WEARABLE LIGHT SENSORS IN CASE STUDY EVALUATIONS

Prof. Werner Osterhaus
and Myrta Gkaintatzi-Masouti
Lighting Design Research Laboratory
Aarhus University, Denmark

Niko Gentile
Energy and Building Design Division
Lund University, Sweden

Danish Energy Agency

EUDP
Energy Technology Development and Demonstration Program

AARHUS UNIVERSITY

Swedish Energy Agency

LUND UNIVERSITY

Presentation Outline

Short overview on “Case Studies”

Why do we need wearable devices?

Which sensors are out there?

Commercial sensors

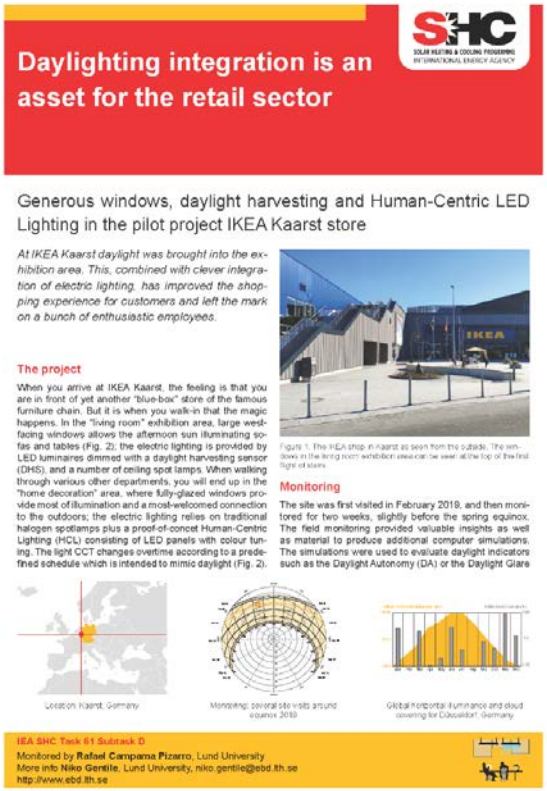
- Actiwatch
- LYS Button
- Movisens

Problems

Recommendations

Case Studies

What you should expect to see



Daylighting integration is an asset for the retail sector

Generous windows, daylight harvesting and Human-Centric LED Lighting in the pilot project IKEA Kaarst store

At IKEA Kaarst daylight was brought into the exhibition area. This, combined with clever integration of electric lighting, has improved the shopping experience for customers and left the mark on a bunch of enthusiastic employees.

The project

When you arrive at IKEA Kaarst, the feeling is that you are in front of yet another "blue-box" store of the famous furniture chain. But it is when you walk-in that the magic happens. In the "living room" exhibition area, large west-facing windows allows the afternoon sun illuminating sofas and tables (Fig. 2); the electric lighting is provided by LED luminaires dimmed with a daylight harvesting sensor (DHS), and a number of ceiling spot lamps. When walking through various other departments, you will end up in the "home decoration" area, where fully-glazed windows provide most of illumination and a most-welcomed connection to the outdoors; the electric lighting relies on traditional halogen spotlamps plus a proof-of-concet Human-Centric Lighting (HCL) consisting of LED panels with colour tuning. The light CCT changes overtime according to a predefined schedule which is intended to mimic daylight (Fig. 2).

Monitoring

The site was first visited in February 2019, and then monitored for two weeks, slightly before the spring equinox. The field monitoring provided valuable insights as well as material to produce additional computer simulations. The simulations were used to evaluate daylight indicators such as the Daylight Autonomy (DA) or the Daylight Glare

IEA SHC Task 61 Subtask D

Monitored by **Rafael Campana Pizarro**, Lund University

More info **Niko Gentile**, Lund University, niko.gentile@ebd.lth.se

http://www.ebd.lth.se

Daylighting integration is an asset for the retail sector

User perspective

Customers could participate to an online survey by using a QR code hanged at some walls of walls of the LR and HD department. Workers who voluteered were interviewed. Ninety customers and twelve workers participated to the survey. None of the customers was new to IKEA, however some were habitual customers of this particular shop in Kaarst, while for other wast the first visit. Figure 7 is self-explanatory. The shop is not the most conveniently located for customers, and it does not provide more facilities or better parking. However, the greate majority of customers think that the overall atmosphere and shopping experience is better than in other IKEA shops. Most important, there is almost unanimity in judging the lighting better in this shop. Many customers took also the time to add some personal reflections on daylighting in the survey, like "*it is nice that the sun is coming in*". While nobody complained about glare from windows, one customer protested that "*The interesting products are not in the daylight*". Glare or direct sun can be sometimes a problem from the staff, for example, an employee at HD reported that "*it's difficult to protect the plants and other items during sunny days*". However, this are minor issues in a bunch of positive comments, spacing from "*a lot of natural sunlight, one can see weather changes, natural light improves my mood*" to "*Light makes customers happy. They don't feel so locked up*". The staff showed appreciation for the HCL lighting too, claiming that was nice to see how electric lighting could follow the daily changes in natural light. Some of the staff complaints were actually about not having enough access to daylight: "(I don't like, na) *No natural light in the neighbor department which also belongs to my workspace*". The interviewed staff have been working in another IKEA shops before and they described their current working environments in these terms: "*Today, my workplace it's much more pleasant*", "*I'm happier now*" and "*One is more positive and feels less like at work*".

"It is nice that the sun is coming in"

"The interesting products are not in the daylight"

Lessons learned

Well-designed lighting means good presentation of products and, eventually, more sales. Lighting design in the retail sector focused on electric lighting, most probably for more than a good reason. But there are niches were daylight integration can actually improve the presentation of products; furniture shops are one of those. This case study demonstrated that integrated lighting schemes providers a number of assets beyond energy saving, the latter being - for that matter - limited.

Customers felt like at home in the new IKEA Kaarst shop and the employees where more satisfied of their working place. In a sense, integrated lighting may even built loyality to the brand.

In such application, we found that common daylight metric sare not always appropriate to describe perception. For example, DGP, which has been developed for office tasks, obviously could not describe the manifold feelings linked to glare in a shop context. This calls for a deeper understanding of integrated design, with more specific recommendations based on space usage and typology of user/activity.

Further information

Acknowledgments

Financial support: The Swedish Energy Agency

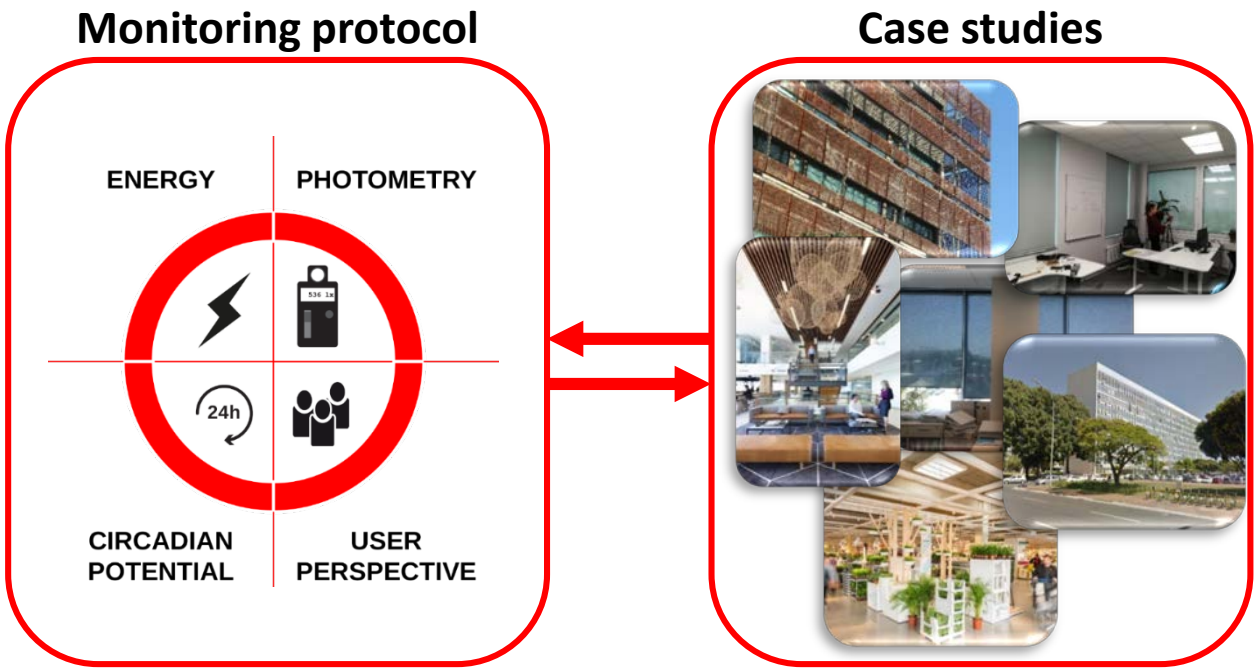
Support on site: IKEA Kaarst team

Special thanks to Jonas Manuel Gremmelspacher (Rescale) and Justin Karst (Tridonic)

Image source: IEA SHC Task 61

Case Studies

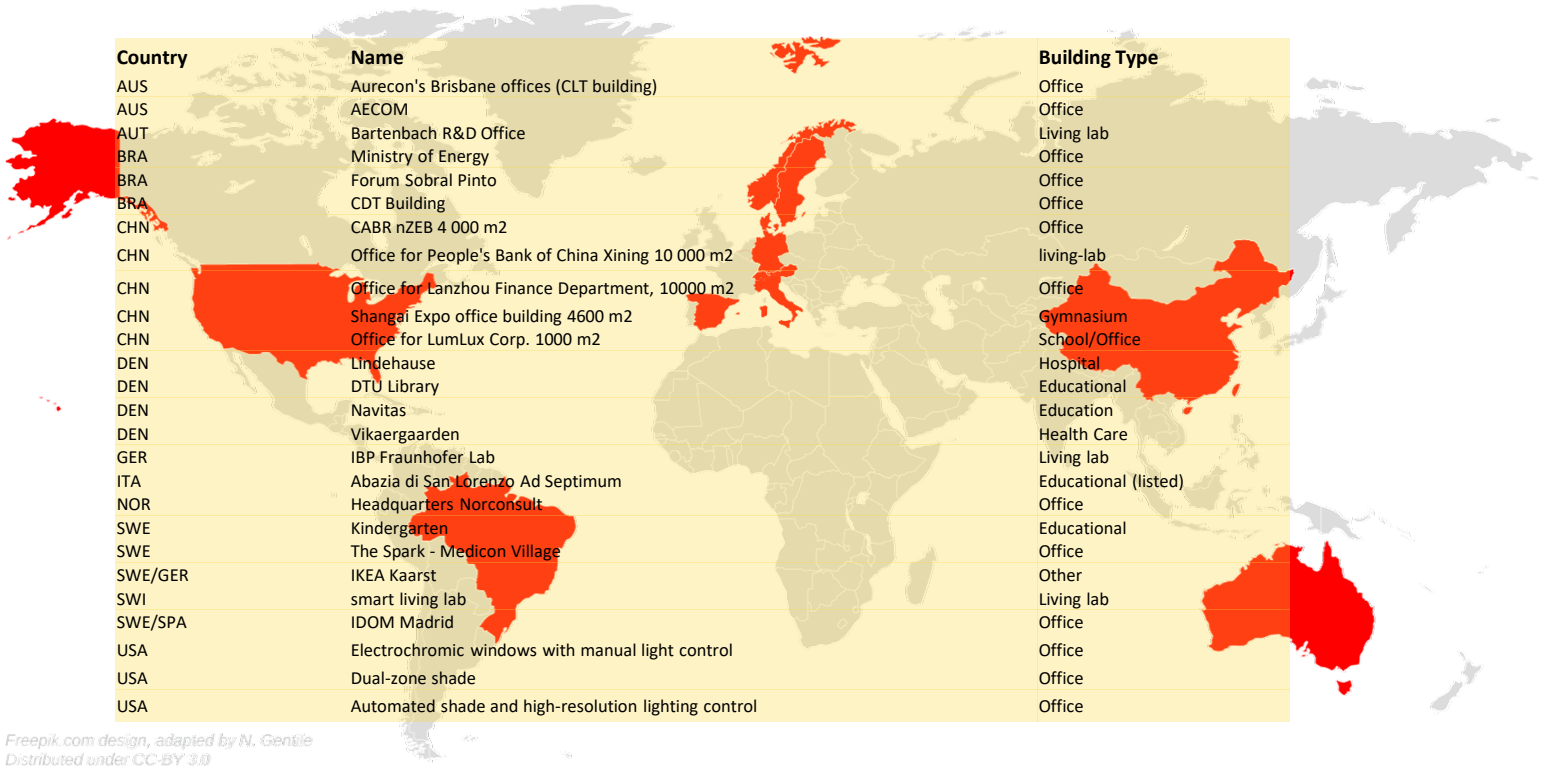
A coherent framework for the evaluation



Icons: Niko Gentile
Pictures: Julio Fernandes Amodia, Rawan Abdulhaq, Ceren Ylmaz, Kieu Pham, Veronica Garcia-Hansen, Claudia David Amorim, Rafael Campama Pizarro

Case Studies

Existing buildings with a “(day)lighting touch”

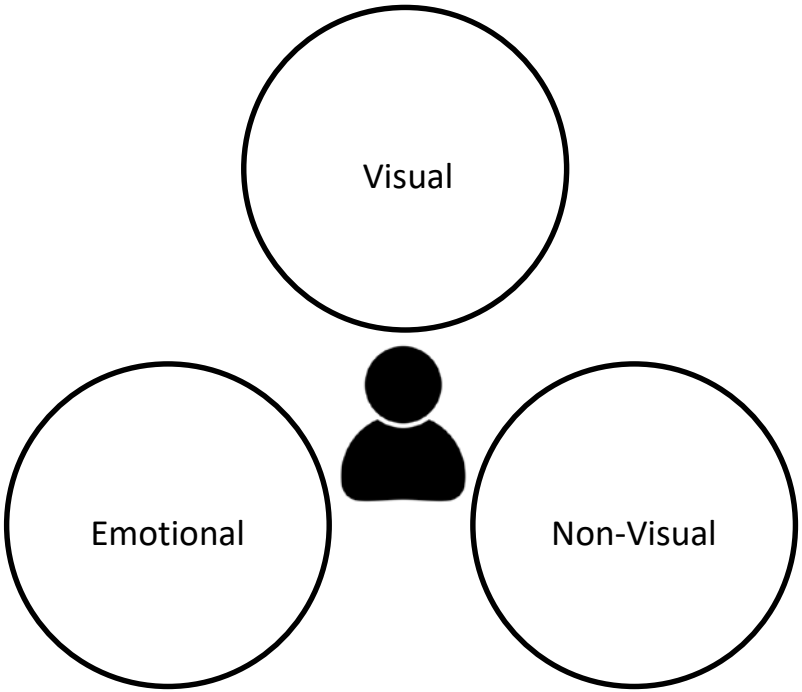


Country	Name	Building Type
AUS	Aurecon's Brisbane offices (CLT building)	Office
AUS	AECOM	Office
AUT	Bartenbach R&D Office	Living lab
BRA	Ministry of Energy	Office
BRA	Forum Sobral Pinto	Office
BRA	CDT Building	Office
CHN	CABR nZEB 4 000 m2	Office
CHN	Office for People's Bank of China Xining 10 000 m2	living-lab
CHN	Office for Lanzhou Finance Department, 10000 m2	Office
CHN	Shangai Expo office building 4600 m2	Gymnasium
CHN	Office for LumLux Corp. 1000 m2	School/Office
DEN	Lindehause	Hospital
DEN	DTU Library	Educational
DEN	Navitas	Education
DEN	Vikaergaarden	Health Care
GER	IBP Fraunhofer Lab	Living lab
ITA	Abazia di San Lorenzo Ad Septimum	Educational (listed)
NOR	Headquarters Norconsult	Office
SWE	Kindergarten	Educational
SWE	The Spark - Medicon Village	Office
SWE/GER	IKEA Kaarst	Other
SWI	smart living lab	Living lab
SWE/SPA	IDOM Madrid	Office
USA	Electrochromic windows with manual light control	Office
USA	Dual-zone shade	Office
USA	Automated shade and high-resolution lighting control	Office

Image source: Elaboration by Niko Gentile on original design by freepik.com (CC-BY 3.0).

Why do we need wearable devices?

We want to investigate light and human experience



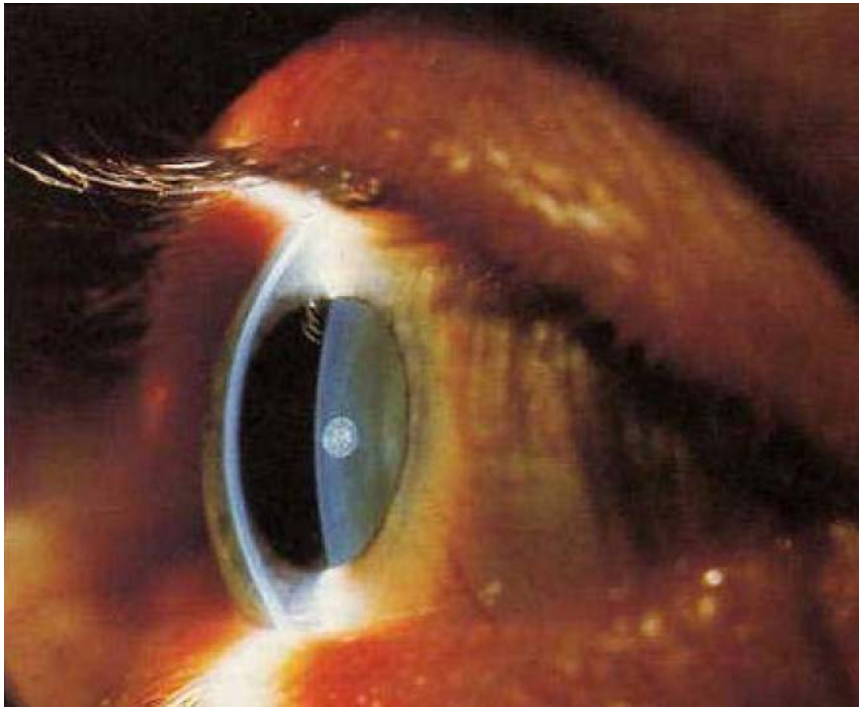
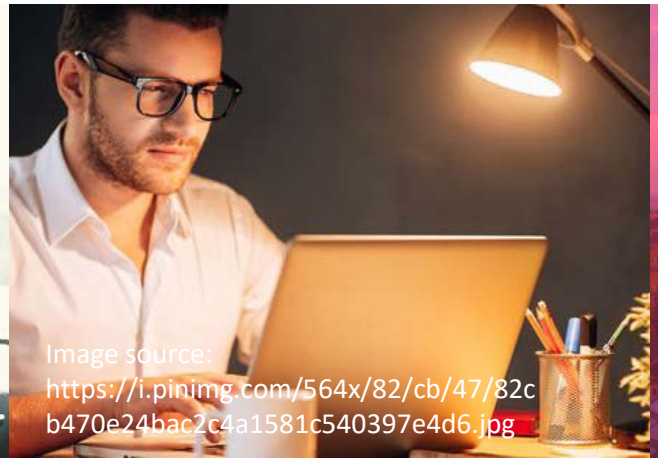


Image source: David Hubel (1988). Eye, Brain and Vision, W.H. Freeman & Co., New York, p. 35.

Why do we need wearable devices?

During the day, a person is exposed to different lighting conditions



We need:

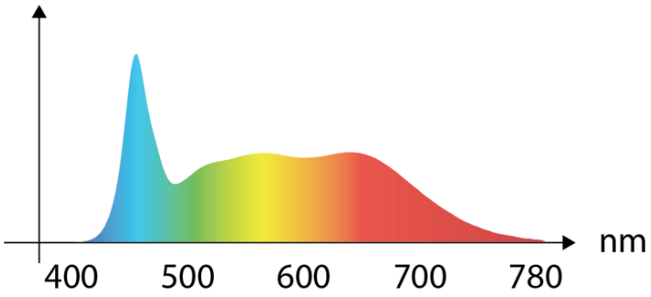
- **dynamic measurement methods**
  (static measurements do not tell us the full story)
- ways to measure **personal light exposure**

Why do we need wearable devices?

Light spectrum has influence on visual and non-visual effects of light on humans

So, we want devices that can measure:

- Full spectrum (ideally)
- Photopic illuminance (at least)
- Different wavelengths (compromise)



And we want to correlate photometric measurements with human factors (e.g. activity levels)

Image source: https://www.gannett-cdn.com/media/2020/04/20/USATODAY/usatsports/gettyimages-104732257.jpg?width=2560

Which sensors are out there?

Commercial devices

- Philips Actiwatch
- LYS Button
- Movisens
- Others …

“Research” devices

- Daysimeter
- LuxBlick
- Others …

Image sources:
https://www.philips.com.au/healthcare/product/HCNOCTN445/actiwatch-spectrum-plus-get-the-actiwatch-advantage/specifications#cb_contact
https://lystechnologies.co.uk/products/lys-1-0-wearable
https://www.movisens.com/en/products/light-and-activity-sensor/
https://www.lrc.rpi.edu/programs/lightHealth/img/oldDaysimeter.jpg
https://www.tu-ilmenau.de/fileadmin/public/lichttechnik/Publikationen/2011/Vandahl_Tagungsband_CIE_2011.pdf

Philips Actiwatch Spectrum Plus

Worn on the wrist

Tracks:

- Activity
- Sleep/wake patterns
- Photopic illuminance
- RGB

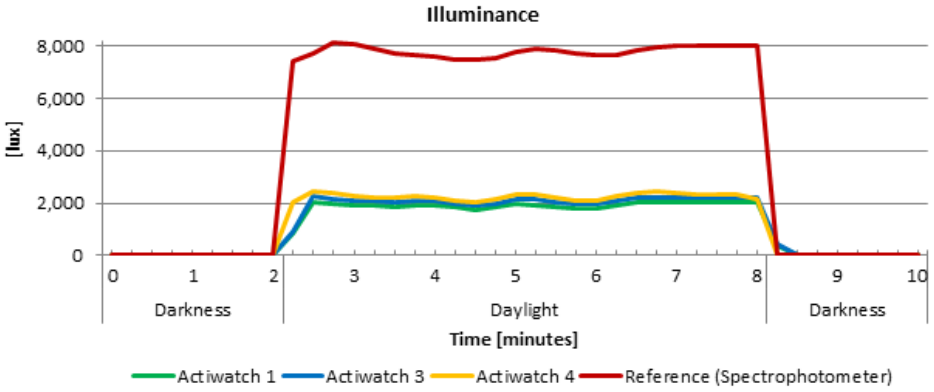
Image source: https://www.philips.com.au/healthcare/product/HCNOCTN445/actiwatch-spectrum-plus-get-the-actiwatch-advantage/specifications#cb_contact

Philips Actiwatch Spectrum Plus

Illuminance measurements

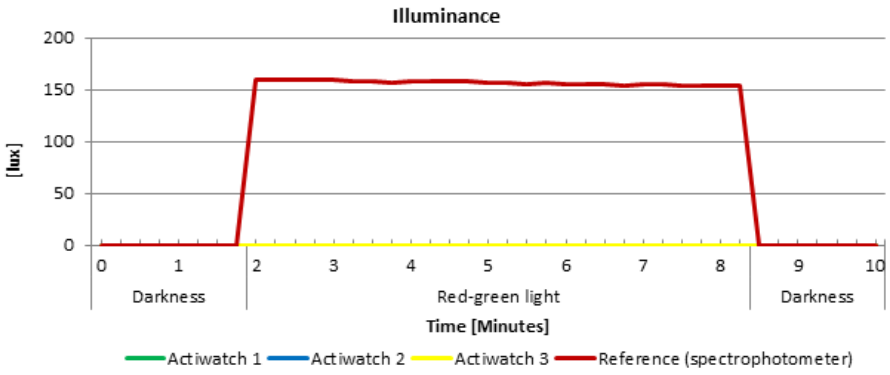
Measured under an overcast sky outdoors

- Need for calibration factor
- According to Markvart et al. (2015), who tested 48 Actiwatches, calibration should be device specific



Measured under a combination of red and green light

- Practically not usable for measuring red/green light
- Not very useful for ”circadian” lighting installations

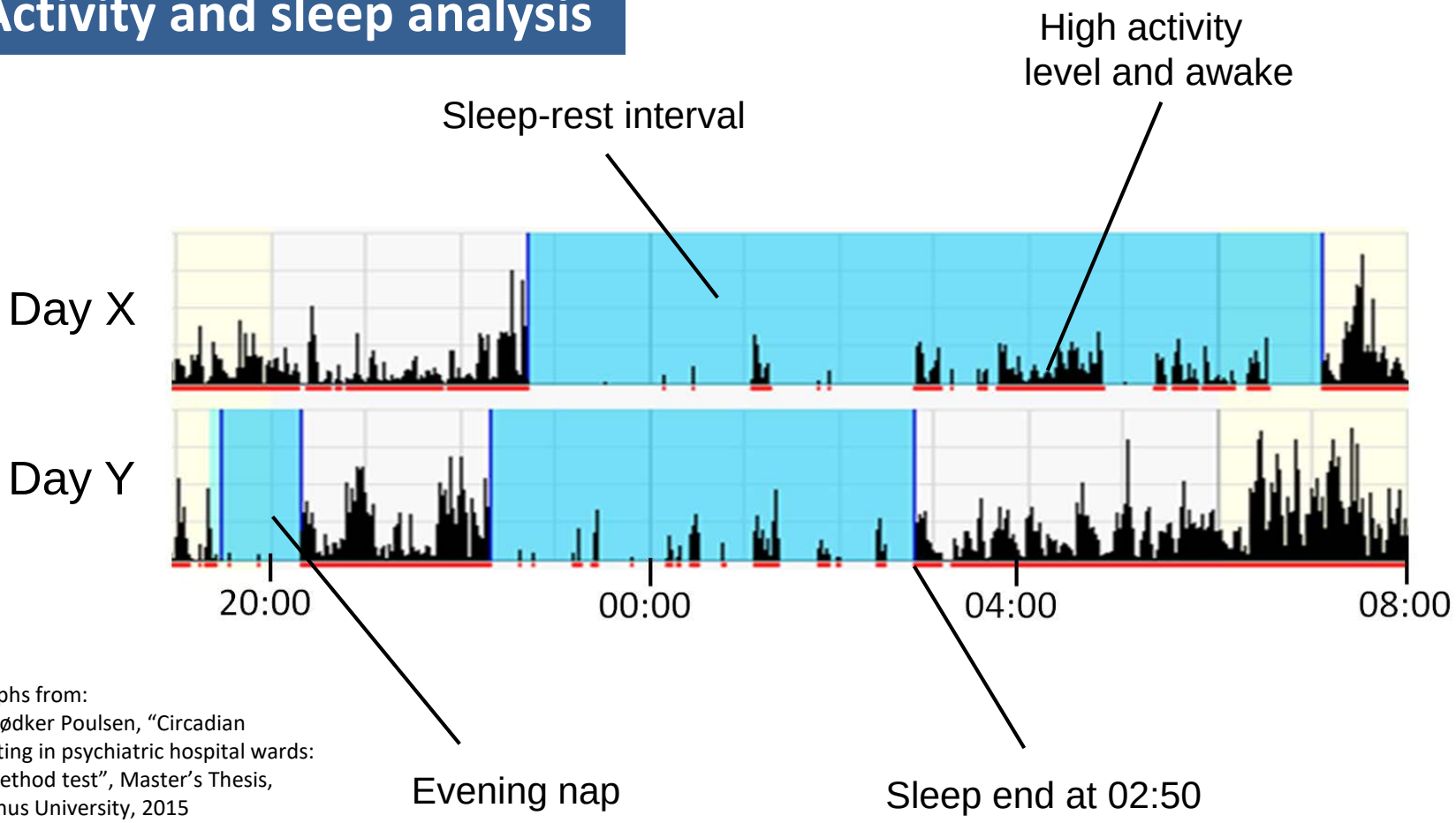


References:
J. Markvart, Å. M. Hansen, and J. Christoffersen, “Comparison and correction of the light sensor output from 48 wearable light exposure devices by using a side-by-side field calibration method,” *LEUKOS*, vol. 11, pp. 155–171, 2015, DOI: http://dx.doi.org/10.1080/15502724.2015.1020948.

Graphs from:
A. Bødker Poulsen, “Circadian lighting in psychiatric hospital wards: A method test”, Master’s Thesis, Aarhus University, 2015

Philips Actiwatch Spectrum Plus

Activity and sleep analysis



Graphs from:
A. Bødker Poulsen, "Circadian lighting in psychiatric hospital wards: A method test", Master's Thesis, Aarhus University, 2015

Philips Actiwatch Spectrum Plus

Activity and sleep analysis

Caution:

Actiwatch data alone are often misleading and not sufficient due to wearing the instrument at the wrist

Image Source:
http://ak1.ostkcdn.com/images/products/7307454/7307454/Marcy-Foldable-Exercise-Bike-P14778368.jpg

LYS Button 1.0

Can be attached to clothing via clip

Image source: https://lystechnologies.co.uk/products/lys-1-0-wearable

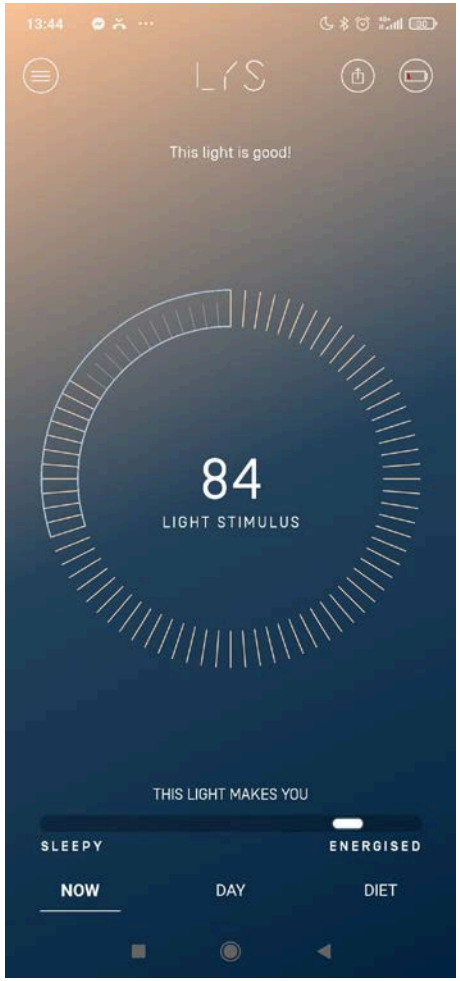
Tracks:

- Photopic illuminance
- Color temperature
- RGB, IR
- Activity level

LYS Button 1.0

- You can get a ”light stimulus” value through an app
- Additional paid software is needed to get the data as Excel file (via email link) → rather expensive

	A	B	C	D	E	F	G	H	I
1	timestamp	sensor	lux	kelvin	rgbR	rgbG	rgbB	rgbIR	movement
2	28-02-2020 10.14.35	Lys11	895	6329	574	805	744	36	0
3	28-02-2020 10.14.51	Lys11	895	6287	579	805	744	36	0
4	28-02-2020 10.15.07	Lys11	891	6303	574	800	740	36	0
5	28-02-2020 10.15.23	Lys11	891	6303	574	800	740	36	0
6	28-02-2020 10.15.39	Lys11	902	6279	583	810	748	37	0
7	28-02-2020 10.15.55	Lys11	908	6270	588	815	753	37	0
8	28-02-2020 10.16.11	Lys11	907	6312	583	815	753	37	0
9	28-02-2020 10.16.27	Lys11	913	6296	588	820	757	37	0
10	28-02-2020 10.16.42	Lys11	756	6492	484	689	648	30	0
11	28-02-2020 10.16.58	Lys11	929	6305	597	835	770	38	0
12	28-02-2020 10.17.14	Lys11	902	6313	579	810	748	37	0
13	28-02-2020 10.17.30	Lys11	907	6312	583	815	753	37	0
14	28-02-2020 10.17.46	Lys11	902	6279	583	810	748	37	0
15	28-02-2020 10.18.02	Lys11	899	6312	583	810	753	37	0

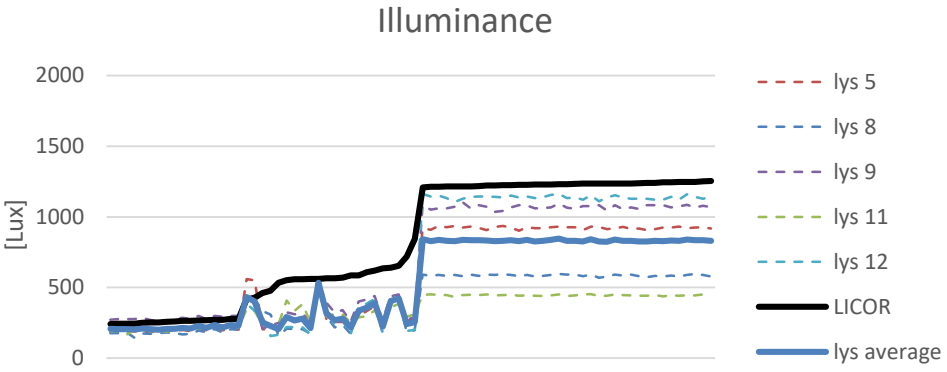


LYS Button 1.0

Illuminance measurements

Measured under daylight on a sunny day indoors

- Need for device specific calibration factor
- Directional sensitivity (rotated device gives different result)
- Error appears to be smaller for lower light levels



Black line: reference calibrated sensor (LI-COR 210SA)

Blue line: average of 5 LYS Buttons

Image source: https://www.azosensors.com/images/equipments/EquipmentImage_824.jpg

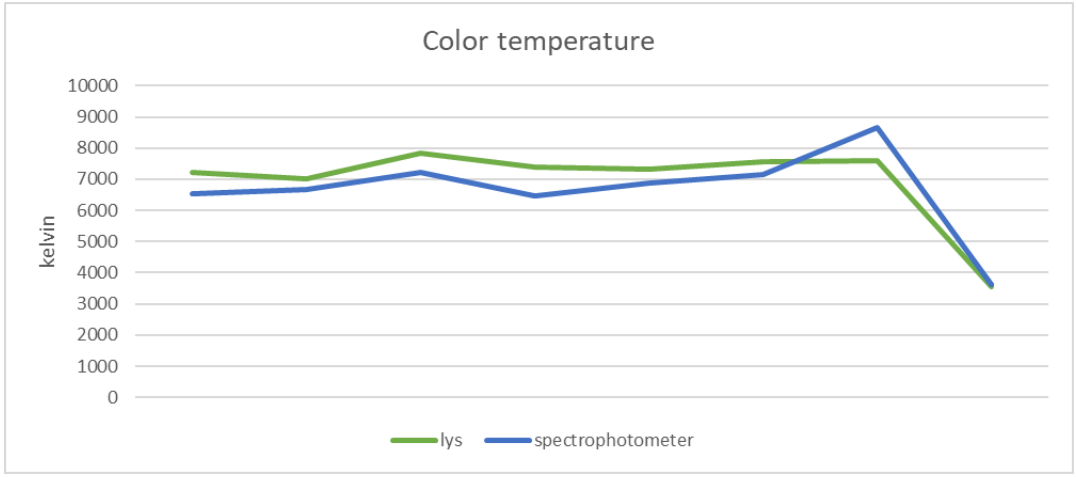
	Average absolute error (lux)	Average relative error (%)
Below 500 lux	-56	-18%
500-1000 lux	-300	-49%
Above 1000 lux	-399	-32%

LYS Button 1.0

Color temperature measurements

Measured under daylight on a sunny day indoors
(one measurement with blinds closed under electric light)

- average error 9%



Blue line: reference spectrophotometer (Konica Minolta CL-500A)
Green line: LYS Button

Image source:
https://www.konicaminolta.com.cn/instruments/products/light/cl500a/img/CL-500A.jpg

LYS Button 1.0

Activity analysis

- Counts how many times within an interval the acceleration exceeds a limit
- Result is expressed in g
- Small investigation is needed to figure out what the results mean

Movement data grouped by activity types measured by LYS button

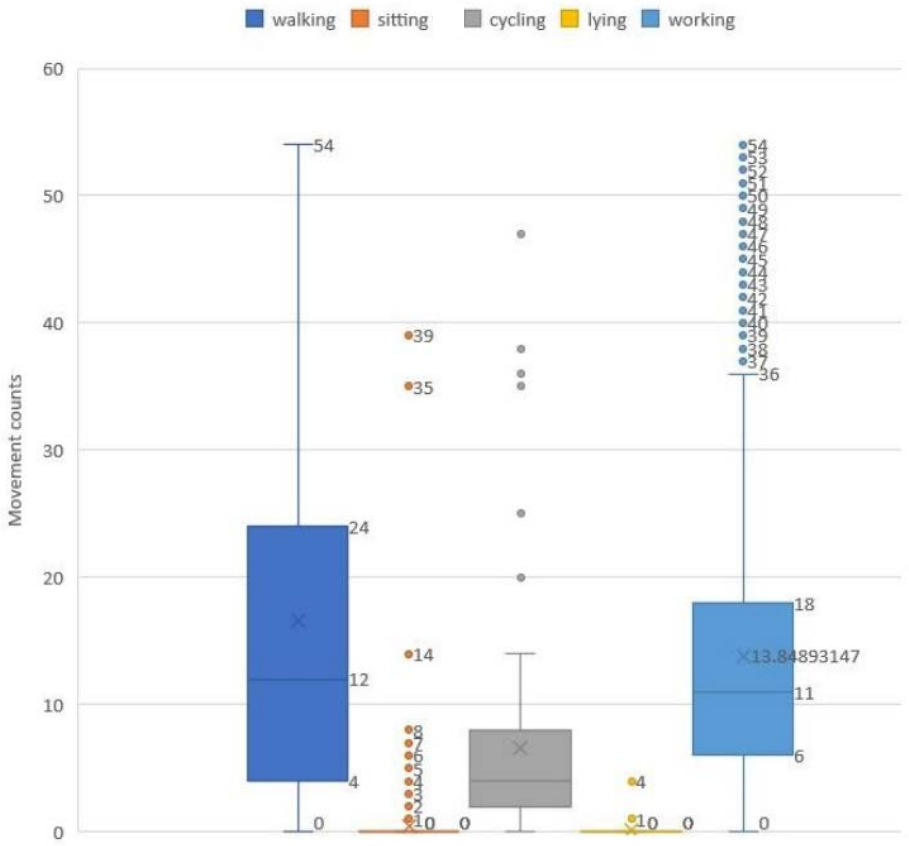


Image Source:
F. Dobos, "Development of a light measurement method: assessing lighting and human light exposure using a Raspberry-Pi camera and dosimeters in a short-term care facility", Master's Thesis, Aarhus University, 2019

Movisens LightMove 4

Worn on the wrist

Tracks:

- Photopic illuminance
- Color temperature
- Activity level
- Sleep/wake patterns
- Temperature

Image source: https://www.movisens.com/en/products/light-and-activity-sensor/

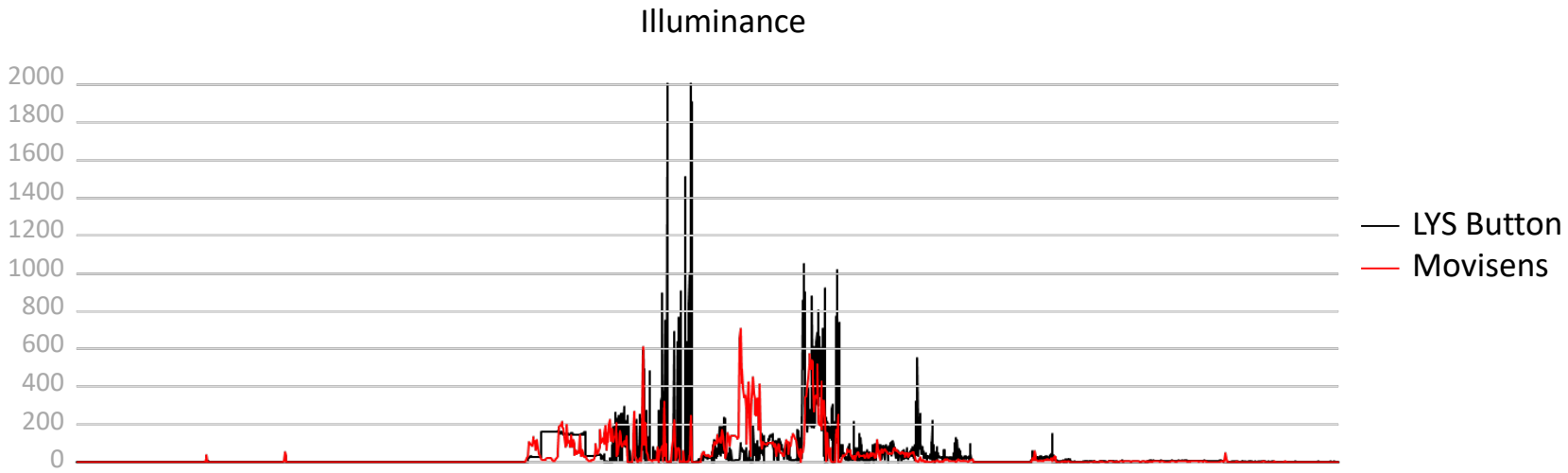
Movisens LightMove 4

Illuminance measurements

Unfortunately, we do not have a comparison with a calibrated sensor

LYS vs Movisens: they don't always tell the same story

- On the shirt vs on the wrist
- Sensor inaccuracies



Movisens LightMove 4

Activity and sleep analysis

- Measures acceleration in 3 axes and provides average
- Small investigation is needed to figure out what the results mean (although some indications for possible activities are provided by the sensor)

Remember:
Data can still be misleading due to wearing the instrument at the wrist

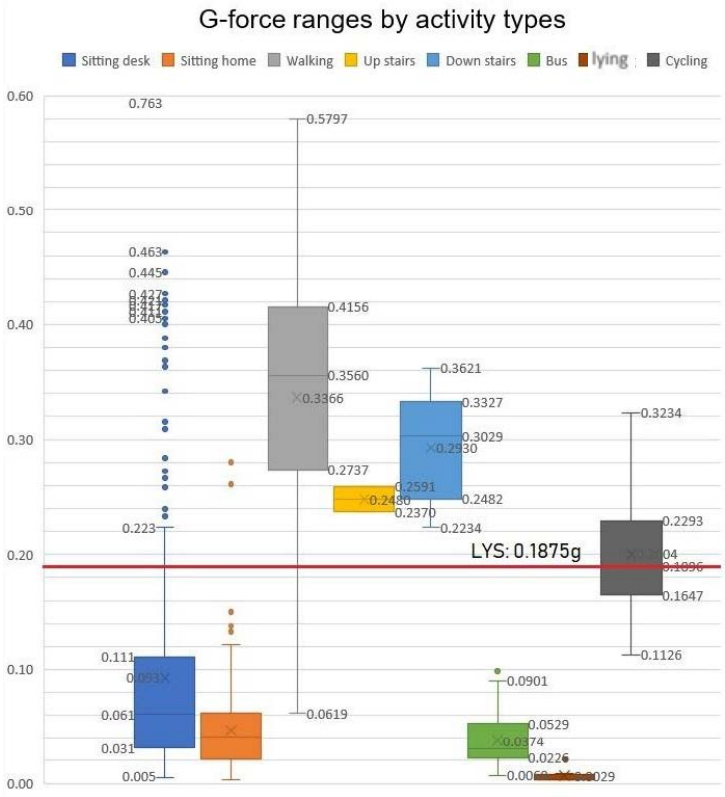


Image Source:
F. Dobos, "Development of a light measurement method: assessing lighting and human light exposure using a Raspberry-Pi camera and dosimeters in a short-term care facility", Master's Thesis, Aarhus University, 2019

Problems

- **Not always reliable light measurements**

  Markvart et al. (2015) have found differences between devices of the same type (Actiwatch) of up to 60% → matches well with our experience

- **Wrist worn sensors: measurements do not match those a person receives at the eye**

  Aarts et al. (2017) have found differences between devices worn by the same person at different body locations (up to 27% when worn on the wrist compared to at the eyes)

- **Some sensor manufacturers claim scientific validation of their products, but often just stop communicating when asked for details**

References:

1. J. Markvart, Å. M. Hansen, and J. Christoffersen, "Comparison and correction of the light sensor output from 48 wearable light exposure devices by using a side-by-side field calibration method," *LEUKOS*, vol. 11, pp. 155–171, 2015, DOI: http://dx.doi. org/10.1080/15502724.2015.1020948.
2. M. P. J. Aarts, J. van Duijnhoven, M. B. C. Aries, and A. L. P. Rosemann, "Performance of personally worn dosimeters to study non-image forming effects of light: Assessment methods," *Build. Environ.*, vol. 117, pp. 60–72, 2017, DOI: 10.1016/j.buildenv.2017.03.002.

Recommendations

- **Use more than one type of measuring device and compare results**
- **Calibration factors**

  Needed for each individual device, but not supplied by manufacturers of these low-cost devices

  Researchers prepared to work with manufacturers on this → cost factor
- **Sensor closer to the eye and facing the same way is preferable**
- **Combine measurement data with observations / diary entries**
- **Be critical when looking at the results you get**

  Avoid making conclusions based on questionable data