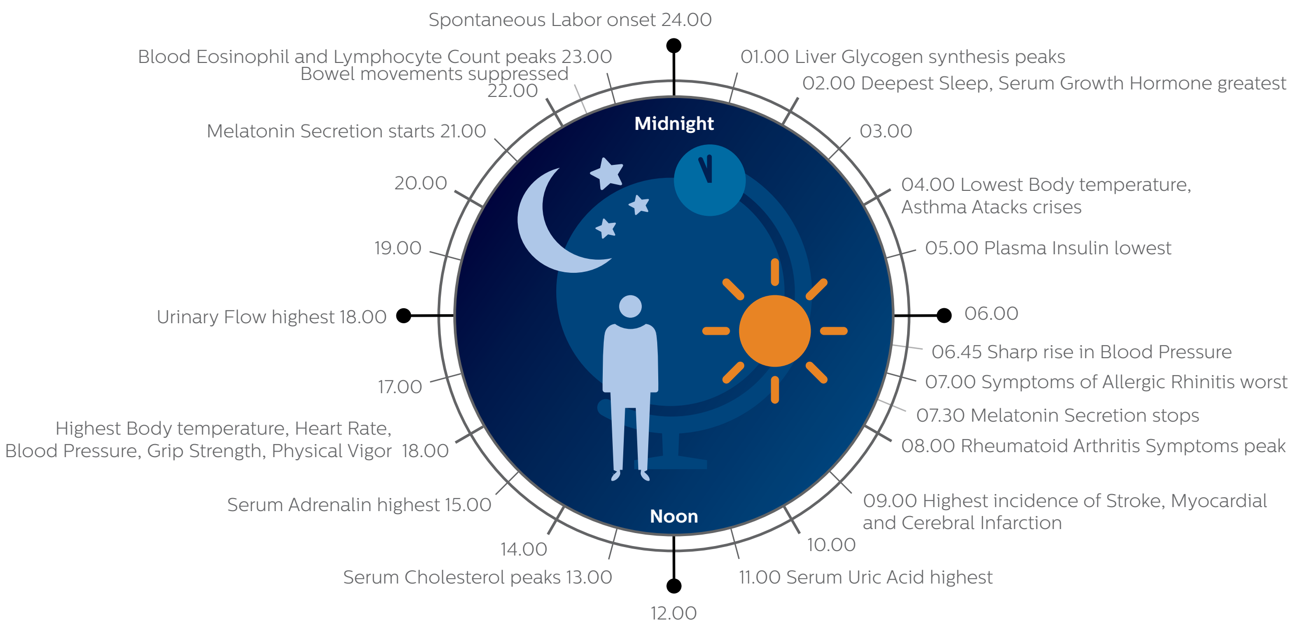

Figure 5: Our body has evolved to behave in a certain way. Many events in physiology and health display a circadian rhythmicity and can be plotted in a typical circadian cycle. The figure gives an example of this.

Consensus Sleep Diary-Core

	Sample		ID/Name:					
Today's date	**4/5/11**							
1 What time did you get into bed?	10:35p.m.							
2. What time did you go to sleep?	11:30p.m.							
3. How long did it take you fall asleep?	55 min							
4. How many times did you wake up, not counting your final awakening?	3 times							
5. In total, how long did these awakenings last?	1 hour 10 min.							
6. What time was your final awakening?	6:35 a.m.							
7. What time did you get out of bed for the day?	7:20 a.m.							
8. How would you rate the quality of your sleep?	☐ Very poor ■ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good
9. How much time in total have you been outside in daylight prior to your bedtime?	1 hour 20 min.							
10. Comments (if applicable)	I have a cold							

Figure 6: Sleep diary after Carney et al, 2013[61] with extra daylight question. Fill it out every day, preferably as soon as possible after getting out of bed in the morning (at this time your entries will be most accurate and valuable). Don't worry about giving exact times, just give your best estimate. This diary can also help you to discover patterns in your sleep on work and free days.

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Literature list:

[1] Santhi N, Thorne HC, van der Veen DR, Johnsen S, Mills SL, Hommes V, Schlangen LJM, Archer SN, Dijk DJ (2011) The spectral composition of evening light and individual differences in the suppression of melatonin and delay of sleep in humans. *J Pineal Res* 53: 47-59. 10.1111/j.1600-079X.2011.00970.x [doi].

[2] Mishima K, Okawa M, Shimizu T, Hishikawa Y (2001) Diminished melatonin secretion in the elderly caused by insufficient environmental illumination. *J Clin Endocrinol Metab* 86: 129-134.

[3] Czeisler CA, Shanahan TL, Klerman EB, Martens H, Brotman DJ, Emens JS, Klein T, Rizzo JF, III (1995) Suppression of melatonin secretion in some blind patients by exposure to bright light. *N Engl J Med* 332: 6-11.

[4] J. M. Zeitzer, D. J. Dijk, R. Kronauer, E. Brown, and C. Czeisler. Sensitivity of the human circadian pacemaker to nocturnal light: melatonin phase resetting and suppression. *J.Physiol* 526 Pt 3:695-702, 2000.

[5] M. A. Carskadon, S. E. Labyak, C. Acebo, and R. Seifer. Intrinsic circadian period of adolescent humans measured in conditions of forced desynchrony. *Neurosci.Lett.* 260 (2):129-132, 1999.

[6] T. L. Kelly, D. F. Neri, J. T. Grill, D. Ryman, P. D. Hunt, D. J. Dijk, T. L. Shanahan, and C. A. Czeisler. Nonentrained circadian rhythms of melatonin in submariners scheduled to an 18-hour day. *J.Biol.Rhythms* 14 (3):190-196, 1999.

[7] C. A. Czeisler, J. F. Duffy, T. L. Shanahan, E. N. Brown, J. F. Mitchell, D. W. Rimmer, J. M. Ronda, E. J. Silva, J. S. Allan, J. S. Emens, D. J. Dijk, and R. E. Kronauer. Stability, precision, and near-24-hour period of the human circadian pacemaker. *Science*284 (5423):2177-2181, 1999.

[8] S. A. Brown, F. Fleury-Olela, E. Nagoshi, C. Hauser, C. Juge, C. A. Meier, R. Chicheportiche, J. M. Dayer, U. Albrecht, and U. Schibler. The Period Length of Fibroblast Circadian Gene Expression Varies Widely among Human Individuals. *PLoS.Biol.* 3 (10):e338, 2005.

[9] S. W. Lockley, G. C. Brainard, and C. A. Czeisler. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *J.Clin.Endocrinol.* Metab 88 (9):4502-4505, 2003.

[10] J. M. Zeitzer, D. J. Dijk, R. Kronauer, E. Brown, and C. Czeisler. Sensitivity of the human circadian pacemaker to nocturnal light: melatonin phase resetting and suppression. *J.Physiol* 526 Pt 3:695-702, 2000.

[11] C. Gronfier, K. P. Wright, Jr., R. E. Kronauer, M. E. Jewett, and C. A. Czeisler. Efficacy of a single sequence of intermittent bright light pulses for delaying circadian phase in humans. *Am.J.Physiol Endocrinol.Metab* 287 (1):E174-E181, 2004.

[12] R. P. Najjar, L. Wolf, J. Taillard, L. J. Schlangen, A. Salam, C. Cajochen, and C. Gronfier. Chronic artificial blue-enriched white light is an effective countermeasure to delayed circadian phase and neurobehavioral decrements. *PLoS.ONE.* 9 (7):e102827, 2014.

[13] N. E. Rosenthal, J. R. Joseph-Vanderpool, A. A. Levendosky, S. H. Johnston, R. Allen, K. A. Kelly, E. Souetre, P. M. Schultz, and K. E. Starz. Phase-shifting effects of bright morning light as treatment for delayed sleep phase syndrome. *Sleep* 13 (4):354-361, 1990.

[14] M. Terman, A. J. Lewy, D. J. Dijk, Z. Boulos, C. I. Eastman, and S. S. Campbell. Light treatment for sleep disorders: consensus report. IV. Sleep phase and duration disturbances. *J.Biol.Rhythms* 10 (2):135-147, 1995.

[15] V. L. Revell, T. A. Molina, and C. I. Eastman. Human Phase Response Curve to Intermittent Blue Light Using a Commercially Available Device. *J.Physiol.*, 2012.

[16] S. B. Khalsa, M. E. Jewett, C. Cajochen, and C. A. Czeisler. A phase response curve to single bright light pulses in human subjects. *J.Physiol* 549 (Pt 3):945-952, 2003.

[17] Z. Boulos, S. S. Campbell, A. J. Lewy, M. Terman, D. J. Dijk, and C. I. Eastman. Light treatment for sleep disorders: consensus report. VII. Jet lag. *J.Biol.Rhythms* 10 (2): 167-176, 1995.

[18] T. Partonen and J. Lonnqvist. Bright light improves vitality and alleviates distress in healthy people. *J.Affect.Disord.* 57 (1-3):55-61, 2000.

[19] G. W. Lambert, C. Reid, D. M. Kaye, G. L. Jennings, and M. D. Esler. Effect of sunlight and season on serotonin turnover in the brain. *Lancet* 360 (9348):1840-1842, 2002.

[20] M. Aan Het Rot, D. S. Moskowitz, and S. N. Young. Exposure to bright light is associated with positive social interaction and good mood over short time periods: A naturalistic study in mildly seasonal people. *J Psychiatr. Res*, 2007.

[21] A. Tuunainen, D. F. Kripke, and T. Endo. Light therapy for non-seasonal depression. Cochrane. *Database.Syst.Rev.* (2): CD004050, 2004.

[22] R. N. Golden, B. N. Gaynes, R. D. Ekstrom, R. M. Hamer, F. M. Jacobsen, T. Suppes, K. L. Wisner, and C. B. Nemeroff. The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence. *Am.J.Psychiatry 162* (4):656-662, 2005.

[23] A. Wirz-Justice, F. Benedetti, and M. Terman. *Chronotherapeutics for Affective Disorders : A Clinician's Manual for Light and Wake Therapy*, Basel:Karger, 2009.

[24] D. J. Dijk, T. L. Shanahan, J. F. Duffy, J. M. Ronda, and C. A. Czeisler. Variation of electroencephalographic activity during non-rapid eye movement and rapid eye movement sleep with phase of circadian melatonin rhythm in humans. *J Physiol* 505 (Pt 3):851-858, 1997.

[25] Hull JT, Wright KP, Jr., Czeisler CA (2003) The influence of subjective alertness and motivation on human performance independent of circadian and homeostatic regulation. *J Biol Rhythms* 18: 329-338.

[26] D. L. Robilliard, S. N. Archer, J. Arendt, S. W. Lockley, L. M. Hack, J. English, D. Leger, M. G. Smits, A. Williams, D. J. Skene, and Schantz M. von. The 3111 Clock gene polymorphism is not associated with sleep and circadian rhythmicity in phenotypically characterized human subjects. *J.Sleep Res.* 11 (4):305-312, 2002.

[27] Hommes, V., Meesters, Y., Geerdink, M., Gordijn, M., & Beersma, D. (2014). Blue Light Implemented (pp. 184–197). *Presented at the 8. Symposium Licht und Gesundheit, Berlin.*

[28] V. Gabel, M. Maire, C. F. Reichert, S. L. Chellappa, C. Schmidt, V. Hommes, A. U. Viola, and C. Cajochen. Effects of artificial dawn and morning blue light on daytime cognitive performance, well-being, cortisol and melatonin levels. *Chronobiol.Int.* 30 (8):988-997, 2013. .

[29] Gabel, V., Maire, M., Reichert, C. F., Chellappa, S. L., Schmidt, C., Hommes, V., et al. (2013). Effects of Artificial Dawn and Morning Blue Light on Daytime Cognitive Performance, Well-being, Cortisol and Melatonin Levels. *Chronobiology International,* 30(8), 988–997.

[30] M. C. Gimenez, M. Hessels, Werken M. van de, B. de Vries, D. G. Beersma, and M. C. Gordijn. Effects of artificial dawn on subjective ratings of sleep inertia and dim light melatonin onset. *Chronobiol.Int.* 27 (6):1219-1241, 2010.

[31] M. V. Werken, M. C. Gimenez, B. D. Vries, D. G. Beersma, E. J. Van Someren, and M. C. Gordijn. Effects of artificial dawn on sleep inertia, skin temperature, and the awakening cortisol response. *J Sleep Res,* 2010.

[32] K. Obayashi, K. Saeki, J. Iwamoto, N. Okamoto, K. Tomioka,S. Nezu, Y. Ikada, and N. Kurumatani. Positive effect of daylight exposure on nocturnal urinary melatonin excretion in the elderly: a cross-sectional analysis of the HEIJO-KYO study. *J.Clin.Endocrinol.Metab* 97 (11): 4166-4173, 2012.

[33] Safety guidelines for daily light exposure of people with healthy eyes are defined by the Photobiological Safety Standard IEC62471.

[34] Wright KP, Jr., McHill AW, Birks BR, Griffin BR, Rusterholz T, Chinoy ED (2013) Entrainment of the Human Circadian Clock to the Natural Light-Dark Cycle. *Curr Biol.* S0960-9822(13)00764-1 [pii];10.1016/j.cub.2013.06.039 [doi].

[35] For more info on melanopsin and ocular photoreceptors see: R. J. Lucas, S. N. Peirson, D. M. Berson, T. M. Brown, H. M. Cooper, C. A. Czeisler, M. G. Figueiro, P. D. Gamlin, S. W. Lockley, J. B. O'Hagan, L. L. Price, I. Provencio, D. J. Skene, and G. C. Brainard. Measuring and using light in the melanopsin age. *Trends.Neurosci.* 37 (1):1-9, 2014.

[36] S. M. Rajaratnam and J. Arendt. Health in a 24-h society. Lancet 358 (9286):999-1005, 2001. See also http://www.iarc.fr/en/media-centre/pr/2007/pr180.html

[37] K. Straif, R. Baan, Y. Grosse, B. Secretan, F. El Ghissassi, V. Bouvard, A. Altieri, L. Benbrahim-Tallaa, and V. Cogliano. Carcinogenicity of shift-work, painting, and fire-fighting. *Lancet Oncol.* 8 (12):1065-1066, 2007.

[38] J. Arendt. Shift work: coping with the biological clock. *Occup.Med.(Lond)* 60 (1):10-20, 2010.

[39] S. Puttonen, K. Viitasalo, and M. Harma. The relationship between current and former shift work and the metabolic syndrome. *Scand.J.Work.Environ.Health.* 38 (4):343-348, 2012.

[40] A J. Lewy, V. K. Bauer, S. Ahmed, K. H. Thomas, N. L. Cutler, C. M. Singer, M. T. Moffit, and R. L. Sack. The human phase response curve (PRC) to melatonin is about 12 hours out of phase with the PRC to light. *Chronobiol.Int.* 15 (1):71-83, 1998.

[41] B. A. Wirz-Justice, K. Krauchi, C. Cajochen, K. V. Danilenko, C. Renz, and J. M. Weber. Evening melatonin and bright light administration induce additive phase shifts in dim light melatonin onset. *J.Pineal Res.* 36 (3):192-194, 2004.

[42] M. Wittmann, J. Dinich, M. Merrow, and T. Roenneberg. Social jetlag: misalignment of biological and social time. *Chronobiol.Int.* 23 (1-2):497-509, 2006.

[43] T. Roenneberg, K. V. Allebrandt, M. Merrow, and C. Vetter. Social Jetlag and Obesity. *Curr.Biol.*, 2012.

[44] T. Roenneberg, T. Kuehnle, P. P. Pramstaller, J. Ricken, M. Havel, A. Guth, and M. Merrow. A marker for the end of adolescence. *Curr.Biol* 14 (24):R1038-R1039, 2004.

[45] K. Olofsson, C. Alling, D. Lundberg, and C. Malmros. Abolished circadian rhythm of melatonin secretion in sedated and artificially ventilated intensive care patients. *Acta Anaesthesiol.Scand.* 48 (6):679-684, 2004.

[46] I. Gogenur, U. Ocak, O. Altunpinar, B. Middleton, D. J. Skene, and J. Rosenberg. Disturbances in melatonin, cortisol and core body temperature rhythms after major surgery. *World J.Surg.* 31 (2):290-298, 2007.

[47] S. Vasquez-Ruiz, J. A. Maya-Barrios, P. Torres-Narvaez, B. R. Vega-Martinez, A. Rojas-Granados, C. Escobar, and M. Angeles-Castellanos. A light/dark cycle in the NICU accelerates body weight gain and shortens time to discharge in preterm infants. *Early Hum.Dev.*, 2014.

[48] D. Pritchett, K. Wulff, P. L. Oliver, D. M. Bannerman, K. E. Davies, P. J. Harrison, S. N. Peirson, and R. G. Foster. Evaluating the links between schizophrenia and sleep and circadian rhythm disruption. *J.Neural.Transm.*, 2012.

[49] A. Wirz-Justice. Chronobiology and psychiatry. *Sleep Med.Rev.* 11 (6):423-427, 2007.

[50] Viola AU, James LM, Schlangen LJM, Dijk DJ (2008) Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scand J Work Environ Health* 34: 297-306.

[51] DOE: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/light_and_health_fs.pdf

[52] http://www.beuth.de/en/technical-rule/din-spec-67600/170956045: *DIN SPEC 67600: Biologisch wirksame Beleuchtung – Planungsempfehlungen / Biologically effective illumination – Design guidelines / Effets biologiques de l´eclairage – Conseils de conception*, 2013 April

[53] P. J. C. Sleegers, N. M. Moolenaar, M. Galetzka, A. Pruyn, B. E. Sarroukh, and B van der Zande. Lighting affects students' concentration positively: Findings from three Dutch studies. *Lighting Res.Technol.* 0 (4):1-17, 2012.

[54] C. Barkmann, N. Wessolowski, and M. Schulte-Markwort. Applicability and efficacy of variable light in schools. *Physiol Behav.* 105 (3):621-627, 2012.

[55] Fetveit A, Skjerve A, Bjorvatn B (2003) Bright light treatment improves sleep in institutionalised elderly--an open trial. *Int J Geriatr Psychiatry* 18: 520-526.

[56] Beauchemin KM, Hays P (1996) Sunny hospital rooms expedite recovery from severe and refractory depressions. *J Affect Disord* 40: 49-51.

[57] Miller CL, White R, Whitman TL, O'Callaghan MF, Maxwell SE (1995) The effects of cycled versus noncycled lighting on growth and development in preterm infants. *Infant Behavior and Development* 18: 87-95.

[58] Taguchi T, Yano M, Kido Y (2007) Influence of bright light therapy on postoperative patients: a pilot study. *Intensive Crit Care Nurs* 23: 289-297.

[59] Walch JM, Rabin BS, Day R, Williams JN, Choi K, Kang JD (2005) The effect of sunlight on postoperative analgesic medication use: a prospective study of patients undergoing spinal surgery. *Psychosom Med* 67: 156-163.

[60] Maastricht University Medical Center, The Netherlands (Dec. 2009 -Sept. 2010) Controlled clinical trial (ClincalTrials.gov NCT01504750)

[61] C. E. Carney, D. J. Buysse, S. Ancoli-Israel, J. D. Edinger, A. D. Krystal, K. L. Lichstein, and C. M. Morin. The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep.* 35 (2):287-302, 2012.

[62] http://www.lightingeurope.org/uploads/files/Human_Centric_Lighting_general_overview_September_2014.pdf, see also http://lightingforpeople.eu/lighting-applications/

[63] Provencio, I. R. Rodriguez, G. Jiang, W. P. Hayes, E. F. Moreira, and M. D. Rollag. A novel human opsin in the inner retina. J.Neurosci. 20 (2):600-605, 2000.

[64] S. Hattar, H. W. Liao, M. Takao, D. M. Berson, and K. W. Yau. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. Science 295 (5557):1065-1070, 2002.

[65] D. M. Berson, F. A. Dunn, and M. Takao. Phototransduction by retinal ganglion cells that set the circadian clock. Science 295 (5557):1070-1073, 2002.

[66] K. P. Wright, Jr., J. T. Hull, R. J. Hughes, J. M. Ronda, and C. A. Czeisler. Sleep and wakefulness out of phase with internal biological time impairs learning in humans. J Cogn Neurosci. 18 (4):508-521, 2006.

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