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!

…Toward the future

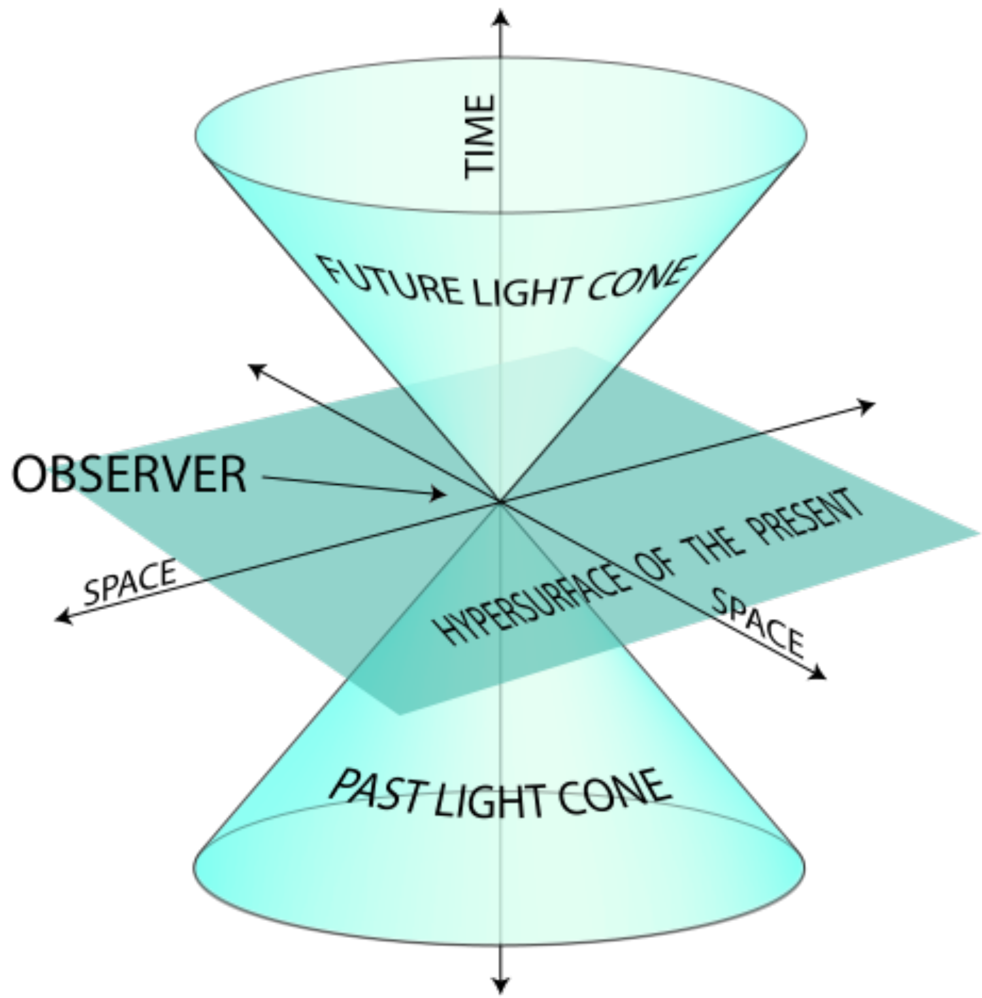
The future is so uncertain and highly complex:

The need to predict the performance of future solutions

→**using computational simulation tools**

→**e.g. RADIANCE!**

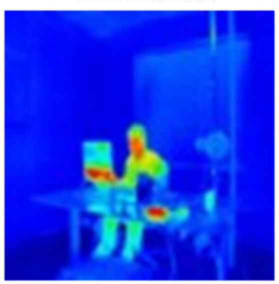
Radiance-online.org (2012)



Some familiar terms

Case #1

Building **Lighting**



Building **Performance**

Lighting

Raytracing

Wavelength

Illuminance

Visual comfort

Uniformity

Sustainability

Material

Sky model

Distribution

Building Simulation

Preference

Light source

Daylight

Optimisation

Behaviour

Contrast

Glare index

Perception

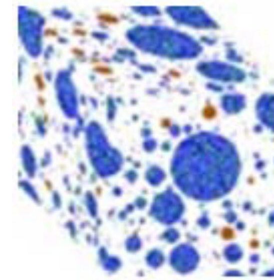
Luminous intensity

Irradiance

Uncertainty

Performance

Case #2



Building **Materials**

Case #1

Virtual Natural Lighting Solutions

Rizki A. Mangkuto
Myriam B.C. Aries
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Jan L.M. Hensen

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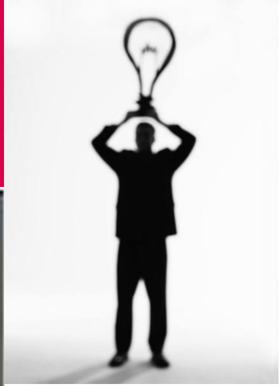
Department of the Built Environment
Eindhoven University of Technology

Technische Universiteit **Eindhoven** University of Technology

Where innovation starts

Low availability of
natural (day-)light!

The idea



Virtual natural lighting solution (VNLS)

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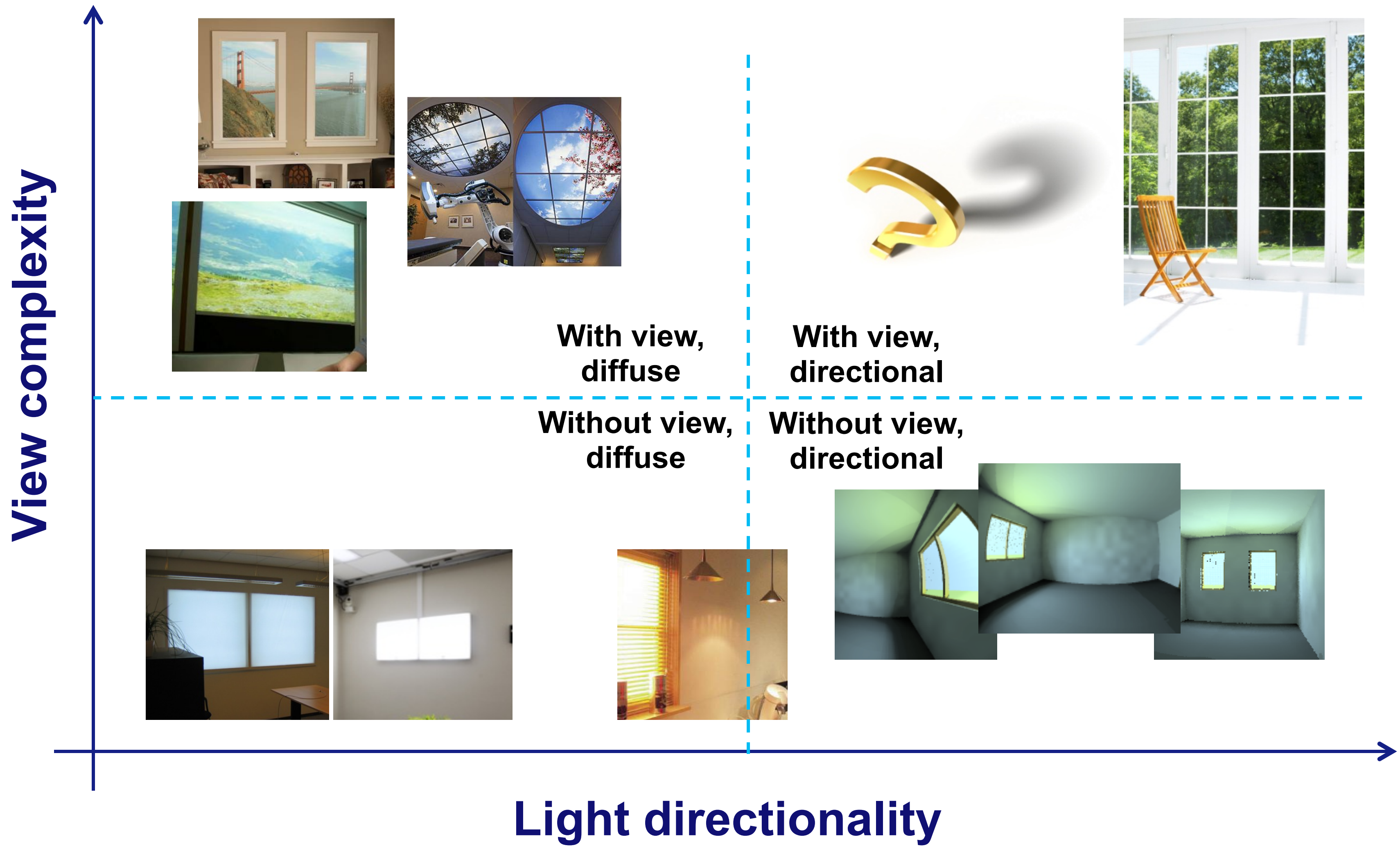
Approach towards VNLS (model)



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)

Model without view, diffuse – (2)

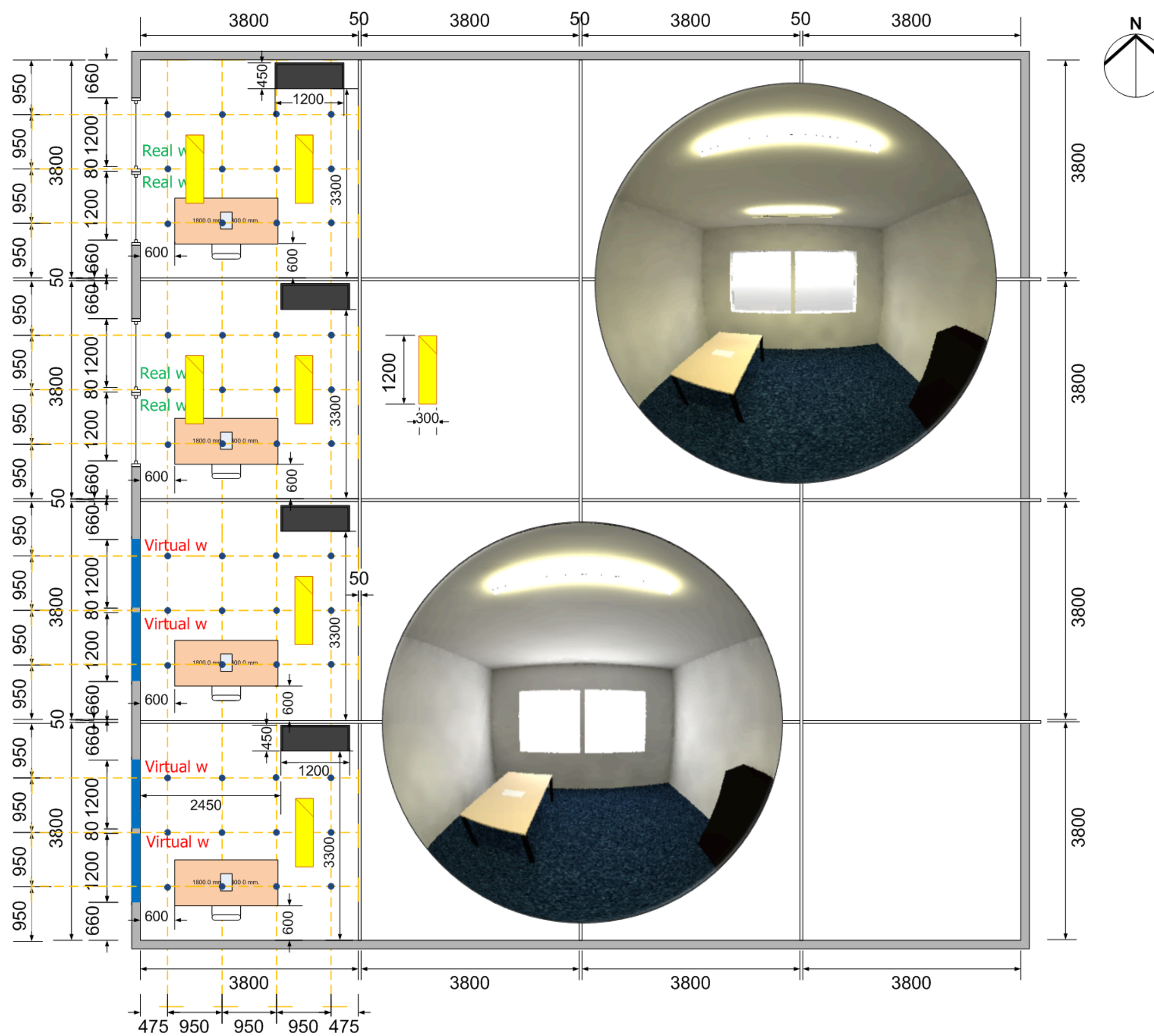
- *For example*, real windows under CIE overcast sky:

  `gensky -c -b 22.9`

- …compared to virtual windows:

  `light 11.856 11.856 11.856`

- Combined with general lighting ETAP luminaire 2x28 W



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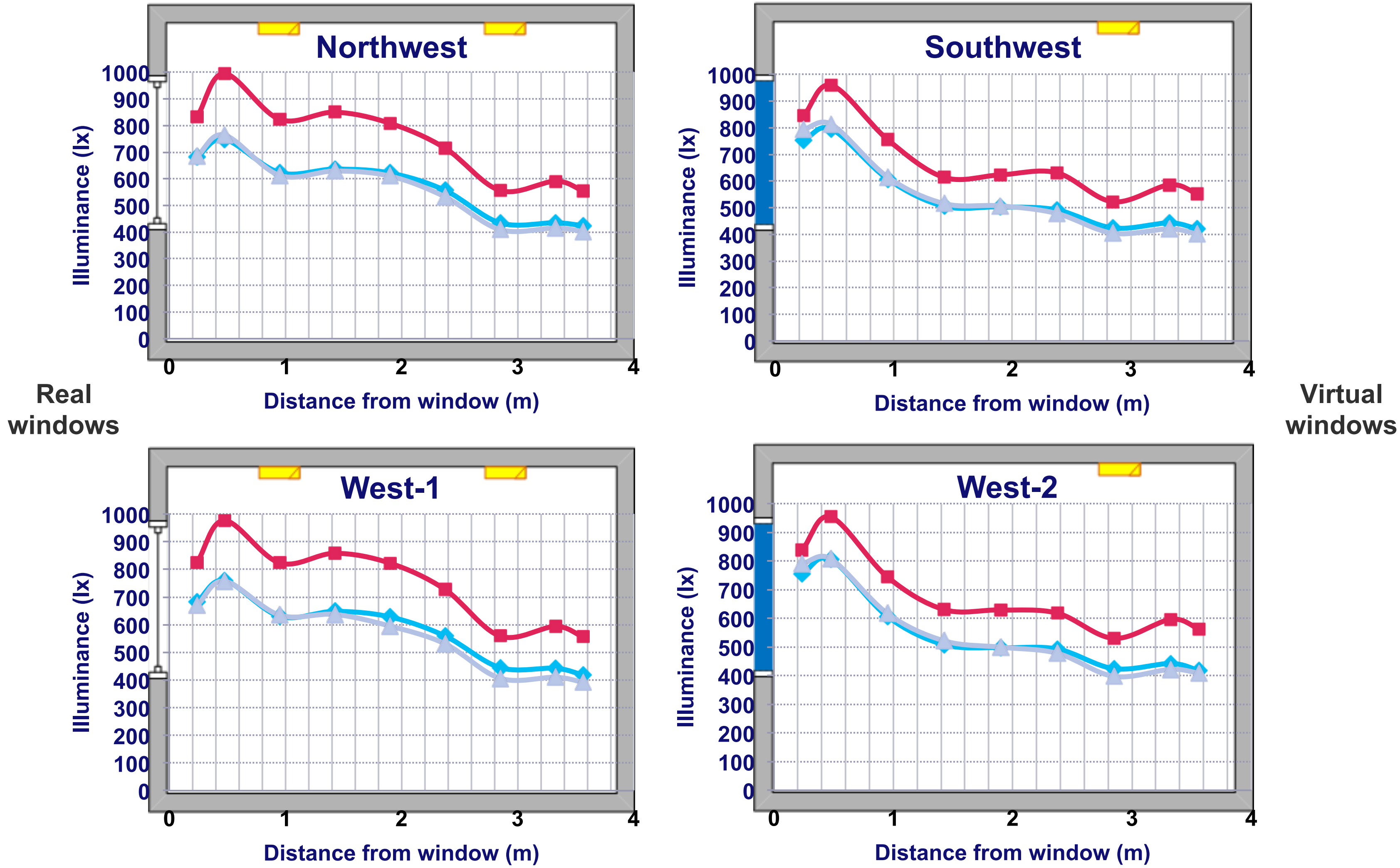
Model without view, diffuse – (3)



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)

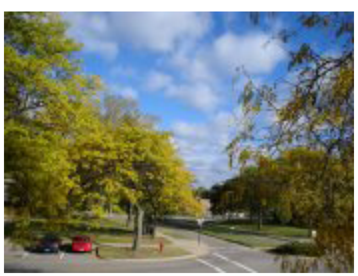
Winscape (2011)

Model with view, diffuse – (2)

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

“Africa”

“Creek”

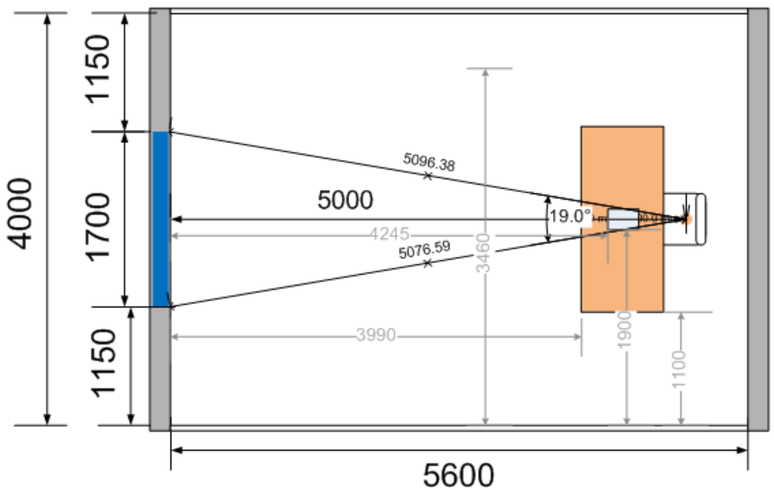


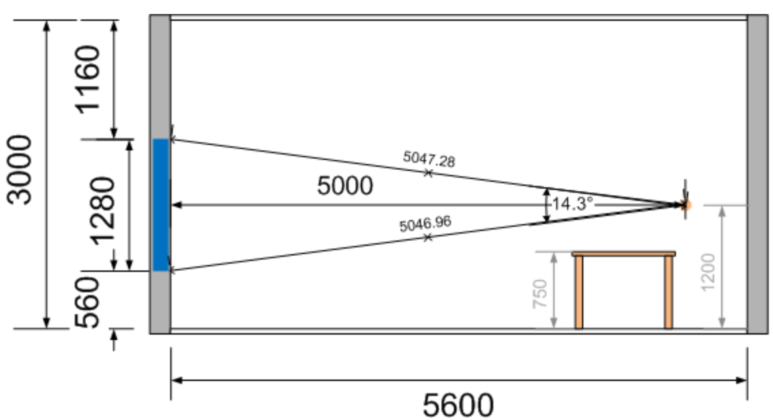
“First Floor”

“Hairdresser”

“Night Skyline”

IJsselsteijn et al. (2008)





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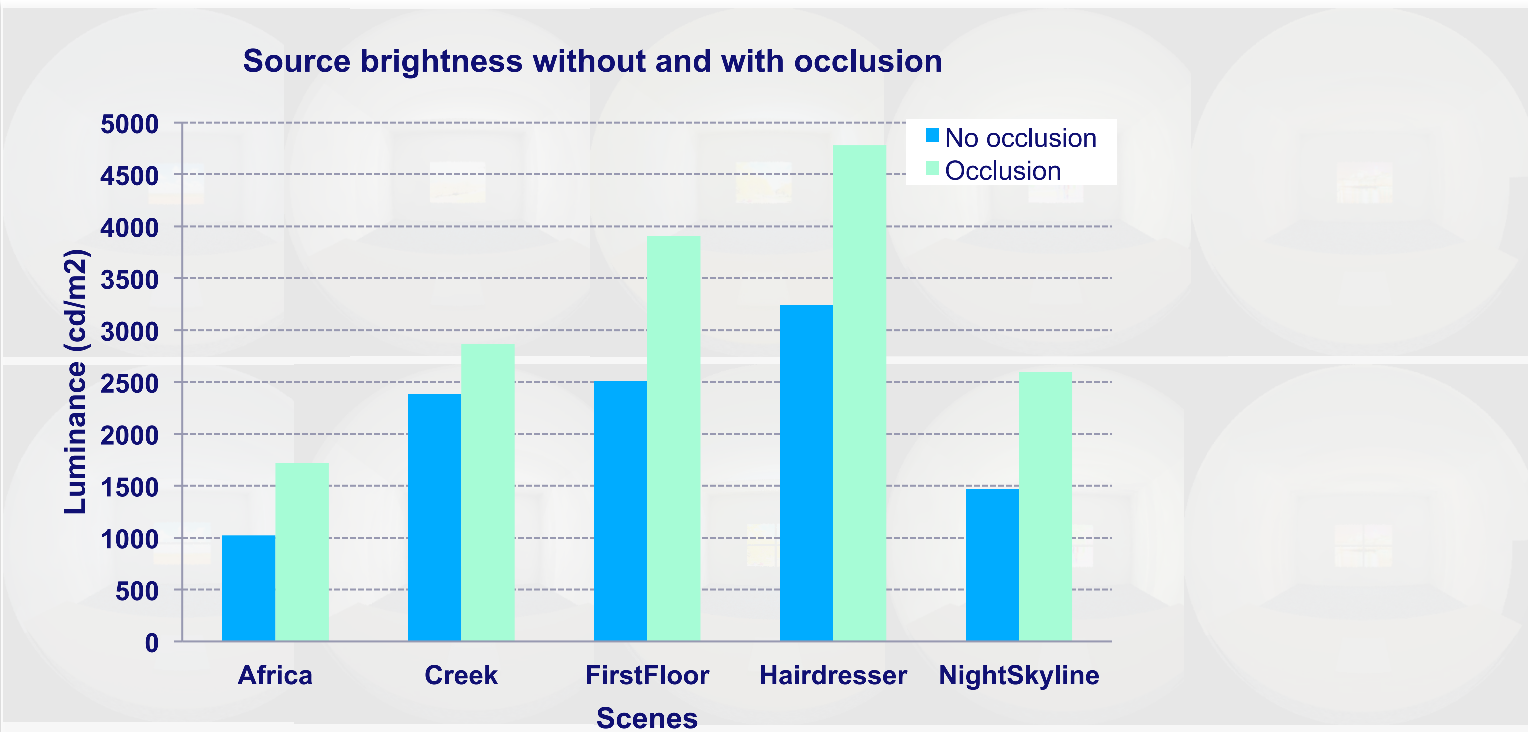
Model with view, diffuse – (3)

- 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`

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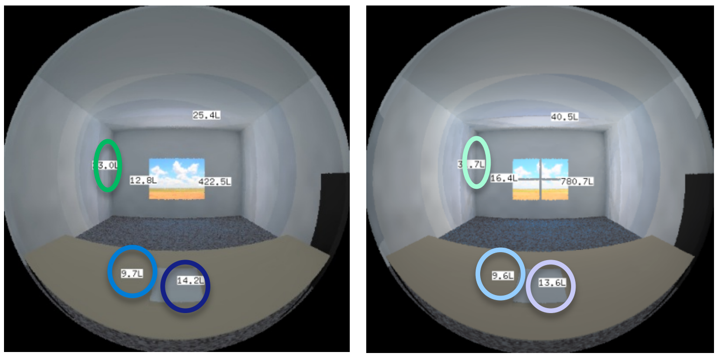
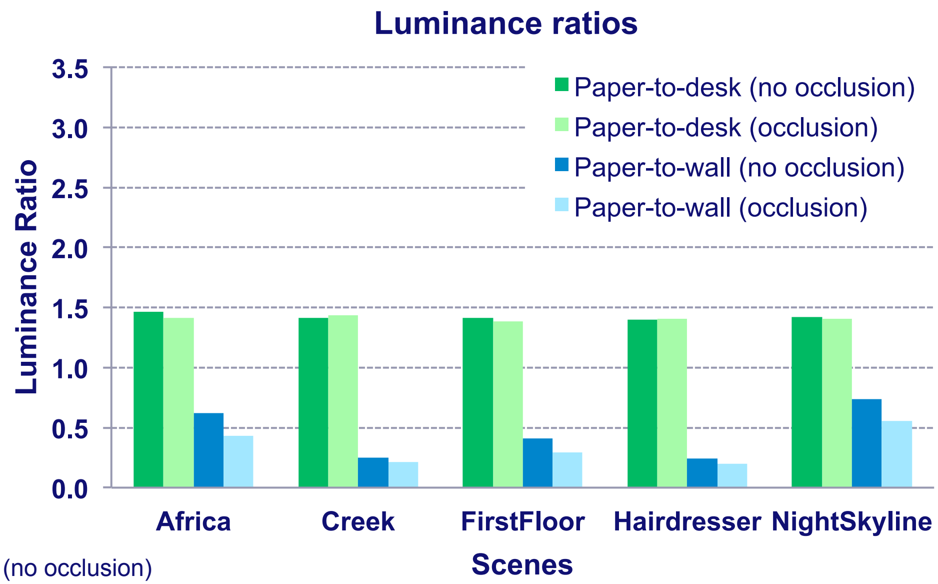
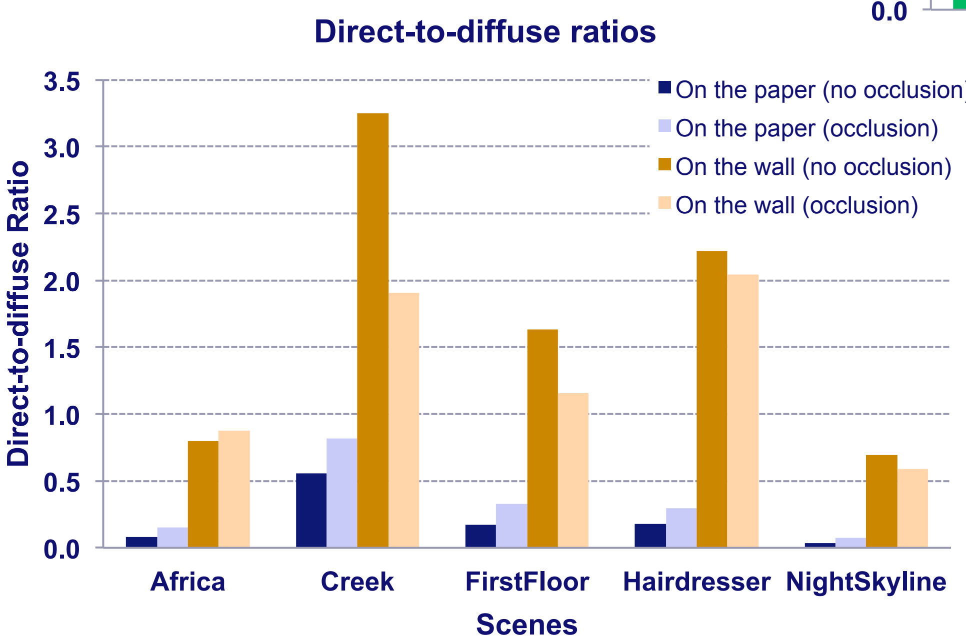
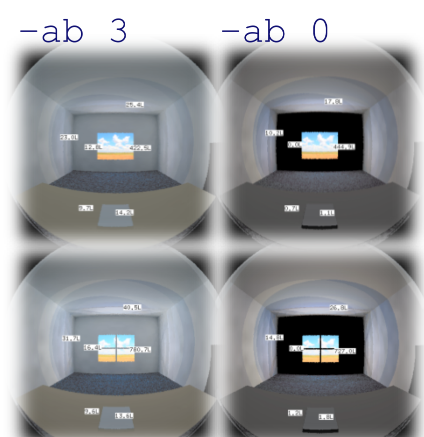
Model with view, diffuse – (4)



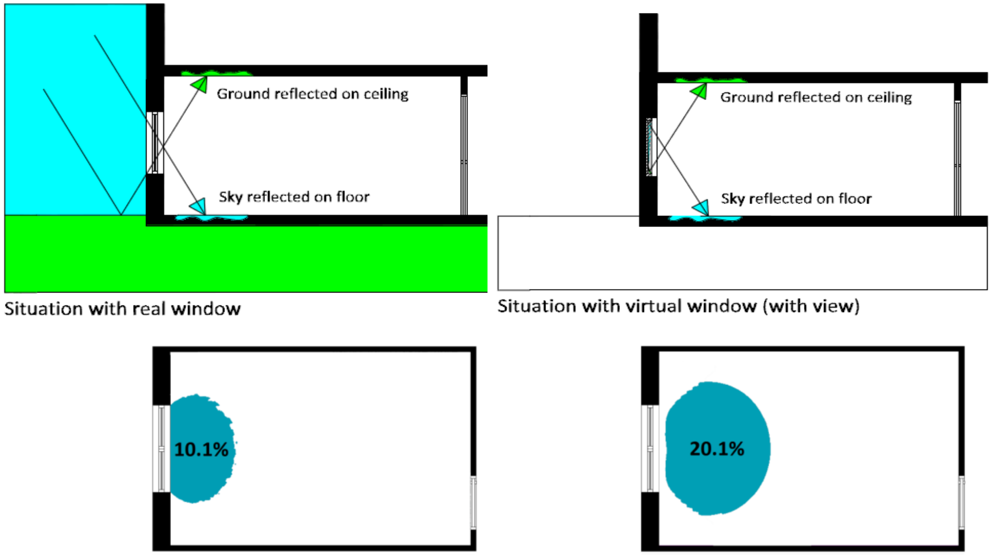






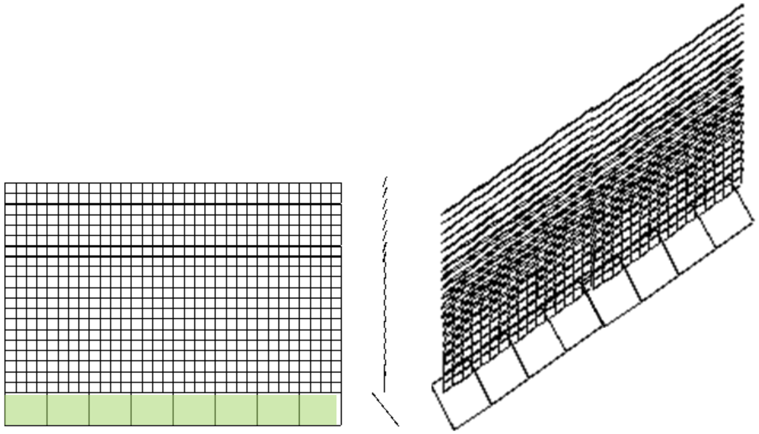
Model with simple view, directional

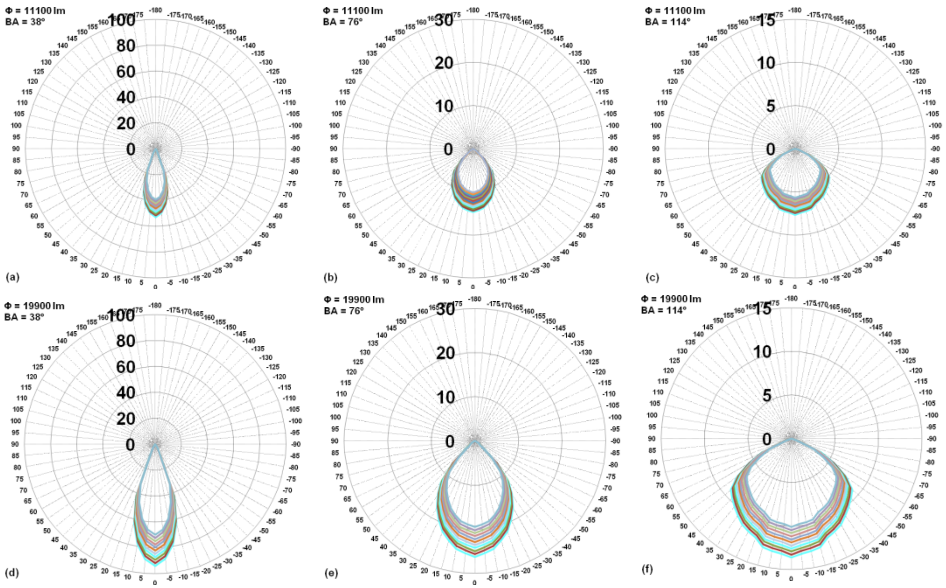
- Still in conceptual model.
- View is simplified: green “ground” and blue “sky”.
- Focused on directional light from the “ground” to the ceiling.
- Applied for optimising space availability and uniformity.

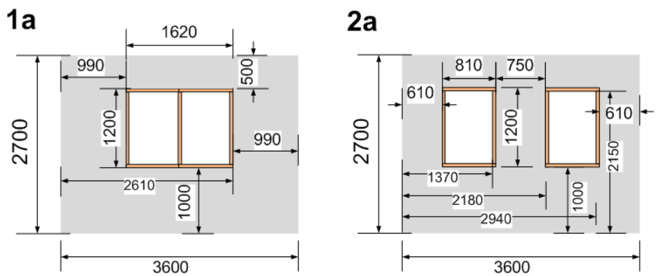


Model with simple view, directional – (2)

- 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:

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

  - Uniformity: $U_0 = \frac{E_{min}}{E_{av}}$

  - Average ground contribution on the ceiling:

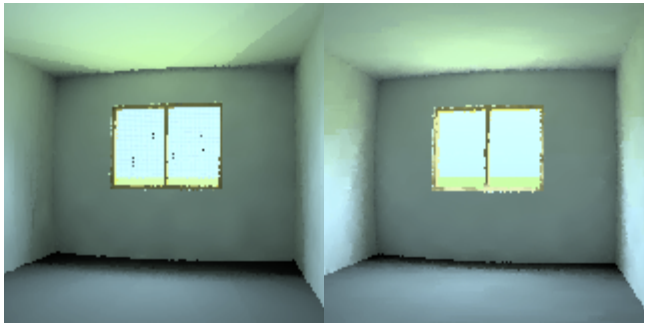
$$\%G_{av} = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{E_{ground\text{-}i}}{E_{total\text{-}i}} \times 100\%\right]; N = 10$$

  - Average probability of discomfort glare:

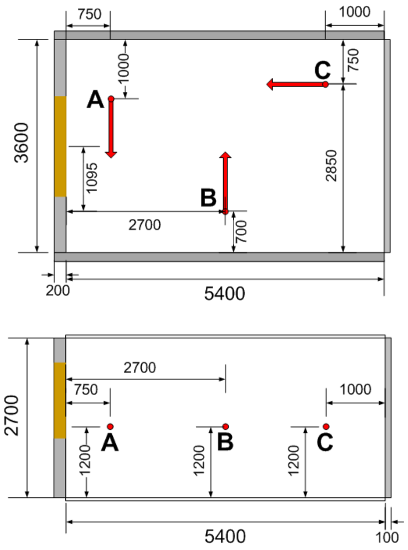
$$PDG_{av} = ¼\ (DGP + DGI_n + UGR_n + CGI_n)$$

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: $L_{av} \leq 3200\ \text{cd/m}^2$



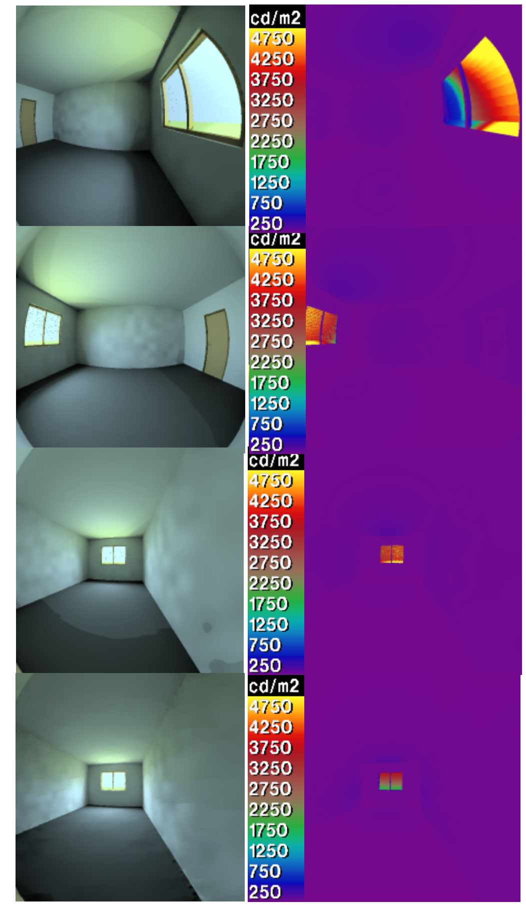
Model with simple view, directional – (5)

- 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

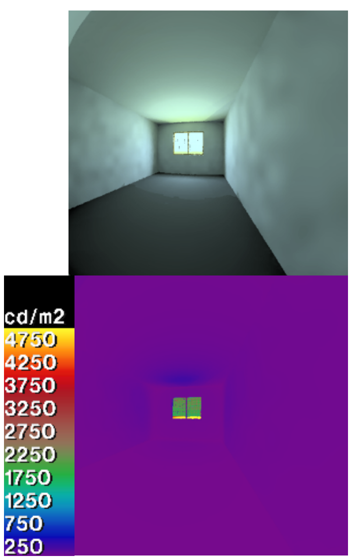


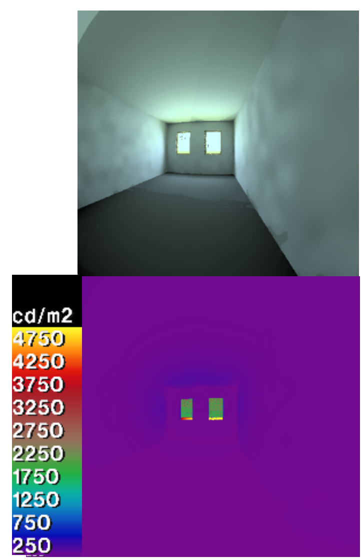
1a, RW

Model with simple view, directional – (6)

- Results example of VNLS vs RW

Type	Conf.	IA (°)	BA (°)	*Φ* (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***





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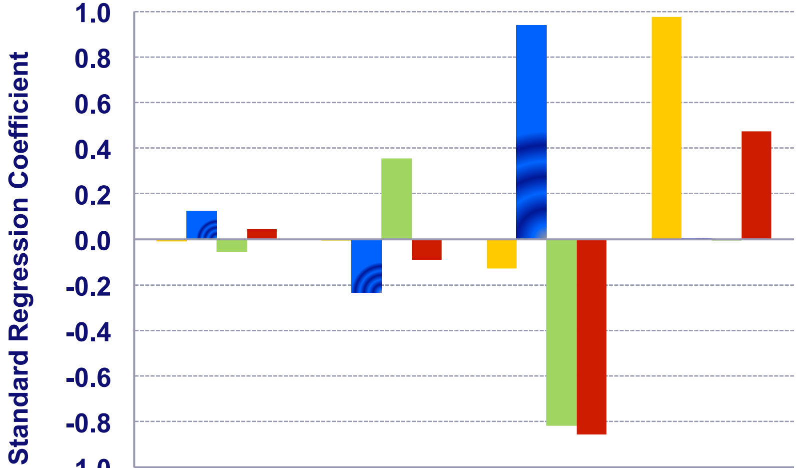
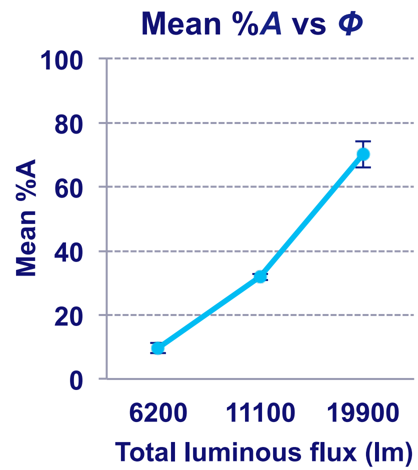
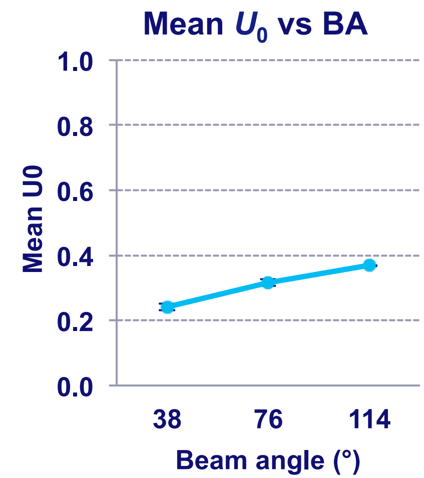
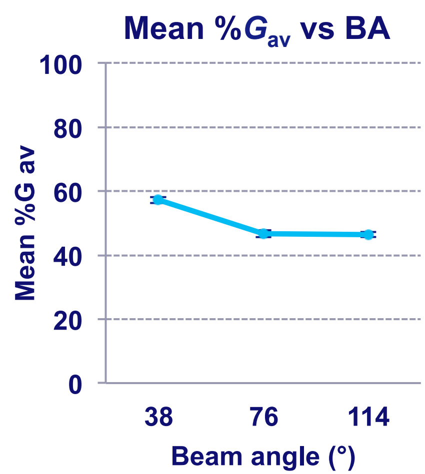
Model with simple view, directional – (7)

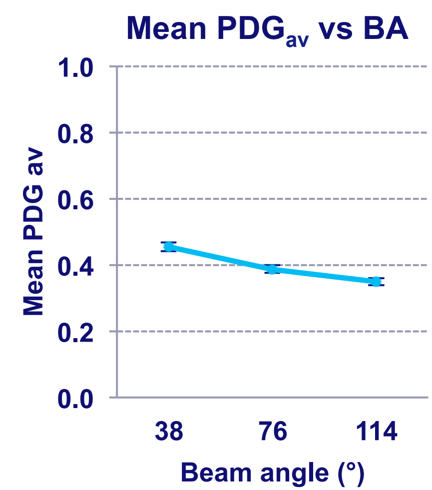


	d (m)	IA (°)	BA (°)	Φ (lm)
%A	-0.01	0.00	-0.13	0.98
U0	0.12	-0.23	0.94	0.00
%G av	-0.06	0.36	-0.82	-0.01
PDG av	0.04	-0.09	-0.85	0.47









- 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

Ruben S. Pelzers
Qingliang Yu
Rizki A. Mangkuto
Marcel G.C. Loomans
Jos Brouwers

Unit Building Physics and Services
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Eindhoven University of Technology

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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

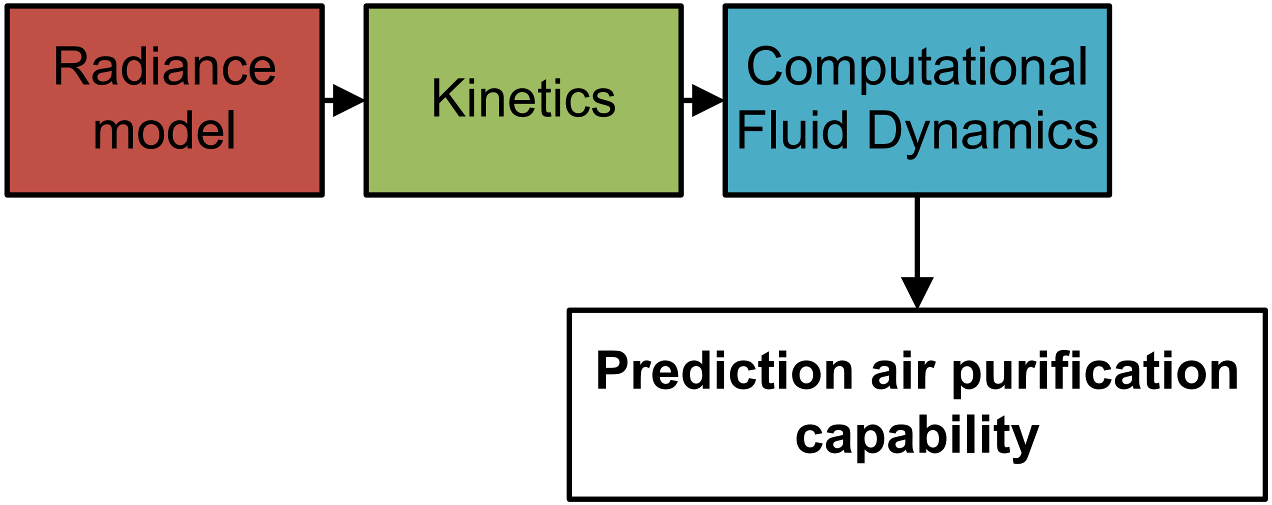
Photocatalytic Oxidation (PCO) modeling

- 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)

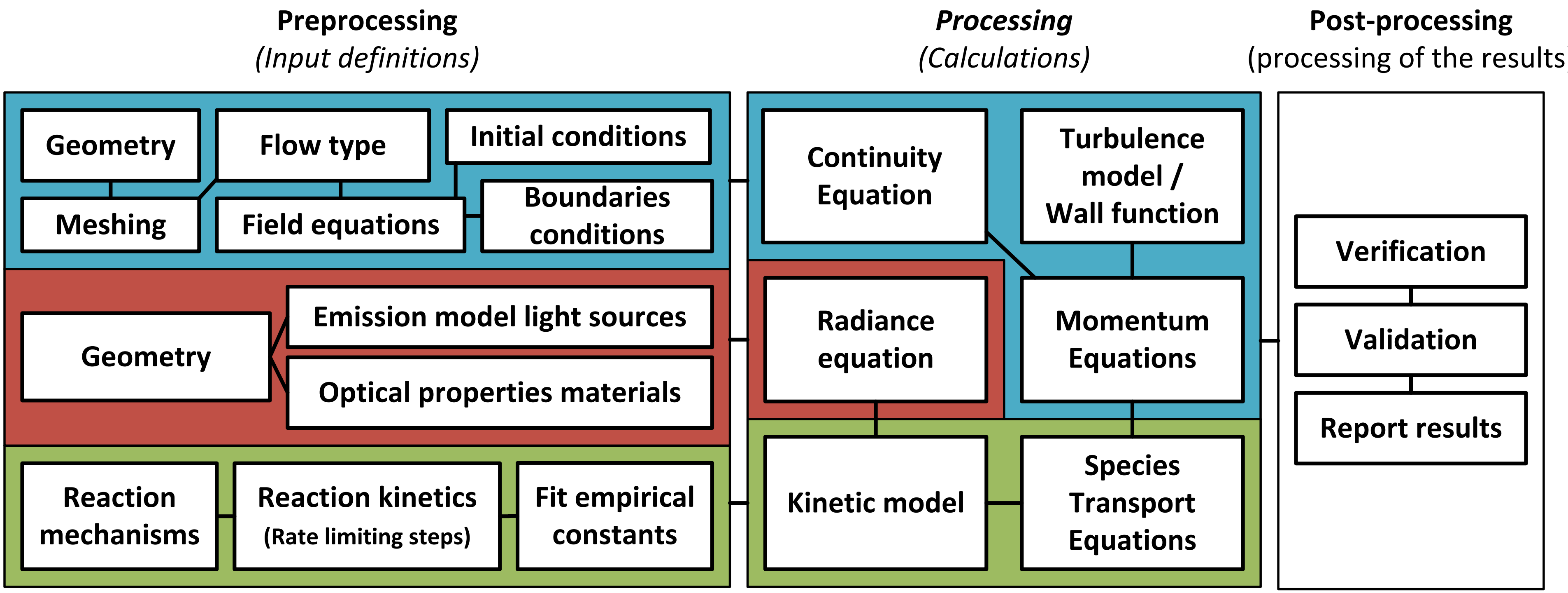
- No radiance model was applied, causing to:
  - Neglect the glass cover in the reactor setup (1)
  - Assume a uniform irradiance distribution during modelling (2)

The concept

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



The framework



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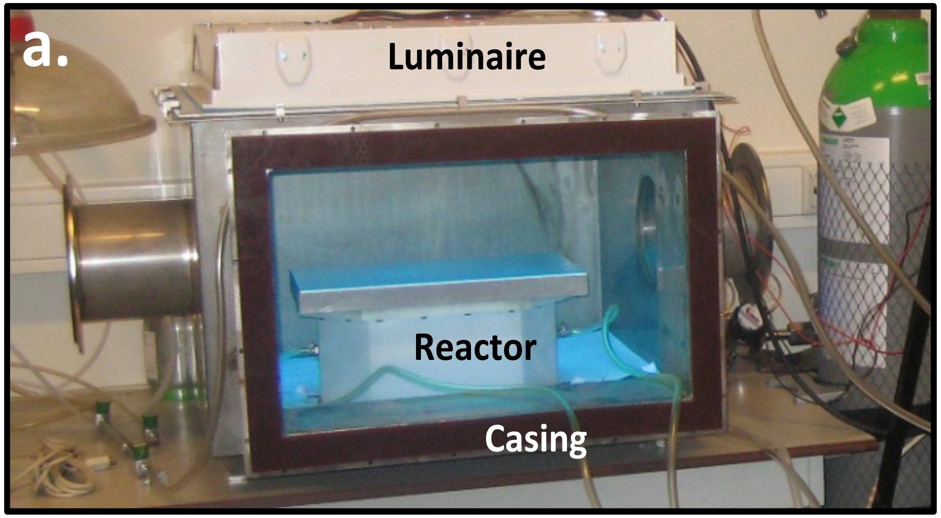
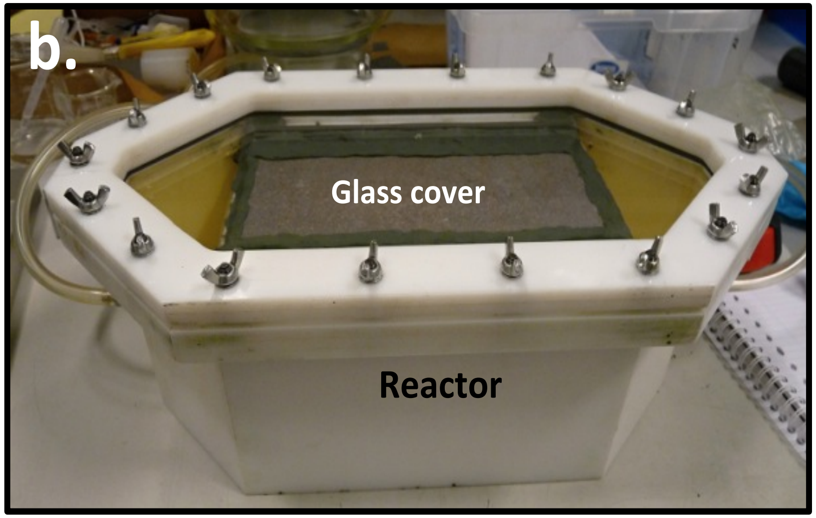
First modeling study of the reactor setup



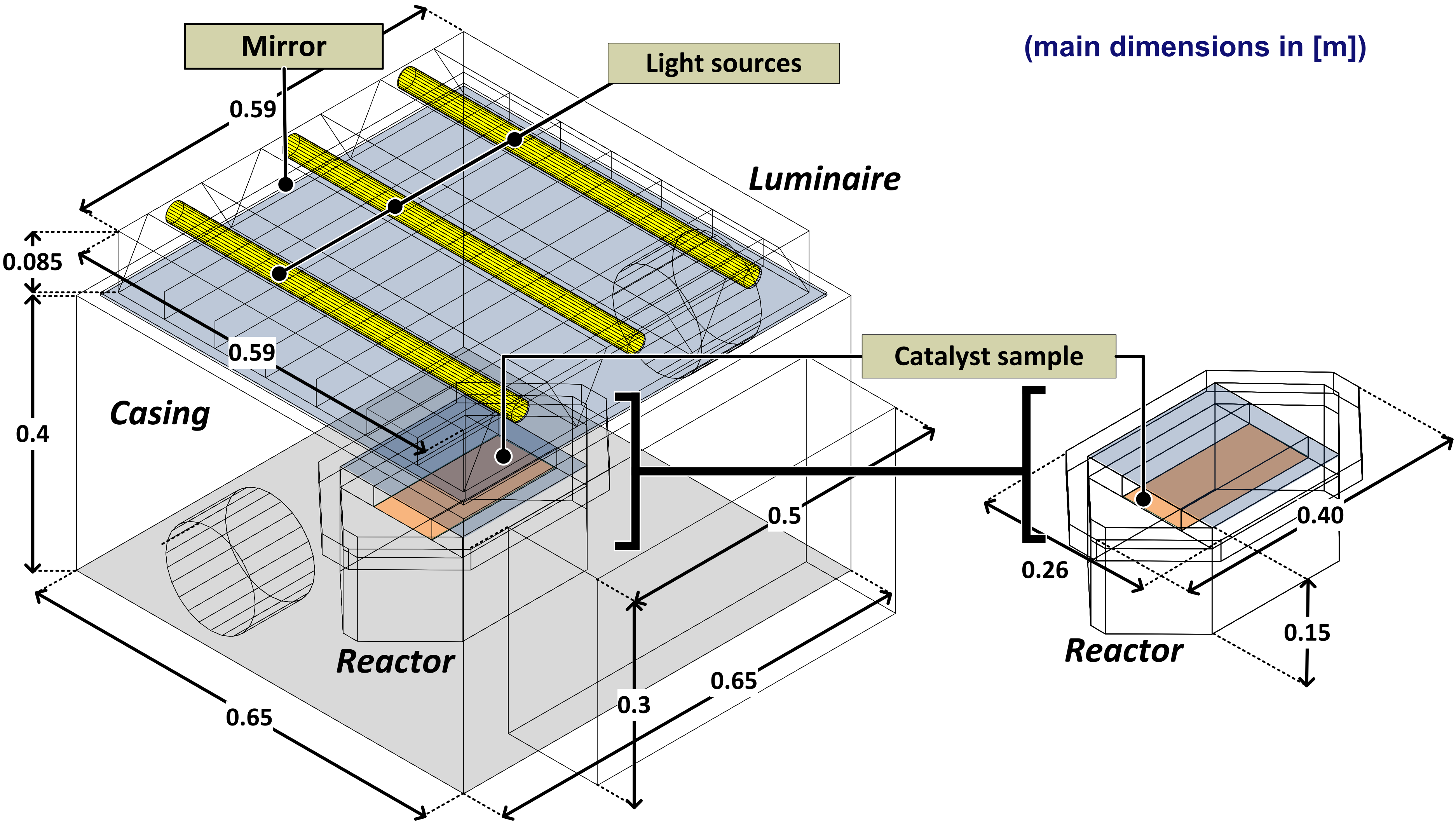
(a) reactor setup



(b) reactor

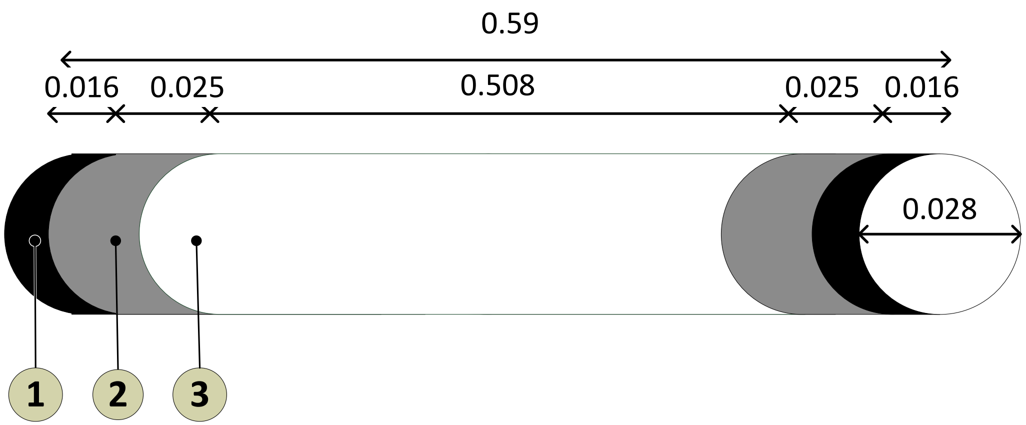
Overview of the reactor setup model

(main dimensions in [m])



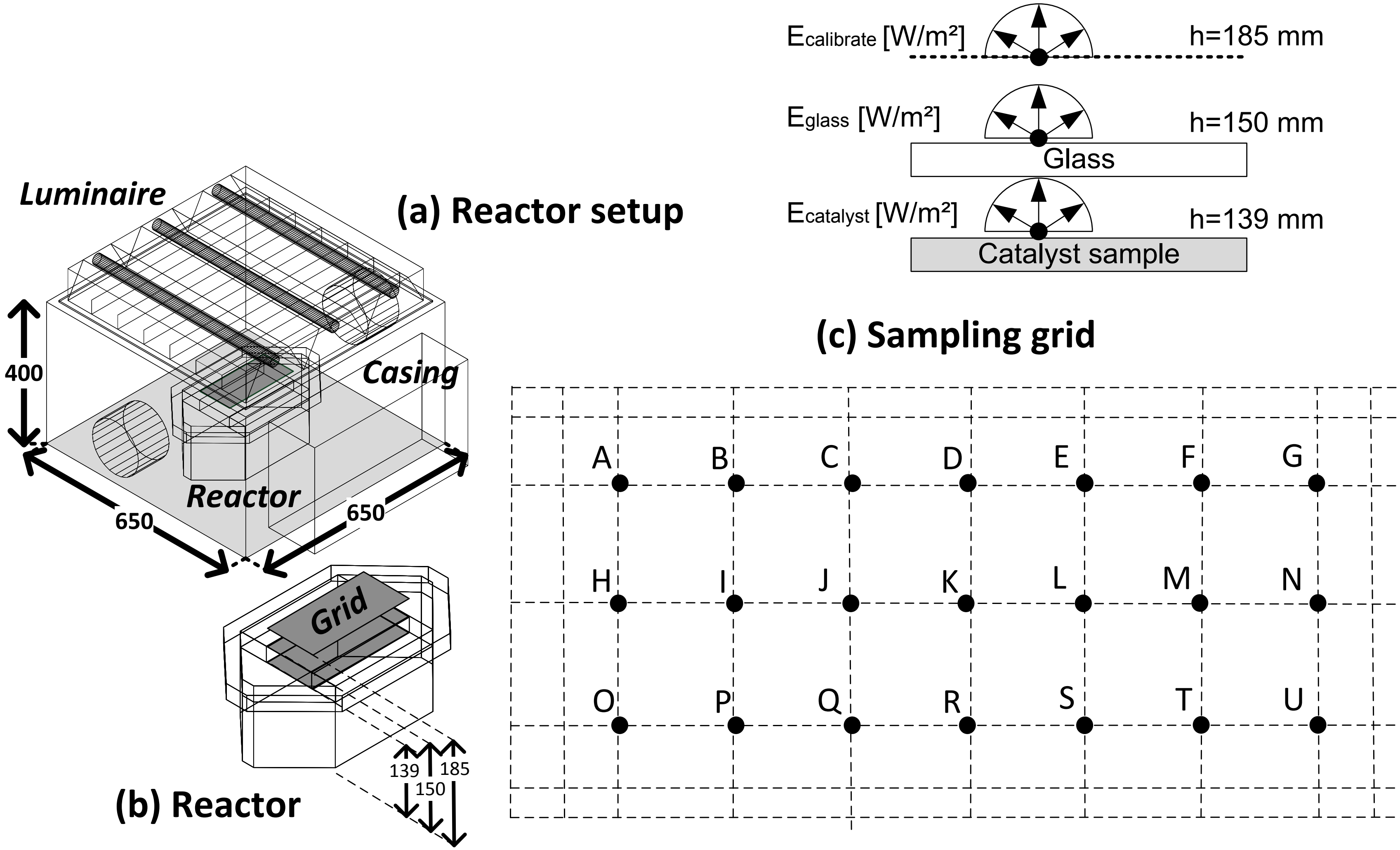
Light source model

- 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

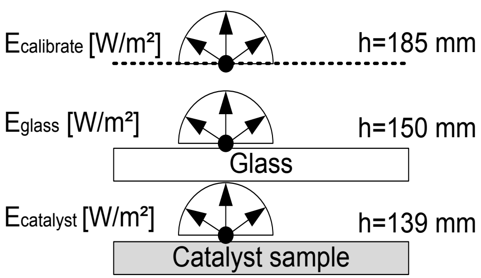


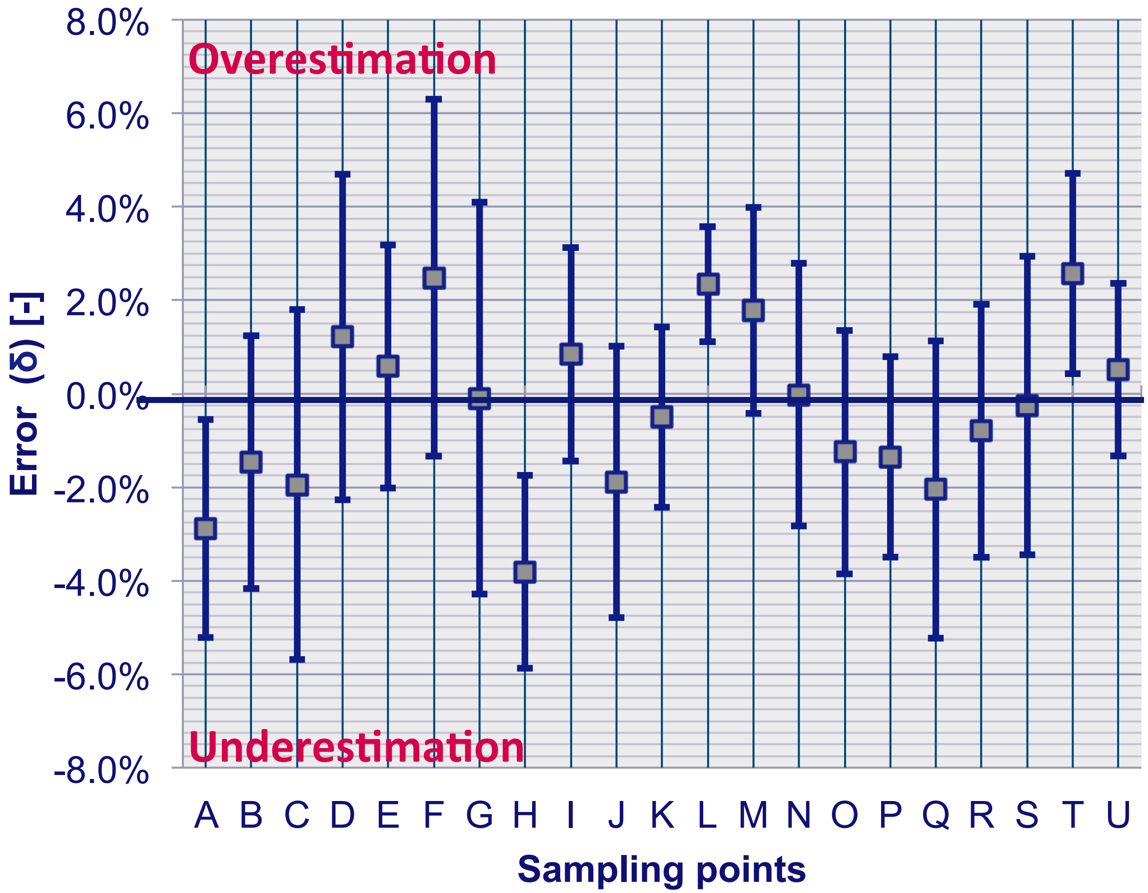
Validation

Transmission coefficient of the glass < 0.9273

Reflection coefficient catalyst surface = 0.88

L_l =34.8 W/(m²sr)

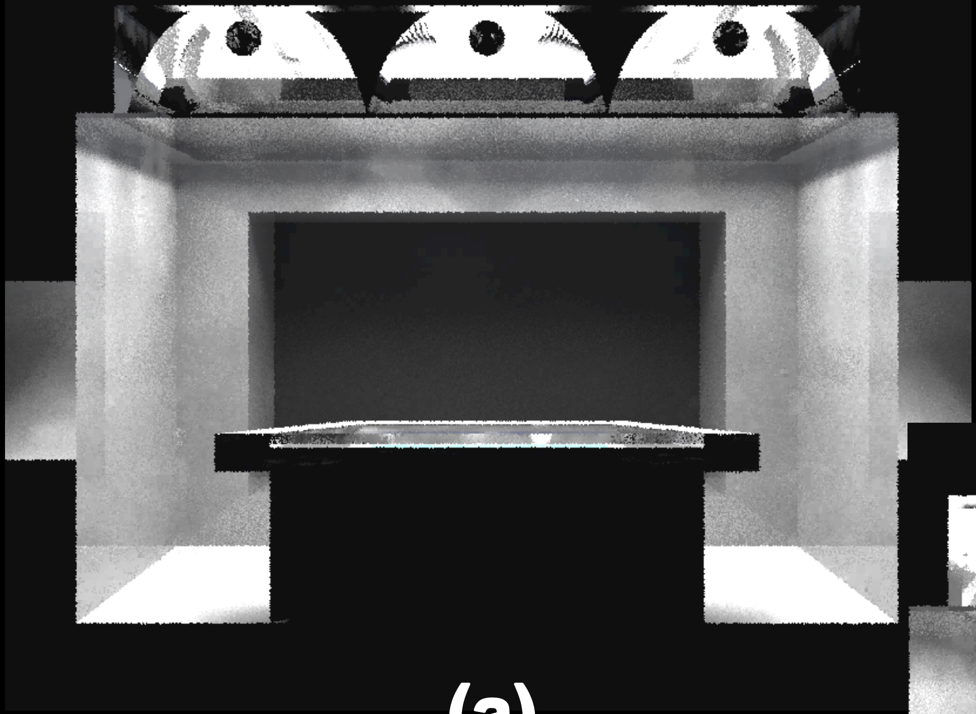





```
(rtrace) -I -ab 5 -dj 1.0 -ds 0.05 -aa 0.1 -ar 256
-st 0.07 -ad 1024 -as 64
```

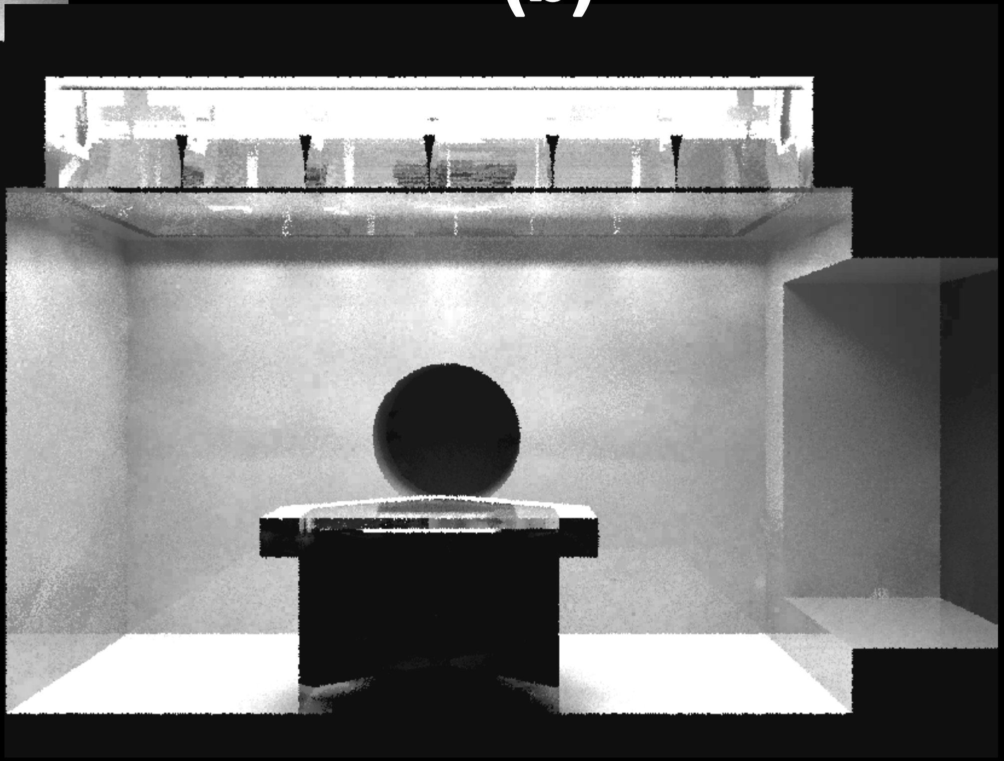
Impression: vertical cross-section

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



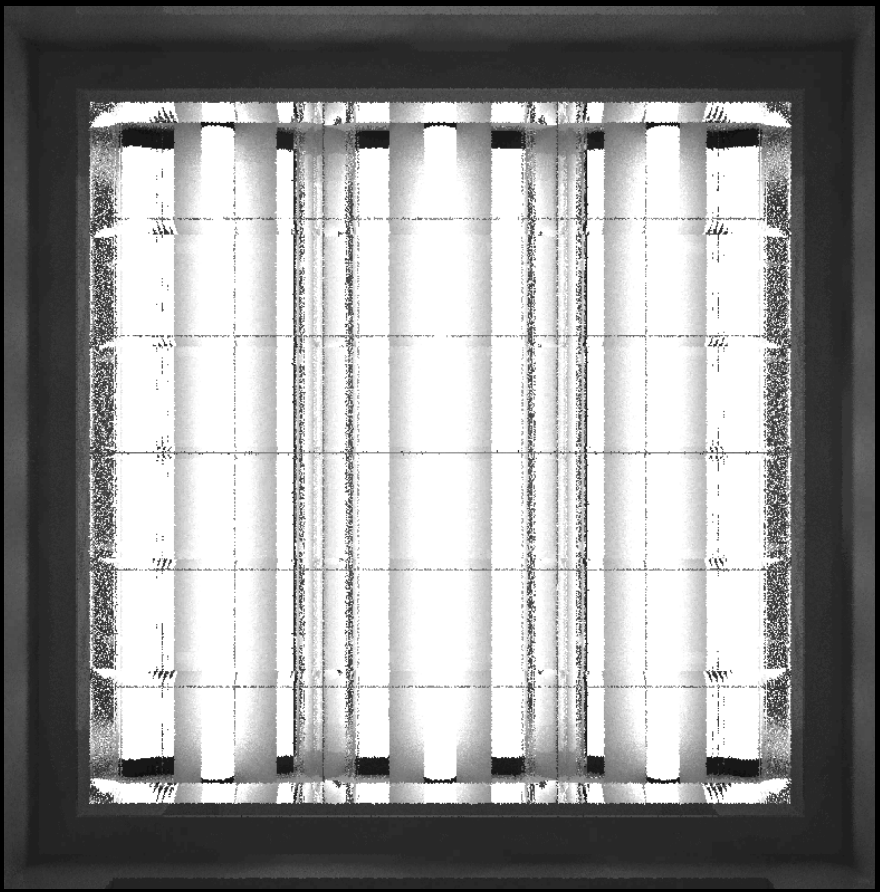
(a)

(b)



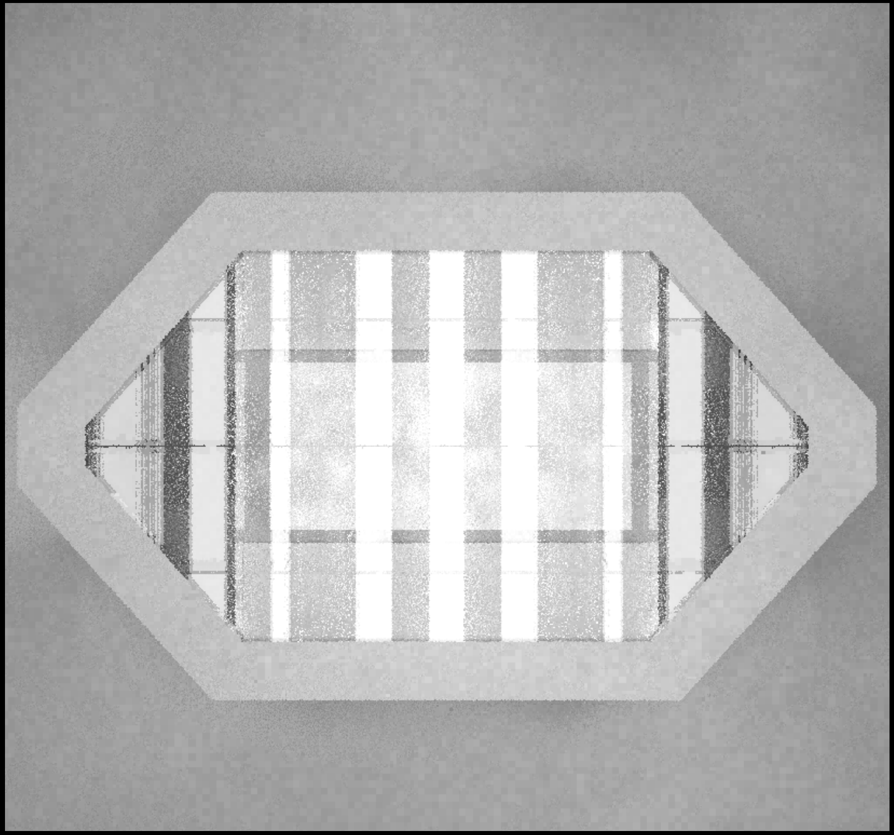
Impression: bottom-top & top-bottom view

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



(a)

(b)



Result of simulation & analytical calculation

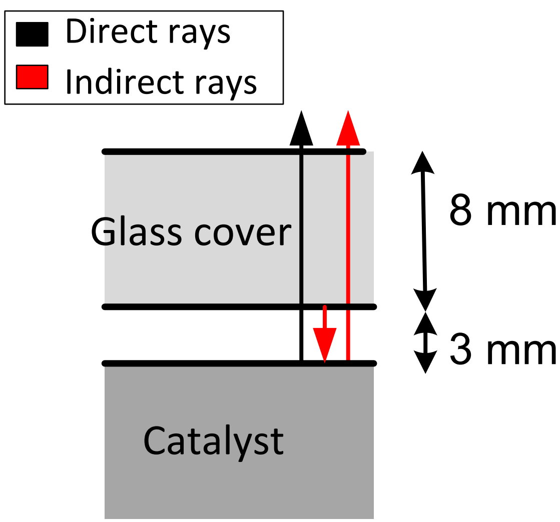
$$\frac{E_{catalyst}}{E_{glass}} = \tau_{direct} + \tau_{indirect}$$

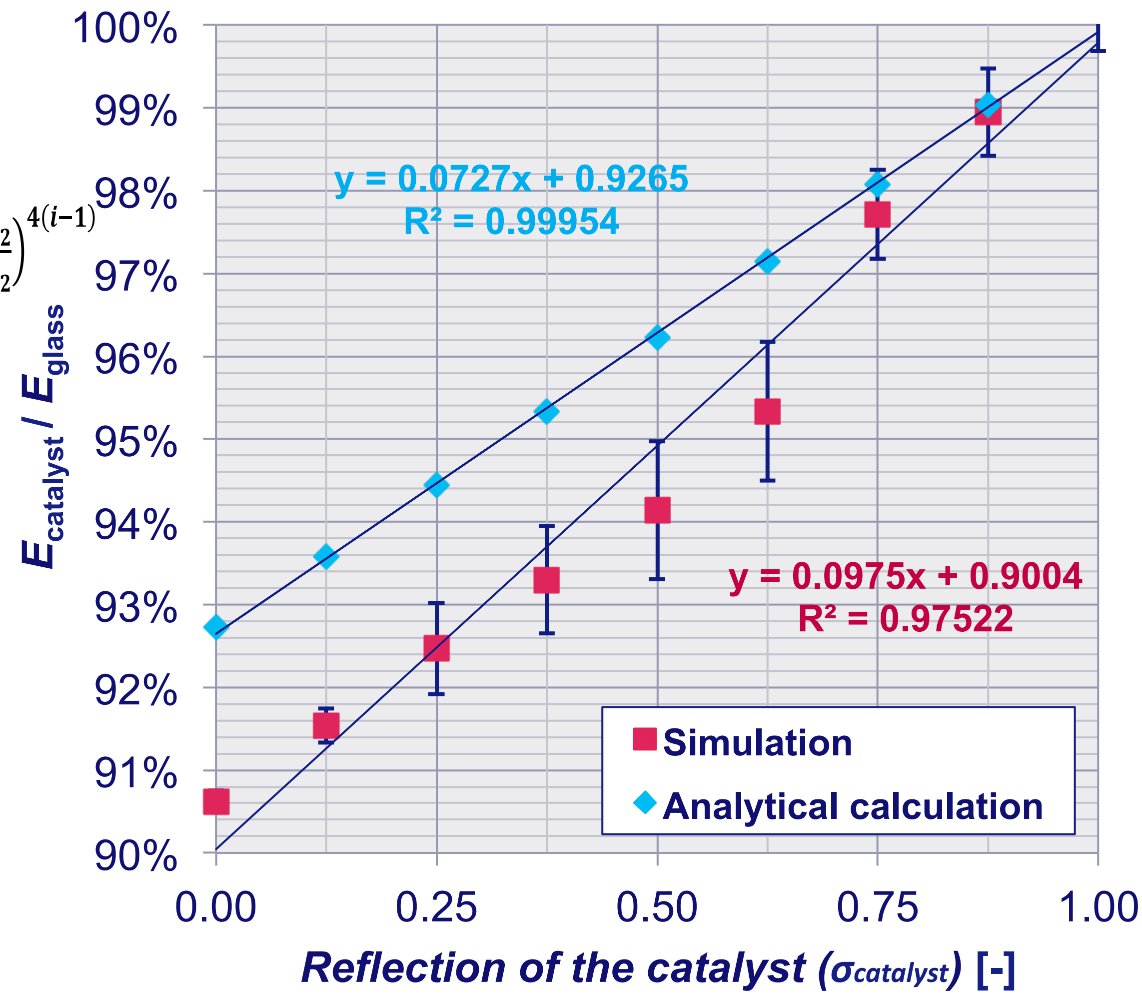
$$\tau_{direct} = \tau_{glass}$$

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

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

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





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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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