

During daytime people spend often more time in office than anywhere else. It is important to design for healthy and productive workspaces. Lighting is one of the key factors in a healthy office. The right type of light at the right time enables us to see better, feel better and sleep better. In the workplace it can help (re)balance our health and enable performance. - LuxBalance Research

### 1. People spend often more time in office, than anywhere else

In our modern work lives 90% of people's time is spent indoors. Most people spend time in office more than anywhere else. The indoor environment impacts our health, productivity and mood.

### 2. Light is more than only to see and be seen

Light's most obvious effect on people in the workplace is to enable vision and the performance of visual tasks. In addition, lighting has also biological effects on people. The right type of lighting at the right time can have a positive influence on health (Riemersma-van der Lek et al 2008), well-being (Partonen and Lonnqvist 2000, Lambert et al 2002, Aan Het Rot et al 2007, Tuunainen et al 2004, Golden et al 2005, Wirz-Justice et al 2009), alertness (Campbell et al 1995, Phipps-Nelson et al 2003), and on sleep (Viola et al 2008, Mishima et al 2001, Santhi et al 2011).

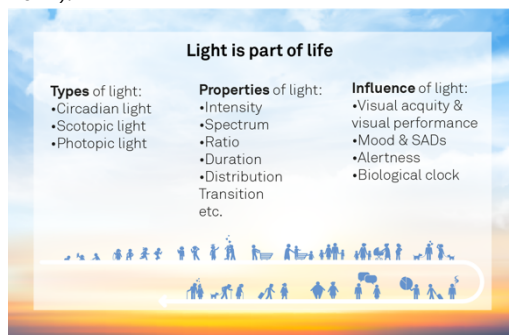


FIGURE 1: THE EFFECT OF LIGHT, ©LuxBalance

### 3. Light influences sleep and health

Recently a 'new' third photoreceptor was discovered that exist within a cell type in the retina of the eye (Berson et al 2002, Hattar et al 2002, Provencio et al 2000). It is referred to as melanopsin and it regulates the biological effects of light. It also influences the production of hormones that are essential for a healthy sleep/waking pattern, the "circadian rhythm" (Czeisler et al 1999, Zeitzer et al 2000).

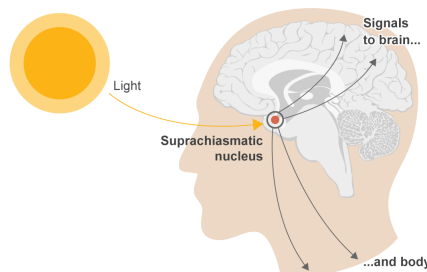


FIGURE 2: LIGHT ENTERS VIA THE EYE AND SIGNALS TO THE BRAIN AND BODY

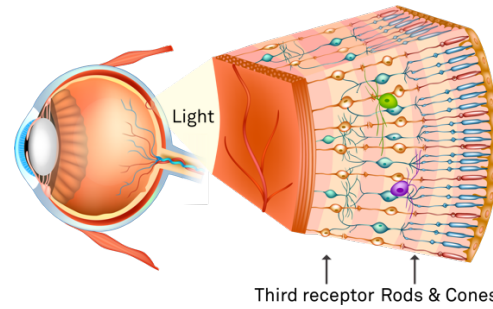


FIGURE 3: LIGHT INFLUENCES OUR CIRCADIAN RHYTHM VIA THE 'THIRD RECEPTOR', ©LuxBalance

The hormones cortisol (makes us feel alert) and melatonin (makes us feel sleepy) play an important role in regulating activity and rest.

In the morning cortisol levels increase and reach its peak. This prepares the body for the coming day's activity. At the same time the level of the 'sleep-hormone' melatonin drops in the morning. This reduce sleepiness in the morning and makes us feel rested and active.

In the evening, when it becomes dark, melatonin levels increase again this enables a healthy sleep (Dijk et al 1997). Disruption of the circadian rhythm of melatonin or cortisol production has negative effects on the quality of sleep and consequently the ability to perform as well as on our overall sense of well-being.



FIGURE 4: LIGHTING REGULATES OUR CIRCADIAN RHYTHM THROUGH THE MELATONIN AND CORTISOL HORMONES, ©LuxBalance

The diagram below illustrates some typical circadian (i.e., 24-hour) rhythms in human beings. The figure shows a few parameters: core body temperature, alertness, and the hormones cortisol and melatonin.

The biological clock controls the biorhythm, and under natural conditions light synchronizes the internal body clock to the earth's 24-hour light-dark rotational cycle. Without the regular 24-hour light-dark cycle, the endogenous circadian rhythm – the internal body clock – would be autonomously running, with its own period.



FIGURE 5: THE RIGHT TYPE OF LIGHT AT THE RIGHT TIME CAN HELP US FEEL ENERGIZED AND SUPPORT OUR WELLBEING, ©LuxBalance

The average circadian period in humans is about 24.2 hours (Czeisler et al 1999), slightly slower than the natural light-dark cycle. Without resetting by light, even this small discrepancy would produce recurrent periods during which our body physiology (melatonin/cortisol/core body temperature) would tell our body that it was time to sleep during the day and to be awake at night. This situation can be compared with jetlag during trans-meridianal travel and is associated with negative effects like fatigue, headache and reduced performance and well-being.

#### 4. Light influences performance

In general we need most light in the morning and during the day, less in the evening, and the least possible at night. Getting outside as much as possible during daytime along with improved (24-hour) control of indoor lighting systems will help increase wellbeing, productivity and sleep.

Light	Amount
Sunny Day	100.000 Lux
Cloudy Day	10.000 Lux
Office Lighting	300 Lux
Home Lighting	150 Lux
Moon Lighting	1 Lux

TABLE 1: ARTIFICIAL LIGHTING MADE IT POSSIBLE TO STAY AND WORK INDOORS, OFTEN WITH VERY LOW LEVELS OF LIGHT COMPARED TO NATURAL LIGHTING

Naturally people experienced much more light in their daily lives than in the current modern indoor life. A sunny day outdoors gives 100,000 lux, a cloudy and rainy day gives 2,000 lux. Indoors, though, light levels are generally a quarter of that or less. In office the regular amount of lux on the desk is 300lux or 500 lux for task lighting. This impacts our circadian rhythm and energy levels.

Research indicates that the wellbeing and performance of people can be significantly improved with the right type of light at the right time. For example we can adjust light level, spectrum, required uniformity, position and time to achieve certain results such as feeling refreshed, increased concentration, alertness and improved sleep and mood (Viola et al 2008, Slegers et al 2012).

In the study (Viola et al 2008, Mills et al 2007) office workers rated their alertness and performance higher with white lights that have more biologically efficient wavelengths. They were also less troubled by evening fatigue and reported improved sleep quality.

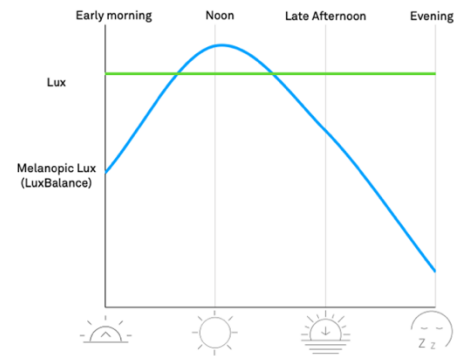


FIGURE 6: WITH LIGHTING ALGORITHMS WE CAN HELP TO DYNAMICALLY ADAPT MELANOPIC LUX AS IN NATURE TO SUPPORT ALERTNESS AND PRODUCTIVITY WHILE SUPPORTING THE NATURAL CIRCADIAN RHYTHM

#### 5. What is the LuxBalance LightScript?

The LightScript is an instruction based on knowledge on how to use light to enhance people's wellbeing and productivity under certain circumstances in a certain environment.

Combining:

- Lighting aspects: Light level, spectrum, required uniformity level, position and time
- Boundary conditions for which the script is valid like environmental conditions (e.g. ceiling height, distance to desk, position of person's head, etc.)
- Results: feeling energized, refreshed, relaxed, and other intended outcomes

Main parameters:

- Light intensity on a certain moment
- Light sum over time, and the transitions of light
- Light at which moment of the day and geolocation
- Light/dark period per day
- Light quality (spectrum)
- Light direction
- Light distribution on person

#### 6. Benefits for Employers and Building owners

Employers spend 92% of their annual operating costs on people. Investing on people centric technology can result in meaningful returns on investment.

Human centric lighting can help to

- Attract and retain employees, clients and investors
- Build brand equity through leadership and innovation
- Maximize performance of employees by contributing to increased productivity, reduced absences, and increased job satisfaction/engagement
- Promote health and wellbeing to all employees
- Differentiate office real estate and increase real estate premiums

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### FREQUENTLY ASKED QUESTIONS

#### Why is circadian lighting relevant today?

One reason is the scientific breakthrough around the millennium when scientists found the third melanopsin receptor, which is an essential part in the body-clock (Berson et al 2002, Hattar et al 2002). In summary, light acts as a regulator on the circadian rhythm in the body, and there is a certain wavelength which influences this response. There is also more interest in circadian rhythms in general, e.g. the Nobel prize for medicine in 2017 was awarded to scientists that researched the circadian clock. Other reasons are an increased interest from people in health and wellbeing in general and the digitalization of light.

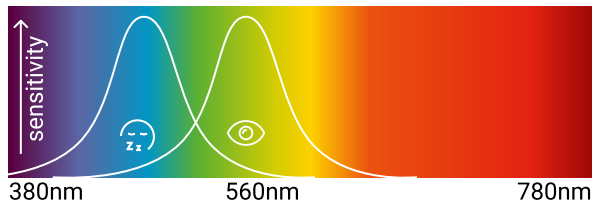


FIGURE 1: RELATIVE SENSITIVITY PEAKS FOR VISUAL AND CIRCADIAN LIGHTING.

#### Is circadian light the same as lux?

In natural day lighting it can be the same at certain moments of the day. E.g. at noon time circadian lighting and regular visual lighting are in sync with each other. However in the late afternoon or early morning they are not the same.

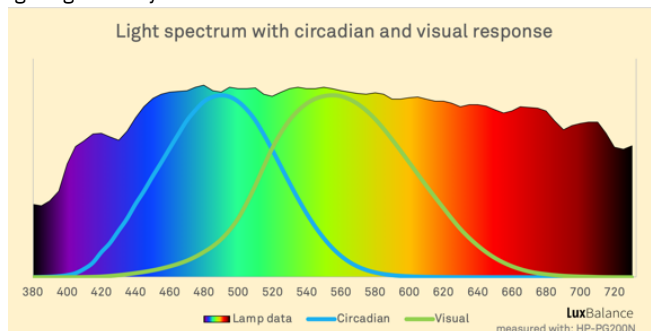


FIGURE 2: LIGHT SPECTRUM DURING THE DAY.

However for lighting in the workspace environment it is often not the same. We measure visual light in lux (which corresponds to the human vision photoreceptor response). However with the identification of the circadian response curve we could use other metrics to make it easier to redefine good lighting. Regular lux suppresses melatonin as well, but the better approach is to take melanopic lux which shows a much stronger correlation with melatonin suppression as in the graph below.

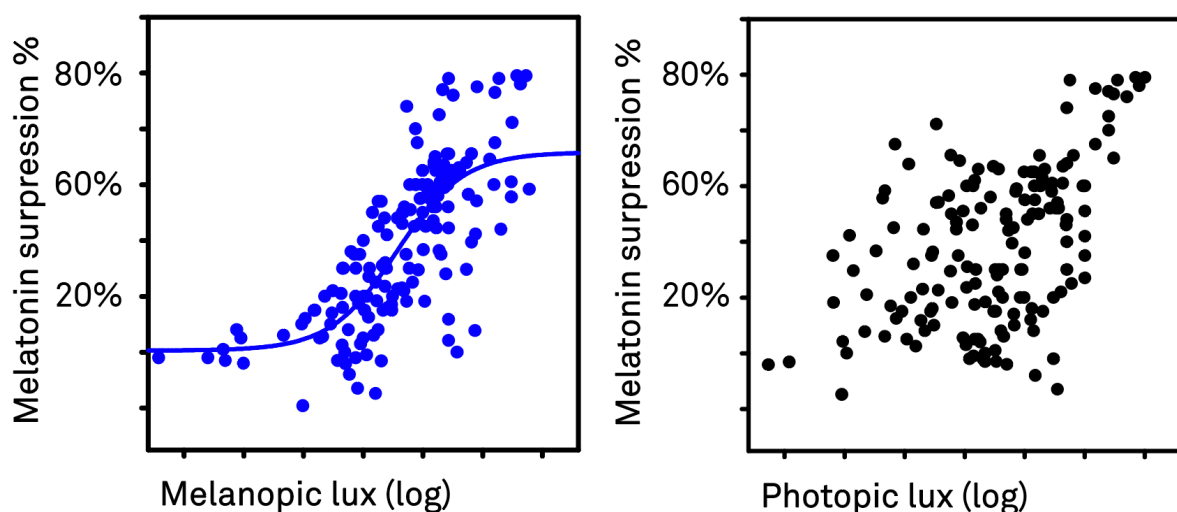


FIGURE 3: THE CORRELATION BETWEEN LIGHT AND ALERTNESS.

Photopic lux (regular light) has a correlation with melatonin suppression. However melanopic lux has a much stronger correlation with melatonin suppression. Melatonin is regarded as a 'sleep hormone' it makes us feel sleepy and relaxed. It is made by the body in a natural way.

Source: Lighting for people, SSL-erate (2016), D. Lang, L. Schlangen.

Visual adaptation: LuxBalance

[What intensity is needed for circadian lighting? And can regular lighting deliver this?](#)

The melanopic lux depends on the time of the day. In general it is suggested to have around 200 melanopic lux. Note that this melanopic lux is measured at the eye-level height on the vertical plane. Most regular fixtures are not able to deliver the required light since they were purely optimized for human vision.

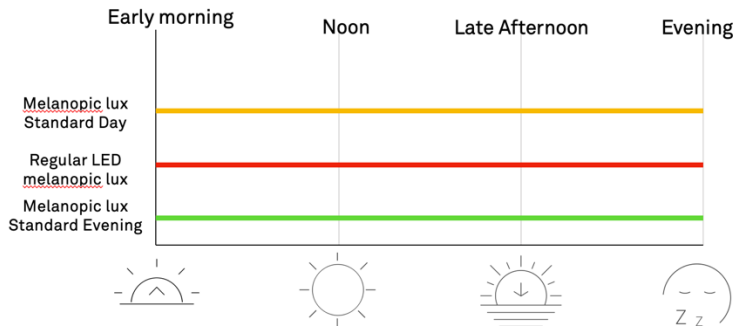


FIGURE 4: A COMMON ISSUE WITH REGULAR COMMERCIAL LIGHTING IS THAT THEY DELIVER TOO LITTLE MELANOPIC LUX DURING THE DAY AND TOO MUCH AT NIGHT WHEN COMPARED TO NATURAL LIGHT.

[Is quality of light still relevant?](#)

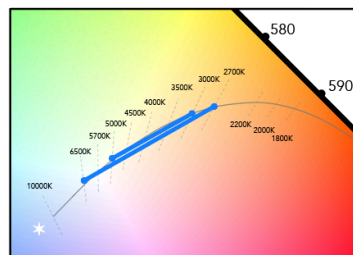
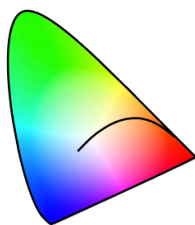
Yes, quality of light remains important. Lux, CRI, UGR are important factors and the right lighting application as well. On top of that we should take Circadian lighting into account.

[What is the difference with Tunable lighting?](#)

The main purpose of tunable white fixtures is to have different CCTs. They jump from one static CCT to the another static CCT in a straight line. As a result the overall CRI will be lower inbetween those points.

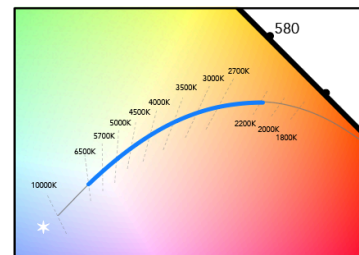
In using algorithms we follow the Black Body Line while maintain high CRI at all CCT points on the way.

### Chromaticity graph Dynamic Tunable White



Jumps directly from one CCT to another CCT

### With LB algorithm



Follows the Black Body Line (BBL)

[What are some lighting design principles for circadian lighting?](#)

*Keep lux levels the same, opt for systems that adjust the melanopic or circadian lighting content.*

In general increase melanopic lux or circadian lighting during the morning and noon times. Reduce them in the late afternoon, so people keep a healthy rhythm.

Note that regular commercial lighting has no ability to adjust the melanopic lux ratio or circadian lighting stimulus ratio. The fixed ratio is often either too high or too low. In the morning they may contain too little circadian light and in the evening too much.

*Track natural course of daylight*

The circadian rhythm is a 24H cycle and linking it to the actual circadian sunrise, noon-time and sunset might provide a better experience and increase effectiveness. Link with the geolocation.

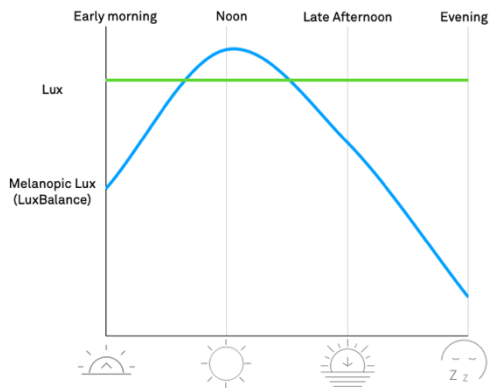


FIGURE 5: EXAMPLE OF FLEXIBLE MELANOPIC LUX WHILE KEEPING THE LUX VALUES CONSTANT.

### Are there any widely accepted standards?

The WELL standard has introduced melanopic lux. Feature 54 includes Circadian Lighting Design. It states that workstations must receive at least 250 melanopic lux for at least 4 hours per day, every day of the year. In night-time this should be reduced to 50 melanopic lux.

In addition, the Lighting Research Center at Rensselaer Polytechnic Institute is promoting Circadian light (CLA) based on the CS (circadian Stimulus) metric. In essence it is a metric that relates to melatonin suppression after one-hour exposure. The center recommends a CS higher than 0.3 in the early part of the day.

They also suggest to measure horizontal and vertical illuminance. Since light enters through the eye, measuring vertical illuminance in addition to horizontal makes the measurement more accurate.

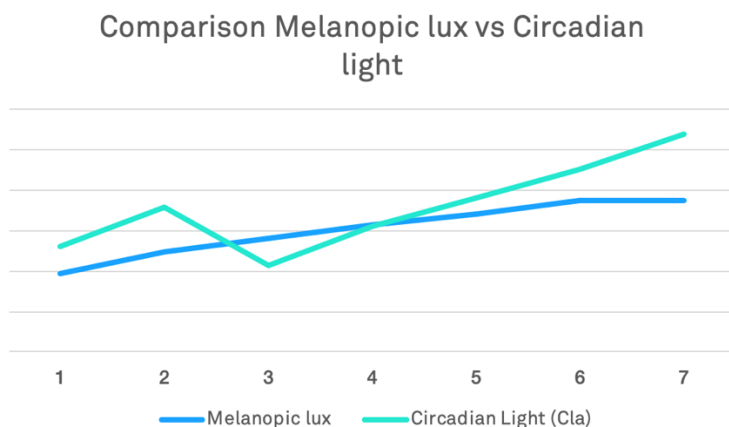


FIGURE 6: COMPARISON OF MELANOPIC LUX VS CIRCADIAN LIGHT, TESTED WITH LUXBALANCE LIGHTING AT VARIOUS SETTINGS.

### What are the system components?

- True-to-Nature LEDs, they produce the right kind of light for both visual quality and circadian properties.
- LightScript™ algorithms to combine lighting aspects that are optimized for circadian outcomes.
- Driver: precision control for individual LEDs.
- Compatibility and digital integration: runs locally or via the cloud and can integrate with APIs.
- UI: control panel of local control

### Can circadian lighting be deployed anywhere?

Yes, it can be deployed worldwide, balancing the circadian rhythm is a concept that can be replicated globally. Note that there needs to be certain custom support for large scale projects to integrate design into the overall design intent.

### What are other applications?

Circadian lighting can be very suitable for any indoor space. But in particular in those where people are spending a lot of time indoor. E.g. offices, hospitals, care-homes, clinics, airports and so forth.

For more info contact:

**Jille Kuipers**  
jille@luxbalancelighting.com

**Banly Cheung**  
banly@luxbalancelighting.com