Concept for an Adaptive Indoor Lighting Solution

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Motivation
Optimization of indoor lighting

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General influencing factors	User-related influencing factors
• Room, geometry • Time of day, season • Weather • Geographical location	• Visual condition, visual task • Age • Individual preference

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Setpoints

chromaticity, spectrum, intensity, light distribution, dynamics (time, local), efficiency

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Technical implementation

- Practical and economical
  - Cheap sensors
  - Small amount of sensors
- Modeling and calibration
- Control loop by sensing different parameters

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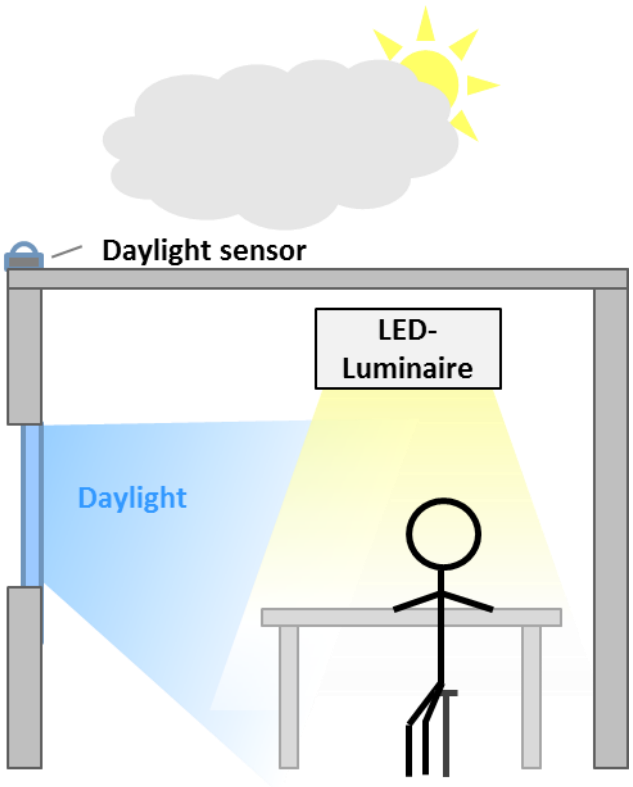
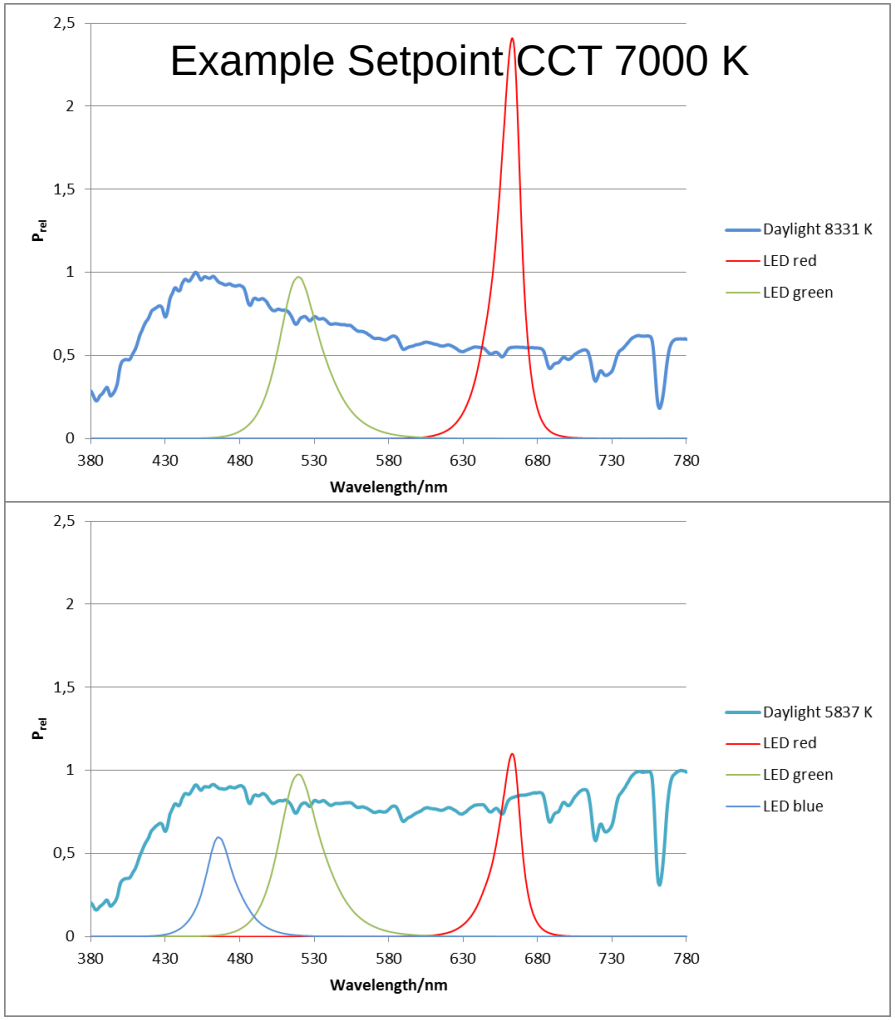
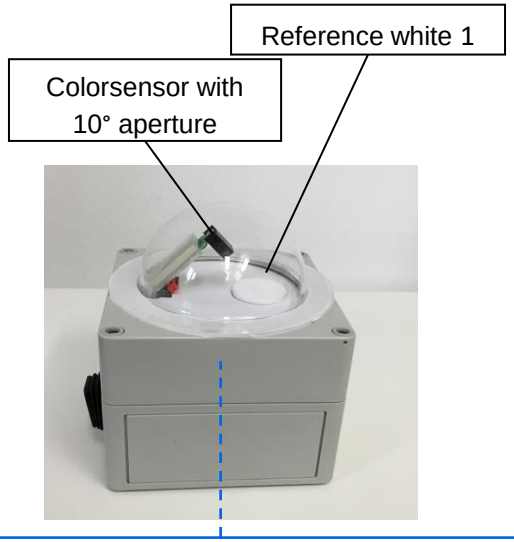
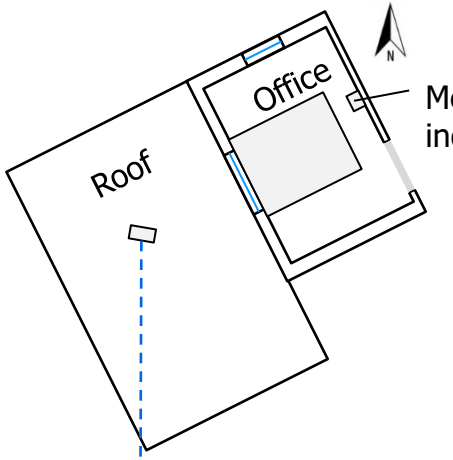
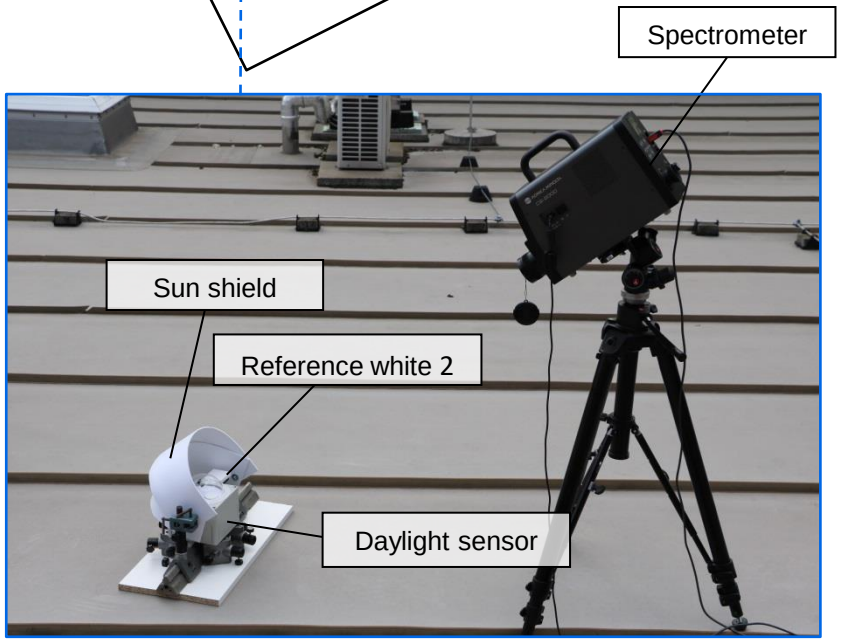




Measurement setup
Spectrometer and daylight sensor

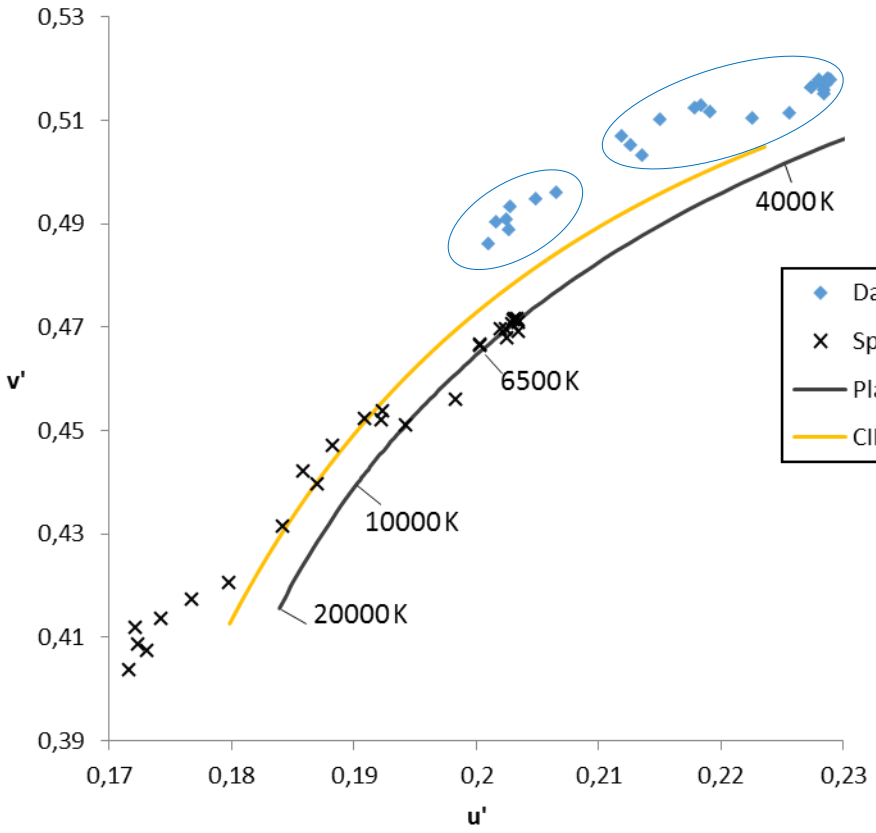






- Sensor sensitivity ≈ color matching functions
- Battery powered
- Weatherproof
- Wireless control (ZigBee)
  - Setting: Integration time, reference-current of the analog-to-digital converter
  - Read out: X,Y,Z

Calibration
Daylight sensor



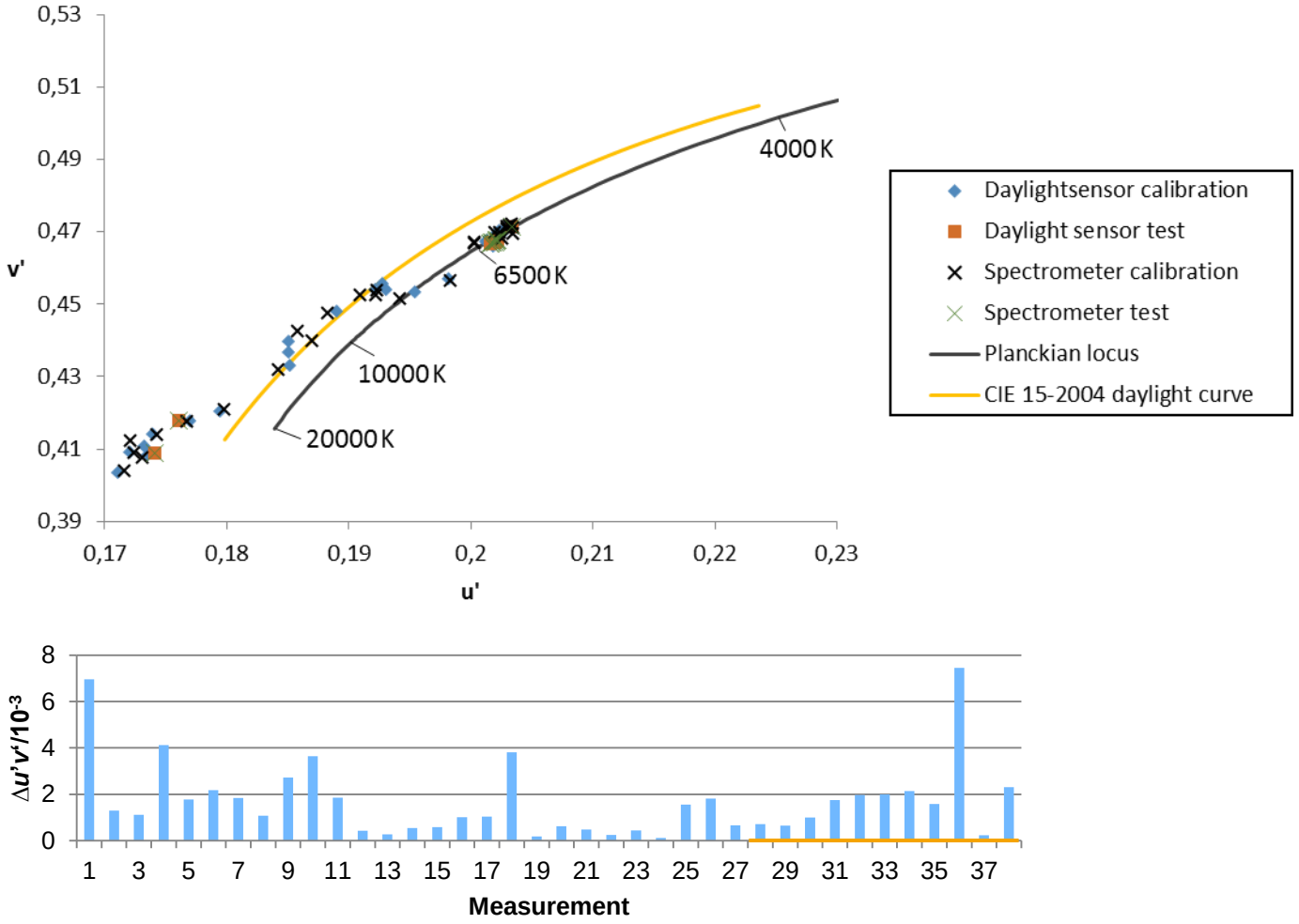
$$S = \begin{pmatrix} x_{DLS,1} & \cdots & x_{DLS,n} \\ y_{DLS,1} & \cdots & y_{DLS,n} \\ z_{DLS,1} & \cdots & z_{DLS,n} \end{pmatrix}$$

$$T = \begin{pmatrix} x_{Sp,1} & \cdots & x_{Sp,n} \\ y_{Sp,1} & \cdots & y_{Sp,n} \\ z_{Sp,1} & \cdots & z_{Sp,n} \end{pmatrix}$$

$$K = (T \cdot S^T) \cdot (S \cdot S^T)^{-1}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = K \cdot \begin{pmatrix} x_{DLS} \\ y_{DLS} \\ z_{DLS} \end{pmatrix}$$

Calibration
Daylight sensor



Daylight reconstruction
CIE daylight model [1)]

$$S(\lambda) = S_0(\lambda) + M_1 S_1(\lambda) + M_2 S_2(\lambda)$$

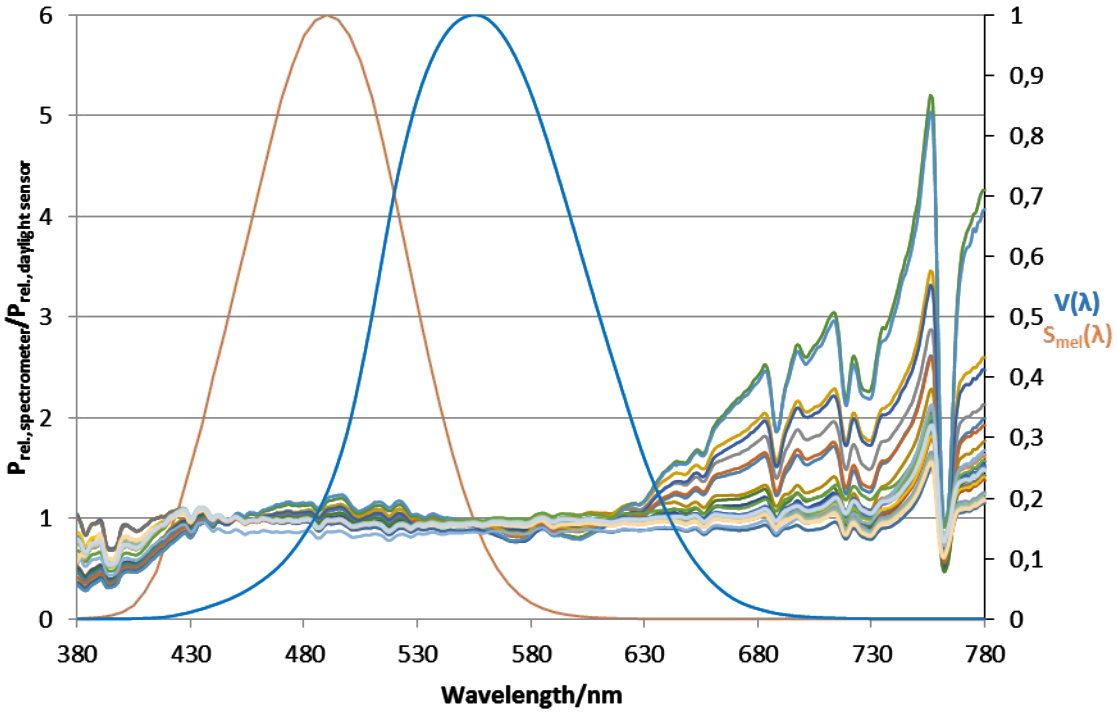
$$M_1(\lambda) = \frac{-1{,}3515 - 1{,}7703 x_D + 5{,}9114 y_D}{0{,}0241 + 0{,}2562 x_D - 0{,}7341 y_D}$$

$$M_2(\lambda) = \frac{0{,}03 - 31{,}4424 x_D + 30{,}0717 y_D}{0{,}0241 + 0{,}2562 x_D - 0{,}7341 y_D}$$

- Based on measurements from 330 nm to 700 nm
- Applicable from 4000 K to 25000 K

[1)] CIE, "Technical Report Colorimetry 15: 2004"

Comparison of real and reconstructed daylight spectra

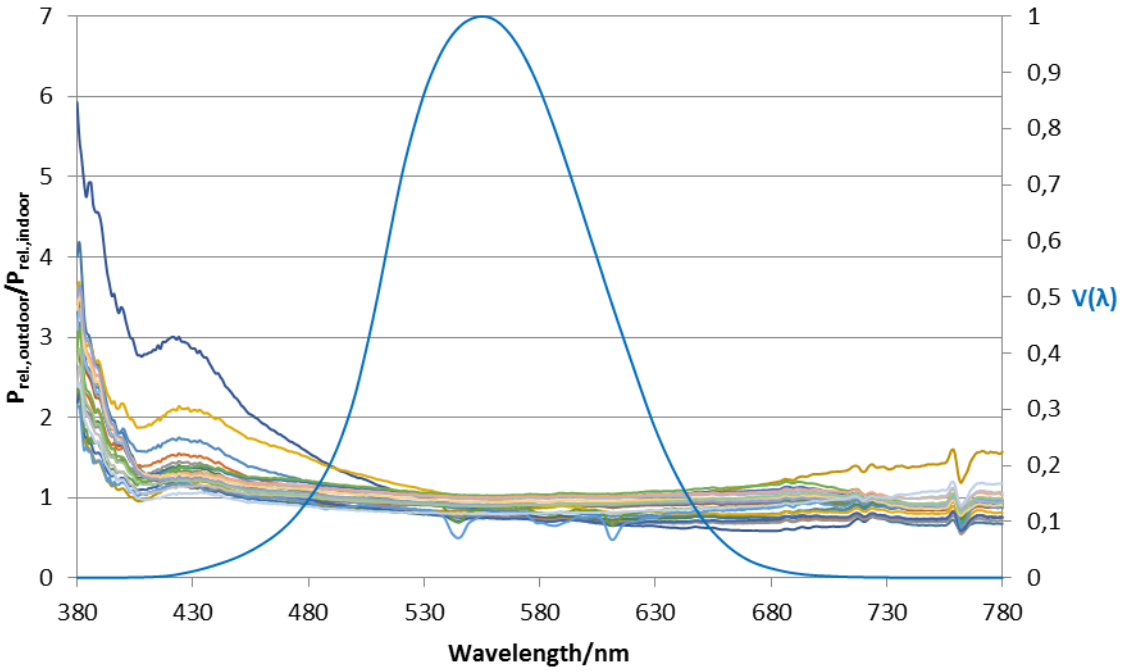


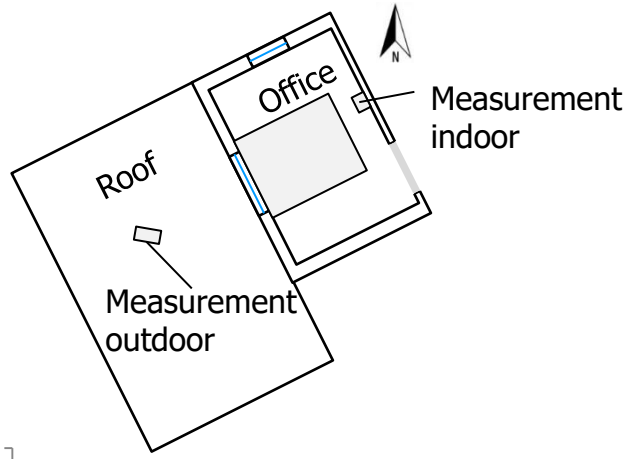
$$a_{mel} = \frac{\int_{\lambda_u}^{\lambda_o} X_\lambda \cdot s_{mel}(\lambda) \cdot d\lambda}{\int_{\lambda_u}^{\lambda_o} X_\lambda \cdot V(\lambda) \cdot d\lambda} \quad 2)$$

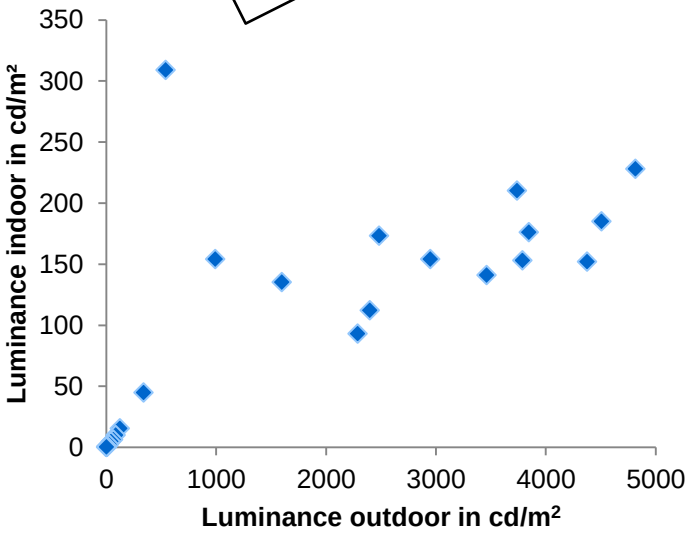
Measurement Nr.	1	2	3	4	5	6	7	8	9	10	11	12
$a_{mel,spectro.}$	1,01	0,90	0,91	0,98	1,03	1,05	1,05	1,11	1,15	1,17	1,24	1,35
$a_{mel,daylights.}$	0,96	0,89	0,89	1,00	1,00	1,01	1,00	1,05	1,12	1,14	1,16	1,27
$\frac{a_{mel,daylights.}}{a_{mel,spectro.}}$	0,95	0,99	0,99	1,02	0,97	0,96	0,95	0,95	0,97	0,97	0,94	0,94

2) DIN SPEC 5031-100

Comparison of outdoor and indoor daylight







Conclusion and outlook

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- Daylight sensor:
  - Quality of chromaticity measurement good (mean $\Delta u'v' = 1{,}7 \cdot 10^{-3}$)
  - Quality of reconstruction of daylight spectra is still to be assessed
    → Admixing LED spectra
    → Comparison of calculated and measured quality factors
- Calibration data for a longer period of time
  - Measurement at 3 days, 1-2: calibration, 3: test
  - Better daylight model beneficial
    - 380 – 780 nm , intervall < 5 nm
- Additional sensor needed to weight the spectrum
  - Integration into luminaire is investigated

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Thank you for your attention!