Project EELYS P2022-00294

Energy-efficient schemes for integrative lighting

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

EBC
Energy in Building and Communities Programme

Swedish Energy Agency

IEA EBC Annex 70

IEA SHC Task 70 / EBC Annex 90

Low Carbon, High Comfort Integrated Lighting

Task Manager: J. de Boer, Germany

Project duration: 1/2023-6/2026

Joint Work

Subtask A

Luo Tao, China
J. de Boer, Germany
(V. Ferreira, Spain)

Low Carbon Lighting and Passive Solar: Scenarios, Strategies, Roadmaps

Subtask B

B. Matusiak, Norway
M. Sarey Khanie, UK, DK

Visual and Non-Visual User Requirements

Subtask C

D. Geisler-Moroder, Austria
Eleanor Lee, USA

Digitized lighting solutions

(Technology & Design Tools / Process)

Subtask D

Niko Gentile, Sweden
Natalia Giraldo Vasquez, DK

Application and Case Studies

Joint Work

IEA EBC Annex 70

https://task70.iea-shc.org/

About our roles

09.2022 – 12.2025

Marziyeh Taghizadeh

PhD Student

Marie-Claude Dubois
Main Supervisor

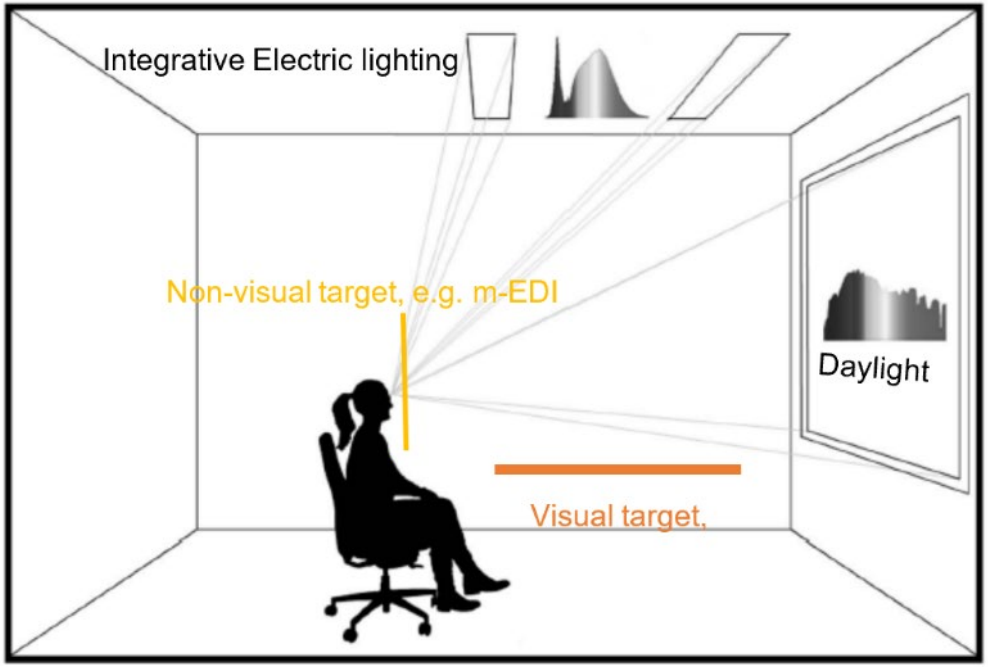
Pimkamol Mattsson
Co-supervisor

Niko Gentile
IEA EBC Annex 90
Co-supervisor

The problem

Visual “vs” non-visual requirements

	Visual target	Non-visual target
Metric	Minimum horizontal illuminance (E_h) on the task area	Melanopic equivalent daylight illuminance (m-EDI) on the vertical plane at eye level during daytime (6:00 – 19:00)
Benchmark(s)	E_h = 500 lx	m-EDI ≥ 250 lx

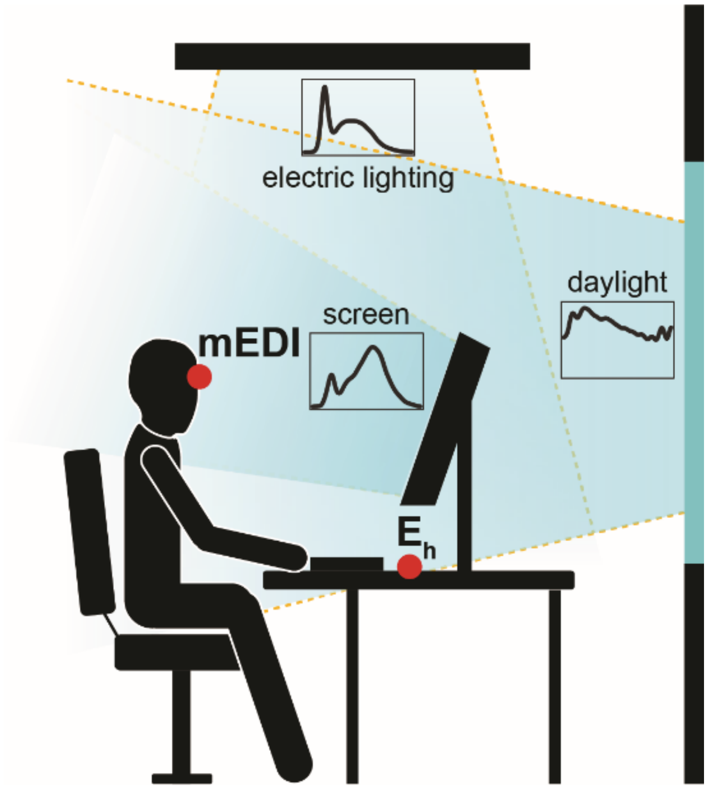


Picture adapted from Martine Knoop, Kai Broszio, Aicha Diakite, Carolin Liedtke, Mathias Niedling, Inga Rothert, Frederic Rudawski & Nils Weber (2019) Methods to Describe and Measure Lighting Conditions in Experiments on Non-Image-Forming Aspects, LEUKOS, 15:2-3, 163-179, DOI: 10.1080/15502724.2018.1518716

What happens in practice?

Threefold energy rebound

Three times higher horizontal illuminance to guarantee right vertical melanopic illuminance



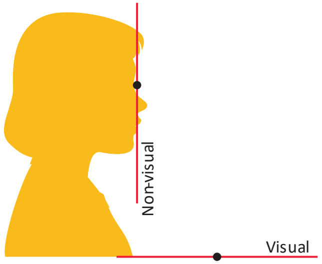
- Electric integrative lighting is not integrated with daylight
- Low luminous efficacies and more delivered lumens -> risk for energy rebound

https://task61.iea-shc.org/case-studies
https://doi.org/10.1016/j.enbuild.2022.112191

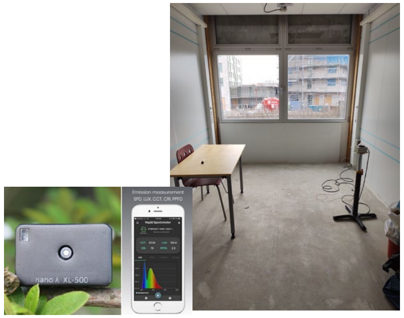
Gentile, N., Lee, E. S., Osterhaus, W., Altomonte, S., Amorim, C. N. D., Ciampi, G., ... & Sibilio, S. (2022). Evaluation of integrated daylighting and electric lighting design projects: Lessons learned from international case studies. Energy and Buildings, 112191.

Overall research question

How can lighting schemes guarantee visual and non-visual requirements minimizing energy rebound?



WP1 Literature review



WP2-3 Lab study

WP4 IEA EBC Annex 90

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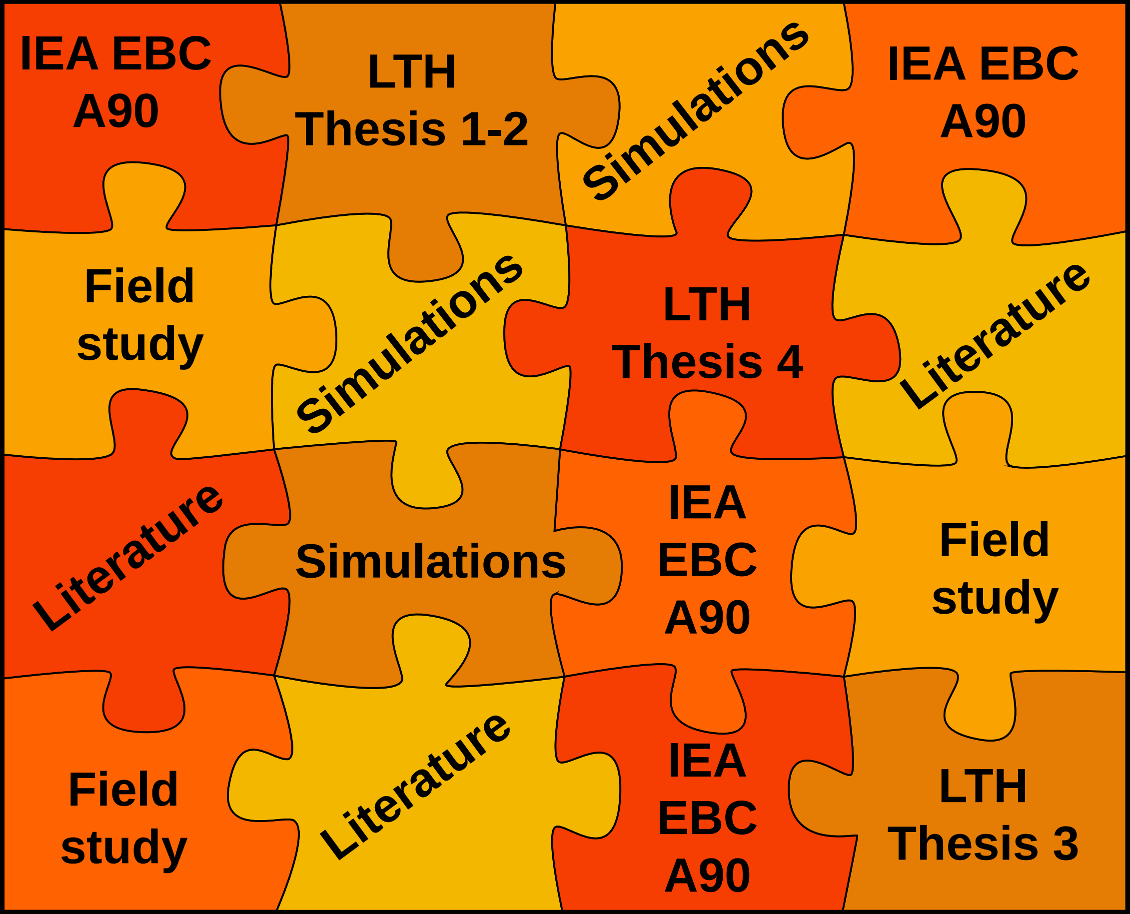

IEA EBC A90
LTH Thesis 1-2
Simulations
IEA EBC A90
Field study
Simulations
LTH Thesis 4
Literature
Literature
Simulations
IEA EBC A90
Field study
Field study
Literature
IEA EBC A90
LTH Thesis 3

Literature review

Lighting schemes impacting energy

Focus on the energy aspects of integrative lighting

Mg{"30 | lighting OR daylighting | AND | Mg{"40 | integrative OR "human centric" OR circadian | AND | Mg{"50 | energy

OR

Non-visual OR "non-image forming"

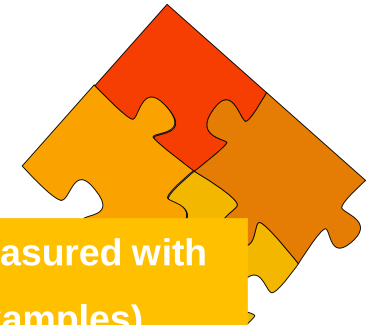
OR

"m-EDI" OR "EML" OR "Cs" OR "M/P"

- 489 relevant hits in the engineering field (over 2 000 excluding "energy")
- 80 articles left after title and 36 abstract screening
- **23** full text articles included

Literature review

Factors affecting Eh and mEDI



Aspect	Description	Affected by (examples)	Measured with (examples)
Light quantity	The amount of light that falls on a surface	Number of luminaires Luminaire intensity Luminaire dimming capability window size shading devices	E_h E_v DF
Light spectrum	Spectral power distribution that governs colour quality	Natural sunlight window glazing and shading properties Luminaire CCT and SPD surface colours and materials	SPD CCT CRI Ra
Spatial pattern	The luminance distribution within the three-dimensional light field	Luminaire placement Luminaire photometry Surface reflectance Furniture placement and reflectance Window placement and orientation	E_h/E_v CBDM M/P Beam angle Cylindrical illuminance MICI Uniformity ratio
Temporal pattern	The timing and duration of light exposure	Sunlight dynamic (day-night cycle) seasonal variation Dynamic lighting adjustment Lighting schedules and routines	Light exposure duration

Marziyeh Taghizadeh, ongoing literature review

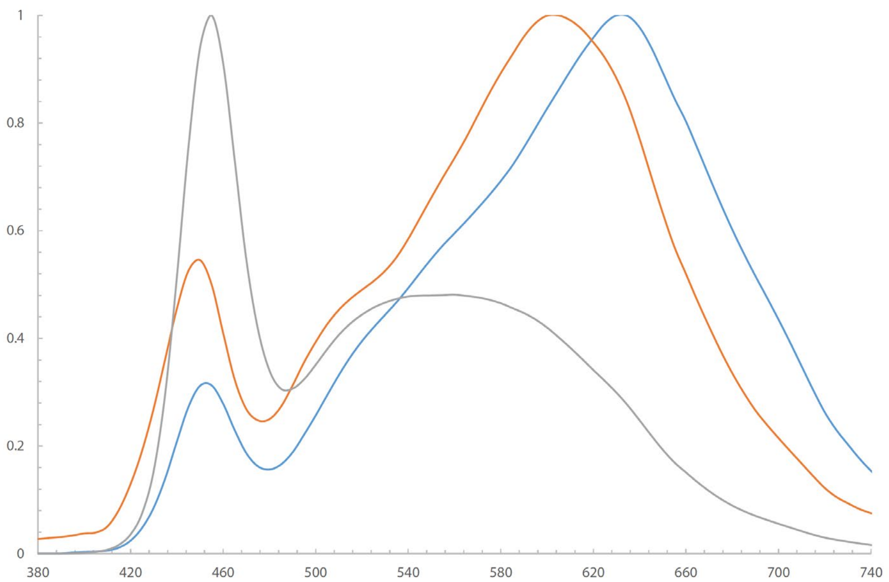
Literature review

Light quantity

- 3-times energy use if daylight not included, 5% more if daylight included
- LPD +64% with conventional tubular LED to reach both requirements
- Combine overhead lighting with task lighting or similar

Literature review

Light spectrum

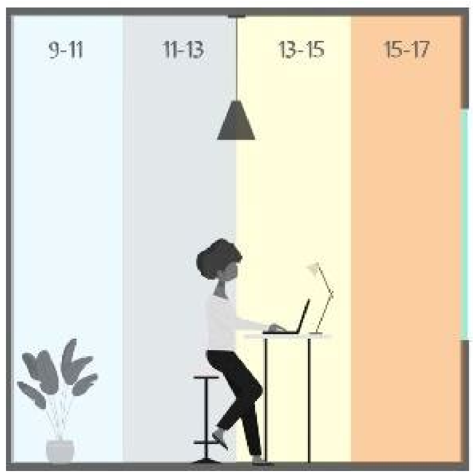


- 20% energy saving using 5500K lighting compared to 4000K, i.e. like having 17% higher WWR, but…
- A 3000K LED must deliver 40% more illuminance than a 6500K LED for the same mEDI, but…
- …wall reflectance can be also used to increase mEDI

Marziyeh Taghizadeh, ongoing literature review. Image Niko Gentile

Literature review

Spatial and temporal patterns



- Redirecting downlight flux to uplight towards highly reflective ceiling increases radiation at eye by 3.6 times
- Restricting high-intensity lighting to just four hours per day: 50% energy savings

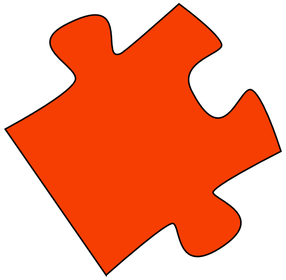
Marziyeh Taghizadeh, ongoing literature review

Study 1: looking at daylight

Densely built space in Brunnshög, Lund

When daylight Eh ≥ 300 lx, then mEDI ≥ 250 lx

As others have said… “*Indoor light exposure in February in Stockholm can be maintained over 1000 lx only with daylight for most of the working day*” Favero, F., Lowden, A., Bresin, R., & Ejhed, J. (2023). Study of the Effects of Daylighting and Artificial Lighting at 59° Latitude on Mental States, Behaviour and Perception. *Sustainability*, *15*(2), 1144.



Lesson learned
- In most of cases, daylight suffices for non-visual requirement

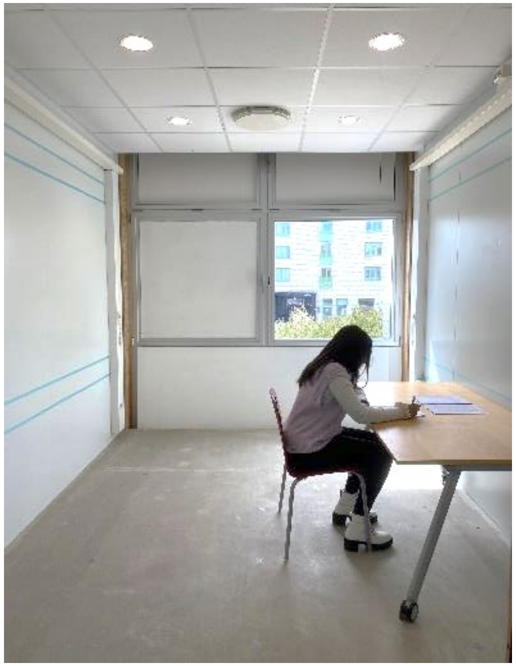
Caroline Süess. People-centred urban transformations with focus on the circadian potential of daylight in dense urban environments, MSc Thesis in Energy Efficient and Environmental Building Design, LTH, Lund University Sweden

Study 2: electric lighting

Pilot study on electric lighting distribution

Same daylighting, check perceived qualities of lighting

Pendants 4000K
Direct-indirect



Spotlights 4000K
Direct

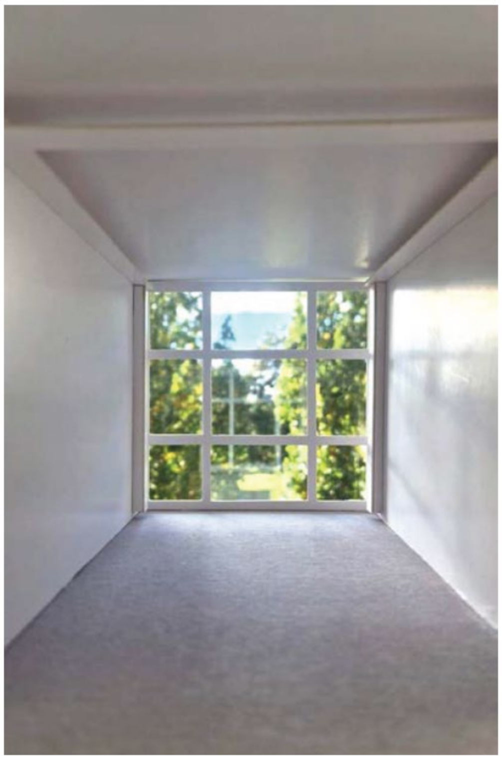
Lessons learned
- Light distribution is a key-determinant (Eh/Ev)
- Circadian lighting simulations are reliable for el lighting

Parvathy, B, Gentile, N, Ståhl, R & Mattsson, P 2023, A pilot test of daylighting and electric lighting to address visual and non-visual requirements. Proceedings of the 30th Session of the CIE. vol. 1, Ljubljana, Slovenien, 2023/09/15. https://doi.org/10.25039/x50.2023.PO055

Upcoming study: daylight again

Daylight in a single-occupant office laboratory

Goal: checking users' response and visual/non-visual targets under different daylight scenarios



- Ev proxy for glare
- Daylight covers non-visual requirements for large part of the year

but…

- Daylight bottleneck in circadian lighting simulations

Future objective

Once the "acceptable" daylighting scenarios are defined, we can simulate ***n*** electric lighting schemes to cover missing "time steps"

Marziyeh Tagizadeh and architectural students from course ASMN01 Light and Colour

Upcoming study: daylight, again

Daylight in a single-occupant office laboratory

01. Independent Variables (IV):

- **Window size**

  30 % WWR

  60 % WWR

- **Surface reflectance**

  Wall: 0.5 - 0.8

  Floor: 0.2 – 0.4

  Mean surface reflectance

02. Dependent Variables (DV):

- **Horizontal illuminance**
- **Vertical illuminance**
- **Mean Indirect Cubic Illuminance (MICI)**
- **User perception**

03. covariates

- **Climate condition**
- **Venetian blinder characteristics**
- **Gender & age**
- **Order of exposure**
- **Time & date**
- **Temperature**
- **Light spectrum**

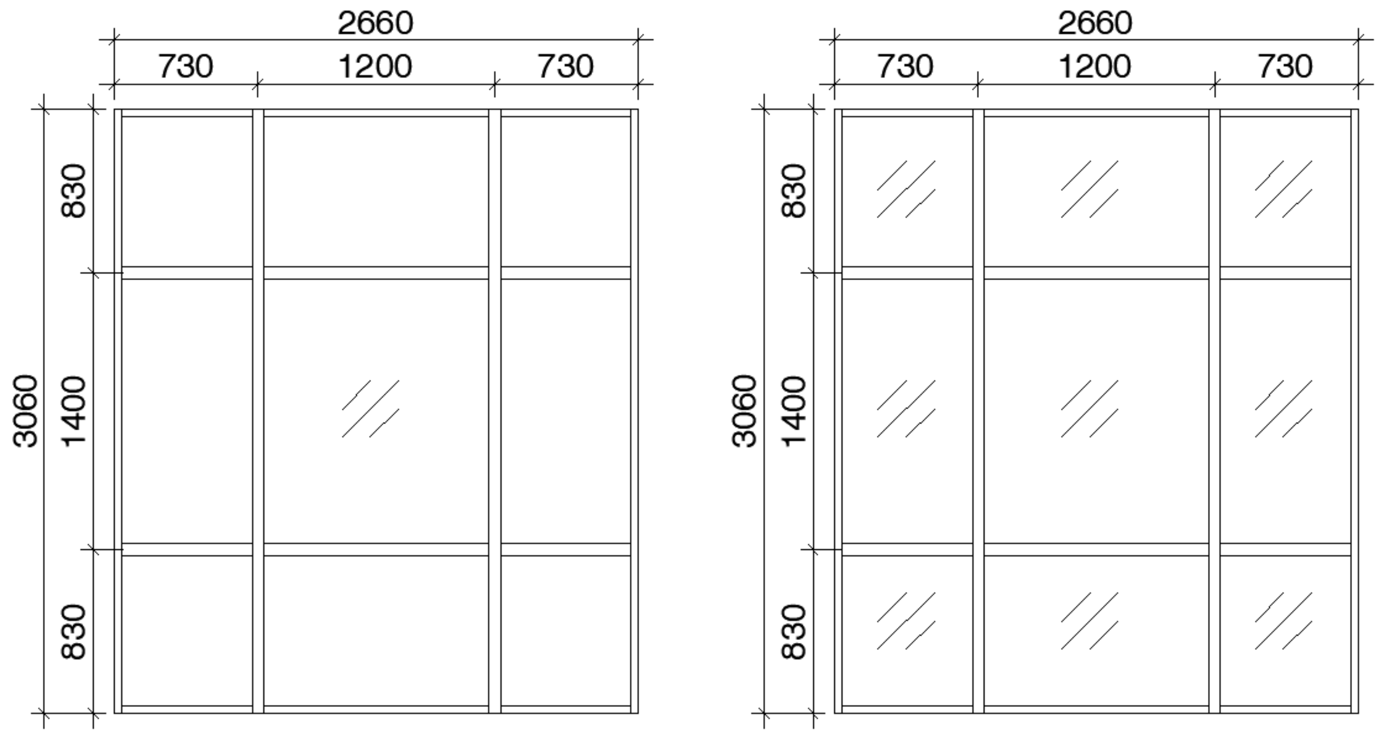
04. Confounding Variables

- **Mood**
- **Individual differences**

Upcoming study: daylight, again

Daylight in a single-occupant office laboratory

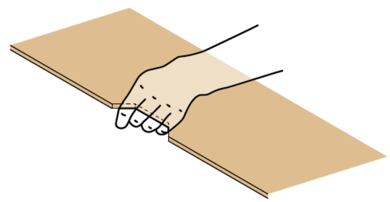
WWR can be changed in minutes



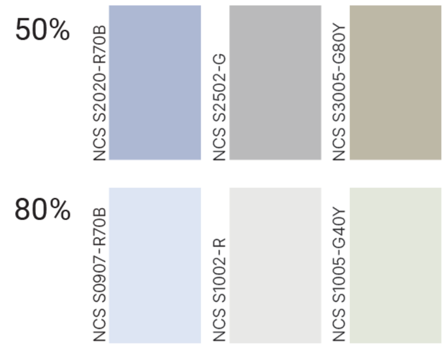
Upcoming study: daylight, again

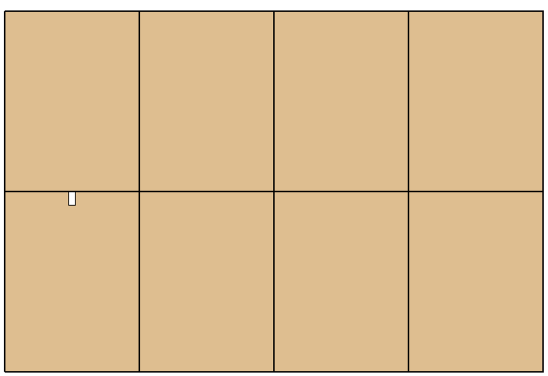
Daylight in a single-occupant office laboratory

Wall reflectance can be changed in minutes



Easy to grip and carry

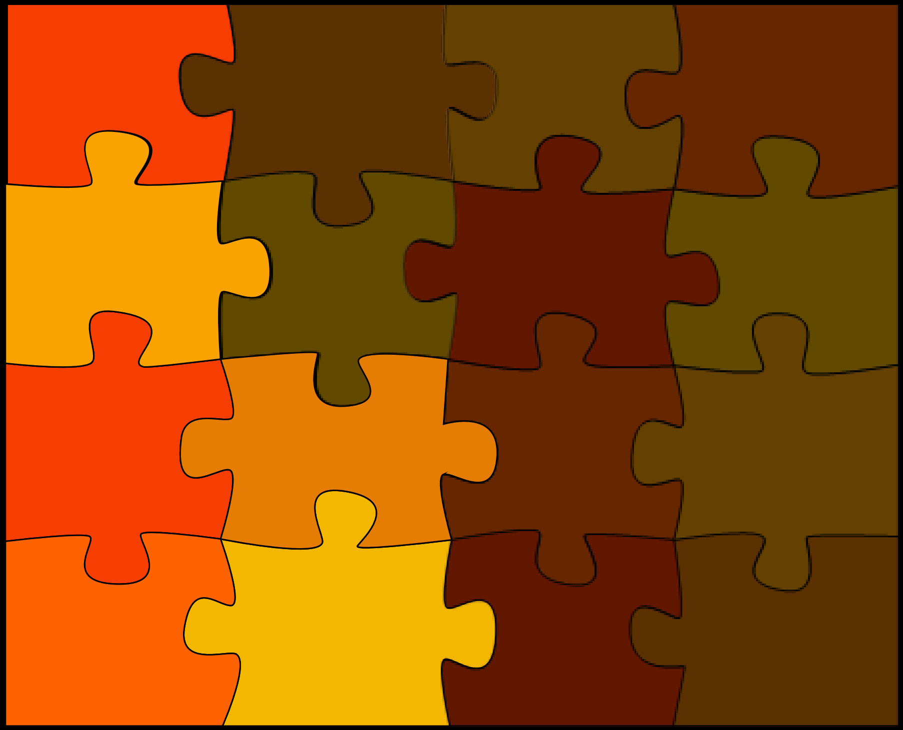




Sunny Day

Cloudy Day

Marziyeh Tagizadeh and architectural students from course ASMN01 Light and Colour



Implication for practice

Still ongoing, but expected implications for practice

- **Legislation > mainly daylight**

Circadian requirements to be reached by daylight mainly

- **Innovation > mainly electric lighting**

A shift on how light fixtures (optics) are designed and installed