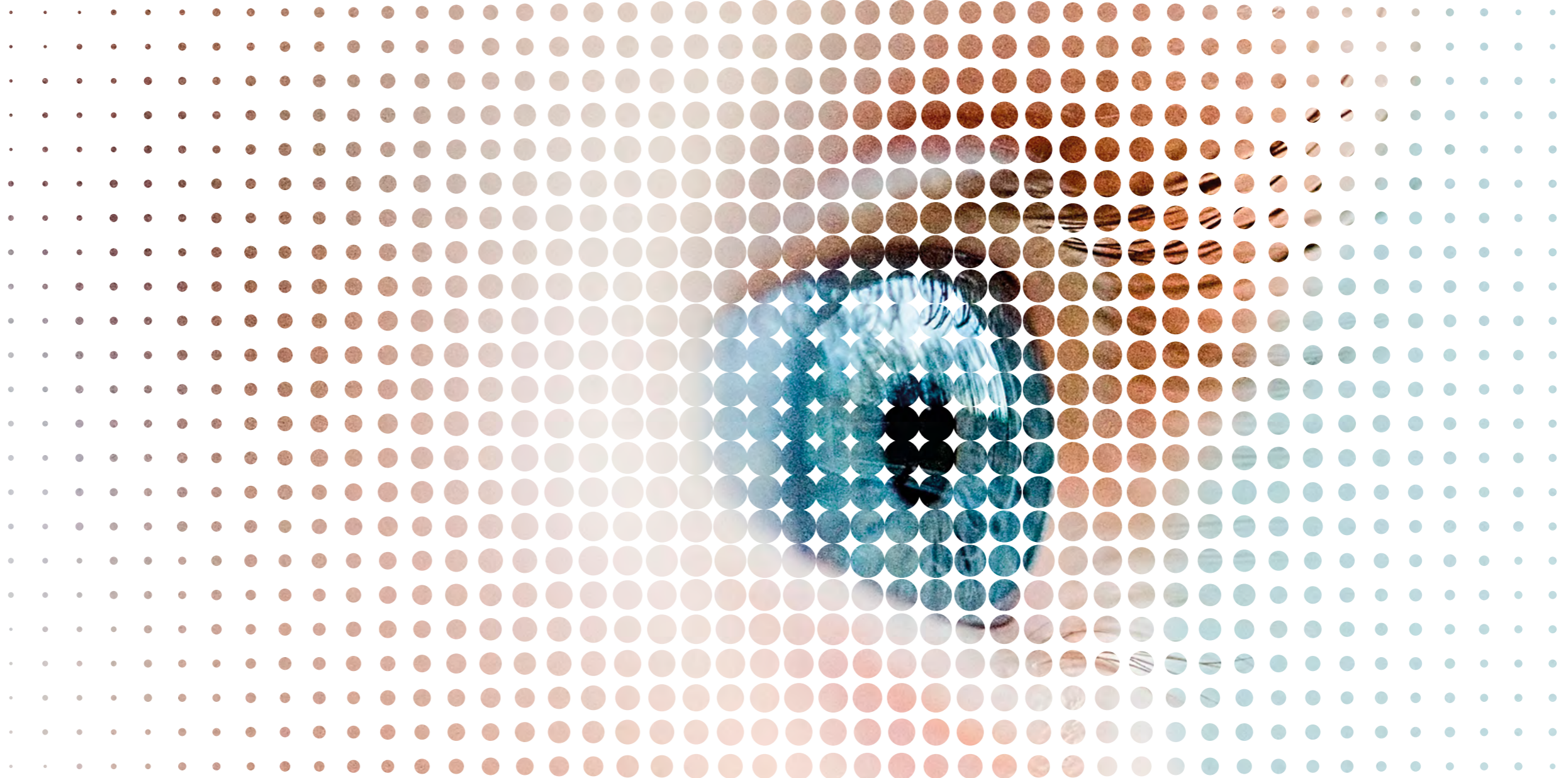




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SMART LIGHTING ENGINEERING



HUMAN CENTRIC LIGHTING FOR INDOOR APPLICATION

# INTRODUCTION



## HUMAN CENTRIC LIGHTING FOR INDOOR APPLICATION

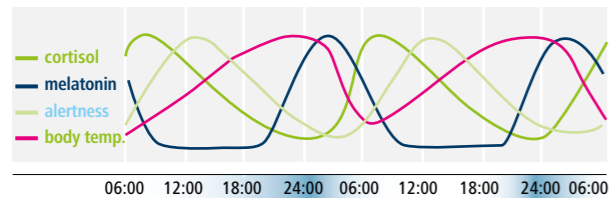
Human centric lighting may well be the next great step forward in the evolution of lighting. Also known as ‘human factors in lighting’ and ‘biophilia’ among others, human centric lighting is based on the idea of enabling the regulation of light direction, colour temperature and level according to need and desire to positively influence alertness and relaxation, mood, visual acuity and productivity. Furthermore, its effective application can result in energy savings, sustainable design and better lighting performance. Ultimately, human centric lighting improves wellbeing and even health as well as bringing great benefits to educational facilities and workplaces through improved concentration, efficiency and safety.

### THE EFFECT OF LIGHT UPON HUMANS

Until the advancement of the industrial revolution, 90 % of our waking lives were spent outdoors; on the contrary we now spend the same proportion of our lives indoors. As humans, our natural need is for daylight, with its properties influencing our physiology and psychology. However, we generally work under light that is monotonous both in terms of light level and colour temperature, which is not consistent with daylight and, therefore, not in tune with our basic human needs. Without regular exposure to lighting that fulfils those needs we are likely to suffer from health issues connected to disruptions and dysfunctions of the circadian rhythm as well as other problems.

The circadian rhythm is a fundamental cycle of biological events such as digestion, sleep and body temperature, that repeat on a roughly 24 hour cycle. It can be classified in three parts. First, the internal 'clock' which is located within the suprachiasmatic nucleus or the hypothalamus. Second, a number of external zeitgebers (cues) which entrain the body's clock to the 24 hour environmental cycle. Third, the hormone melatonin secreted by the pineal gland to regulate the body according to the entrained circadian rhythm, the production and levels of which are determined by physiological reactions to illumination level and colour temperature. Melatonin works in partnership with the hormones cortisol, serotonin and dopamine. During the day, if we consider a natural circadian rhythm, appropriate amounts of these three supplementary hormones are secreted. Cortisol has a balancing effect on melatonin and ensures a stress response, serotonin controls impulses and food cravings, and dopamine ensures healthy mood, alertness and muscle coordination.

Figure 1  
The circadian rhythm



Melatonin, however, is the primary hormone involved in the control of the circadian rhythm by determining energy and activity levels. High levels cause drowsiness and low levels are related to a state of alertness. If there is an insufficient amount of daylight or suitable replacement artificial light during the day, the natural suppression of melatonin does not happen resulting in sleepiness, a lack of concentration and low mood during waking hours.

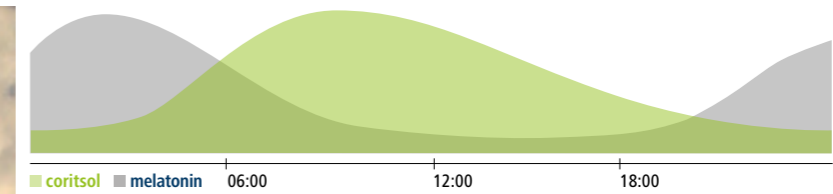
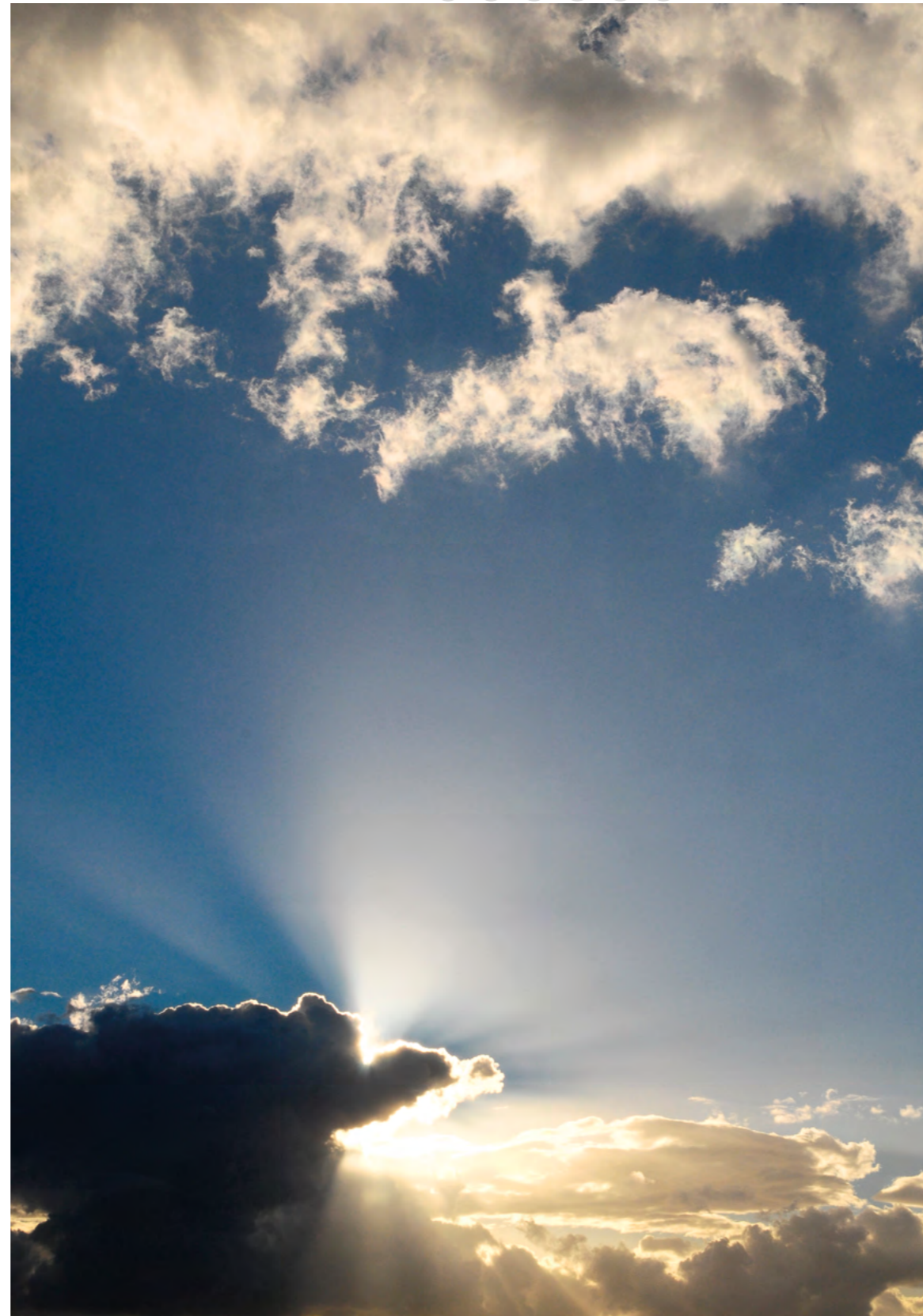


Figure 2  
The daytime cortisol and melatonin cycle

NIGHT	DAWN	DAY	DUSK
Have a good nights sleep	A good start to the morning	Have a break and refresh	Relax and unwind
• Lowest light levels	• Cooler increasing light levels	• Warmer decreased light levels	• Warmer decreasing light levels
• Undisturbed sleep	• Increased energy		• Melatonin production starts

Dopamine pathways

Serotonin pathways

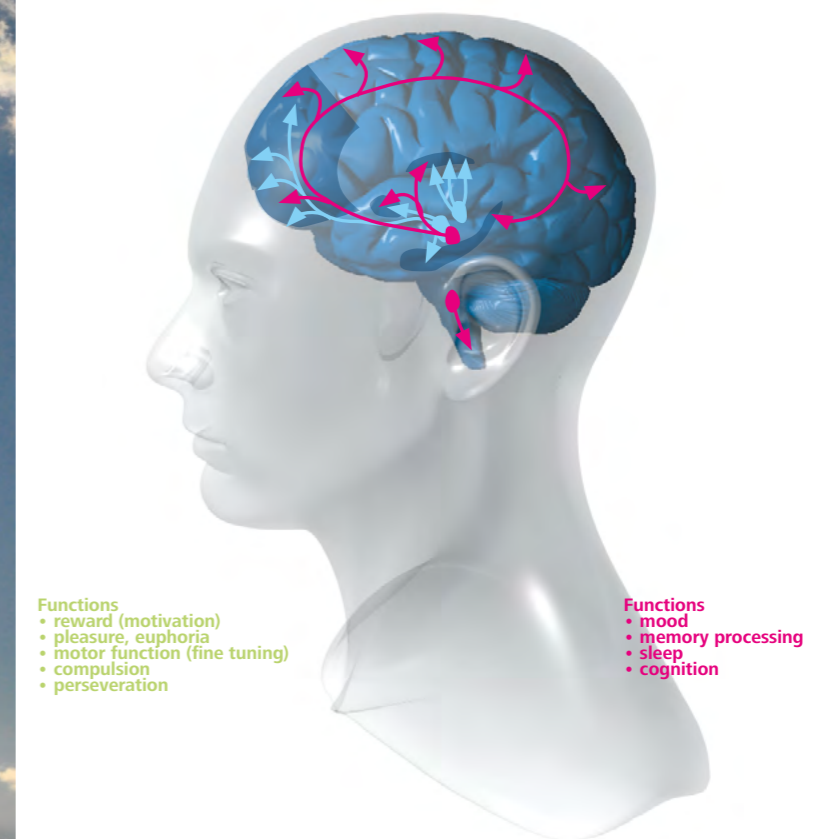


Figure 3  
Dopamine and serotonin pathways

Functions

- reward (motivation)
- pleasure, euphoria
- motor function (fine tuning)
- compulsion
- perseverance

Functions

- mood
- memory processing
- sleep
- cognition

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# LIGHT IN SCHOOLS

The primary objective of lighting in any building is to provide suitable levels of illumination to enable the performance of visual tasks and promote feelings of comfort and wellbeing. However, it is important that lighting also make a space visually interesting and stimulating but not distracting or deterring. Research into the biological effects of light has made it possible to implement new ideas and technologies into the illumination of educational spaces to improve mood, performance, alertness and engagement. For example, studies show that the incidence of mistakes can be reduced by as much as 30 % and work speed by the same amount when task areas are illuminated by with a neutral light of 4000 K and peripheral areas such as walls with a cool light of around 6500 K. Appropriate lighting can even increase reading speed.

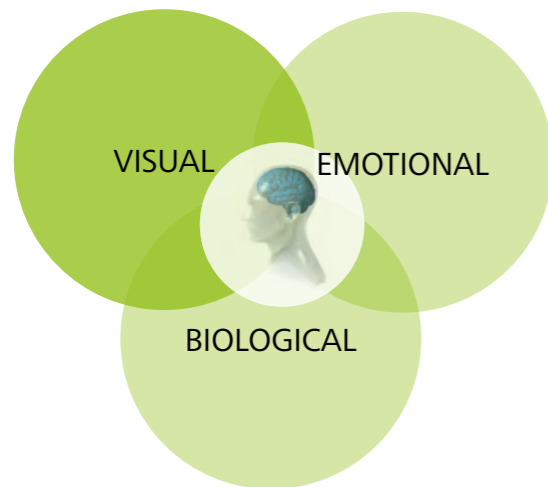


## LIGHT IN THE MODERN LEARNING ENVIRONMENT

Modern learning environments are flexible in their use of space and therefore require adaptable lighting. Learning is no longer restricted to the classroom, with all areas becoming a natural extension to these primary learning environments. For example, a school canteen is the perfect setting for a group discussion and halls ideal places for informal teaching, not to mention the array of events that can be held such as plays, celebrations and ceremonies. It is also important to account for the use of display screen technologies in all spaces, as the use of laptops and tablets in class is becoming more common.

Educational facilities should be illuminated by daylight to the extent possible, with standards requiring a minimal proportion of the overall lighting to be provided by daylight entering a room. Daylight is, of course, the highest quality light and the one to which humans are most adapted and which the body needs. It is also beneficial from a practical point of view to maximise the use of daylight as it reduces energy usage and ensures that a lighting solution, and therefore a building, is more sustainable and environmentally friendly. Artificial lighting should play a supplementary role only, by becoming involved or taking over when natural light levels are not sufficient.

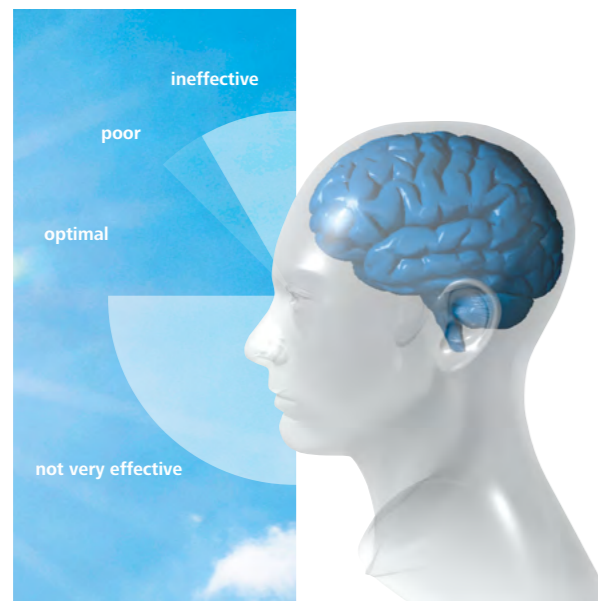
**Figure 4**  
Every school lighting system must take into account the three essential building blocks needed to create a healthy and effective learning environment



It is possible to use artificial lighting in such a way as to mimic certain properties of natural light. The use of warm white accent lighting that looks like sun beams makes a space feel vibrant as well as being useful to draw attention to items placed on walls such as maps or charts. The illumination of walls and ceilings will help to promote wellbeing by copying the light distribution of daylight outdoors, where light is all around and not only directed downwards, something which can be achieved by using luminaires that emit light in both a direct and indirect manner. Furthermore, the use of different illumination levels and colour temperatures can have a physiological impact on the body, affecting not only the circadian rhythm but also blood pressure, heart rate and temperature. This highlights the benefit of using lighting in school environments that allows for both the easy adaptation of lighting to need as well as the creation of lighting sequences that mimic the natural changed of daylight to affect both the physiological and psychological state of students and teachers.



**Figure 5**  
Effect of blue light at  
different angles





## EMOTION

Light plays a key role in evoking emotions. It can be used to make a space more appealing as well as to create specific atmospheres, both of which are highly influential on emotional responses and resultant behaviours.

Light direction, colour, contrast and level are central parameters in the creation of psychologically beneficial and influential lighting. However, the light must be tailored to the task at hand and the people involved. Gender affects the perception of illumination level and colour meaning that one lighting concept can achieve different outcomes with different people. For example, one study showed that girls performed best in spaces illuminated by warm white light, while boys performed better on cognitive tasks when cool white light was provided but girls performed markedly worse and their mood was lowered.

Another consideration to bear in mind is the effect of light on what happens outside of the school environment. Students who have a healthy circadian rhythm and sleep well are undoubtedly more likely to perform well and remain alert and engaged during the learning period as well as have improved memory and concentration capabilities.





## DYNAMIC LIGHTING

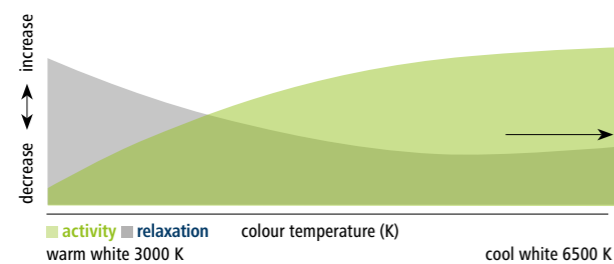
Dynamic lighting provides varied light with different parameters such as colour temperature and illumination level. These changes in light parameters can be used to support the natural circadian rhythm, improve performance and alertness as well calm aggressive and restless behaviour. Studies into the use of dynamic lighting show that its use is highly beneficial for students in terms of visual, physiological and psychological wellbeing and comfort. Below are three examples of how lighting parameters can be changed according to a specific need.

Exams: An average maintained horizontal illuminance of between 650 lx and 1000 lx on the task area with an activating light colour temperature of 6500 K.

Breaks: An average maintained horizontal illuminance of 300 lx on the task area with a relaxing light colour temperature of 3000 K.

Standard lessons: An average maintained horizontal illuminance of 300 lx on the task area with a relaxing to neutral light colour temperature of 3000 K to 4000 K.

Figure 6  
Activity and relaxation



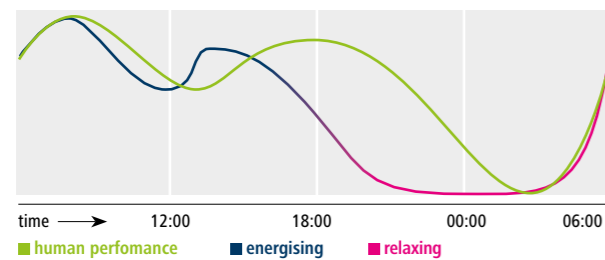
# LIGHT IN OFFICES

Good lighting in offices brings many advantages, such as increased performance and motivation. Performance cannot be measured only according to work output but also based on the quality of that output, employee satisfaction and overall health and comfort, employee retention, company image and ultimately business success.

## LIGHTING THAT MAKES A DIFFERENCE

Human performance changes throughout the day, peaking at around 10 am and then again later in the afternoon. Lighting can be used to support, modify and regulate the human body in order to improve performance at times when naturally it would decrease, as well as to help employees relax at appropriate times so that they have the energy to perform their work tasks.

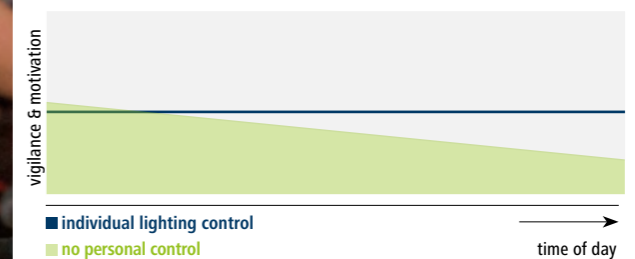
**Figure 7**  
Human performance fluctuates according to the circadian rhythm and the production and levels of certain hormones. Light can be used to support, modify and regulate this natural rhythm in order to improve performance throughout the day.



Research has been done into various aspects of light and its use in offices. The overall result was that 91 % of participants preferred lighting which consisted of a combination of direct and indirect light distribution, wall washing and individual control of illumination level over each employee's workplace.

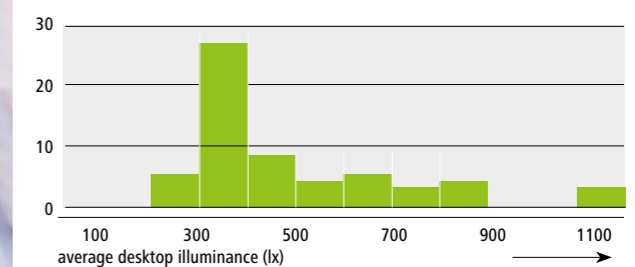


Employee satisfaction with the lighting was not the sole result, with it affecting other areas of preference also. Those who liked their lighting rated the space as more pleasant, felt happier and more comfortable and were more contented with their work environment generally. Furthermore, the research went on to show a direct correlation between the use of individual lighting control and the motivation and vigilance of employees when performing tasks. Normally motivation and vigilance decreases throughout the day, but those with access to individual control of the lighting over their workplace were able to sustain consistent performance.



**Figure 8**  
The effect of individual lighting control on vigilance and motivation

Each person has a preference for different light, regardless of general trends. Some like bright light and some lower illumination levels. On average, participants chose lower illumination levels over their workplaces than those defined by standards, however some chose similar or even higher levels. The diversity of preference suggests that it would be suitable to lower overall illumination levels in combination with some means of providing higher local illumination levels for those who want it.

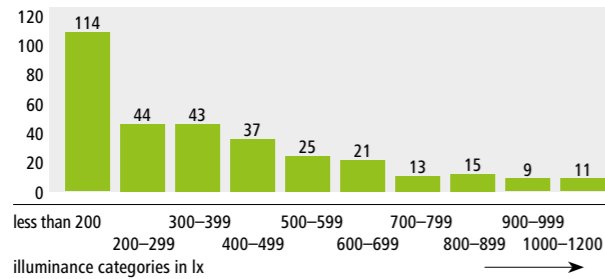


**Figure 9**  
Employee preference for desktop illumination level by number

# LIGHT IN INDUSTRIAL WORKPLACES

Studies show that workers are more alert and focused under the right light, which leads to the reduced error rates and less waste, the incidence of fewer accidents and improved productivity.

Figure 10  
Number of persons injured

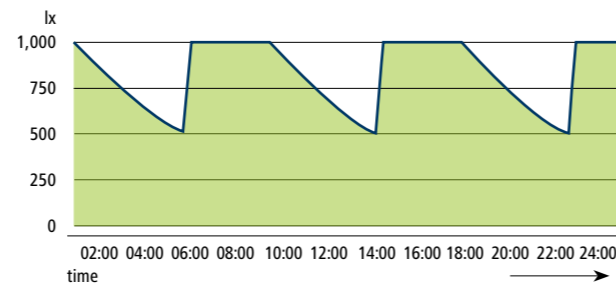


## LIGHT IS ABOUT MORE THAN SEEING

Research conducted in this field have consistently concluded that manual workers, if given the choice, will choose higher illumination levels that required by standards. This preference for higher illumination levels cannot be fully attributed to visual acuity reasons, but is in fact largely connected with physiological effect it has. Brighter light not only enabled the performance of tasks but enhances concentration and performance and increases general feelings of wellbeing.

In order for industry to meet the physiological and psychological needs of their employees as well as meeting visual requirements it is necessary to provide effective lighting that is not obtrusive but rather supportive. The two key light parameters in this case are illumination level and light colour temperature. The use of such lighting is especially beneficial for those who work varying shifts or consistently night shifts, as such workers often suffer from poor health and sleep problems associated with the disruption of the circadian rhythm by their work patterns.

Figure 11  
Illuminance levels for shift working



For workers who have varied shifts, it is not possible for the circadian rhythm to adapt to a solid deviation from the natural rhythm of day and night. In this case it is highly useful to use higher illumination levels at the beginning of shifts to support activity and alertness. For workers who consistently work night shifts it is also useful to use higher illumination levels as well as cooler light colour temperatures, both of which help to entrain the circadian rhythm to the unnatural sleep/wake cycle.

# LIGHT IN HEALTHCARE FACILITIES

In healthcare facilities light and lighting can be viewed from two distinct angles: from the point of view of employee and patient wellbeing, and from the point of view of treatment. However, even though different the two areas diverge at times due to the fact that light is fundamental to human existence on every level, having a direct influence over physiological and psychological health. Furthermore, light has many therapeutic effects, red and blue light especially have been shown to influence various biological processes.

## LIGHT FOR EMPLOYEE AND PATIENT WELLBEING

As previously mentioned, the primary hormone involved in the setting and regulation of the circadian rhythm is melatonin. When daylight or appropriate artificial light are absent the natural suppression of melatonin fails to occur and is accompanied by feelings of depression and sleepiness. For those working night shifts and patients who have little or no access to daylight, it is often the case that their circadian rhythm does not match their actual sleep/wake cycle, resulting in physiological and psychological fatigue, which is detrimental to both work performance as well as recovery times. To overcome this, suitable lighting must be provided for all employees and patients, lighting that can adapt to the needs of particular times and circumstances.

Night shift work is necessary in healthcare facilities because the clock never stops. For those working such shifts it is important to ensure high enough illumination levels as brightness acts as an artificial suppressor of sleep-inducing melatonin. A level of 1000 lx is considered sufficient in this regard based on various studies in which different illumination levels were used during night shifts. Those who worked under the standard 500 lx struggled with fatigue and low mood and made more mistakes, whereas those who worked under high levels were astonishingly alert throughout the shift, felt less fatigued and had a better mood. Measurements of melatonin levels showed that those who worked under higher illumination levels had successfully had their circadian rhythm entrained to the current sleep/wake cycle.



Many patients spend days, weeks and sometimes months indoors in rooms with limited access to the circadian rhythm regulating cues of daylight. Good lighting can have a positive effect on mood, sleep/wake cycles, rest/activity patterns and recovery times. Studies into this aspect of patient care have had rewarding results, with patients in sunnier rooms recovering statistically faster than those in poorly lit rooms. What's more, for patients suffering from depression, those who stayed in east-facing rooms were discharged an average of 3.67 days earlier than those in west-facing rooms. It is also suggested that exposure to bright light in the morning is more effective than exposure later in the day. It is possible to induce the benefits of daylight exposure using artificial light by providing higher illumination levels and suitable colour temperatures in rooms that do not have access to suitable amounts of daylight. Furthermore, in some cases light is actually used as an out-patient treatment for depressed patients, especially those with Seasonal Affective Disorder (SAD), with illumination levels ranging between 2500 lx and 10,000 lx providing encouraging outcomes.



Figure 12 A  
Limited natural light

Figure 12 B  
Simulated daylight



Another interesting use of light in healthcare facilities is based on the theory of distraction, where interesting lighting effects are used to divert patient attention during stressful, painful or unpleasant procedures. This is especially useful for children, whose attention can be easily drawn away by bright, colourful and dynamic lighting.

### THE THERAPEUTIC USES OF LIGHT

Light is commonly used for treating various health problems, however the range of physiological processes which can influence is far wider than we may imagine. Below is a list of just a few of the effects light can have on our bodies.

- It increases blood capillary circulation and vascular activity by improving the metabolism of nitric oxide, which in turn provides additional oxygen and nutrients to tissues, accelerating the healing process and causing a cascade of beneficial biochemical processes.
- It reduces scar tissue and stimulates the healing process, including the production of collagen, one of the most important components in the healing of wounds.
- It stimulates fibroblastic activity and tissue granulation, aiding the repair of connective tissues and the formation of collagen fibres, important in the healing of wounds, ulcers and inflamed tissues.
- It reduces the inflammation and swelling associated with chronic conditions such as arthritis, bursitis and tendonitis.



- It increases lymphatic system activity and relieves oedema and the discomfort associated with swelling.
- It activates the immune system, especially increasing phagocytosis, the body's natural process of disposing of dead and degenerated cells, and important for infection control and healing.
- It increases RNA/DNA synthesis, which stimulates cellular reproduction and the replacement of damaged cells.
- It stimulates the synthesis of adenosine triphosphate, an immediate energy source for muscle contraction and essential to cell metabolism.
- It has a relaxing influence on muscle tissue.
- It stimulates nerve transmission and reduces nerve excitability.
- It stimulates acupuncture points and immune response.
- It increases the production of endorphins and enkephalin, elevating mood and reducing pain responses.
- It stimulates adrenal production, facilitating long-term pain relief and resilience to stress.

### LIGHT FOR WORK

Bright light is not only for staff working night shifts, it is also very useful for those working during the day. Studies show that increased illumination levels are preferred by staff during the performance of critical tasks such as the dispensing of medication. It is also the case that fewer prescription dispensing errors were reported under high illumination levels, with a rate of 2.6 % under 1500 lx compared to 3.8 % under 450 lx.

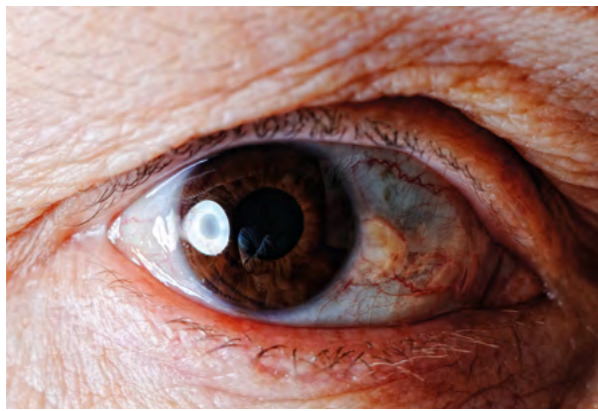


Figure 13  
The impact of different illumination levels on prescription dispensing errors

# LIGHT IN HEALTHCARE FACILITIES

Light's impact on us as we age is not limited to visual acuity, but also involves its ability to aid healthy sleep/wake and rest/activity cycles, improve mood and cognition as well as being able to help those with Alzheimer's and dementia better navigate their world. Good lighting makes life more comfortable, less stressful and safer for the ageing, and its power should not be underestimated.

Figure 14  
Our eyes change as we grow older



## VISUAL ACUITY AND SAFETY

Age-related changes to our eyes restrict the amount of useful light able to enter. This makes it important to increase overall illumination levels and contrasts in order to facilitate the same level of visual perception. It is also important that the light be uniform in and between rooms and glare-free as ageing eyes cannot adapt to changes in brightness easily and are more sensitive to both direct and indirect glare, which reduces visual acuity and the perception of detail, especially in combination with insufficient illumination levels. Another factor to take into account is the yellowing of the lens with time, something that can also be compensated for with the light with a cooler colour temperature.

Lighting that is designed with older eyes in mind results



in a safer and more suitable environment. Appropriate illumination levels will highlight the unevenness of floors and clearly illuminate stairs and steps as well as make facial recognition easier, while the use of uniform lighting with both direct and indirect distribution will minimise glare and reflections on floors and surfaces to help orientation. For example, in the workplace a 60 year old employee will require twice as much light as a 20 year old employee to achieve the same perception of brightness. This is due to changes in the diameter of the pupil and clouding of the lens, the onset of which tends to start around the age of 35. To account for these different needs, it is practical to use separately switched luminaires that allow employees to have the light they need. Alternatively, the lighting could be designed to provide high enough illumination levels for older employees but be dimmable according to need for younger employees. This is, however, a more costly solution.

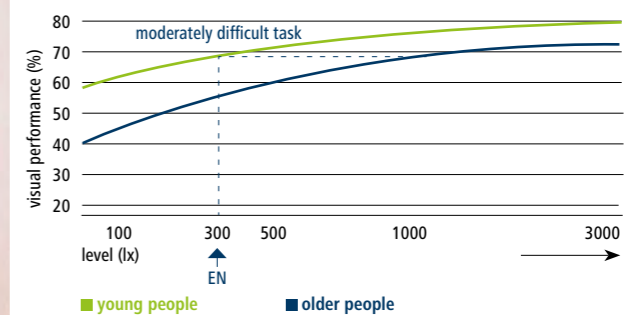


Figure 15 A  
The relation between relative visual performance (%) and light level (lx) for moderately difficult tasks

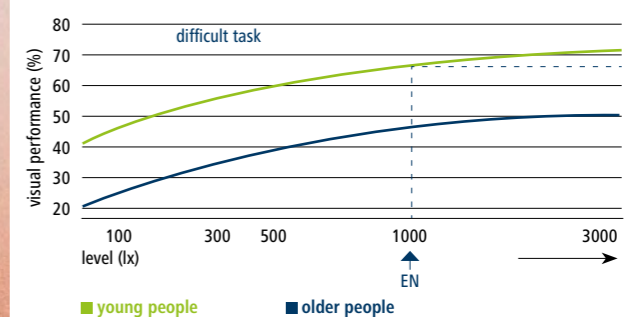


Figure 15 B  
The relation between relative visual performance (%) and light level (lx) for difficult tasks

## MAINTENANCE AND REPAIR OF THE CIRCADIAN RHYTHM

Older people often have problems sleeping and their rest/activity cycles do not match natural daytime routines. This is mainly due to lack of exposure to daylight or suitable artificial light as most spend their time indoors in poorly lit rooms. In order to improve sleep/wake and rest/activity cycles it is appropriate to use a high illumination level of 1000 lx with a cool colour temperature of 4000 K or 5000 K between the hours of 9 am and 6 pm. This mimics some of the natural properties of daylight and in turn stimulates the healthy functioning for the circadian rhythm.

## HOW LIGHT HELPS THOSE WITH ALZHEIMER'S AND DEMENTIA

Alzheimer's disease is a degenerative condition affecting the brain, and the most common cause of dementia. Light can have an influence on the behaviour and abilities of those suffering from the disease, both in terms of visual and non-visual functions. Studies have shown that Alzheimer's patients have reduced visual acuity and contrast sensitivity when compared to those of the same age without the disease. This is consistent with reports of both retinal and cortical cell loss in those with the disease. It seems that the reduced visual capability of Alzheimer's sufferers, who are already struggling to make sense of the world around them, intensifies the effects of other cognitive losses, increasing confusion and social isolation. One suggestion is that an increased illumination level and heightened visual stimulation could improve the day-to-day functioning of those with the disease.



**Figure 16A**  
A 24 hour lighting cycle that is stimulating and physiologically supportive is especially beneficial for those with Alzheimer's

By exposing sufferers to a 24 hour lighting scheme that provides bright high-stimulation artificial light during the day, low-stimulation levels in the evening and a night light that is not disturbing but enough to aid safe orientation, natural visual cues are maintained or even enhanced, helping to reinforce and stabilise healthy sleep-wake and rest-activity cycles. For light to have a high-stimulating effect it must be at a minimum level of 400 lx and a colour temperature of 6500 K or higher. Light with a low-stimulating effect must be no more than 100 lx and a warmer colour temperature.

The night light should be a maximum of 5 lx with a warm colour temperature and be used in combination with perceptual information such as coloured walls and rails to aid orientation relative to vertical and horizontal surfaces. Such provisions have been shown to improve safety and stability during night activity.



**Figure 16B**  
Lighting that is monotonous in terms of illumination level and light colour temperature cannot support healthy functioning of the body

## PSYCHOLOGICALLY BENEFICIAL LIGHT

The lighting used in a room, and the creation of a suitable ambience, can change the way we experience and perceive our surroundings. It can calm a stressed mind, help the tired to sleep better and generally improves feelings of wellbeing. Changes to the colour and brightness of light in a room can have an immediate effect on mood, a powerful tool by which to promote psychological health and balanced behaviours. Below are explained different types of lighting and their effects that will promote the psychological health of older people.

- Daylighting is ideal to enliven and brighten a space with vibrant beams of light entering the room. This is natural, stimulating and lifts the mood.
- Warm lighting strong in red and golden tones creates an inviting, relaxing and cosy ambience and is ideal for calming and preparing people for sleep.
- Neutral lighting feels natural and comfortable and is balancing, it also has the correct spectrum to supplement daylighting. Ideal for use in the middle of the day or when you want to focus attention.
- Dynamic lighting that incorporates changes in illumination level and light colour are especially beneficial when provided with a wide direct and indirect distribution, and can be used to stimulate the human body. This is useful at any time of the day and is highly adaptable to need, whether it be to entertain, stimulate, calm or sooth.





# LIGHT IN THE HOME

Physiologically and psychologically effective lighting is currently only used in the home for home-light therapy procedures and to wake us in the morning. However, there is a huge scope for application in addition to a wide range of potential benefits. A sophisticated lighting concept can create a unique atmosphere in each room and allow for that atmosphere to be changed according to need and desire. Here, the combination of general, accent and mood lighting allows for the greatest flexibility.

## LIGHT FOR VISION, COMFORT AND PLEASURE

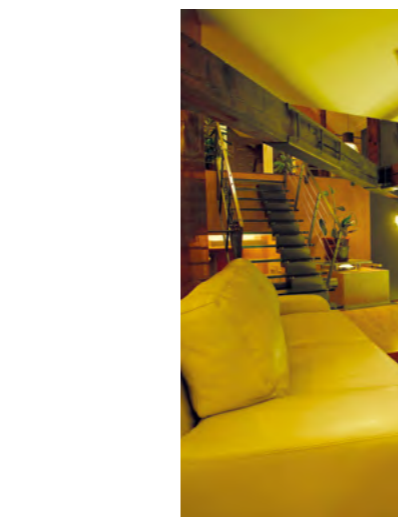
The privacy of the home is a blank canvas upon which each of us can paint our personal ideals for each space. Illumination levels, colour temperatures and light colours influence mood, alertness and whether we feel stimulated or relaxed. It is ideal to incorporate lighting that can adapt precisely to evoke the desired emotional response.



**Figure 17**  
Use general lighting to facilitate visual acuity by effectively illuminating surfaces such as table tops, kitchen counters and desks to enable the performance of tasks, as well as floors to aid navigation.



**Figure 18**  
Use accent lighting to add flexibility, such as the use of table luminaires for reading or spotlights to highlight special items and create visual interest and stimulation. During the night, accent lighting can be used to provide lower level indirect illumination that enables navigation but is not enough to disturb.



**Figure 19**  
Use coloured mood lighting to evoke emotional responses and create any atmosphere desired in a room.

## A NATURAL START TO THE DAY

One of the most common uses of health-focused light in the home is the light alarm clock. 30 minutes before the defined wake up time it begins to increase the illumination level in the room to 300 lx, mimicking the rising of the sun. This illumination level is determined to be sufficient to ensure a measured improvement in the way we awaken. People using this kind of alarm clock report waking easier and more refreshed than when using a standard alarm clock.

