# Application of RADIANCE for Development of Future Solutions

## *Case Studies of Virtual Natural Lighting Solutions and Photocatalytic Oxidation Modelling*

**Rizki A. Mangkuto**

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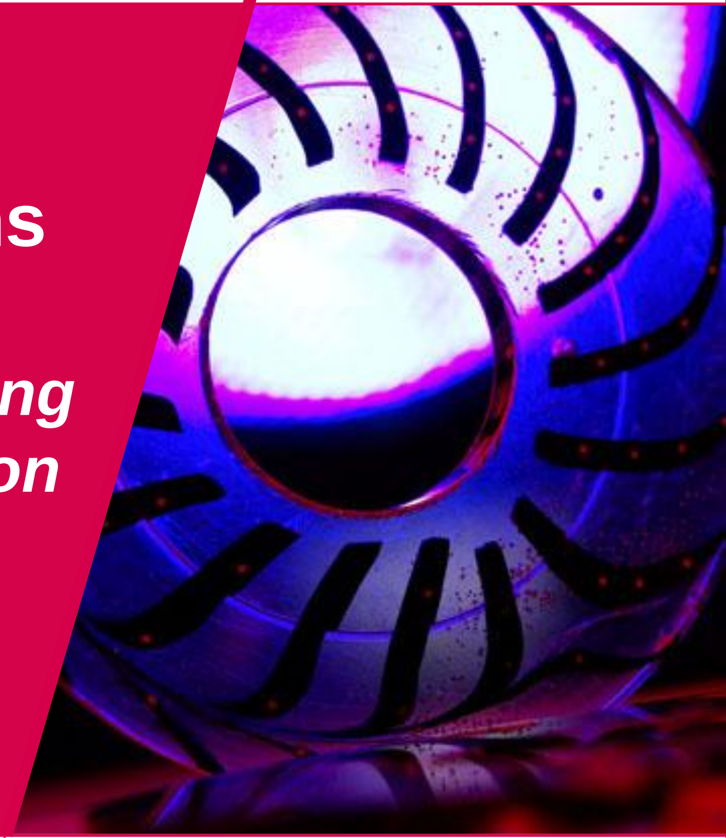

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**Eindhoven University of Technology**

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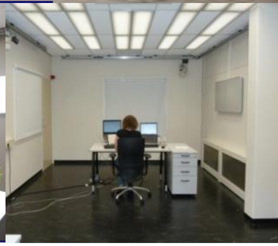
**Where innovation starts**

# The built environment…

- In the future, the built environment will need to deal not only with “energy saving”, but also “very high-quality indoor environment”
  - Healthy
  - Productive
  - Comfortable
  - Energy-producing
  - …..
- Solutions are needed!





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# …Toward the future

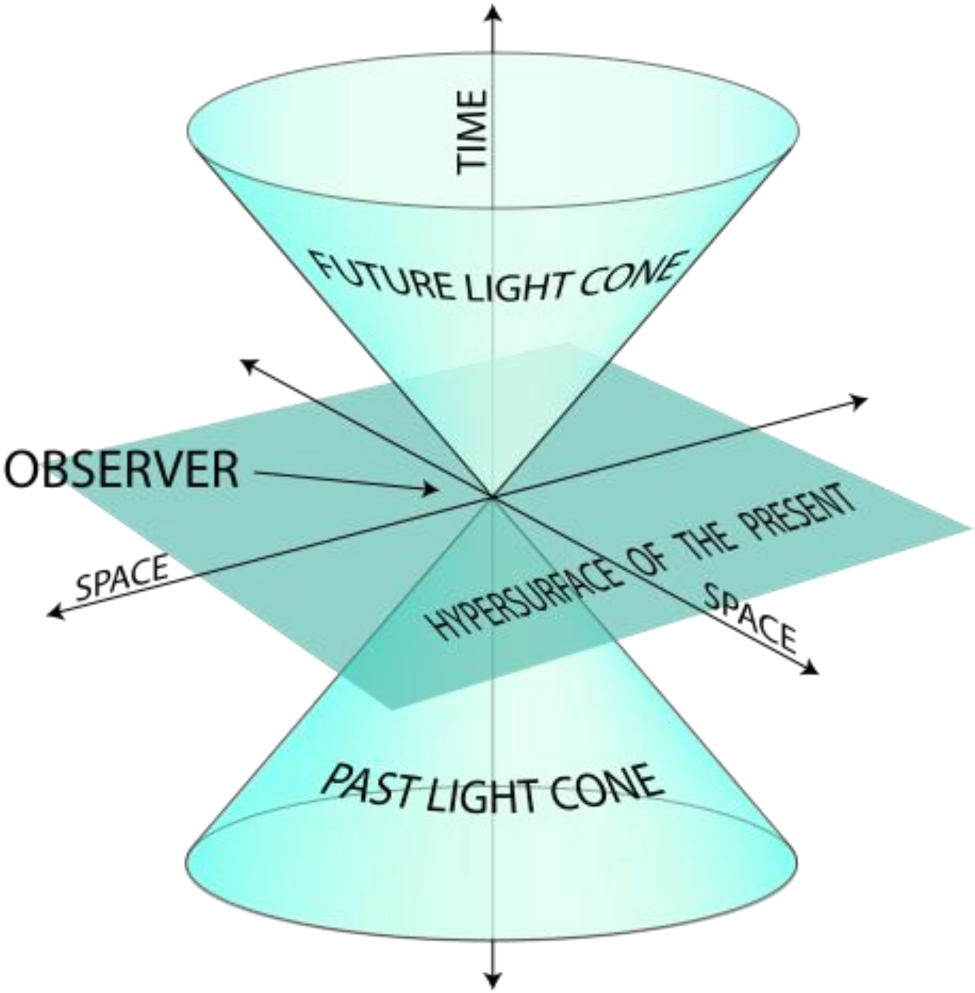
**The future is so uncertain and highly complex:**

The need to predict the performance of future solutions

**→using computational simulation tools**

**→e.g. RADIANCE!**

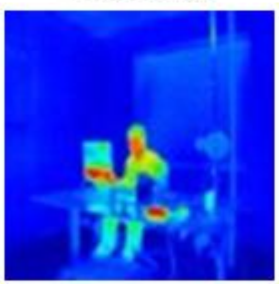

Radiance-online.org (2012)



# Some familiar terms

Case #1

Building
**Lighting**



Building
**Performance**

**Lighting**

***Raytracing***

**Wavelength**

Illuminance

Visual comfort

Preference

**Light source**

Daylight

Optimisation

*Behaviour*

Contrast

**Uniformity**

Sustainability

Material

*Sky model*

Glare index

*Perception*

***Luminous intensity***

Irradiance

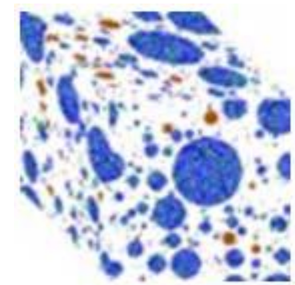
**Distribution**

***Building Simulation***

**Uncertainty**

**Performance**

Case #2



Building
**Materials**

*Case #1*

# Virtual Natural Lighting Solutions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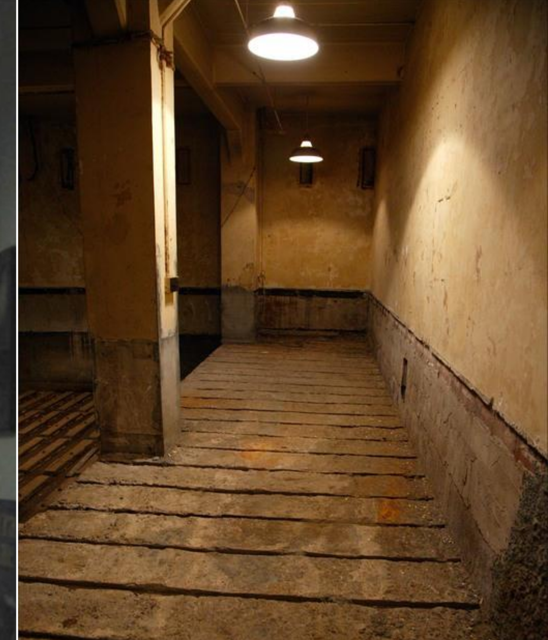
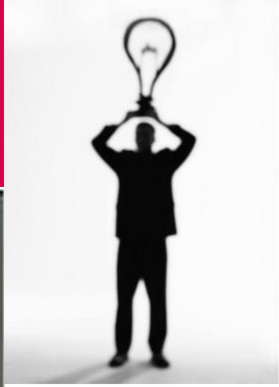
**Where innovation starts**

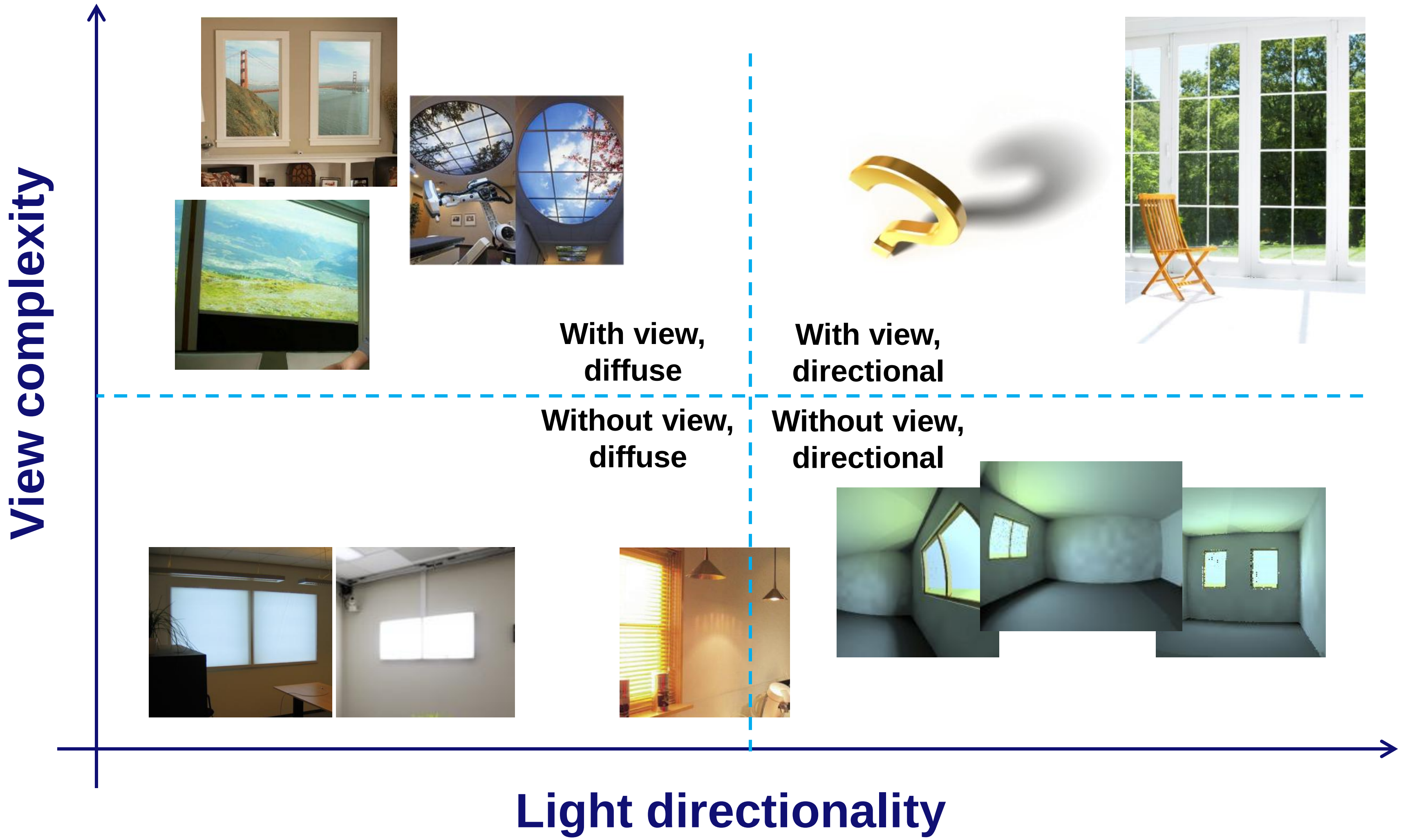
Low availability of
natural (day-)light!

# The idea



Virtual natural lighting solution (VNLS)

# Approach towards VNLS (model)



# Model without view, diffuse

- Typically diffuse light distribution
- Applied for situations where view is not considered the most important thing, e.g. when comparing energy consumption.

Philips Lighting (2007)

De Vries et al. (2009)

Smolders & de Kort (2012)



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# Model without view, diffuse – (2)

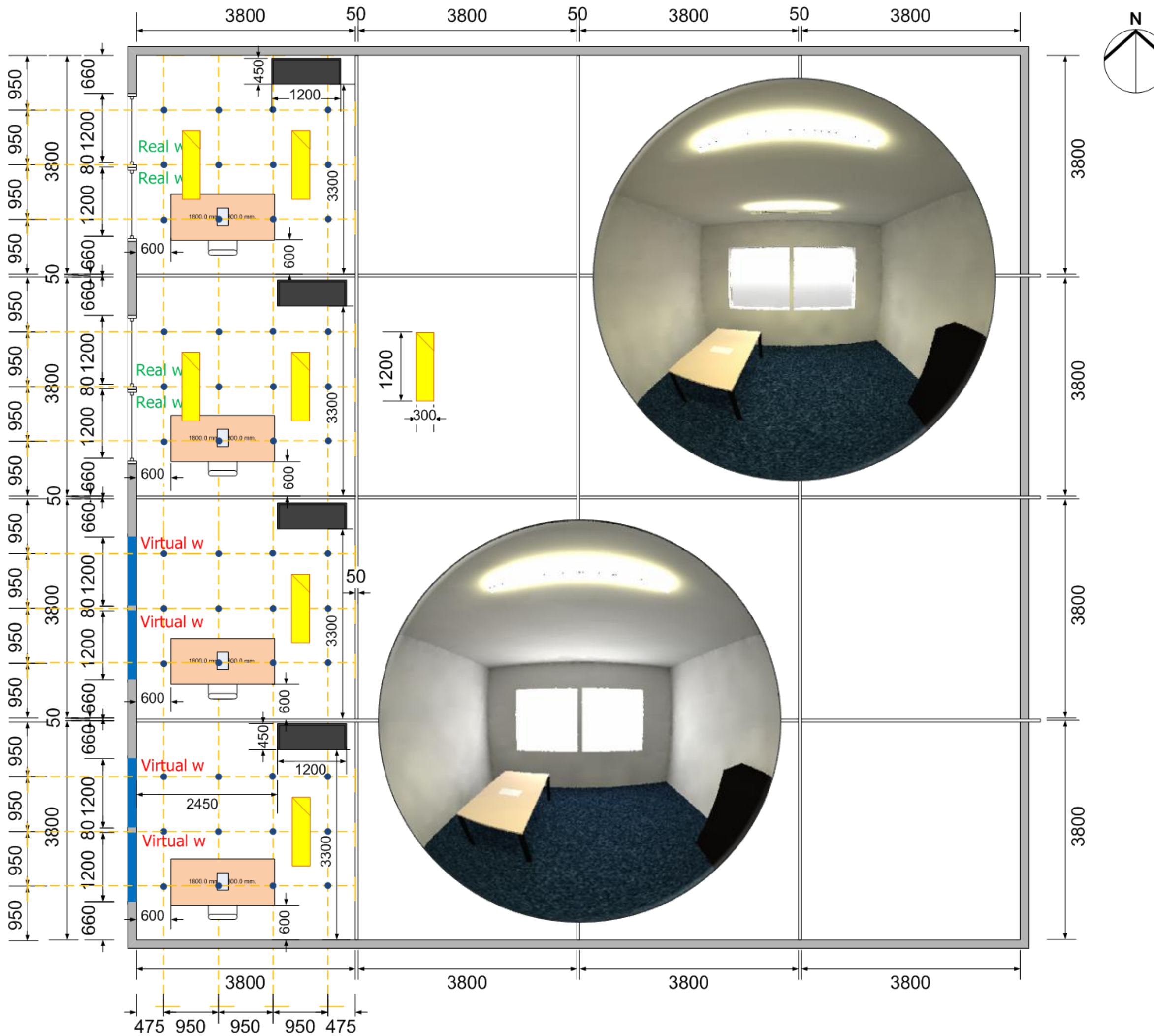
- *For example*, real windows under CIE overcast sky:

  ```
  gensky -c -b 22.9
  ```

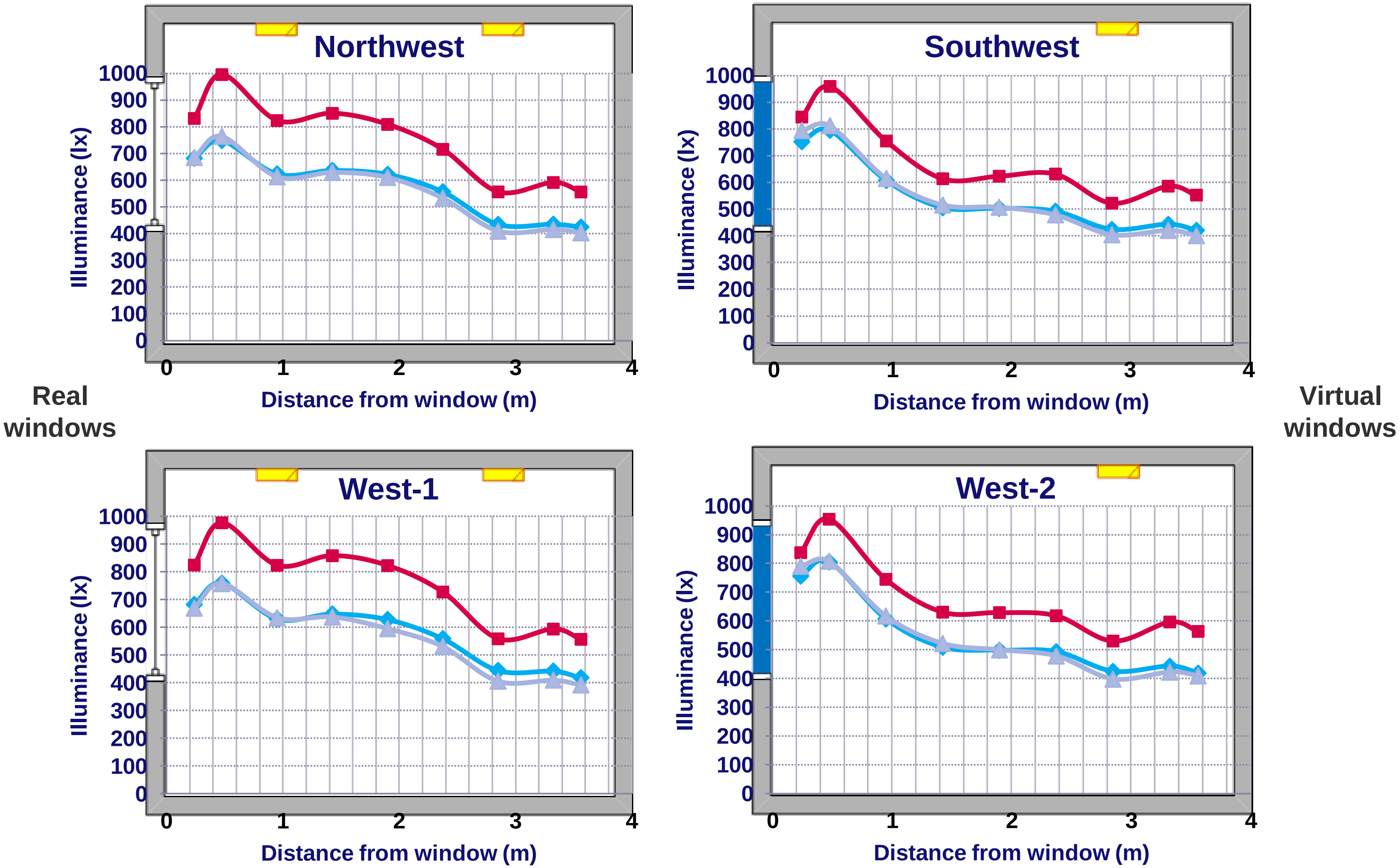
- …compared to virtual windows:

  ```
  light 11.856
  11.856  11.856
  ```

- Combined with general lighting ETAP luminaire 2x28 W



# Model without view, diffuse – (3)



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# Model with view, diffuse

- Typically (also) diffuse light distribution, but with image projected or displayed.
- Applied for situations where view is considered influential, e.g. when comparing glare perception from various view types.

Philips Homelab (2006)

Winscape (2011)

# Model with view, diffuse – (2)

- *For example*, comparing 5 different images as viewing scene

“Africa”

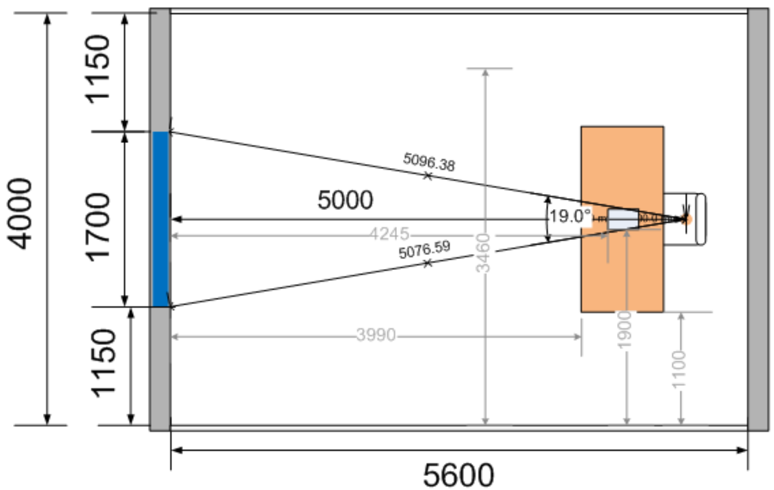
“Creek”

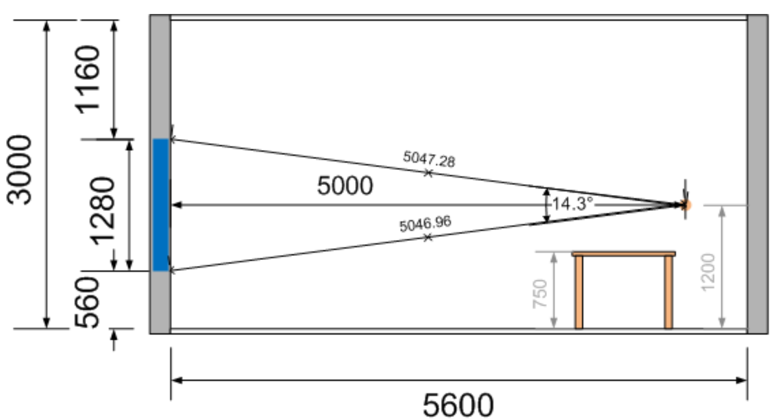
“First Floor”

“Hairdresser”

“Night Skyline”

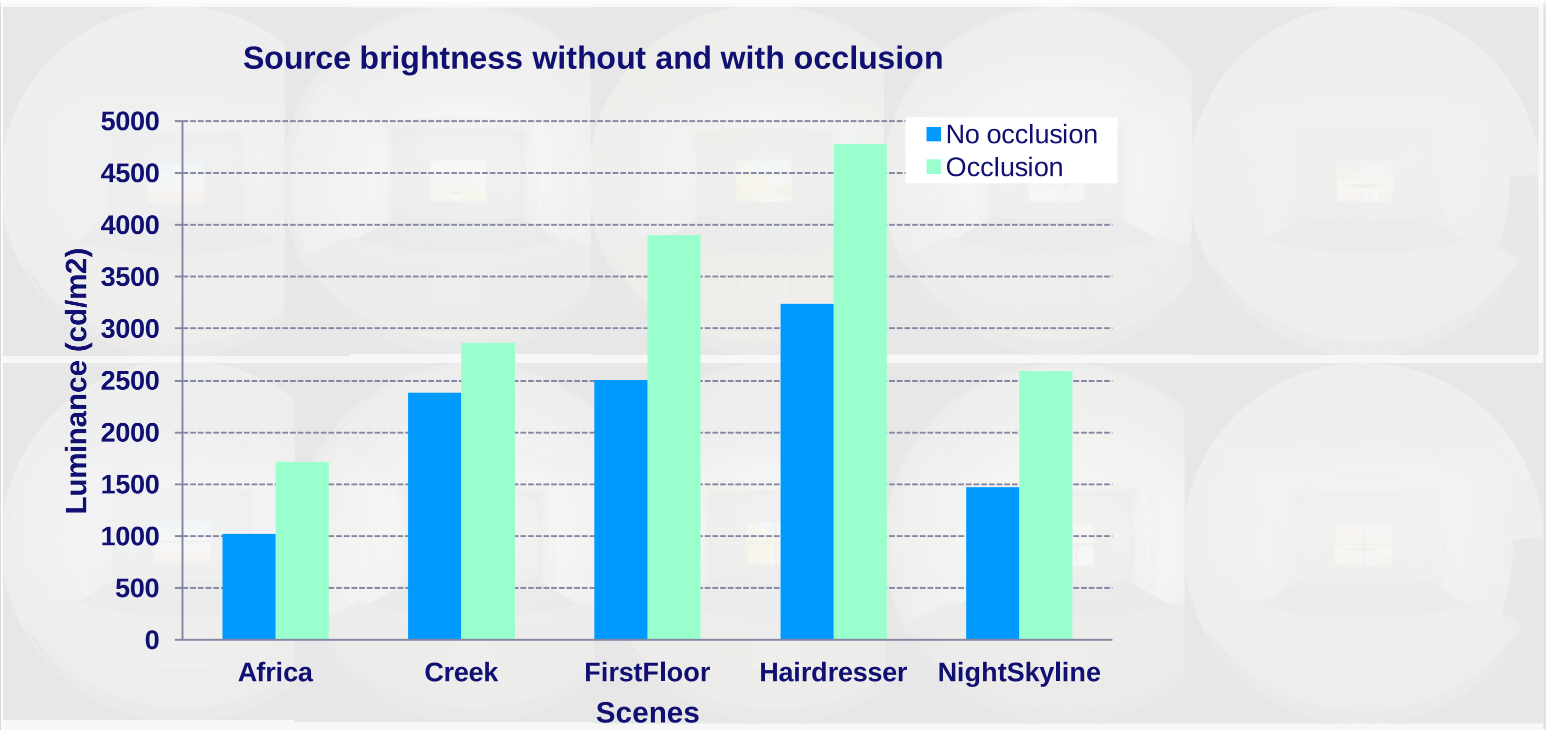
IJsselsteijn et al. (2008)



# Model with view, diffuse – (3)

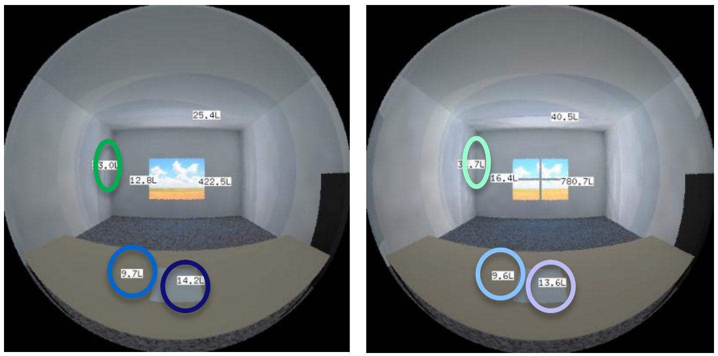
- 2D image mapped on `light` material

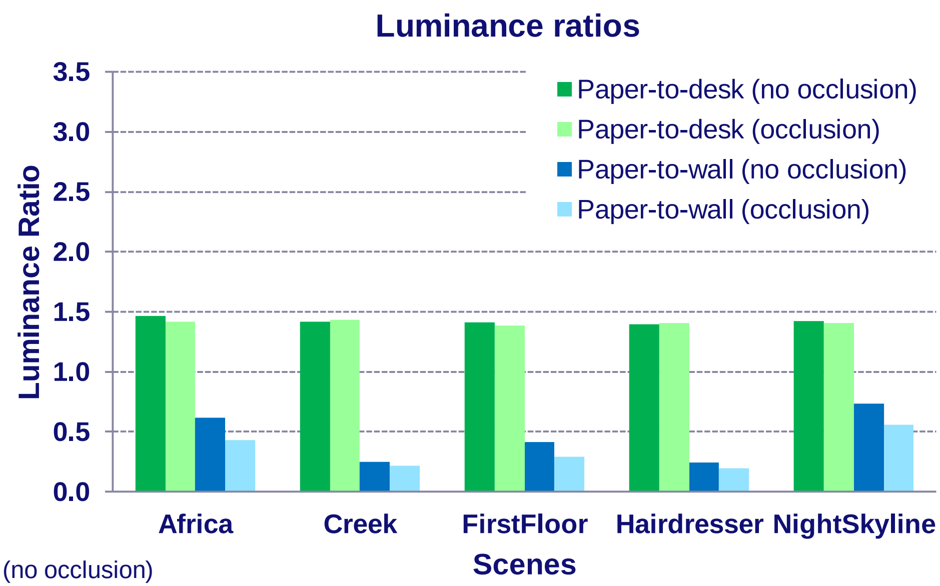


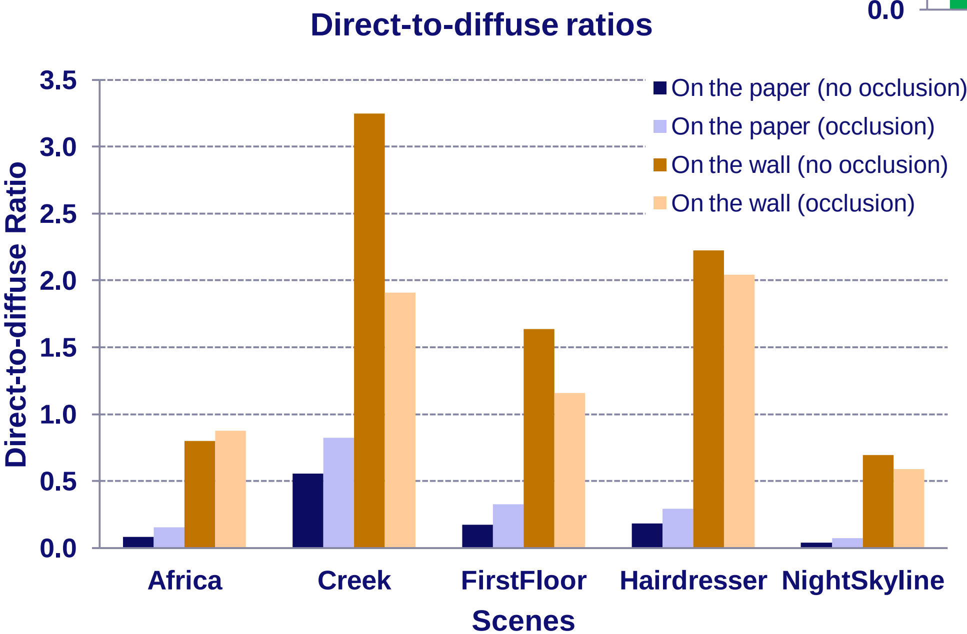

Maintain 40 lx on the desk

Ambience parameters: `-ab 3 -aa 0.15 -ar 128 -ad 512 -as 256`

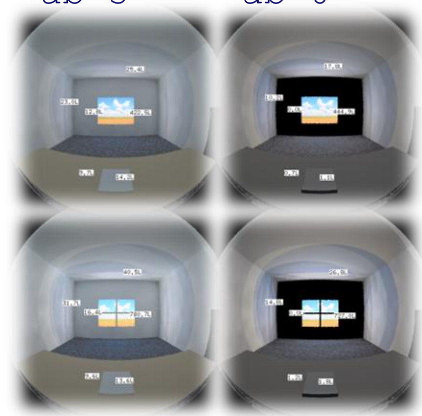
# Model with view, diffuse – (4)



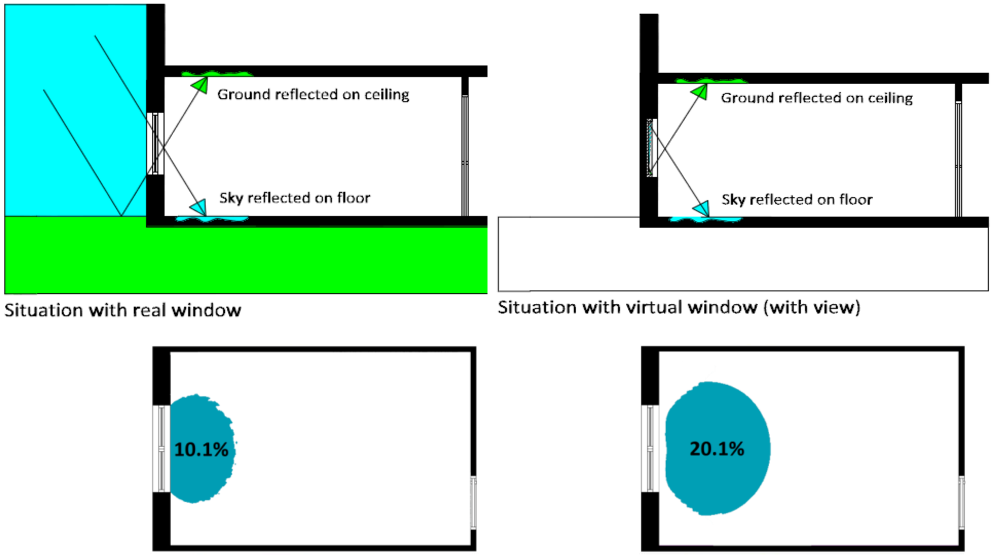




-ab 3 -ab 0



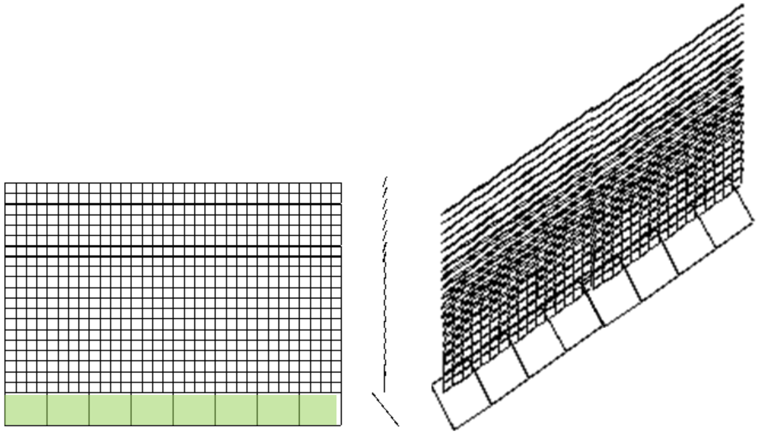
# Model with simple view, directional

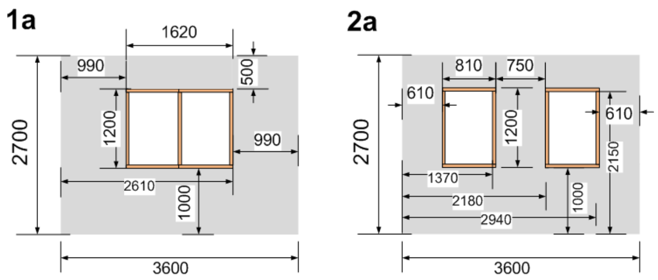
- Still in conceptual model.
- View is simplified: green “ground” and blue “sky”.
- Focused on directional light from the “ground” to the ceiling.
- Applied for optimising space availability and uniformity.

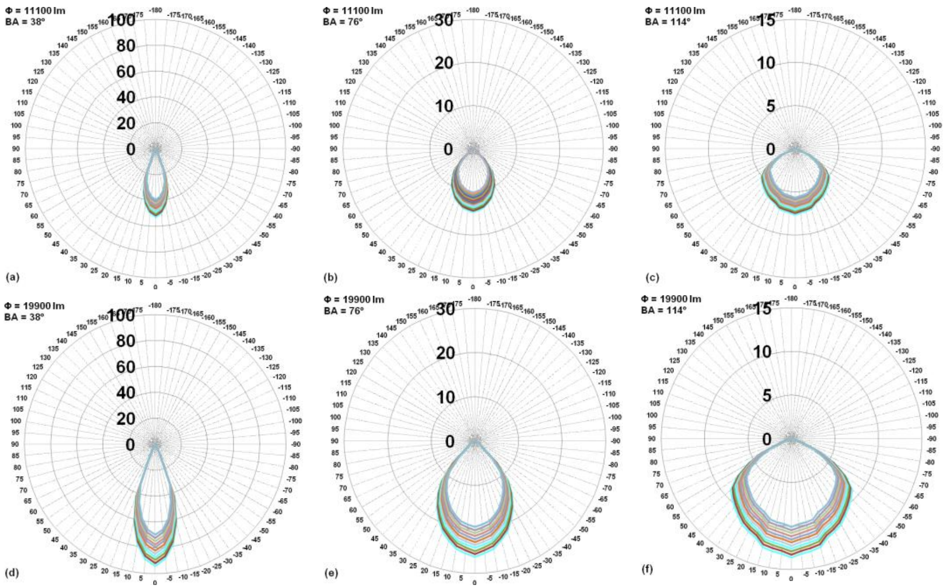


# Model with simple view, directional – (2)

- Input variables:
  - Interval of tilt angle (°): 1.0; 1.5; 2.0
  - Beam angle (°): 38; 76; 114
  - Total luminous flux of the “sky” (lm): 6200, 11100, 19900
  - Distance between windows (m): 0; 0.75






Ambience parameters: `-ab 4 -aa 0.15 -ar 128 -ad 512 -as 256 -ds 0.2`

# Model with simple view, directional – (3)

- **Output variables:**
  - Space availability:

$$\%A = \frac{n(E \geq 500\ \text{lx})}{N} \times 100\% \quad ; \; N = 1944$$

  - Uniformity: $U_0 = \dfrac{E_{min}}{E_{av}}$
  - Average ground contribution on the ceiling:

$$\%G_{av} = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{E_{ground\text{-}i}}{E_{total\text{-}i}} \times 100\%\right] \; ; \; N = 10$$

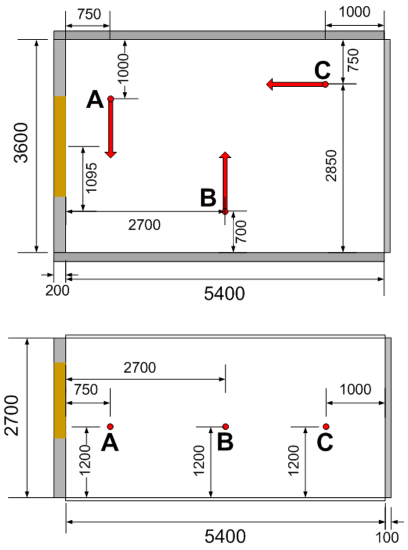
  - Average probability of discomfort glare:

$PDG_{av} = \frac{1}{4}\,(DGP + DGI_n + UGR_n + CGI_n)$

where $DGI_n = 0.01452 \times DGI$; $UGR_n = 0.01607 \times UGR$; $CGI_n = 0.01607 \times CGI$; (Jakubiec & Reinhart, 2012)

# Model with simple view, directional – (4)

- Compared to a similar scene where VNLS is replaced with real windows under CIE overcast sky, with equal average surface luminance.
- The proposed criteria:
  - Space availability: $\%A_{\text{VNLS}} > \%A_{\text{RW}}$
  - Uniformity: $U_{0\ \text{VNLS}} \geq U_{0\ \text{RW}}$
  - Average ground contribution on the ceiling: $0.9(\%G_{av\ \text{RW}}) \leq \%G_{av\ \text{VNLS}} \leq 1.1(\%G_{av\ \text{RW}})$
  - Average probability of discomfort glare: $\text{PDG}_{av\ \text{VNLS}} \leq \text{PDG}_{av\ \text{RW}}$
  - Average surface luminance: $L_{av} \leq 3200\ \text{cd/m}^2$



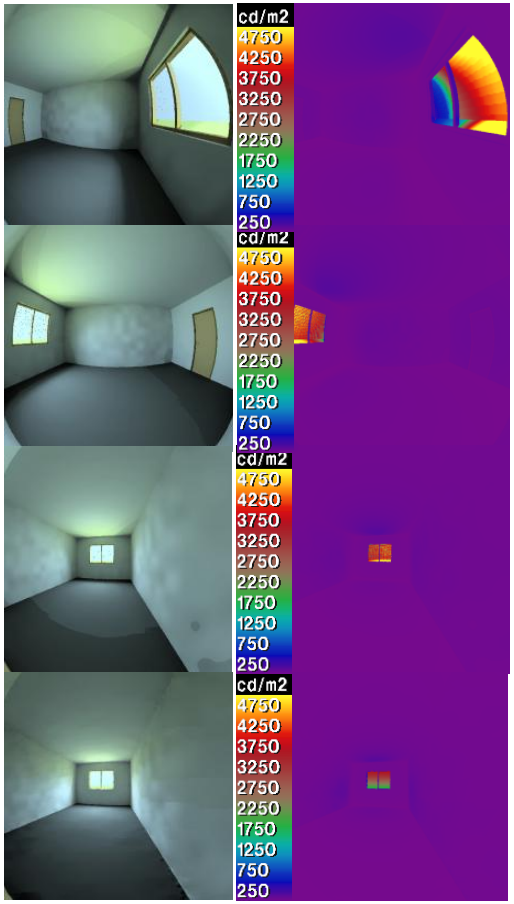
# Model with simple view, directional – (5)

- Probability of discomfort glare at position A, B, C:

| Type | Conf. | IA (°) | BA (°) | *Φ* (lm) | Pos. | DGP | $DGI_n$ | $UGR_n$ | $CGI_n$ | $PDG_{av}$ | Stdev |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **VNLS** | **1a** | 2.0 | 76 | 11100 | A | 0.24 | 0.21 | 0.36 | 0.39 | *0.30* | *0.09* |
| | | | | | B | 0.21 | 0.20 | 0.32 | 0.35 | *0.27* | *0.08* |
| | | | | | C | 0.27 | 0.33 | 0.46 | 0.48 | *0.38* | *0.10* |
| **RW** | **1a** | *L* = 3200 cd/m² | | | A | 0.24 | 0.21 | 0.35 | 0.39 | *0.30* | *0.08* |
| | | | | | B | 0.21 | 0.19 | 0.31 | 0.33 | *0.26* | *0.07* |
| | | | | | C | 0.26 | 0.31 | 0.43 | 0.45 | *0.36* | *0.09* |

- Position C experiences the largest prob. of discomfort glare
- Standard dev. in VNLS scenes are comparable to those in RW scenes → $PDG_{av}$ can be used for comparing both VNLS and RW

**1a, VNLS**




**1a, RW**



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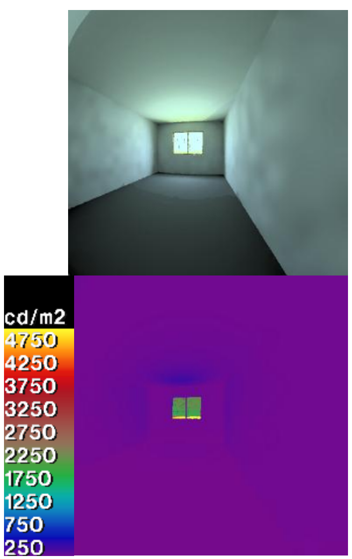
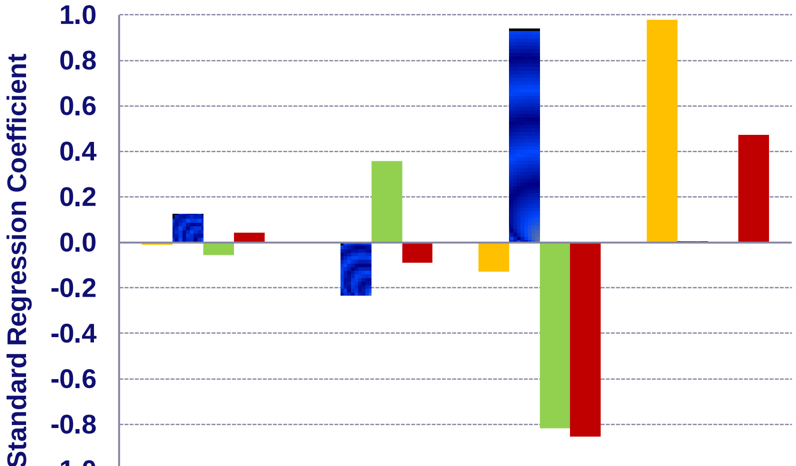
# Model with simple view, directional – (6)

- Results example of VNLS vs RW

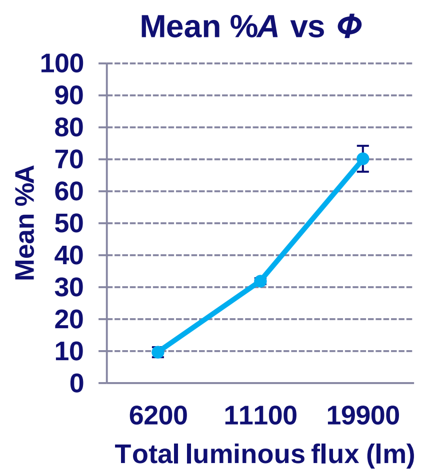
| Type | Conf. | IA (°) | BA (°) | $\Phi$ (lm) | %*A* | $U_0$ | %$G_{av}$ | PDG$_{av}$ |
|---|---|---|---|---|---|---|---|---|
| VNLS | 1a | 2.0 | 38 | 11100 | 28.0 | 0.37 | 48.8 | 0.35 |
| | 1a | 1.5 | 38 | 11100 | 29.3 | 0.37 | 46.8 | 0.35 |
| | 1a | 1.0 | 38 | 11100 | 29.9 | 0.37 | 44.6 | 0.35 |
| RW | 1a | $L$ = 1800 cd/m$^2$ | | | ***14.3*** | ***0.18*** | ***14.3*** | ***0.39*** |
| VNLS | 2a | 2.0 | 76 | 6200 | 11.5 | 0.32 | 49.2 | 0.36 |
| | 2a | 1.5 | 76 | 6200 | 9.4 | 0.33 | 46.5 | 0.36 |
| | 2a | 1.0 | 114 | 6200 | 5.3 | 0.35 | 44.1 | 0.36 |
| RW | 2a | $L$ = 1800 cd/m$^2$ | | | ***14.7*** | ***0.16*** | ***14.7*** | ***0.40*** |

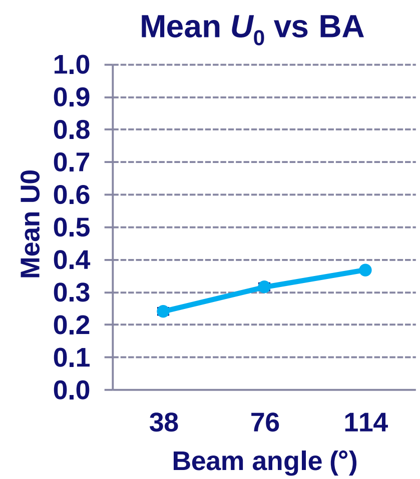


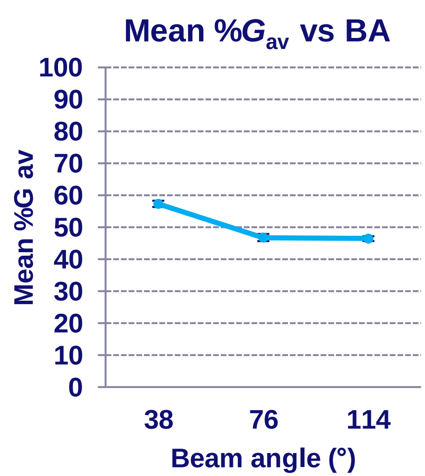
# Model with simple view, directional – (7)

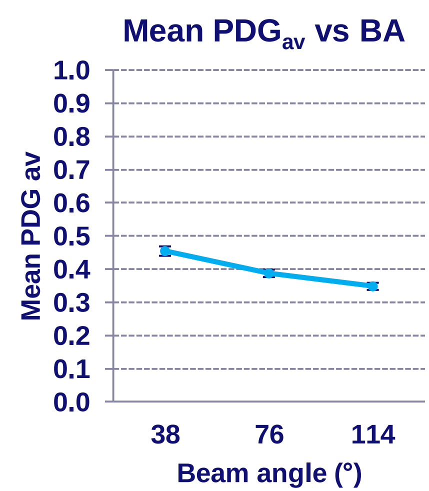



| | d (m) | IA (°) | BA (°) | Φ (lm) |
|---|---|---|---|---|
| %A | -0.01 | 0.00 | -0.13 | 0.98 |
| U0 | 0.12 | -0.23 | 0.94 | 0.00 |
| %G av | -0.06 | 0.36 | -0.82 | -0.01 |
| PDG av | 0.04 | -0.09 | -0.85 | 0.47 |




- Most of the VNLS with **BA = 114°** (wide) satisfy all performance criteria.
- The **total luminous flux** is highly influential to the space availability.
- The **beam angle** is highly influential to the uniformity, average ground contribution, and average probability of discomfort glare.

# Conclusions & outlook

- As a simulation tool, RADIANCE can be employed for predicting lighting performance of future solutions such as VNLS.
- The modeling approach is driven towards providing good directionality and complex view, while keeping the visual comfort comparable to the real window situation.
- The next steps will be improving all of the lighting aspects, as well as evaluating energy performance of the selected solutions with other simulation tools.

*Case #2*

# Photocatalytic Oxidation Modelling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**Where innovation starts**

# Indoor Air Quality & Photocatalytic Oxidation

- Indoor Air Quality (IAQ) is important:
  - People in modern urban areas spend 85%-90% of their time indoor
  - Synthetic materials, combustion, human activities, industrial processes can release a range of pollutants, resulting in indoor air pollution
- Pollutants can be removed by source control, increasing ventilation rates or air purification.
- Photocatalytic Oxidation (PCO) is a potential technology for (passive) indoor air purification.

Wallpaper

# Photocatalytic Oxidation (PCO) modeling

- Previous research:
  1. Development of a kinetic model for $NO_x$ (inorganic compound)
     *Q.L. Yu, M.M. Ballari, H.J.H. Brouwers (2009) (2010)*
  2. Implementation of the kinetic model in a Computation Fluid Dynamics (CFD) model
     *H.A. Cubillos Sanabria, (2011)*

- No radiance model was applied, causing to:
  - Neglect the glass cover in the reactor setup (1)
  - Assume a uniform irradiance distribution during modelling (2)



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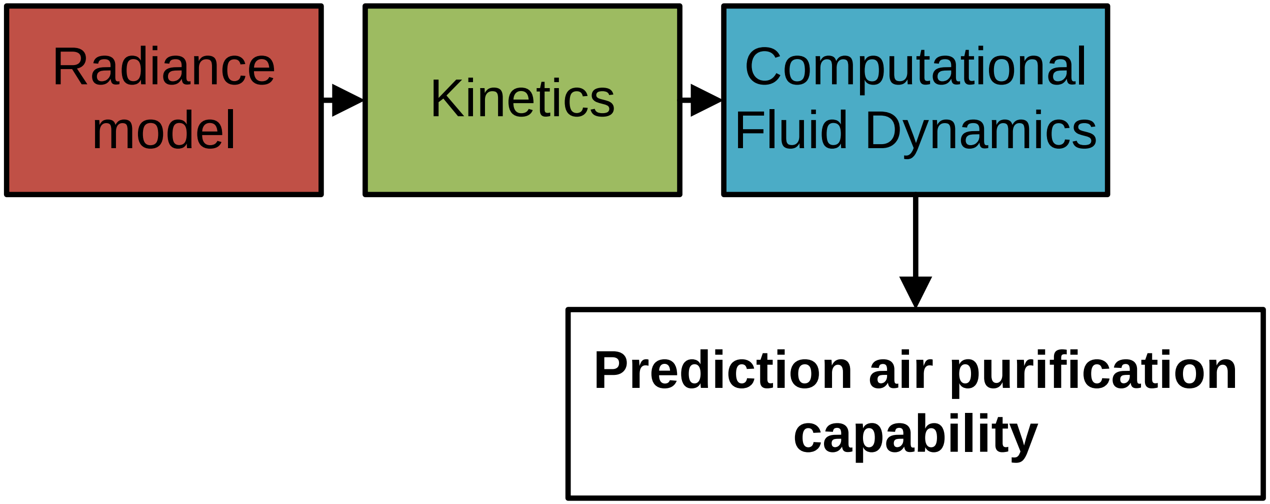
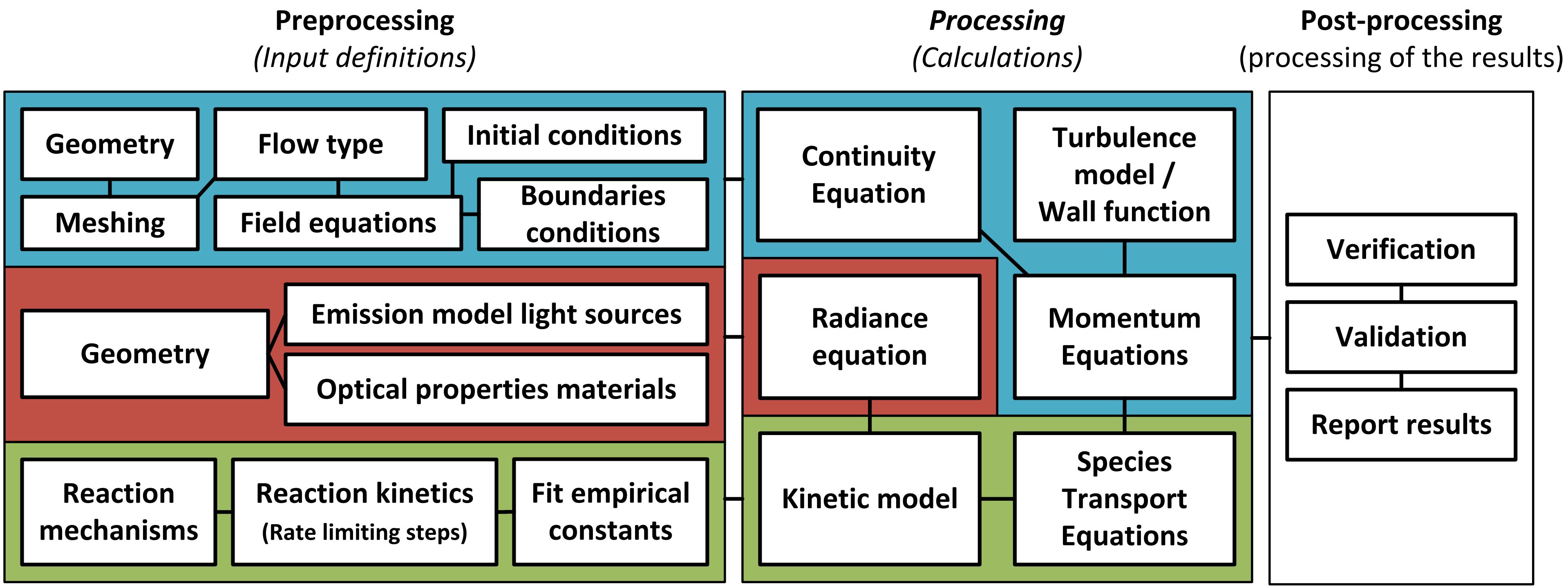
# The concept

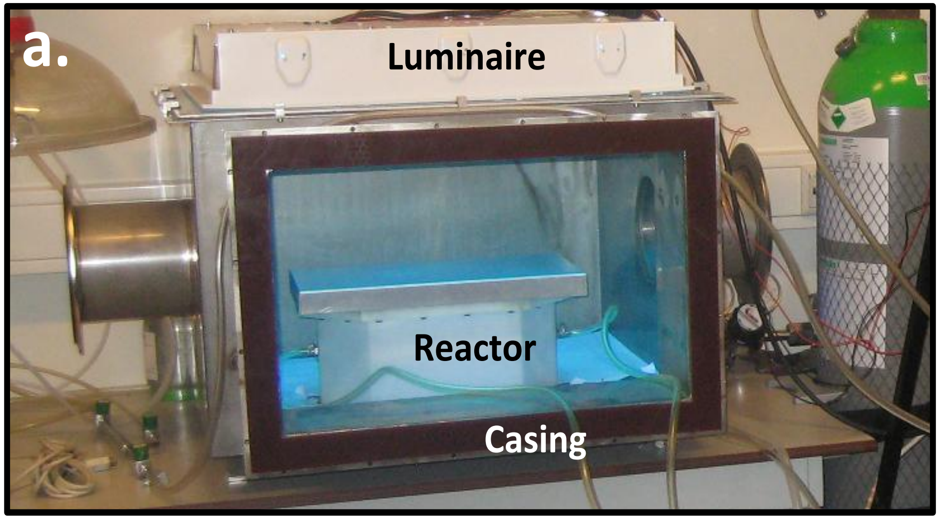
- **A concept for PCO modelling is proposed, based on the previous research**
  - **Radiance model**
  - **Kinetics**
  - **Computation Fluid Dynamics**



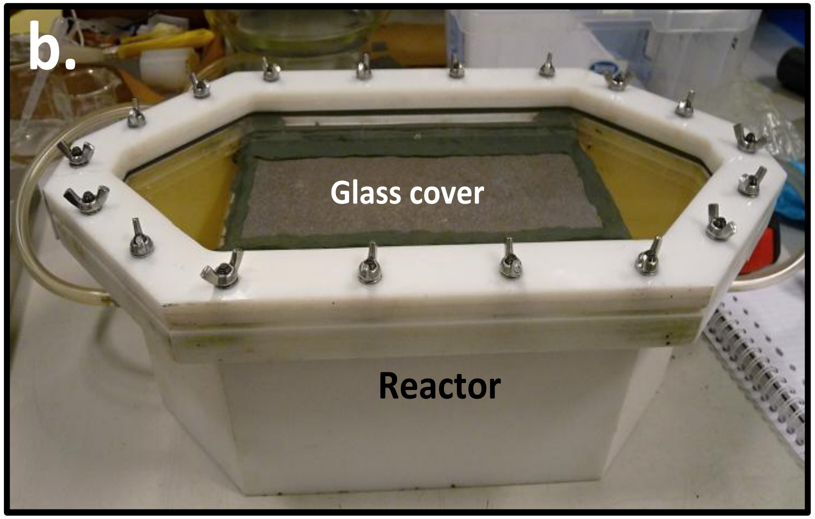
# The framework



# First modeling study of the reactor setup



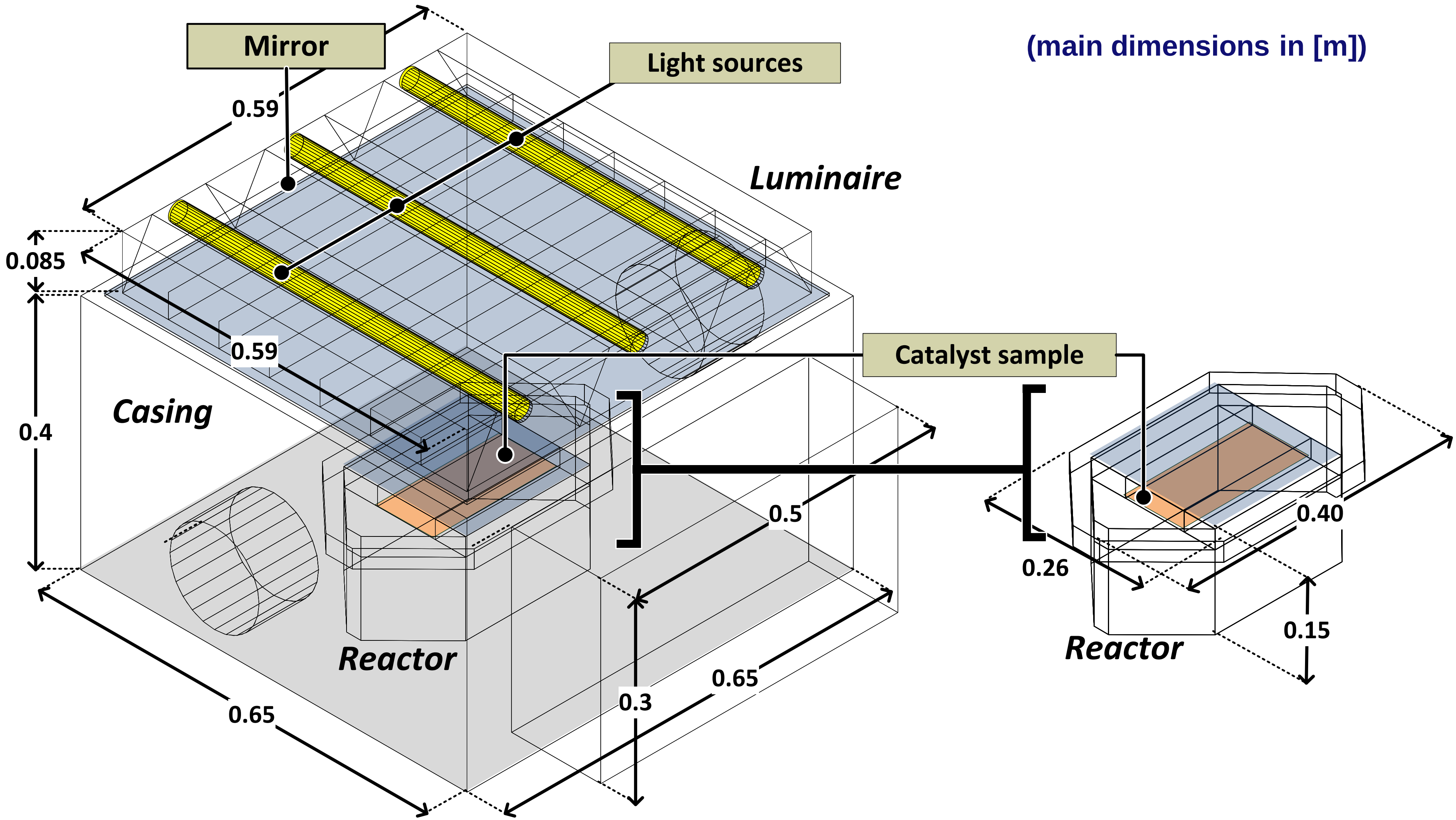

(a) reactor setup




(b) reactor

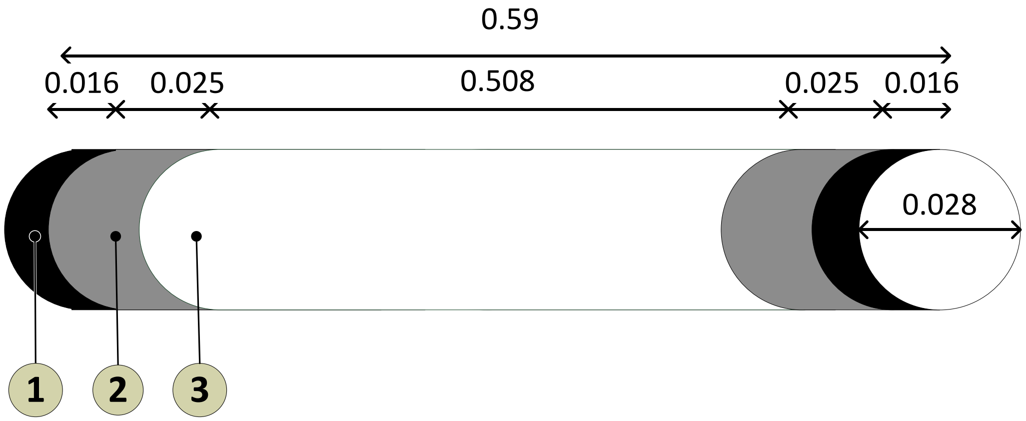
# Overview of the reactor setup model

**(main dimensions in [m])**



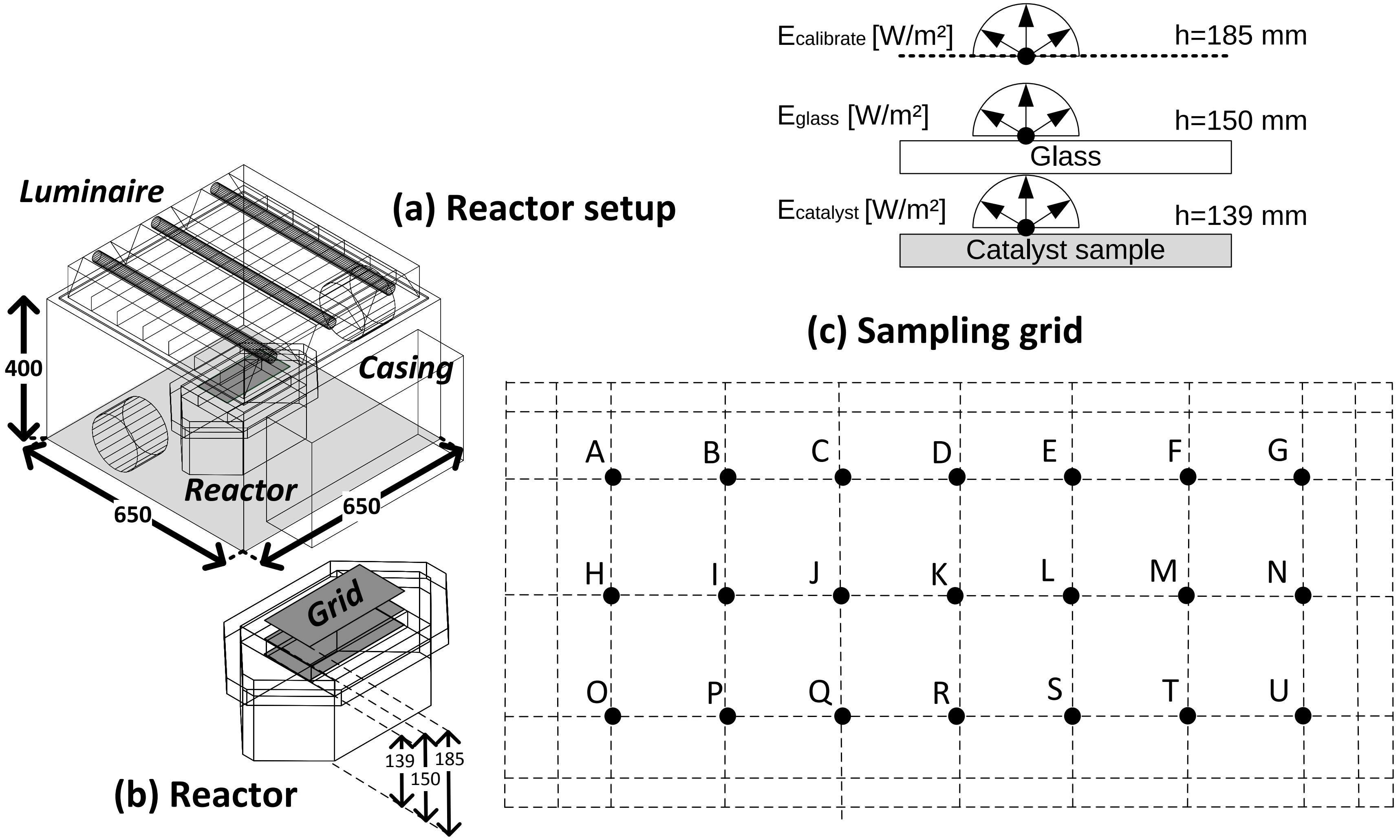
# Light source model

- An omnidirectional radiant intensity distribution over the longitudinal axis of the light source model is assumed, expressed in $L_i$ [$Wm^{-2}sr^{-1}$].




- The light source model is composed out of a:
  (1) lamp base (no emission)
  (2) border region ($L = L_l /2$)
  (3) main light emitting area ($L = L_l$)

# Sampling grid



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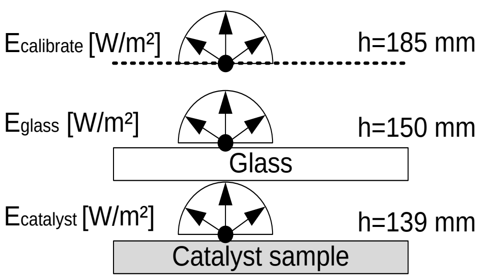
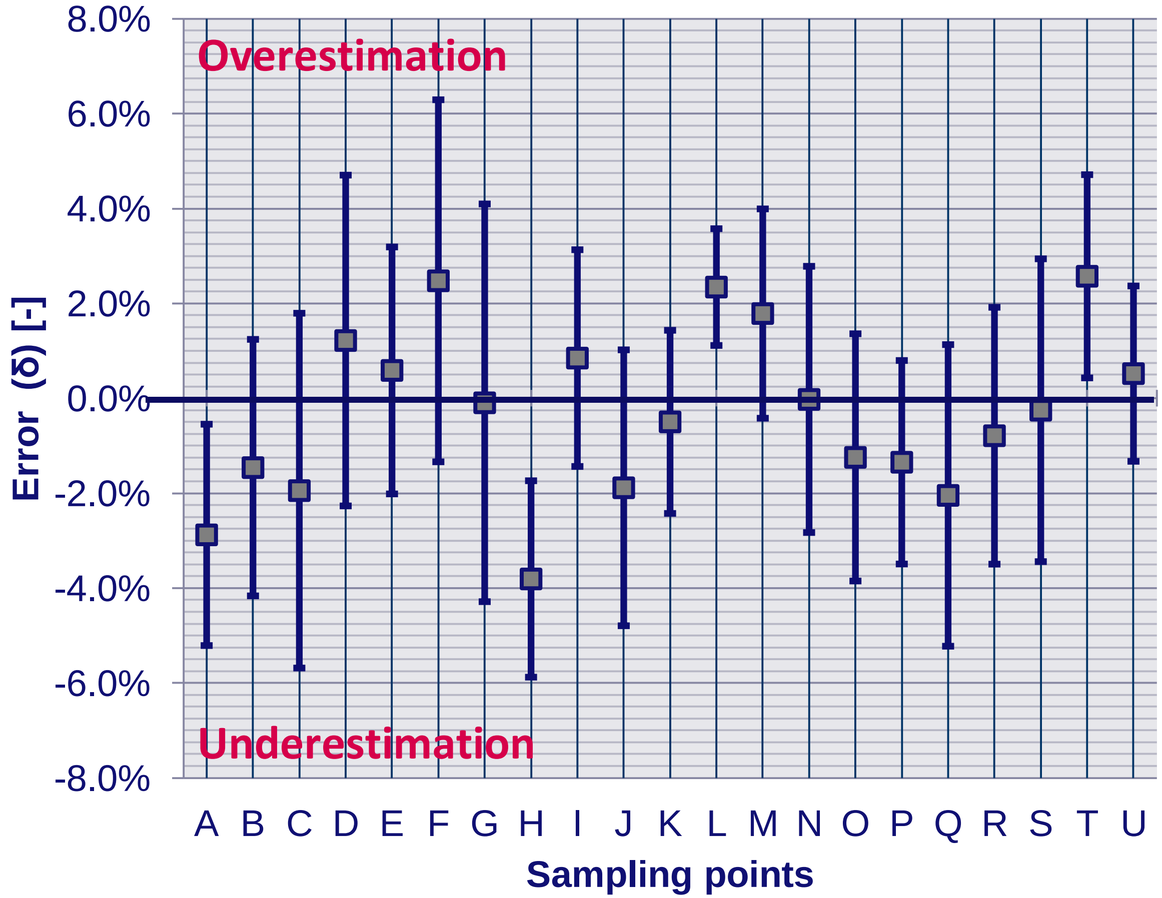
# Validation

Transmission coefficient of the glass < 0.9273

Reflection coefficient catalyst surface = 0.88

$L_l$ =34.8 W/(m²sr)



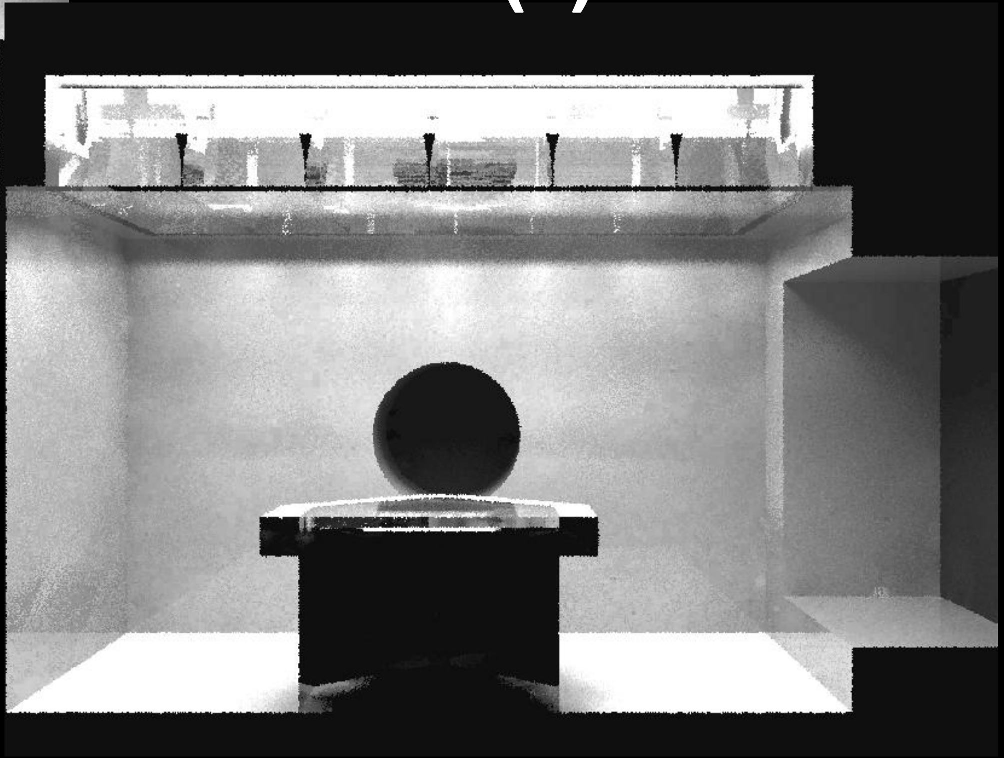

```
(rtrace) -I -ab 5 -dj 1.0 -ds 0.05 -aa 0.1 -ar 256
-st 0.07 -ad 1024 -as 64
```

# Impression: vertical cross-section

```
(rvu) -ab 1 -aa 0.3 -dj 1 -ds 0.1
```

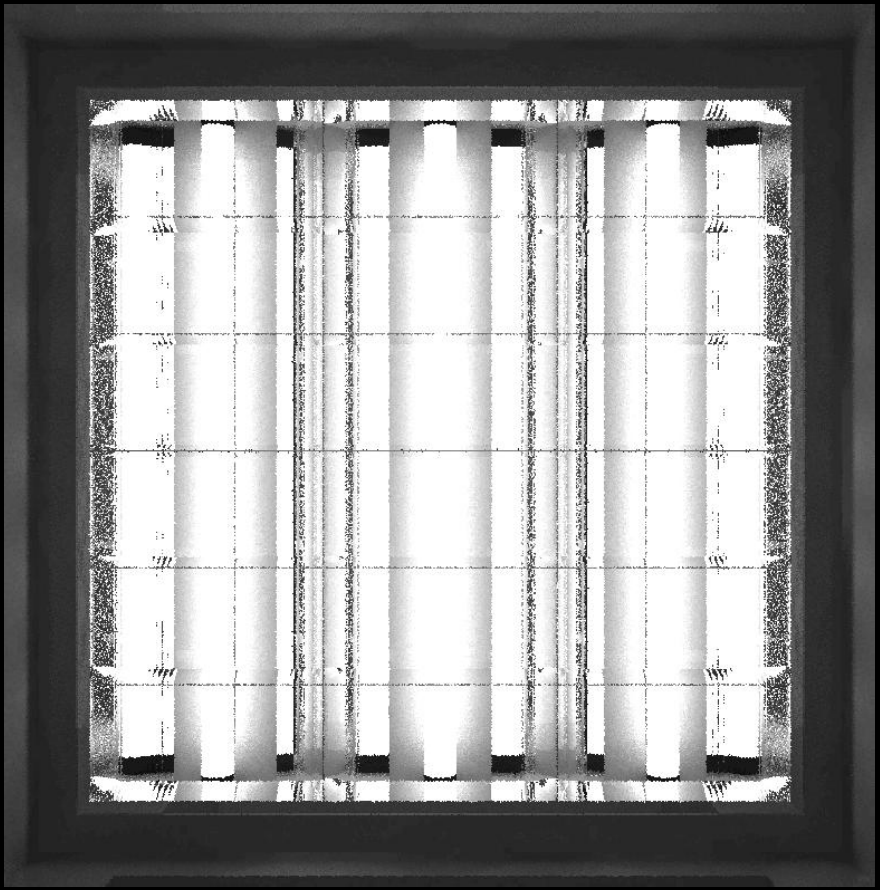
(a)

(b)



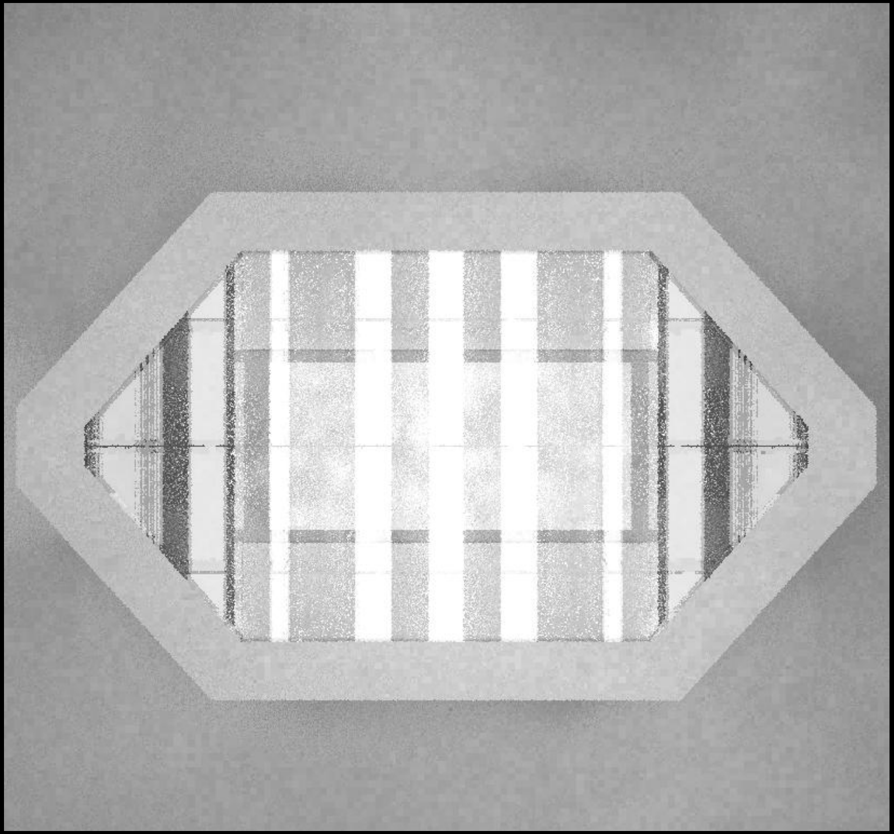
# Impression: bottom-top & top-bottom view

(rvu) -ab 1 -aa 0.3 -dj 1 -ds 0.1



(a)

(b)



# Result of simulation & analytical calculation

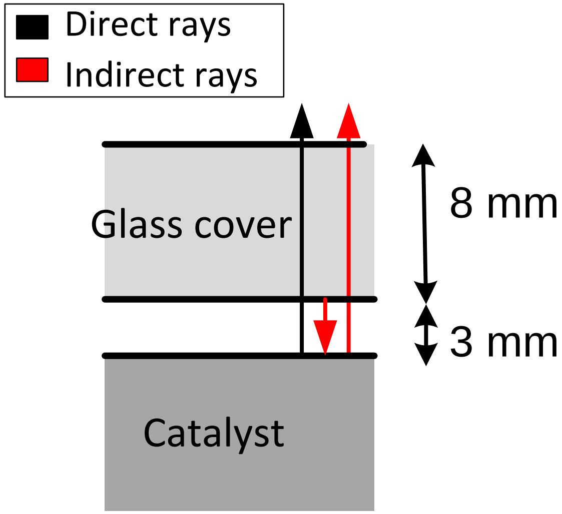
$$\frac{E_{catalyst}}{E_{glass}} = \tau_{direct} + \tau_{indirect}$$

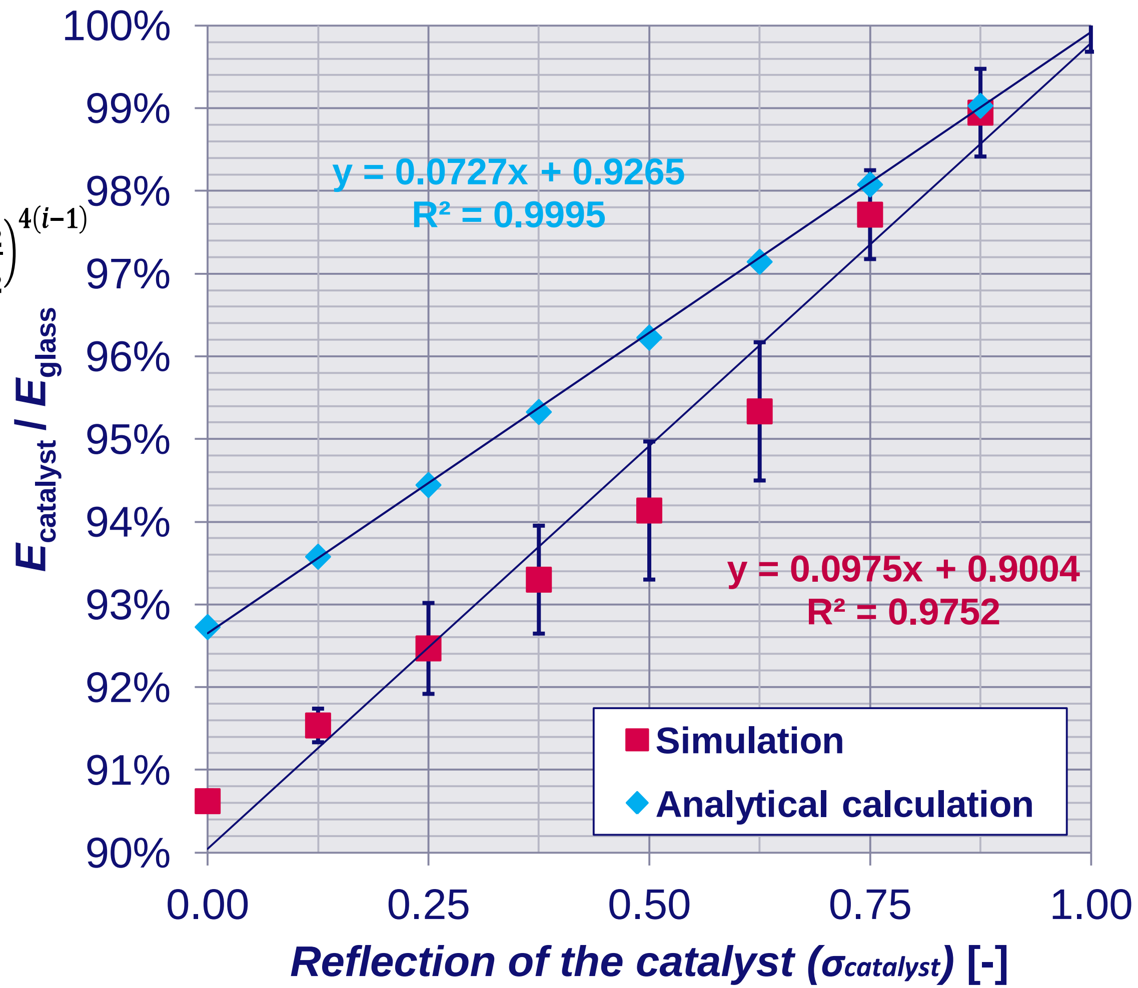
$$\tau_{direct} = \tau_{glass}$$

$$\tau_{glass} = \sum_{i=1}^{n}\left(1-\left(\frac{n_2-n_1}{n_2+n_1}\right)^2\right)\cdot\left(1-\left(\frac{n_1-n_2}{n_1+n_2}\right)^2\right)\cdot\left(\frac{n_1-n_2}{n_1+n_2}\right)^{4(i-1)}$$

$$\tau_{indirect} = \sum_{i=1}^{n}\left((1-\tau_{glass})^i \sigma_{catalyst}{}^i \tau_{glass}\right)$$

$$\bar{E}_{glass} = \bar{E}_{catalyst}/(\tau_{direct} + \tau_{indirect})$$



# Conclusion and outlook

- Both the measurement and the simulations have inaccuracies; the inaccuracy of the stochastic calculation is obtained with statistics.
  - The maximum error of the average values is ~4%, but due to uncertainty the error is raised to ~6%

- The analytical calculation could not provide a correct estimation of the $E_{catalyst}/E_{glass}$ ratio. Therefore, an equation from simulated data was derived:

$$E_{glass} = (0.0975 \cdot \sigma_{catalyst} + 0.904) E_{catalyst}$$

  - The equation can be used to improve the kinetic model of $NO_x$

- Secondary modeling study in which:
  - The improved kinetic model is employed
  - Radiance model is integrated into a CFD model
  - Several cases are simulated in which the PCO is studied, using a benchmark office model for CFD

# Questions?

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