Energy efficient outdoor lighting for reduced light pollution

and

Measurement methodology for evaluation of spill light in protected urban environments

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Why do we need outdoor lighting?

- People are active around the clock
- Traffic safety
- Experience safety and security, see obstacles on the road, orient ourselves, feel good, quality of life, freedom, etc
- Darkness evokes negative associations but is a crucial natural resource

Why is it a problem now?

Effects of new technologies

Shifting baseline syndrome – every generation redefines what is normal/natural

Artificial light is increasing over the Earth's surface

Artificial light is already impacting protected areas

New knowledge on impacts

Examples of unwanted effects of the use of light at night

Human-made sky glow

Degradation of astronomical observations and ability to see stars

Increase of obtrusive light, causing discomfort

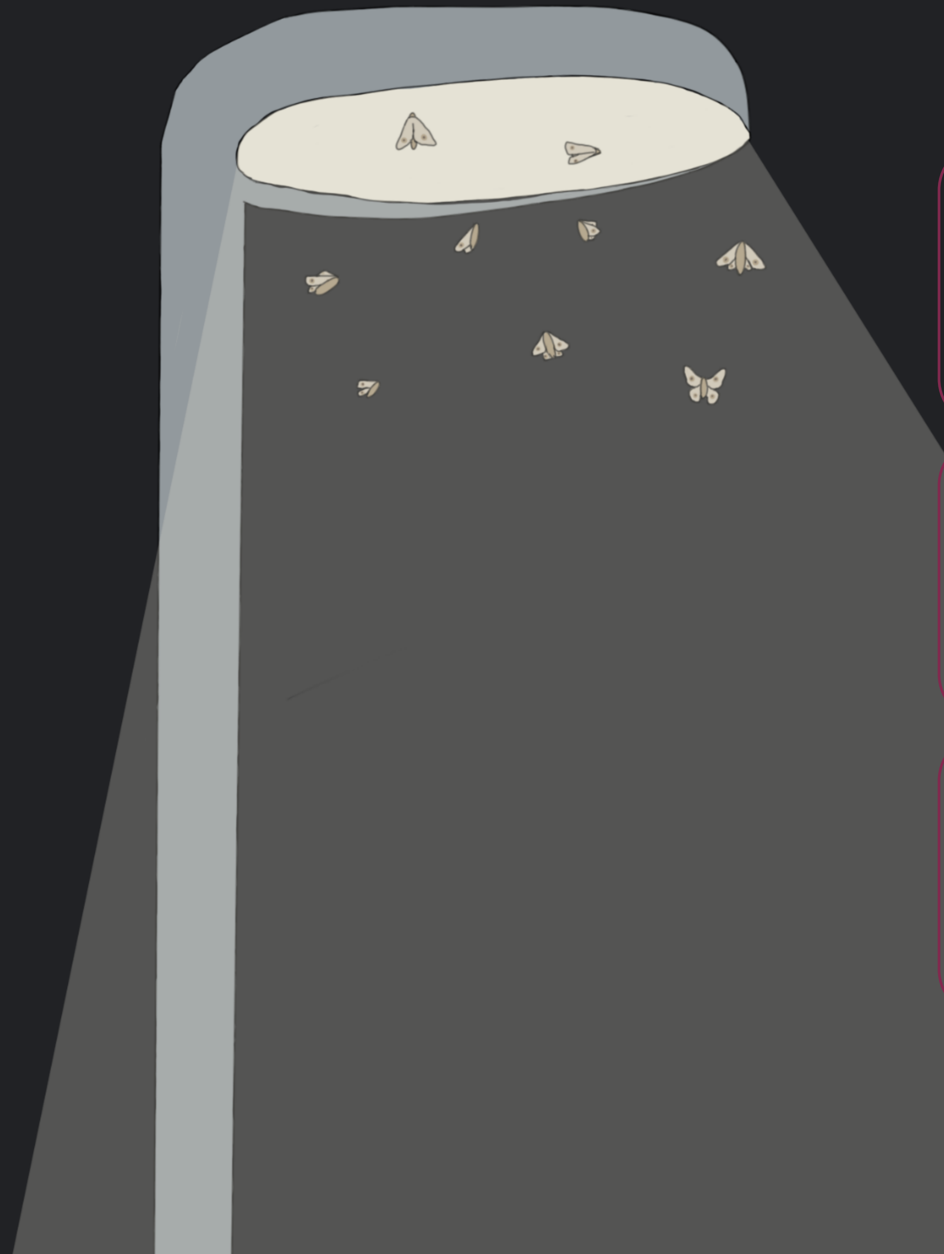
Health impacts: circadian disruption

Impact on species, ecosystems

Astronomical light pollution

- **Skyglow impact**: creates diffuse glow over populated areas and obscure celestial bodies.
- **Decreased data quality**: reduces accuracy and quality of telescope observations and images
- **Loss of observatories**: limits suitable locations for astronomical research
- **Reduced public stargazing**: hinders educational and recreational stargazing activities

Attraction and deterrence to light affects ecosystem species composition and biodiversity



Traditional knowledge has long recognized that certain species are drawn to light, such as insects, turtles, and nocturnally migrating birds

Studies have shown that certain species refrain from utilizing illuminated environments as nesting or breeding grounds, or as temporary feeding sites during migration

The attraction and repulsion to light may seem straightforward to predict, but it depends on the type of behavior and the environment.

Illustration by Elin Jägerbrand

General impacts of light at night

Source: Unsplash

Diurnal or light-opportunistic species:

- Increased time of activities
- Increased area of activities

Nocturnal species:

- Decreased time of activities
- Decreased area of activities

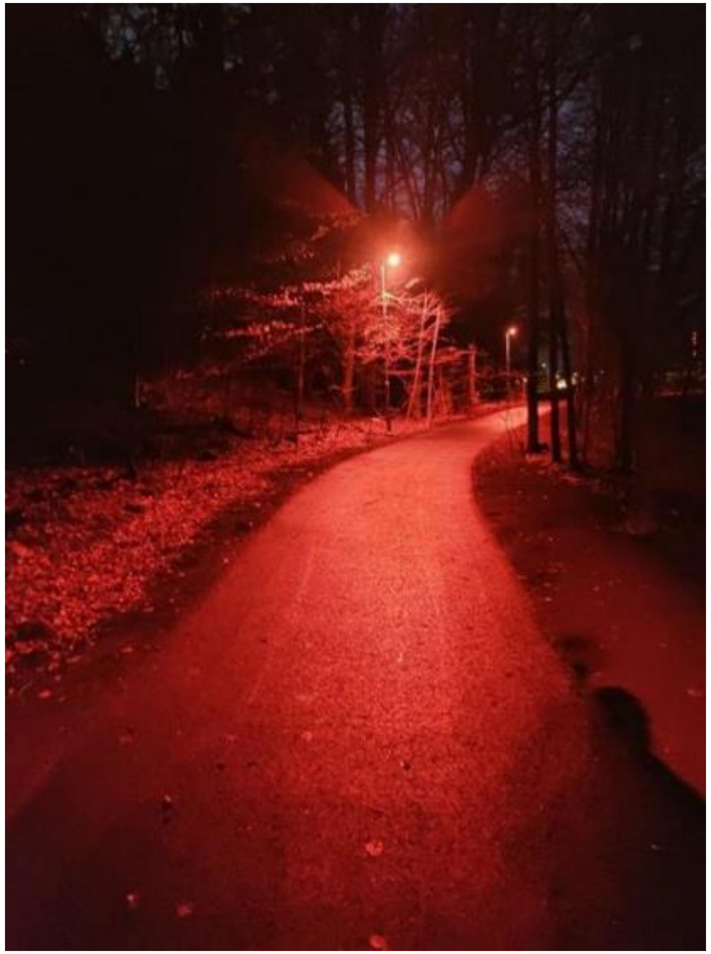
Anthropogenic light at night affects:

- **Natural rhythms and alters behaviors of both diurnal and nocturnal species.**
- **Can lead to reduced survival and activity, as well as decreased habitat availability for nocturnal species.**

Visual sensitivity of some insects and bats

Bat and insect friendly Lighting?

2024 in Borås, Sweden



Source: Mölndal Municipality (Gothenburg area, Sweden)

Impact on humans

Who is ALAN?

ALAN – Anthropogenic (Artificial) Light At Night

- Non-Image Forming Effects; Health impact.
- Visual effects: Obtrusiveness, glare, annoyance

Photo by Adam Dore on Unsplash

RISE

Impacts on Human Health (Outcome of literature review)

- Effects on circadian rhythm, sleep, alertness, etc. (ipRGC, photosensitive cells involved in the production of melatonin)
- Psychological (e.g., mood, depression)
- Metabolic disorders (i.e., obesity, diabetes)
- Other health impacts (e.g., cardiovascular and immune system disruptions)
- Cancer(?) (i.e., breast and prostate cancer)

Case studies

Field experiment in Borås, Sweden investigating users’ perception and experience of various correlated color temperatures and light distribution

Mitigation measures in Rågelund, Kungsbacka on a pedestrian and bicycle pathway in a sensitive coastal area.

Testbed outside Borås, Sweden

- Outdoor lighting with different light sources, white and warm white, and amber.
- The lamps were characterized in the lab
- Measurement of scattered light above the lighting installation with a drone.
- Evaluation of visual comfort and perceived safety and security with test subjects.
    - Investigate acceptance for amber lighting from a user perspective.

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Field test preparation March 14-16, 2023

9 poles

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3 different CCT, 2 different optics

Pole distance 22 m.

Height: 3,75 m over ground.

Total luminous flux the same for all settings.

3000 K

2200 K

1800 K (Amber)

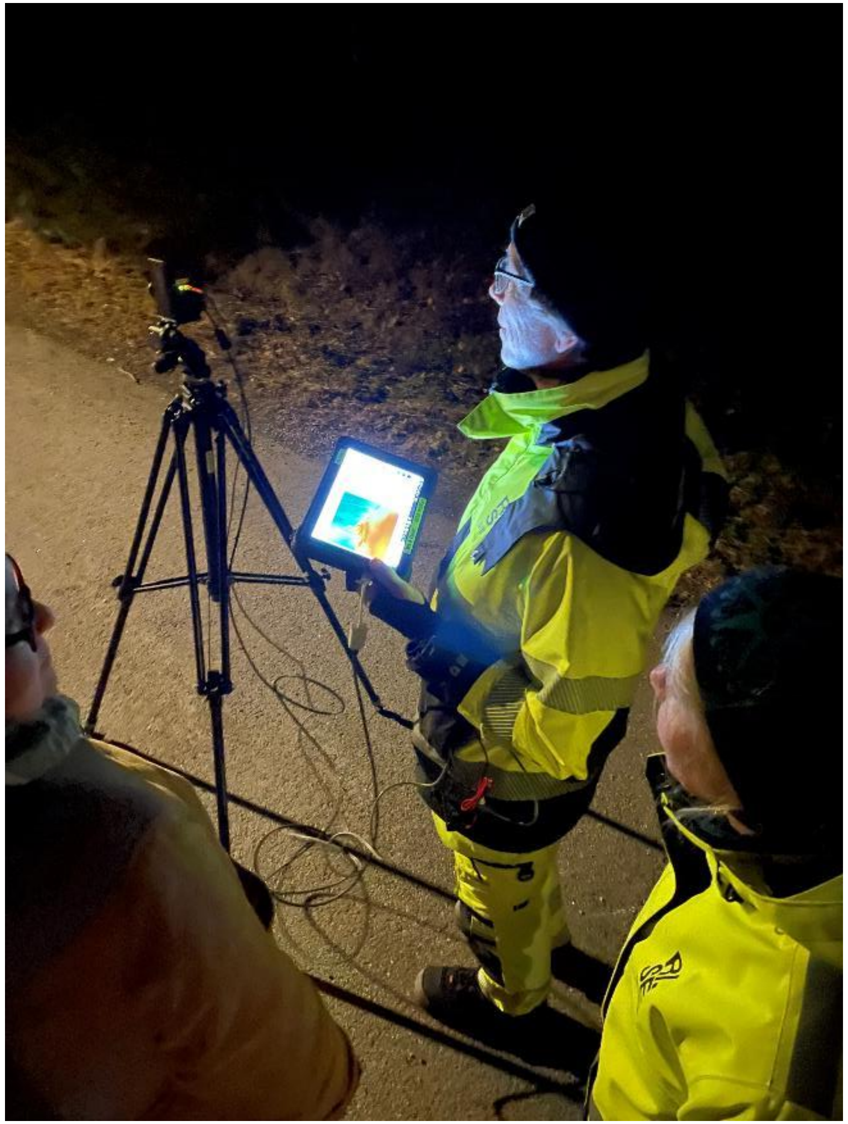
Evaluation with questionnaire

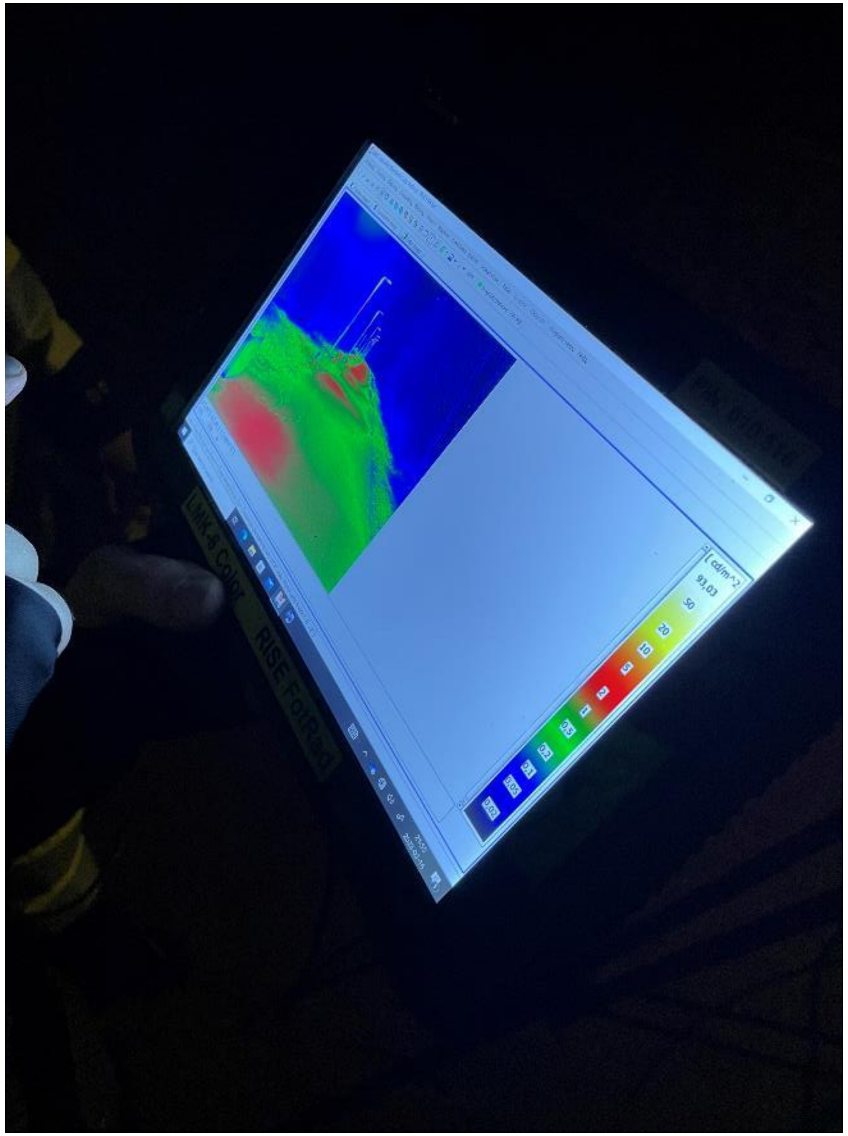
- 55 test persons over three nights
- Ages 15-90

On average

- Wide optics perceived as "brighter"
- Preference for wider optics
- Younger people (<25 years) preferred 3000K and felt unsafe in Amber lighting.
- People aged >65 preferred 2200K

Measuring with luminance camera



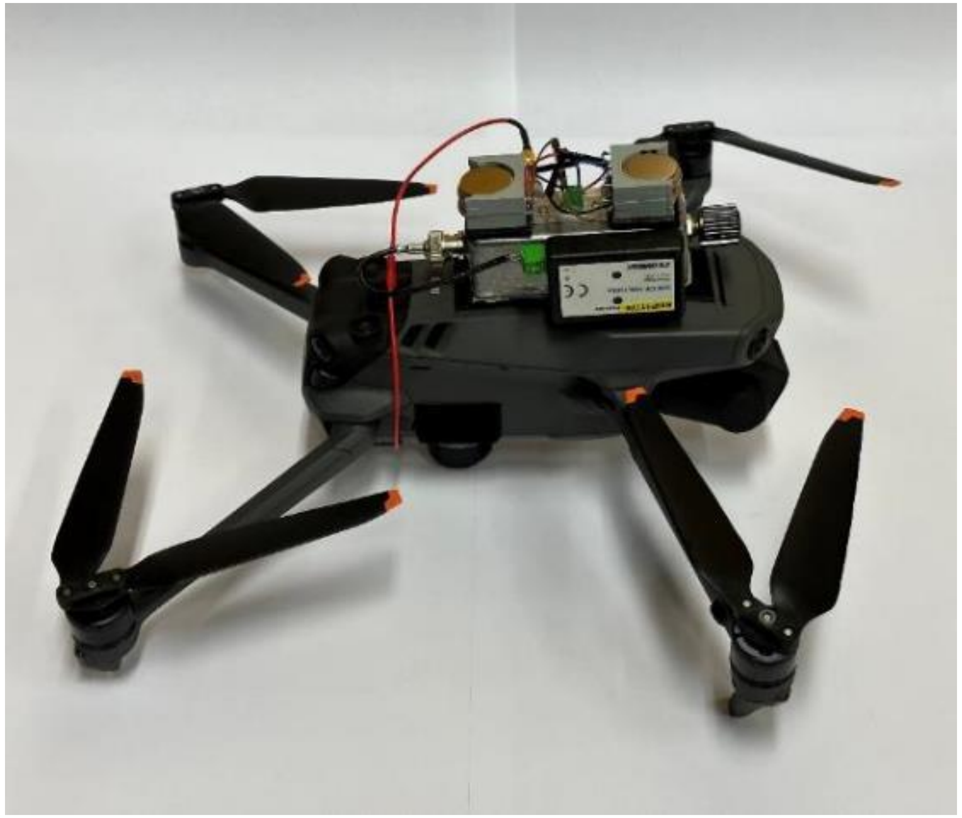


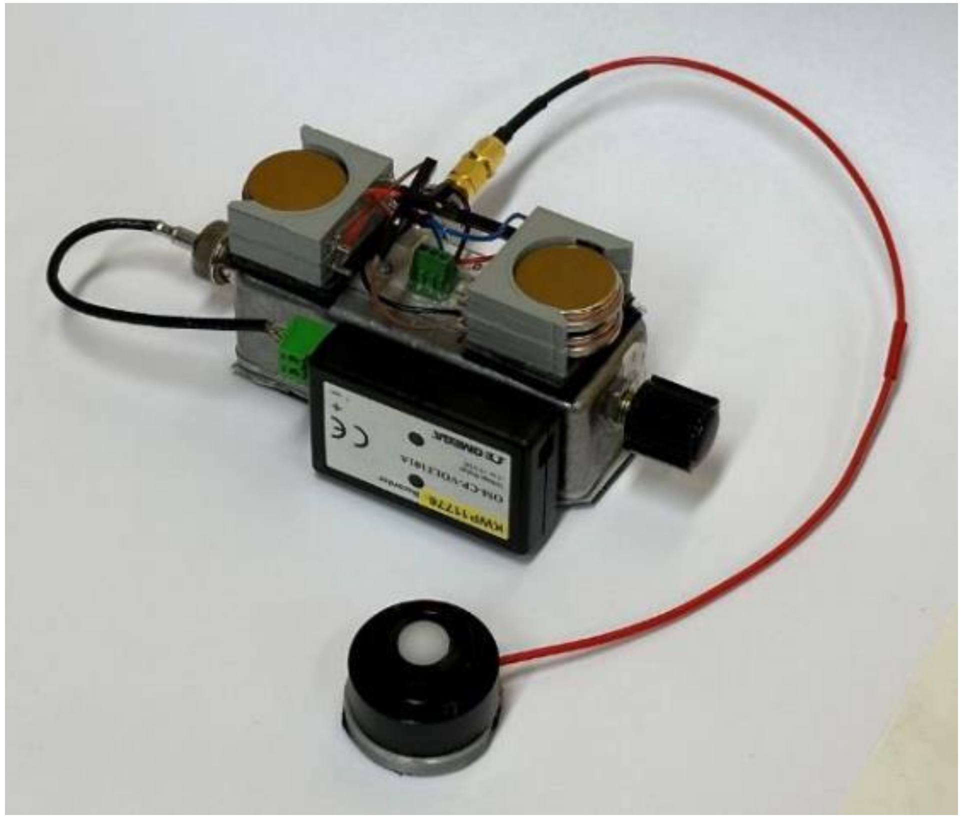
Measurements utilizing drones

- Cover large areas
- Relatively low cost
- Difficulties when there are many trees or when flying close to protected areas (e.g., no-fly zones near airport or prisons)

Obs! Using the drone camera as a photometer requires calibration

Drone (DJI Mavic 3) equipped with photometer





- Consumer grade drone
- No (official) payload
- Standard GPS accuracy (~0.5 m)
- Low weight (<0.9 kg) ➡ EU class C1

Less restrictions to use with people and/or buildings nearby

- Photometer: V(λ)- and cosine-adapted detector
- Transimpedance amplifier: 10^6 – 10^{10} (OPA128LM)
- Voltage data logger: 0-3.2 V, up to 4 Hz, resolution 0.0001 V
- Powered with six 3V lithium batteries
- Total weight: <250 g

Measuring luminance with a digital camera[1]

Principle

- Convert pixel values (N) to absolute luminance values (L, cd/m2)

$$L = Const \cdot \frac{f^2}{t \cdot S} \cdot N$$

Const = calibration constant for the camera
t = exposure time (s)
f = aperture number (f-stop)
S = ISO sensitivity

- For an ideal camera, determining the relationship for one pixel and one setting would be enough.
- In practice, additional steps (may) need to be taken

[1]For more information, see e.g., Hiscocks, P. D. (2011). *Measuring Luminance with a Digital Camera*. https://www.atecorp.com/atecorp/media/pdfs/data-sheets/tektronix-j16_application.pdf

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Practical considerations using a camera as a luminance meter

- Be careful with compressed image files (JPEG or similar)

  - normally coded using perceptual gamma (non-linear relationship between image pixel brighness and ”raw” sensor signal)

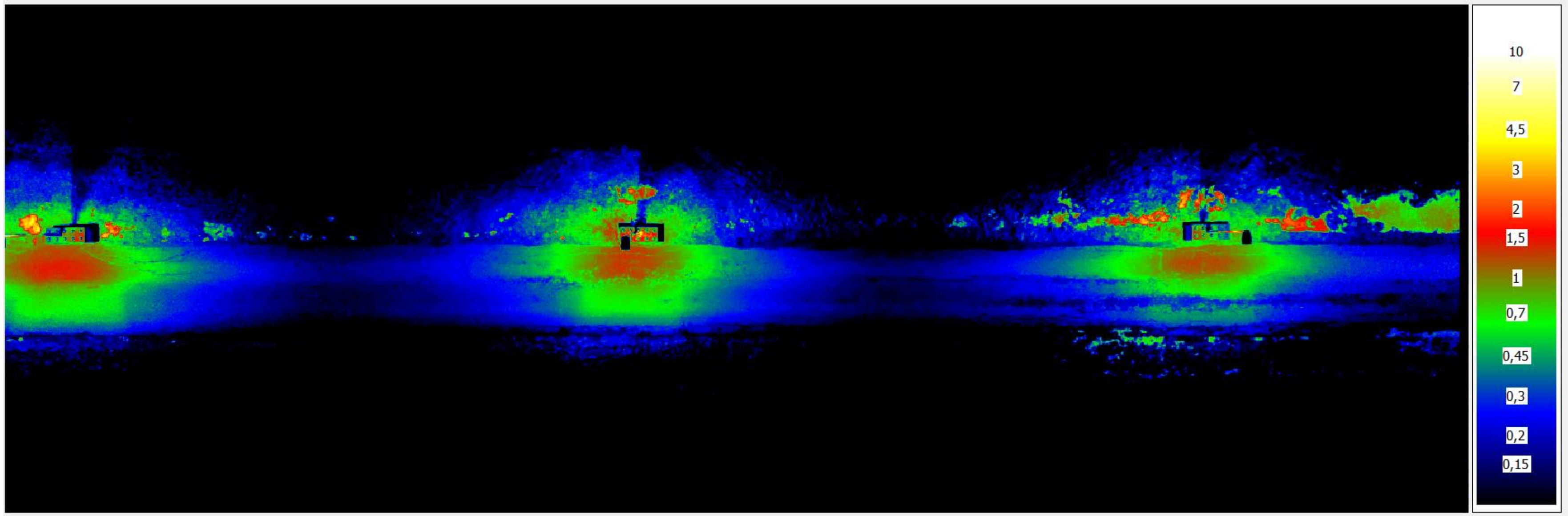
- Use manual camera settings and determine (or verify) the calibration factor for each settings (if feasible)
- Consider vignetting effects (lower brightness away from image center)
- Consider the colorfulness of the scene, may require separate calibrations for each channel (R, G, B)

Perceptual gamma (JPEG from camera)

Linear gamma (from “raw” file)

Drone images from the lakeside path

3000K wide optics
at 40 m

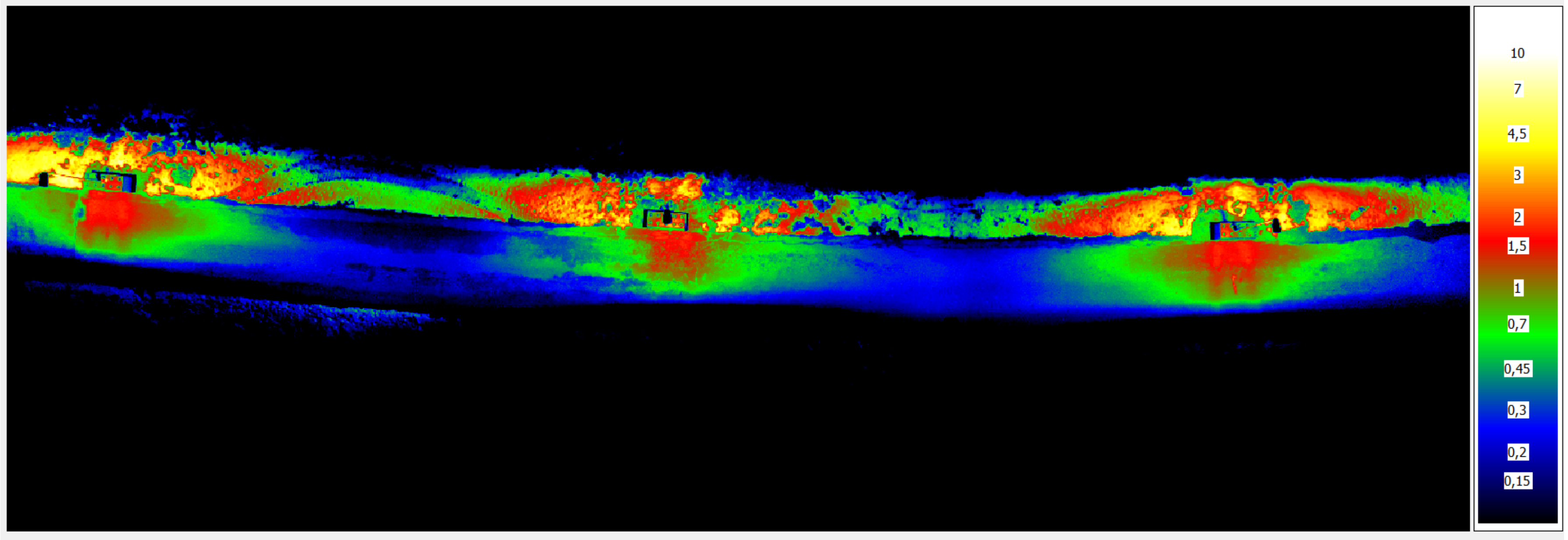


Camera image converted to luminance image (absolute in cd/m^2, logaritmic scale)

Calculated illuminance at 40 m: 0,067 lux

Drone images from the lakeside path – Amber lighting

1800K Amber,
narrow optics
at 40 m

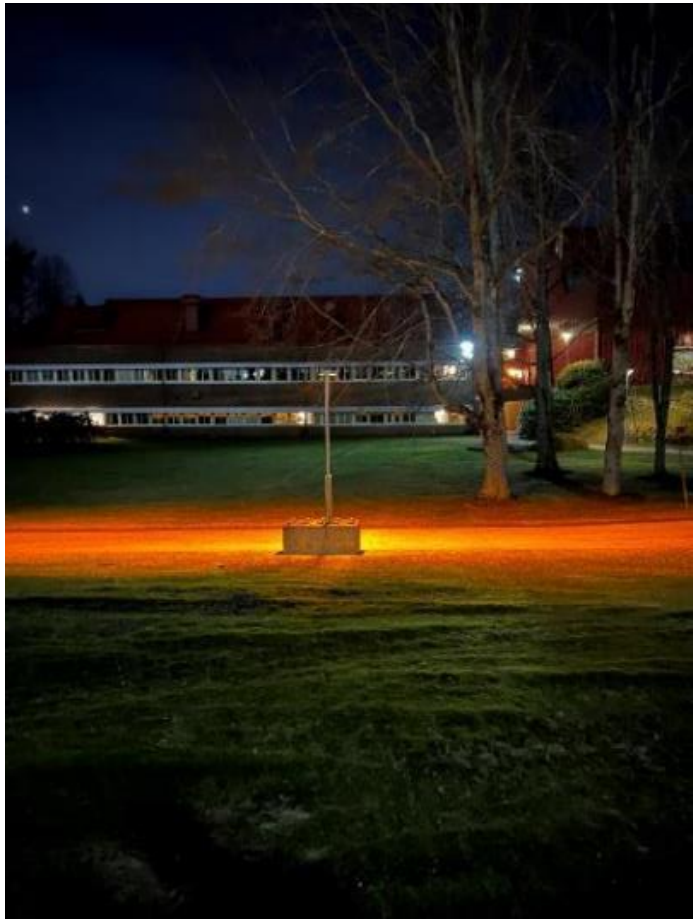


Camera image converted to luminance image (absolute in cd/m^2, logaritmic scale)
Calculated illuminance at 40 m: 0,112 lux

Significant contribution from reflections on the snow

New field test at RISE

- Three poles, replacing the luminaires between each run -> better comparability
- Lessons learned from the first field test



Overview field test at RISE

Wide optics

Narrow optics

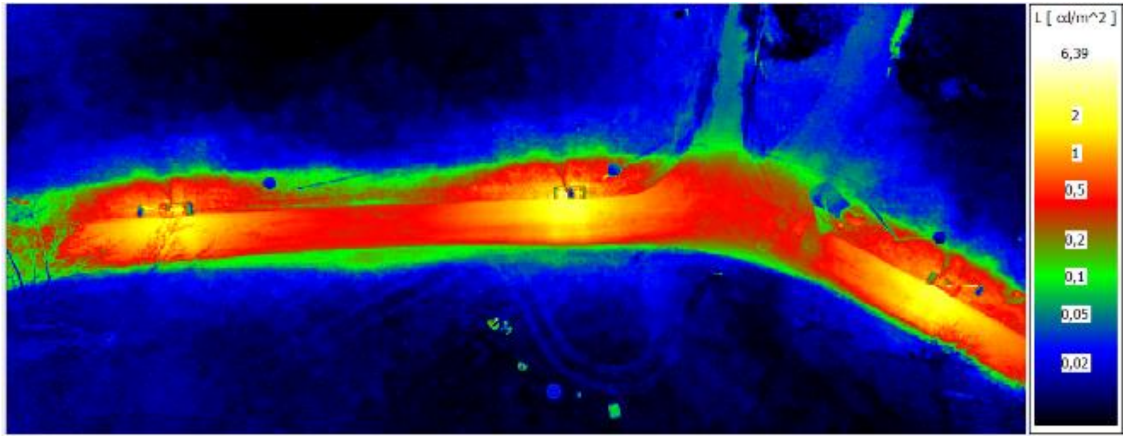
Comparison between measured and calculated illuminance

2200 K luminaire (narrow) at 42 m

- Calculated illuminance from images: 0.070 lx
- Measured illuminance: 0.084 lx
  (total 0.481 lx)

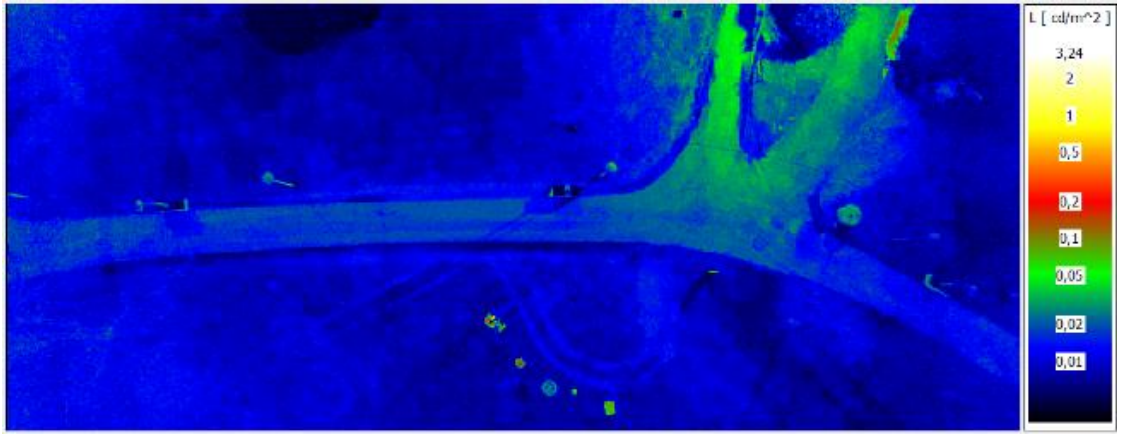
A small part of the area illuminated by the luminaires are not seen in the picture

Luminance (light on, log 3 scale)



Picture of the scene (JPG)

Luminance (light off, log 3 scale)

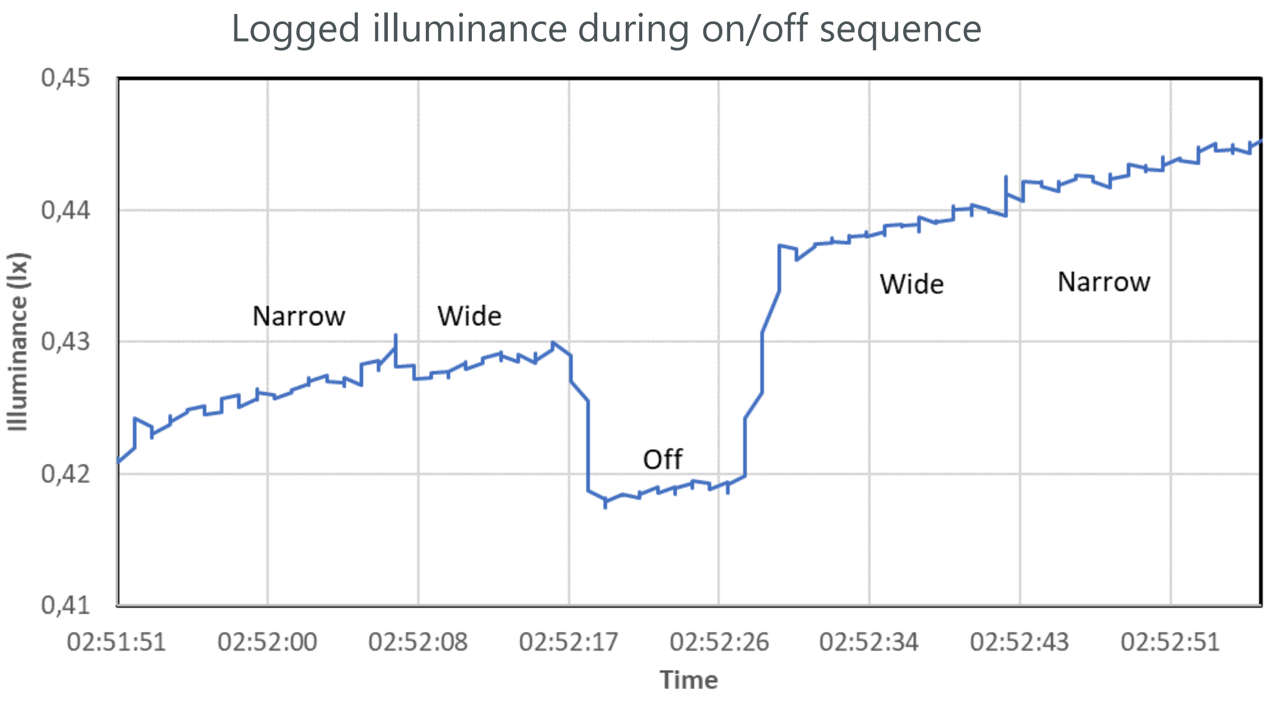


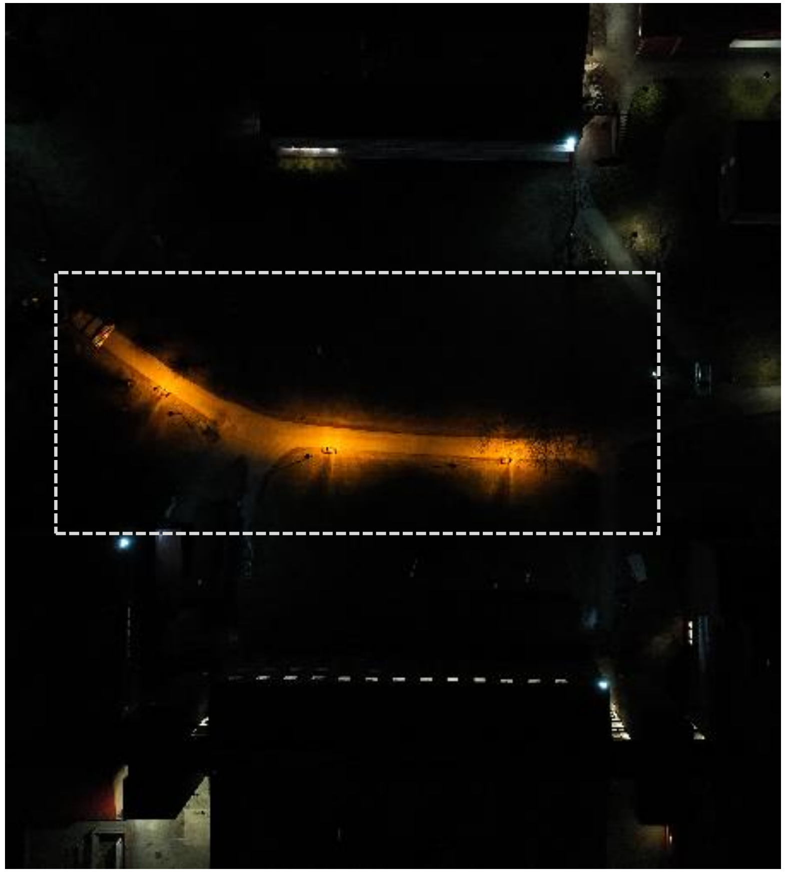
Comparison between measured and calculated illuminance

1800 K luminaire (wide) at 110 m

With isolated luminaires:

- Calculated illuminance from images: 0.013 lx
- Measured illuminance: 0.014 lx (0.012-0.016 lx)
  (total 0.433 lx)





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Measurement methodology for evaluation of spill light in protected urban enviroments

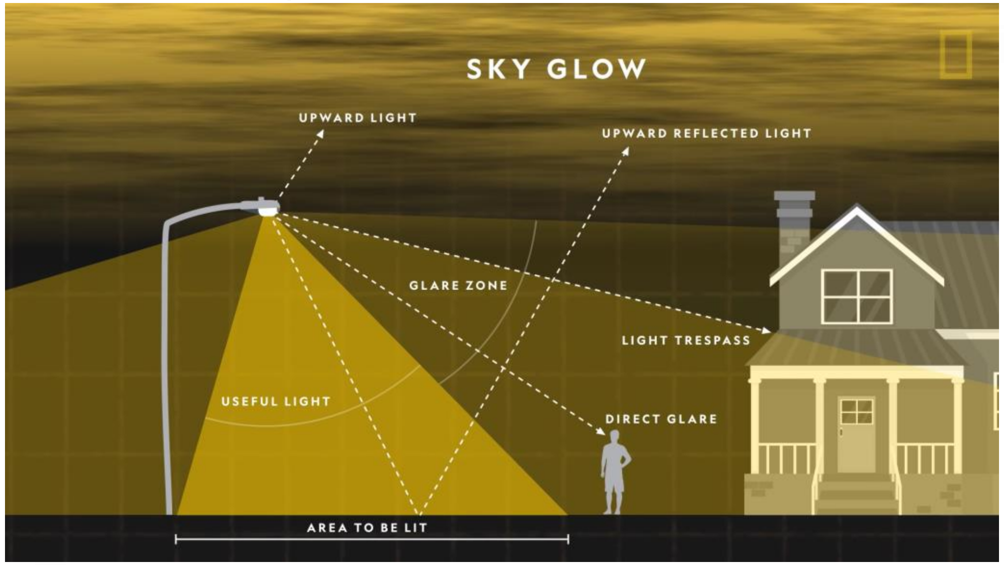
Background – Spill light

Spill light (or light spill), refers to any light that goes beyond the intended area of illumination.

Spill light is problematic for several reasons

- **Wasted energy / reduced effectiveness**.
  Light that falls outside the target area results in unnecessary energy consumption and reduces the overall effectiveness of the lighting system.

- **Environmental impact**.
  Spill light can negatively affect the surrounding environment by causing glare, endanger sensitive species and contribute to the skyglow.



Source: National Geographic

Background –reduce the effect of spill light

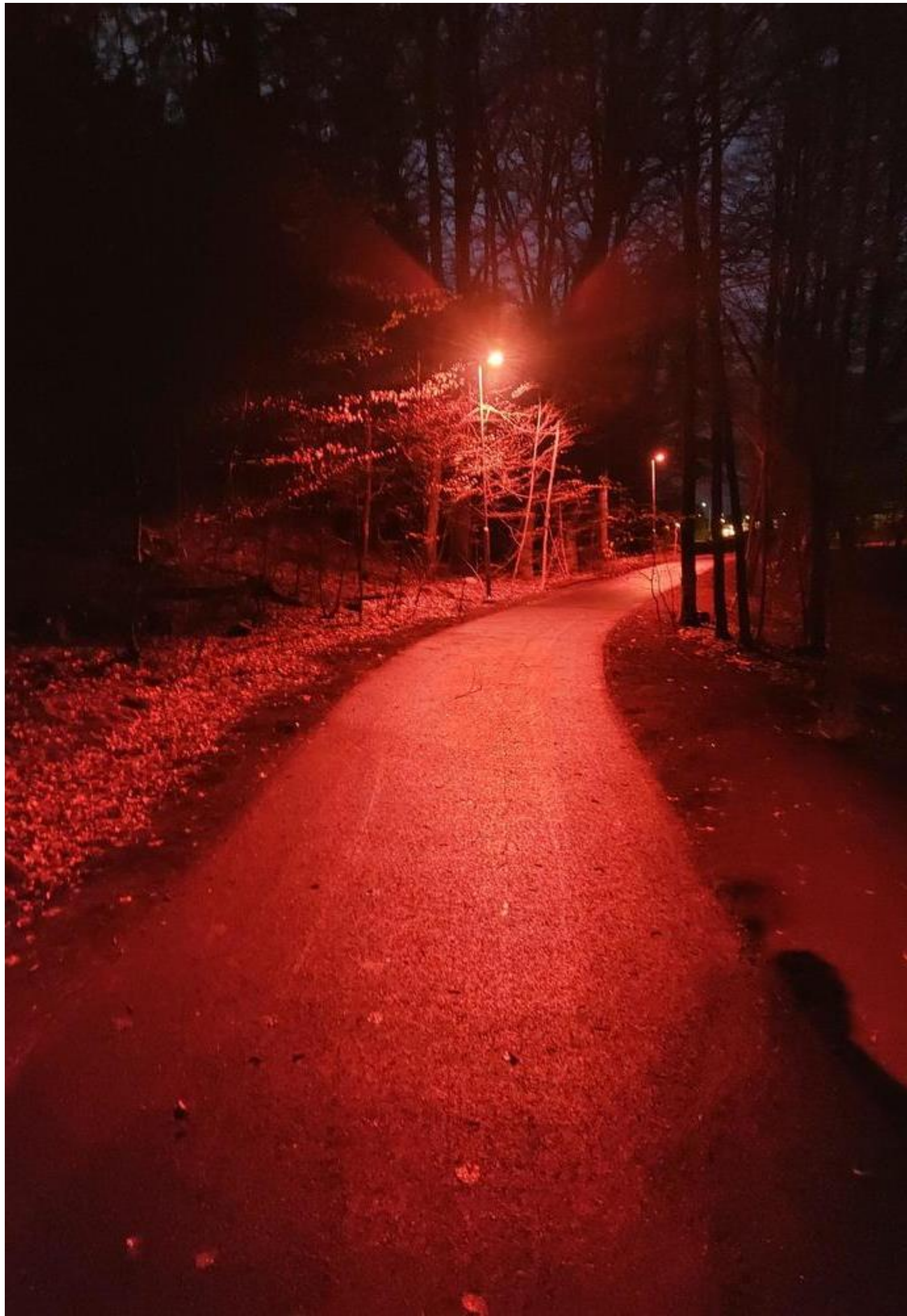
Current initiatives

- **Reducing the color temperature of the light**
  In extreme cases even to monochrome red
- **Installing proximity sensors and/or dimming**
- **Replace luminaires**
  Using lower luminaires (bollards, handrail lighting etc.) or luminaires with lower output and/or narrower light distribution

General drawbacks (for the users)

- **Darker surroundings**
- **Harder to see other people**

→ **Reduced sense of safety**



How should we design a sustainable outdoor lighting?

Acknowledgement

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Energimyndigheten

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Thank you!

Questions?

Photometry and Radiometry group

Measurement Sciene and Technology; RISE Research Institutes of Sweden