Light and Health
NTVA seminar

28th of January 2020

Kunnskap for en bedre verden

Daylight: *What* makes the difference?
Is it possible to mimick it?
Is it desirable?

Barbara Szybinska Matusiak
Professor, the head of **Energy & Environment Group**
http://www.ntnu.edu/iat/people-sustainability
Department of Architecture and Technology
Faculty of Architecture and Design, NTNU
-------- and -------
The head of the **LIGHT & COLOUR CENTRE, NTNU**
http://www.ntnu.edu/bff/lightandcolour

LIGHT & COLOUR CENTRE

Daylight Academy, https://daylight.academy/

The Daylight Academy wants to promote international and interdisciplinary cooperation among scientists, architects and other professionals involved in daylight research or with a strong interest in daylight related topics.

The aim is to strengthen daylight research and its applications for the benefit of humanity and nature.

DLA was inaugurated in November 2016.

The first DLA publication

DLA workshop in Berlin, July 2018
Differences between daylight and el. light

Participants:

Martine Knoop [a], Oliver Stefani [b], Bruno Bueno [c], Barbara Matusiak [d], Richard Hobday [e], Anna Wirz-Justice [b], Klaus Martiny [f], Thomas Kantermann [g], Mariëlle Aarts [h], Noureddine Zemmouri [i], Siegrun Appelt [j], and Brian Norton [k]

[a] Department of Lighting Technology, Technische Unversität, Berlin, Germany.
[b] Centre for Chronobiology, Transfaculty Research Platform Molecular and Cognitive Neurosciences, Psychiatric Hospital of the University of Basel, Basel, Switzerland
[c] Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany.
[d] Light and Colour Centre, Department of Architecture and Technology, Faculty of Architecture, Norwegian University of Science and Technology, Trondheim, Norway.
[e] Independent Researcher, United Kingdom.
[f] Psychiatric Centre Copenhagen and Institute of Clinical Medicine, University of Copenhagen, Denmark.
[g] University of Applied Sciences for Economics and Management (FOM), Essen, Germany.
[h] Department of the Built Environment, Eindhoven University of Technology, Eindhoven, Netherlands.
[i] Department of Architecture and Urban Design, University of Biskra, Biskra, Algeria.
[j] Langsames Licht/Slow Light, Vienna, Austria.
[k] Dublin Energy Lab, Technological University Dublin, Grangegorman, Dublin, Ireland.

Daylight: *What* makes the difference?

The article in the Lighting Research & Technology

Daylight

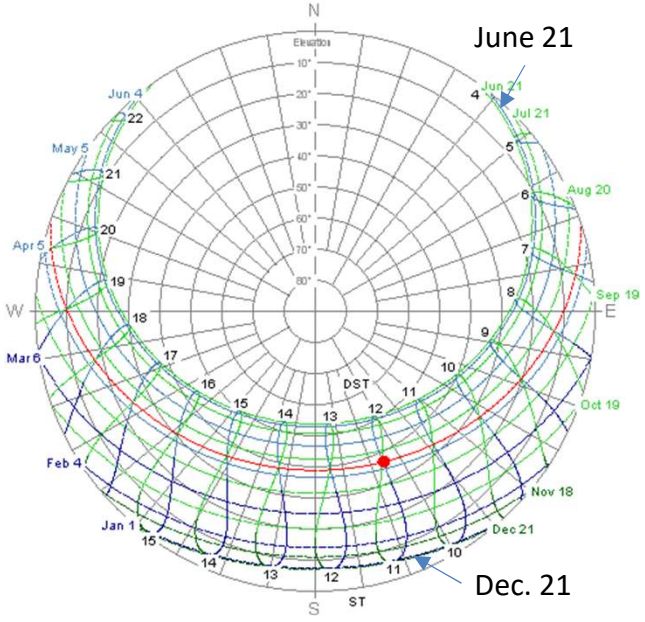
the holistic combination of the luminous characteristics of sunlight from **direct solar radiation** and **skylight** from **diffuse solar** radiation.

Unlike electric lighting, daylight is highly dynamic, changing across days, throughout the year and with weather conditions.

Qualities:

- Diffuseness
- …

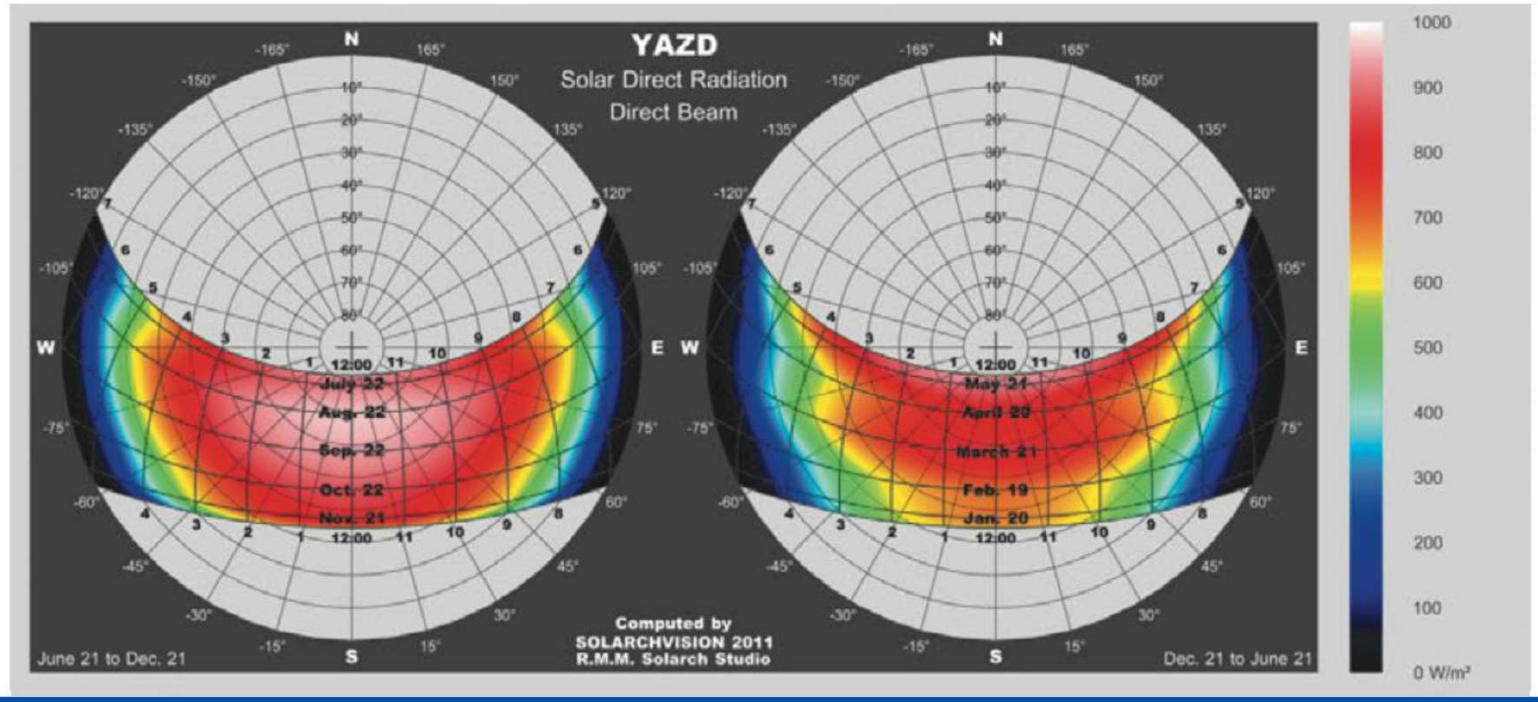
- Direction
- Intensity
- Colour….



Solar diagram for Oslo
59.9° N, 10.7° E

…….

and Yazd (Iran)
31.9° N, 54.3° E



The topics:

- Visual performance
- Good eyesight
  - Myopia
  - Colour vision
- Circadian entrainment
- Acute non-image forming effects
- Room, objects and human appearance
- Comfort
- Well-being due to view through windows

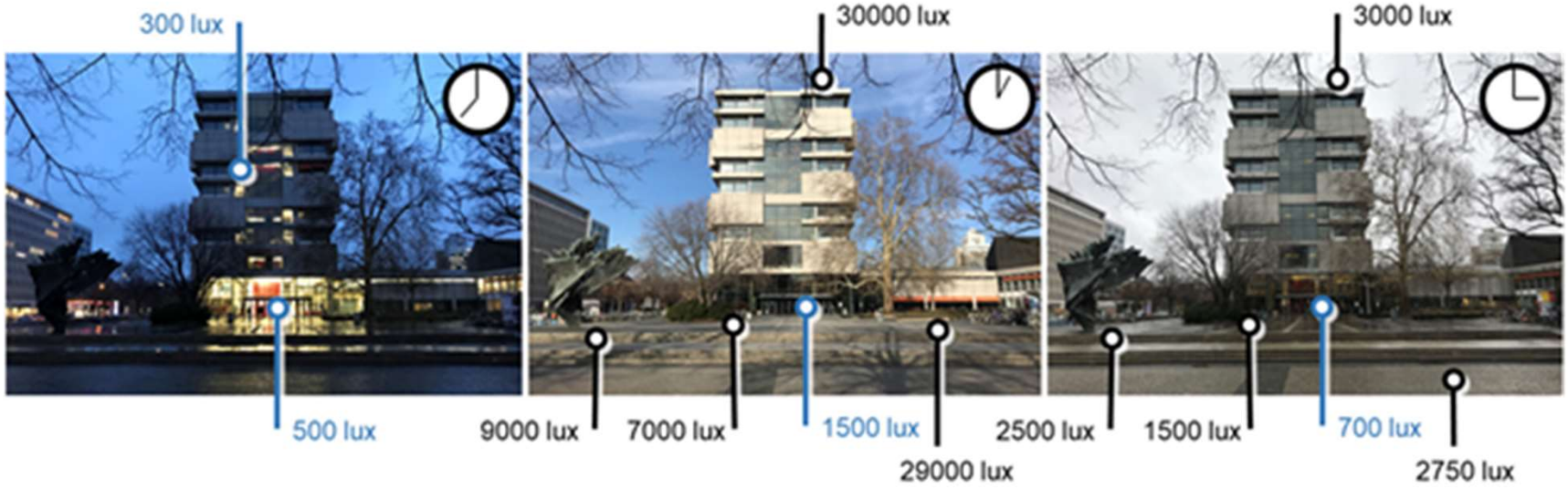
- Discussion about mimicking daylight….

Visual performance

the speed and accuracy of processing visual information

Daylight is a very good light source to support visual performance during daytime.
It is a flicker-free (pulsation-free) light source with a continuous spectral power distribution covering the full visible range and high intensity.

The high illuminance levels enable discrimination of fine details supporting visual acuity as long as glare is controlled.



Range of approximate horizontal illuminance levels **indoors (blue)** and **outdoors (black)** in exemplary situations during winter time in Berlin.

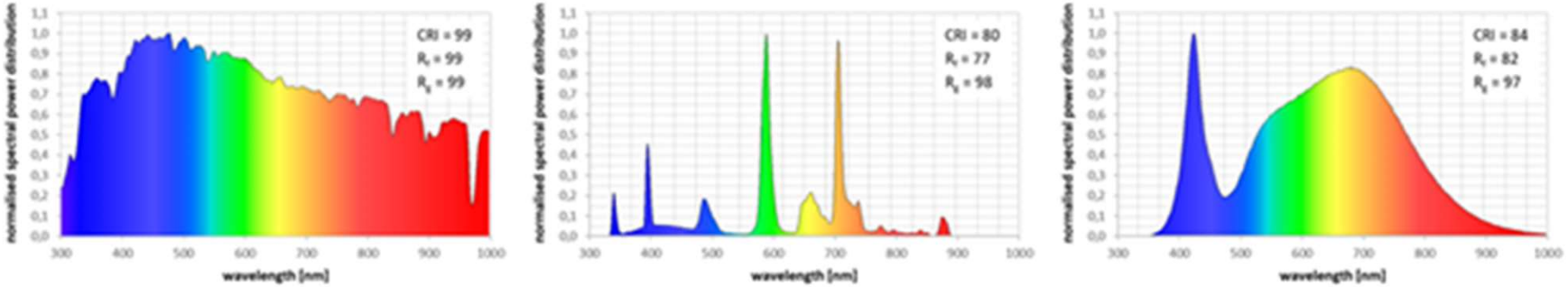
Visual performance

CRI - the ability of a light source to reveal the colour of objects faithfully in comparison with an ideal or natural light source.

The even spectral power distribution offers

- optimal colour rendering (CRI)
- better colour discrimination than most electric lighting sources

The directionality of daylight (from windows) can produce shadows that enhance details for three-dimensional tasks.



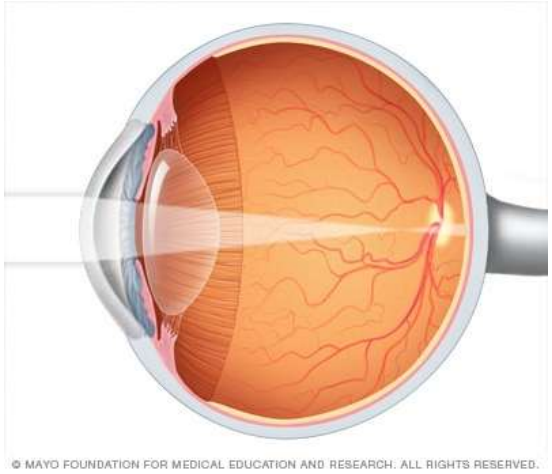
daylight indoors | fluorescent lamp | LED

Examples for spectral power distribution (according to IES TM-30-15 and CIE 013.3:1995)

Good eyesight - myopia

Lack of daylight exposure seems to be linked to developing myopia, or short-sightedness, the most common visual disorder affecting young people; it has reached epidemic level in East Asia. The hypotheses:

- bright light stimulates the release of the retinal neurotransmitter dopamine, which inhibits the axial growth of the eye that causes short-sightedness
- since circadian (diurnal) rhythms in the eye affect ocular growth, disruption of such rhythms by low light has been proposed as a factor in myopia development
- there is a geographical, seasonal, component, as both eye elongation and myopia progression increase as day-length shortens



"*A person with little exposure to daylight has a fivefold risk of developing myopia, which can rise as high as a 16-fold risk if that person also performs close-up work*"

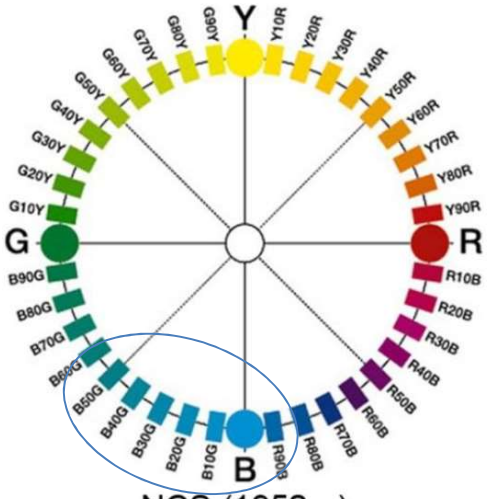
(Legreze and Schaeffel)

Good eyesight – colour vision

The **spectral component** of daylight exposure may affect colour performances of eyes.

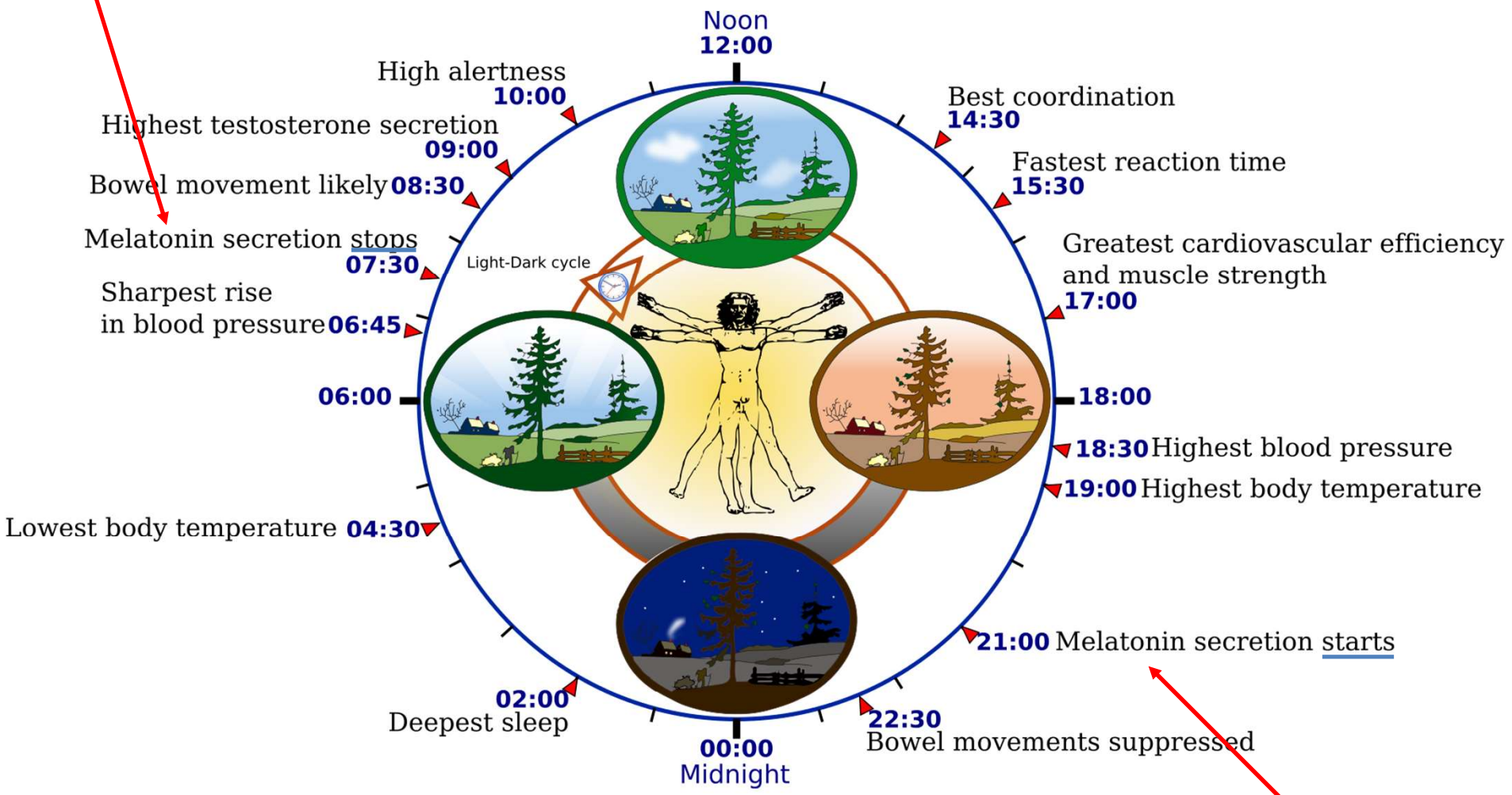
Research shows that colour deficiencies are more common in northern latitudes, where twilight is a more significant part of the day than at the equator, where colour deficiencies are very uncommon. Reimchen (1987)

A study of human visual perception of individuals born below and above the Arctic Circle, in different seasons, indicated that a reduction of daylight and an increase of exposure to twilight and electric lighting during infancy changes colour sensitivity; participants born in autumn above the Arctic Circle showed the lowest overall colour performance (Laeng et al. 2007).



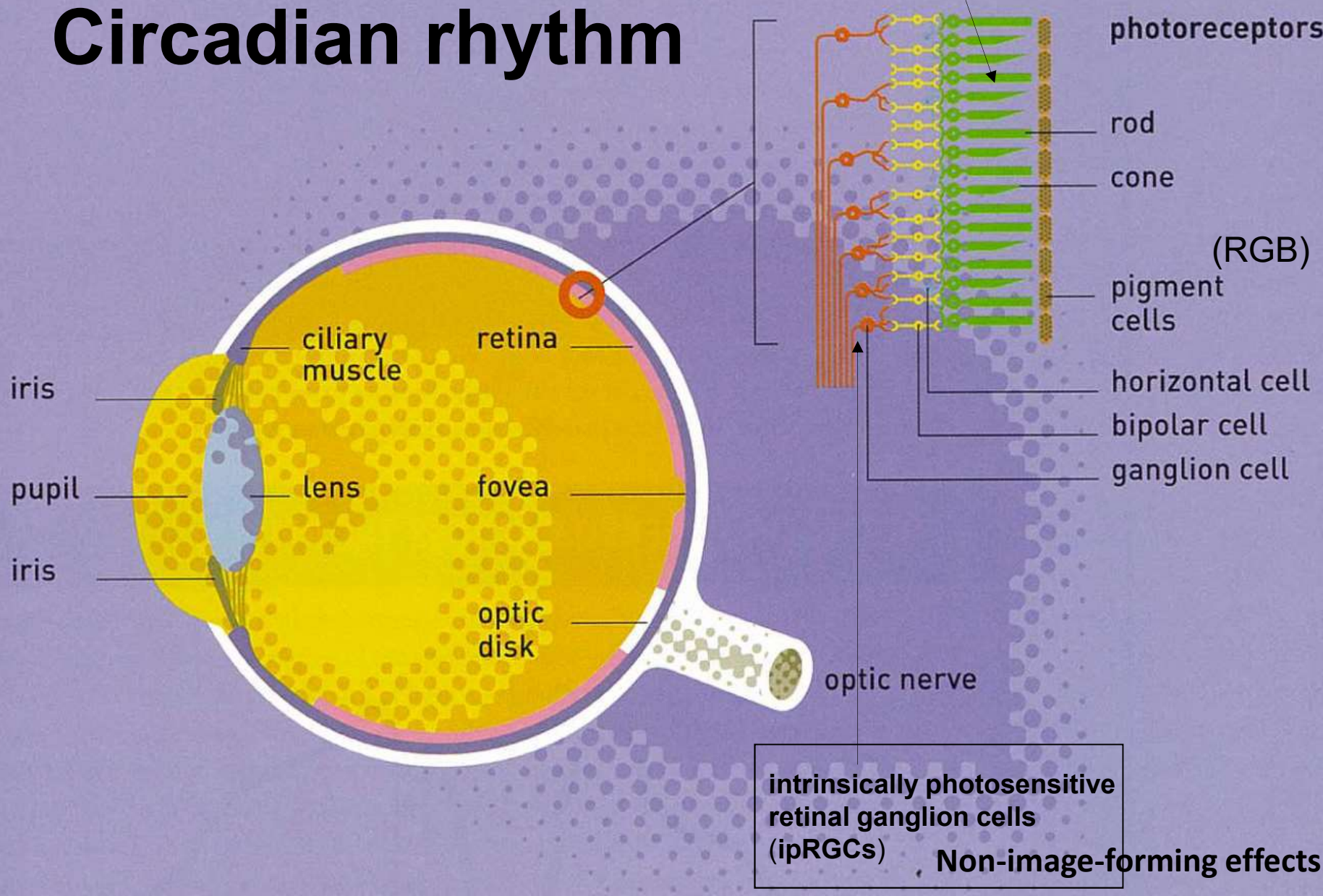
NCS (1952 -)

Circadian (diurnal) rhythm



NTNU

Circadian rhythm



NTNU

Circadian entrainment

Well-timed lighting can entrain the circadian system, which is important for **sleep quality, health, mood** and **cognitive abilities**.
Daylight, due to its temporal variations in intensity and spectral power distribution (dawn and dusk signals) is the natural 'zeitgeber' (tidsur) for the synchronization of the circadian system and the day-night cycle.

Temporal characteristic: Colour of daylight throughout one day, at high latitudes in midsummer

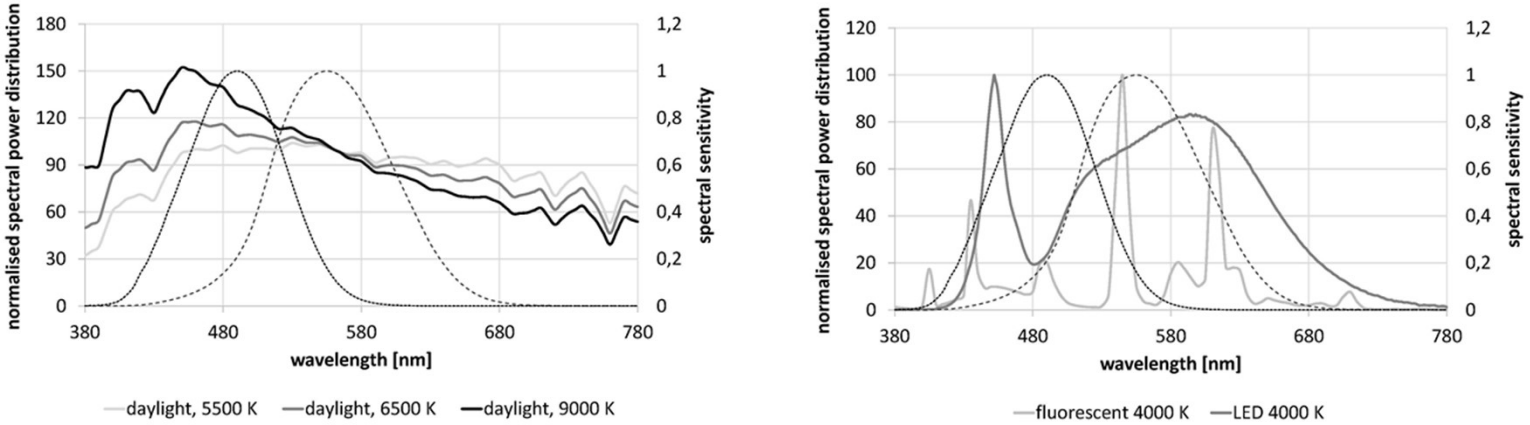
Circadian entrainment

Depending on the daylighting design, **indoor daylight** can provide an adequate stimulus and support to the circadian system.

- Office workers with access to windows have reported better sleep quality than those without windows. (Boubreki et al. 2014),
- Sleep quality increases with higher daylight availability (Figueiro and Rea 2016),
- the duration of light exposure of minimum 1 000 lx at eye level is an indicator for better sleep quality (Hubalek et al. 2010).
- Typical residential illuminance [on average 100 lux or less, due to electric lighting] is too low for circadian needs even in young adults.
- Properly timed exposure to sunlight or other bright light sources is vital for mental and physical well-being in all age groups. […]

In general, several hours of at least 2 500 lux of blue weighted light exposure (ideally sunlight) starting early in the morning benefit most people.

Acute, non-image forming effects



Exemplary spectral power distributions of daylight and electric lighting including spectral sensitivity of **ipRGC**s and cones.

Many acute effects, such as **melatonin suppression, increase of heart rate or alertness** can be realized by light through the **intrinsically photosensitive retinal ganglion cells** (**ipRGCs**), by both, natural and electric light.

Bright light immediately and directly enhances:

cognition,

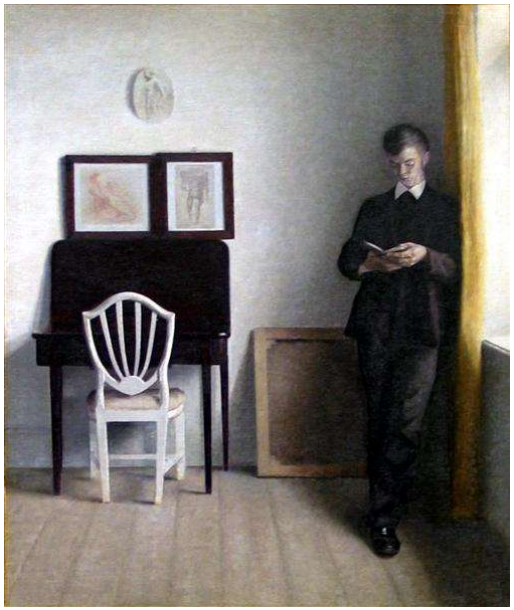
alertness, and ability to concentrate (reduction of daytime sleepiness)

performance (daytime)

mood,

So, bright environments throughout the day provide benefits, especially for middle-aged or older adults".

Room, object and human appearance



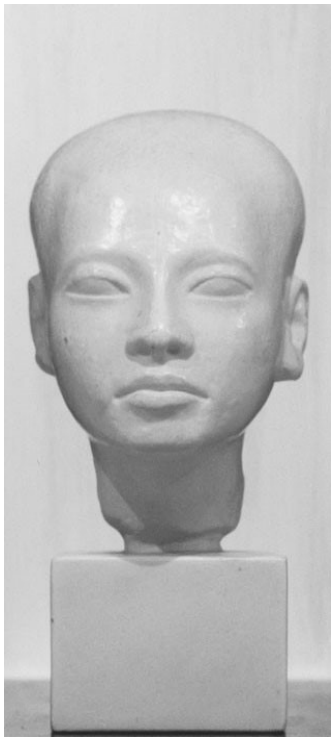
Interior with Young Man Reading
Vilhelm Hammershøi, 1898.

Spatial light distribution due to daylight (left and right) and electric light (middle)

Daylight delivered through a window has a main direction inward to the room, with its intensity decreasing with distance from the window. This creates visual clarity that can provide an impression of serenity of the space. This spatial light distribution also affects room appearance, as well as the perceived representation of objects and human faces.

Electric light systems used nowadays in common spaces, usually deliver light from a number of points distributed over a space leading to light rays of various intensities and directions creating overlapping shadows that can be perceived as visual noise.

Room, object and human appearance



The form and texture of people and objects are revealed clearly and pleasingly, without confusing shadows, when light comes predominantly from one direction. The appearance of faces of people seated near the window, side-lit by daylight, has been shown to be labelled with positive attributes, and high contrasts are not perceived as disturbing (Liedtke 2009). Light from the side supports aesthetic perception of human faces and objects;

Room, object and human appearance

A full-scale study of a series of room quality attributes showed that high levels of daylight from large windows are crucial in order to achieve a more

spacious, open, pleasant, exciting, legible and coherent space

(Moscoso, Matusiak 2016).

Comfort

The brightness and the strong infrared component of daylight may be appealing, but can cause **visual and thermal discomfort**. Still, interviews in field studies showed that occupants can be satisfied with daylight even though they sometimes experience visual discomfort.

Satisfaction with the temperature in the room is affected by lighting conditions, with a lower satisfaction under lower lighting levels. This could suggest a greater tolerance for thermal discomfort in situations with daylight.

Flicker can cause headaches, eye strain or seizures, and reduce visual performance. Electric lighting can be sources of flicker, whilst daylight is a flicker-free light source.

Well being due to views through windows

Both content and perceived quality of a view can affect human responses to daylight.

The number of view layers,
the width and distance of the view,
the perceived quality of the landscape elements and
the composition of the view ……are important influential parameters.

Tolerance of **discomfort glare** from daylight through a window is partly determined by how interesting the scene outside is, its attractiveness and its content.




insufficient, sufficient, good excellent

Examples of the view in four view quality categories

Well being due to views through windows

Busy and narrow scenes require constant accommodation and adaptation processes by the eye muscles, to keep an image fixed at the fovea centralis.

Conversely, views into a deep space can relieve the eye and the eye muscles, and free the cerebral cortex from processing information, leading to cognitive relaxation. Looking at a distant view speeds-up physiological recovery from a stressful experience.

Why we need a view out of the window?

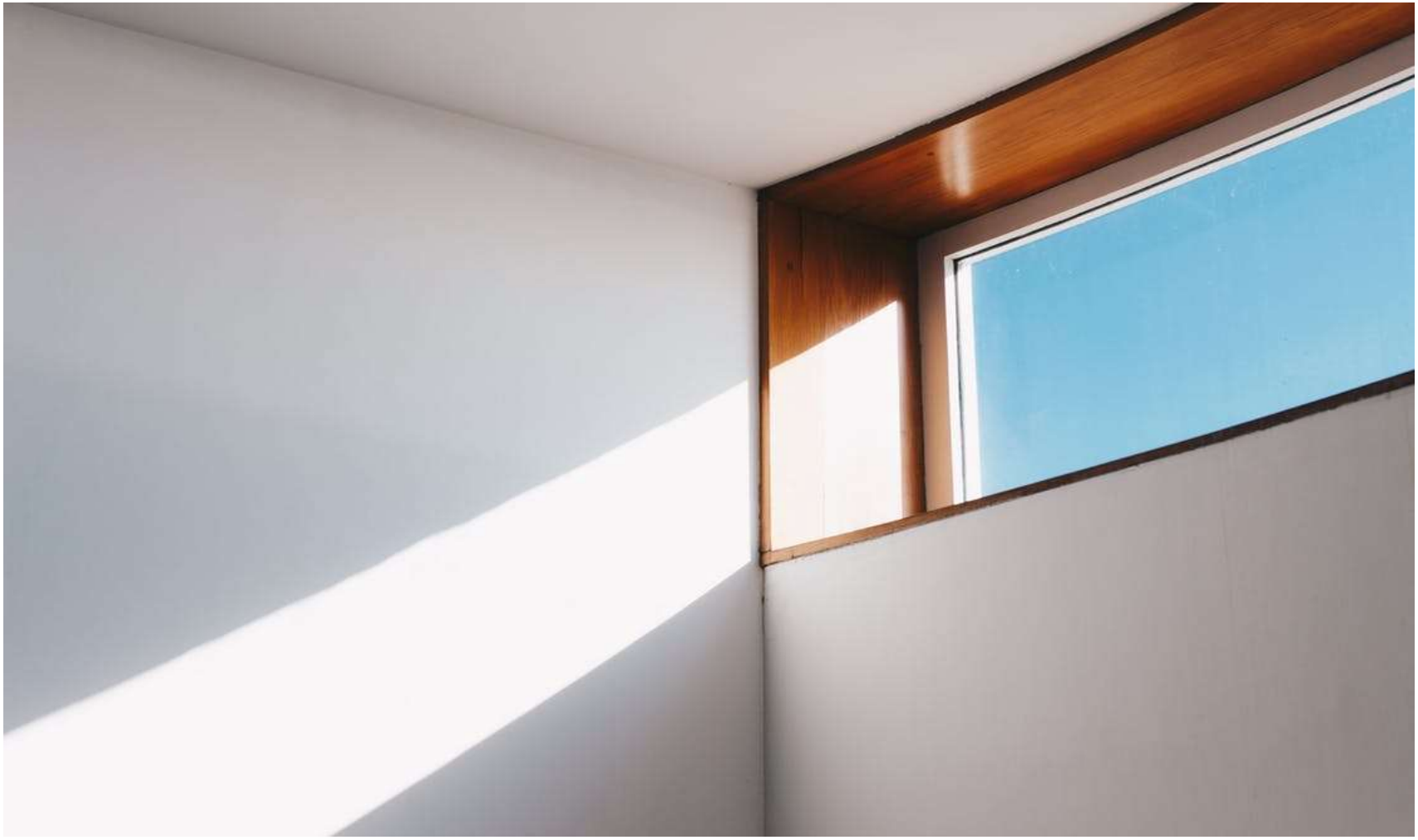
- information
- restoration
- aesthetic experience

The good view from a window can affect several aspects of physical and mental well-being. It can, for example **increase job satisfaction**, support **restorative processes or relieve stress**.

A view from an office at Gløshaugen, evaluated as **excellent.**

Characteristics	Daylight	Electric lighting
Spectral **Figures 2, 6, 10**	Continuous spectral power distribution (containing all visible wavelengths), with a strong short- wavelength component during daytime; includes infrared (IR) and ultraviolet (UV) radiation Outdoors: approx. 290 nm – 2600 nm Indoors: approx. 320 nm – 2600 nm	Various spectral power distributions, some continuous, others discontinuous. For typical general lighting: 380 – 780 nm
Temporal and absolute photometric and colorimetric characteristics. **Illuminance and correlated colour temperature (CCT)**	Temporal variations in intensity, spectral power distribution and CCT Dusk and dawn: lower light intensity During daytime: high light intensities, variable CCT	Static or pre-programmed dynamic intensities; static CCT (typically 2700, 3000 or 4000 K) or pre-programmed dynamic colour change, available during day- and night-time
Spatial light distribution indoors **Figures 7-9**	Daylighting from windows: - lighting from the side, - vertical surfaces can be illuminated, with high light intensities, - under clear sky conditions: parallel beams, realise distinct shadows and sun patches.	Typical, functional, electric lighting: - lighting from above, - focus on horizontal surfaces, - no parallel beams, distinct shadows or patches only with accent lighting.
Temporal fluctuation	Stable on a short timescale (no flicker, no spectral fluctuations)	Source can display flicker and / or have spectral fluctuations
Polarisation	Direct sunlight is not polarised. Daylight from a particular region of the sky (relative to the sun's position) is partially polarised	Partial polarisation is introduced in lamp configurations involving specular reflections or direct transmission (e.g. through a flat glass pane) where the light is incident on the material close to its Brewster angle
Energy—requirements and costs **Figures 3, 10**	Freely available	Energy required for electric lighting
Visual information **Figures 1, 2, 12**	View through a window provides contextual clues	No information beyond the presence of light

Is it possible to mimick daylight?
Is it desirable?

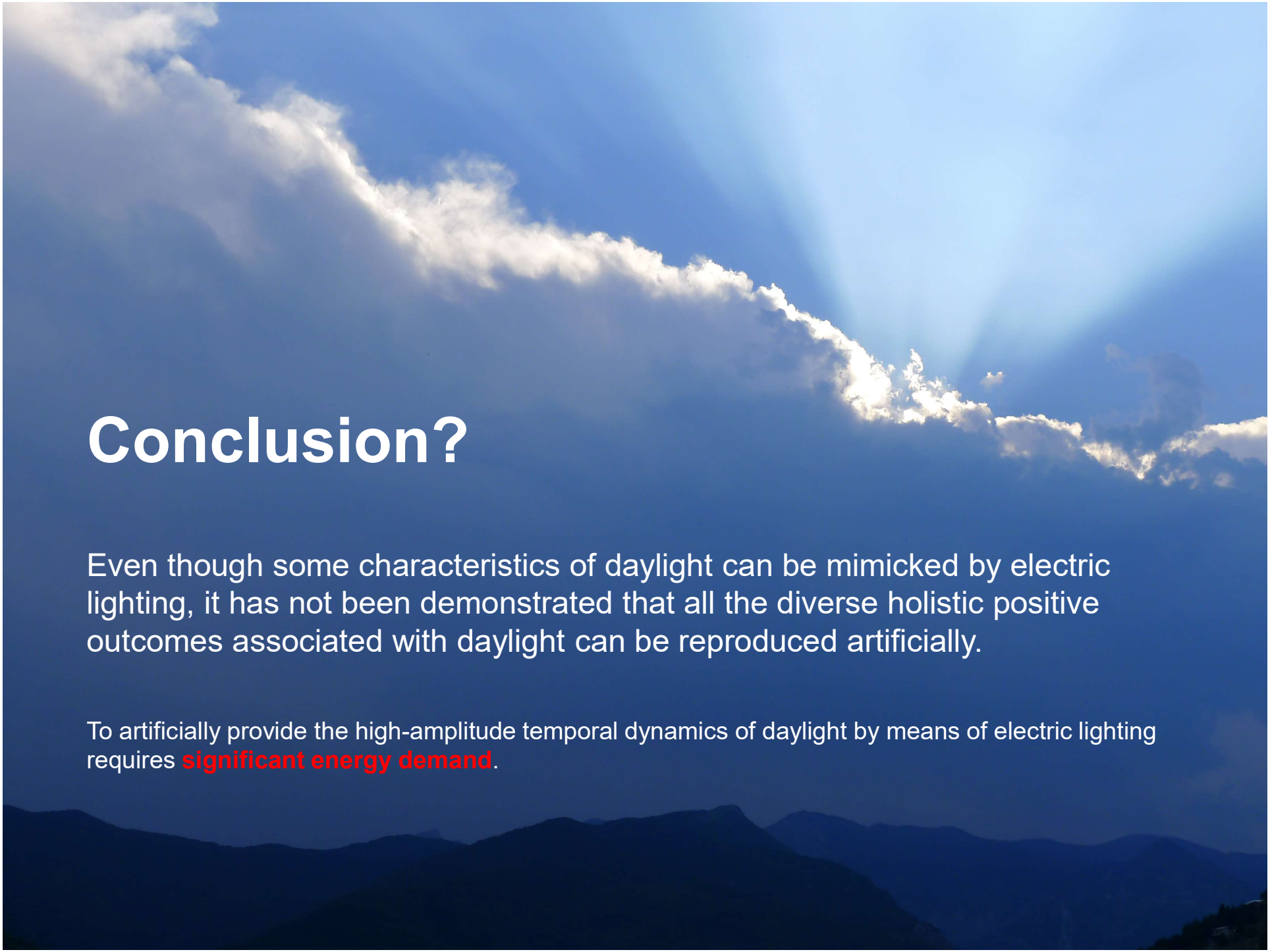


https://www.pexels.com/photo/clear-glass-window-with-brown-and-white-wooden-frame-921294/

Is it possible to mimick daylight?
Is it desirable?

CoeLux Artificial Skylights

http://www.dudeiwantthat.com/household/lighting/coelux-artificial-skylights.asp ……posted: April 27, 2016



Conclusion?

Even though some characteristics of daylight can be mimicked by electric lighting, it has not been demonstrated that all the diverse holistic positive outcomes associated with daylight can be reproduced artificially.

To artificially provide the high-amplitude temporal dynamics of daylight by means of electric lighting requires **significant energy demand**.