Development and Validation of a Radiance model for a Translucent Panel

Photo

Radiance

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Outline

- Online survey on Daylight Simulations
- Previous Radiance Validation Studies
- Translucent Panel Validation
  - Goniophotometer/ Integrating Sphere Measurements
  - Development of a Radiance Material Model
  - Material Model Validation
  - Practical Considerations
- Conclusion

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Survey on the current use of daylight simulations during building design

- **online survey (January 2004)**
- **185 individuals from 27 countries – 20% from Canada, 20% from the United States**
- **"*out of 40 selected tools, over 50% of votes went to Radiance*"**
- **sign up for a copy of survey results if you are interested**

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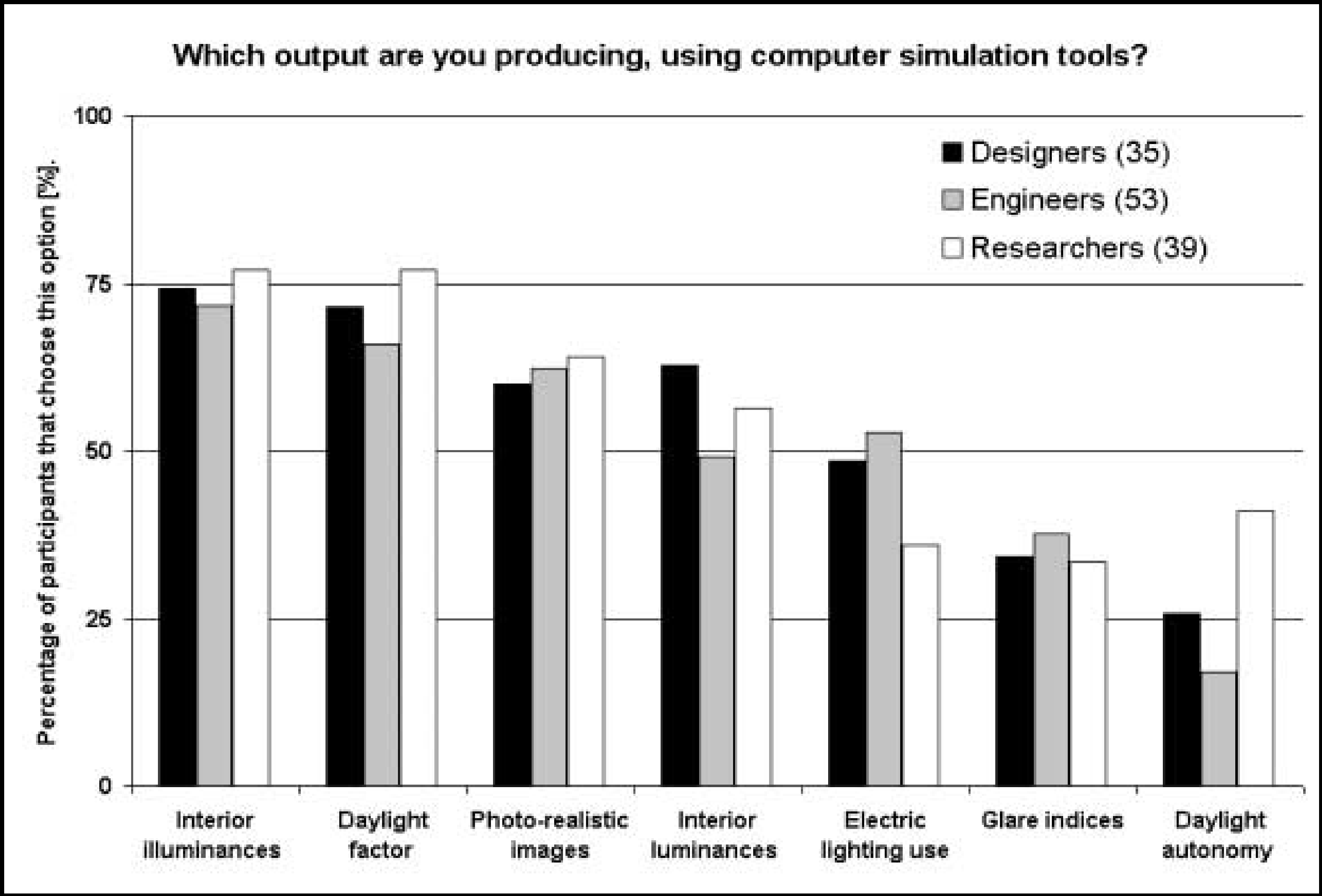
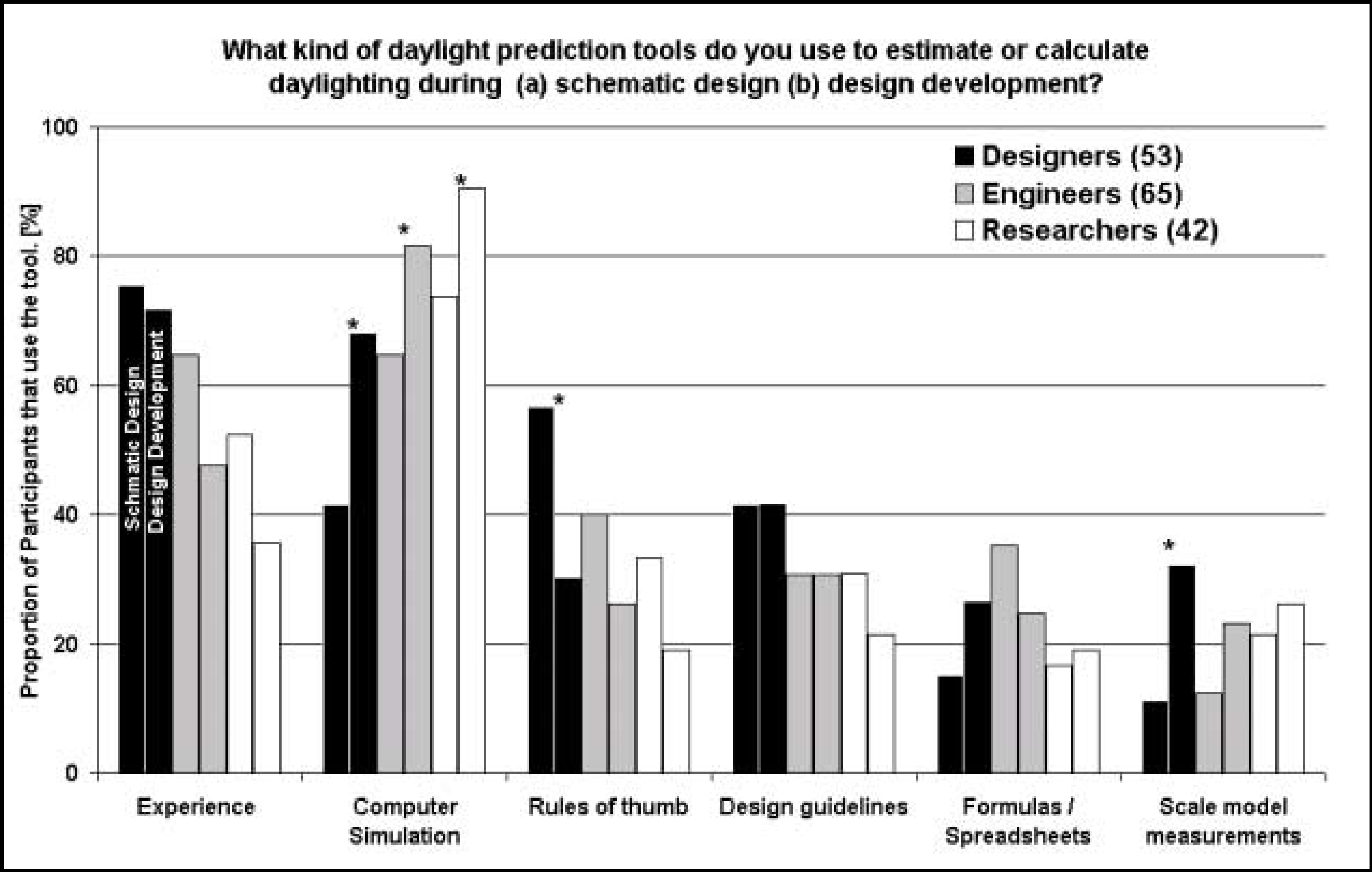
Simulation Output

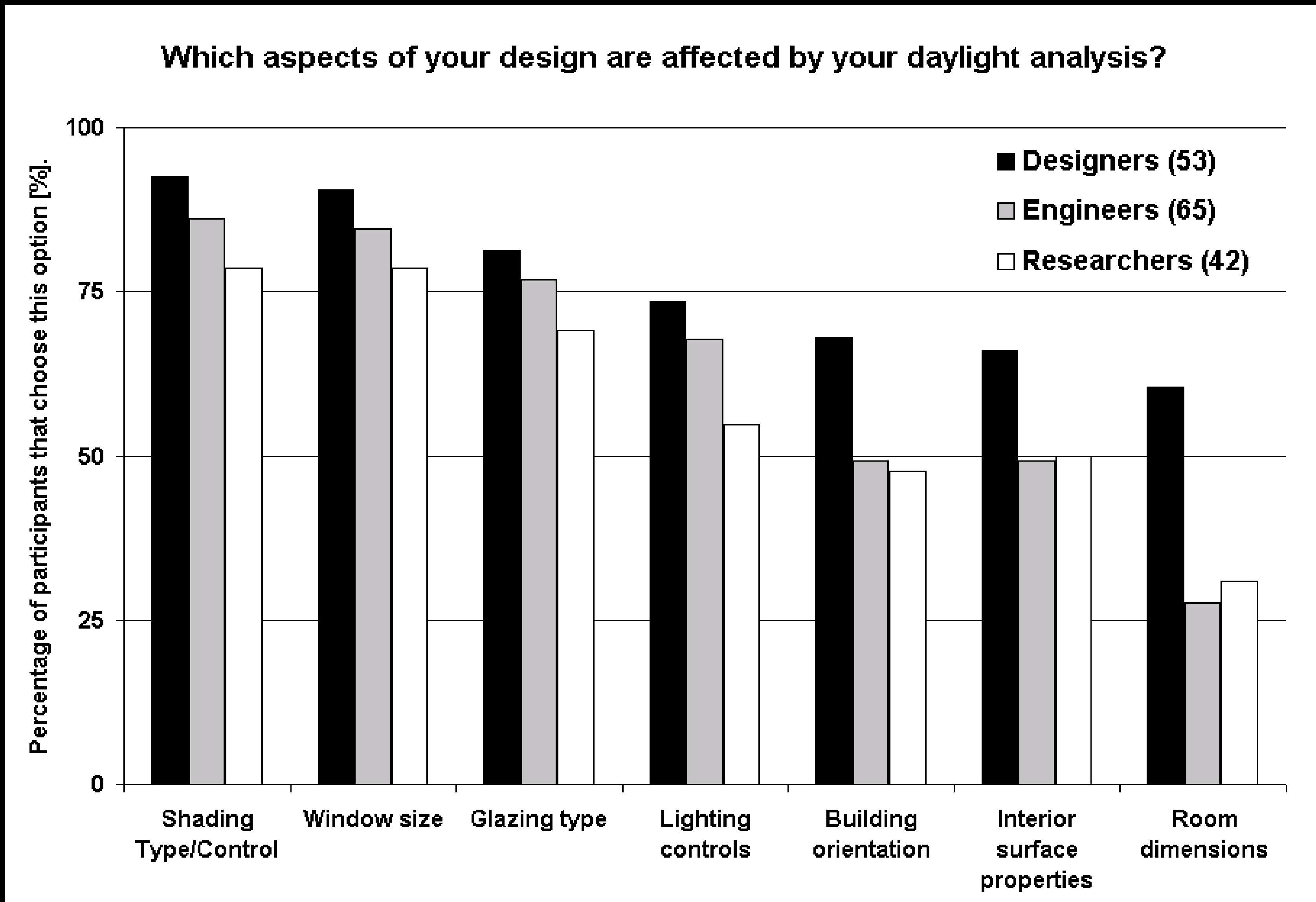


Prediction Tools Used



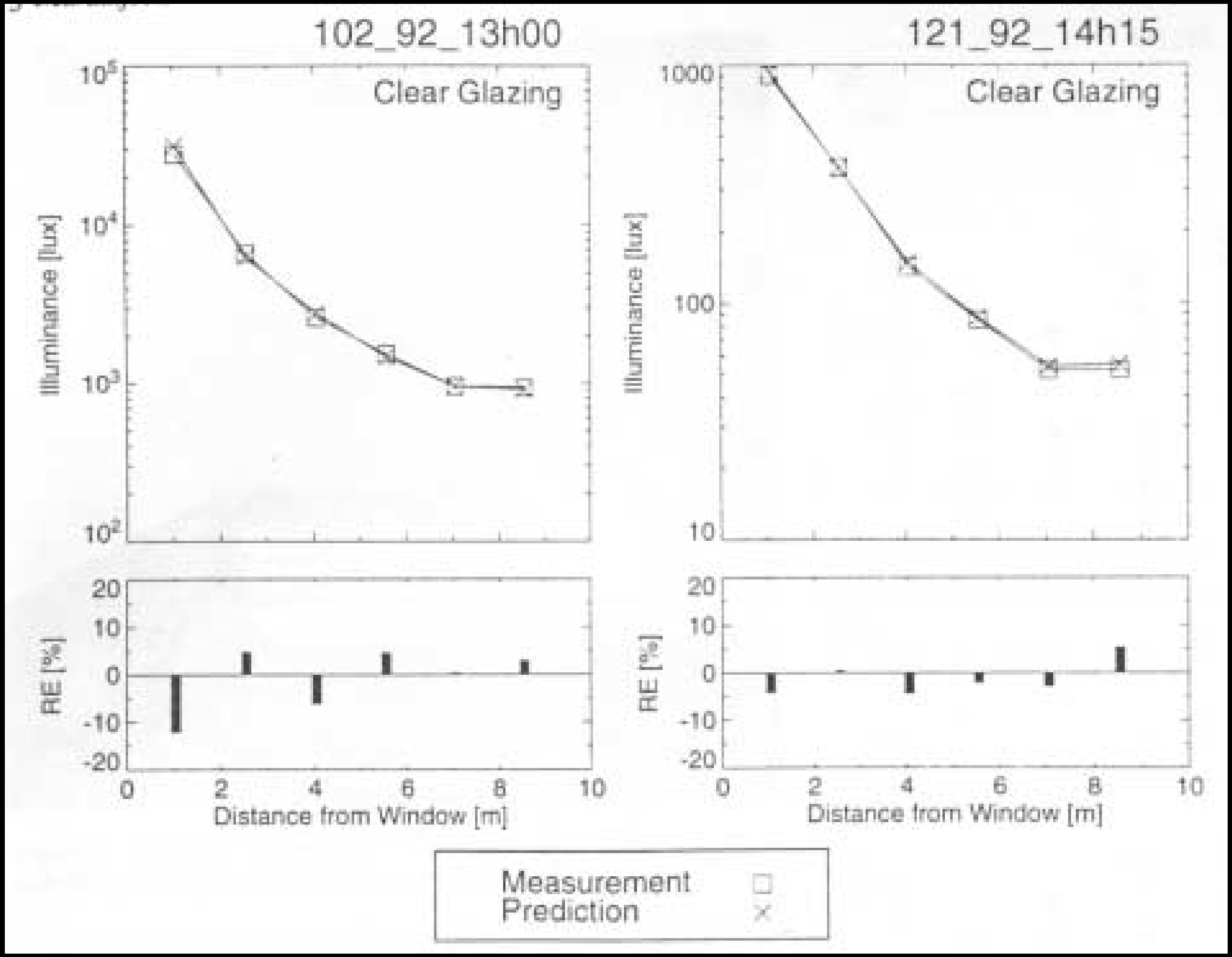
Increased use of simulations during design development… less use of scale models… digitalization is a general trend in building design.

Effected Design Parameters



Previous Radiance Validation Studies

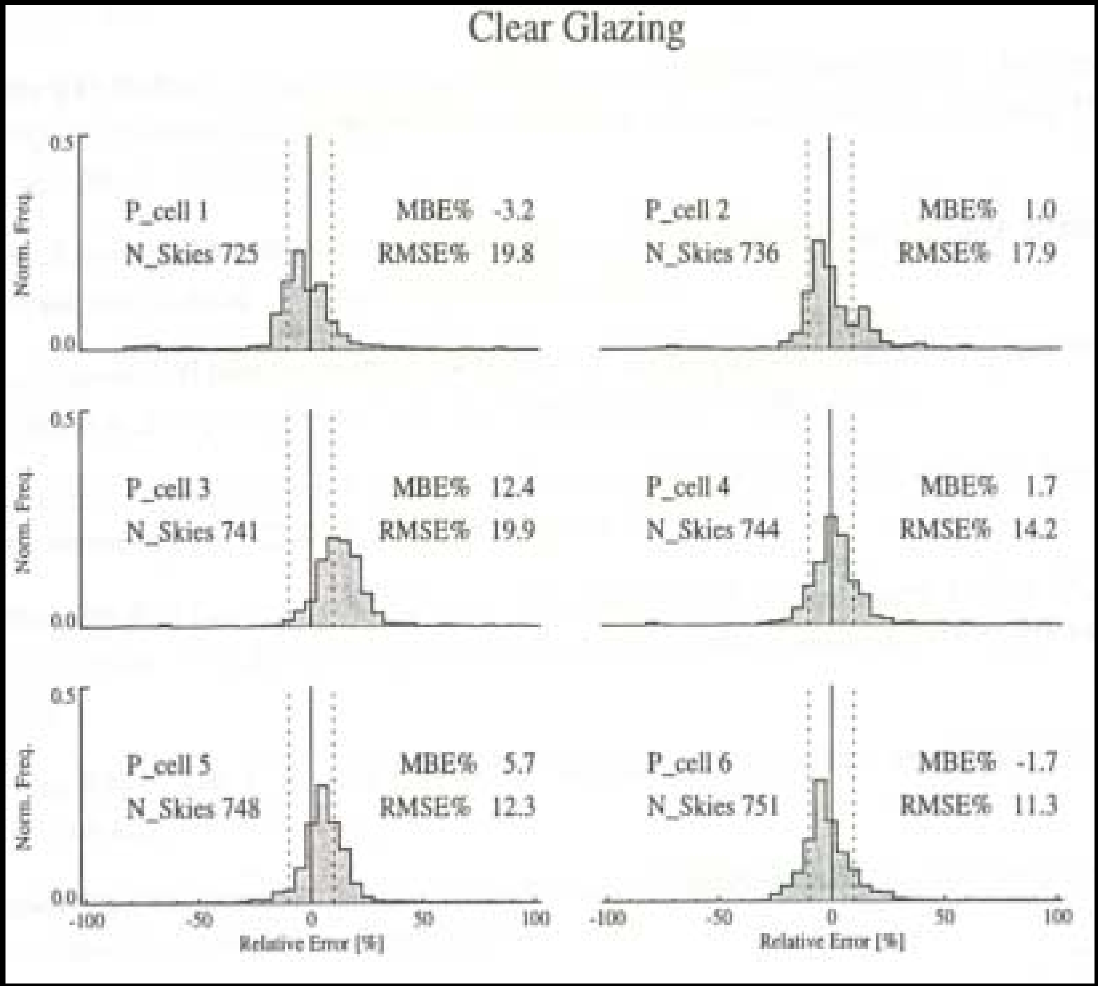
Light. Res. & Technology
Mardaljevic, 1995



Validation Radiance/ sky scanner data for a clear glazing with/without a lightshelf (Radiance materials: "plastic", "metal", "glass")

Previous Radiance Validation Studies

Light. Res. & Technology
Mardaljevic, 2000

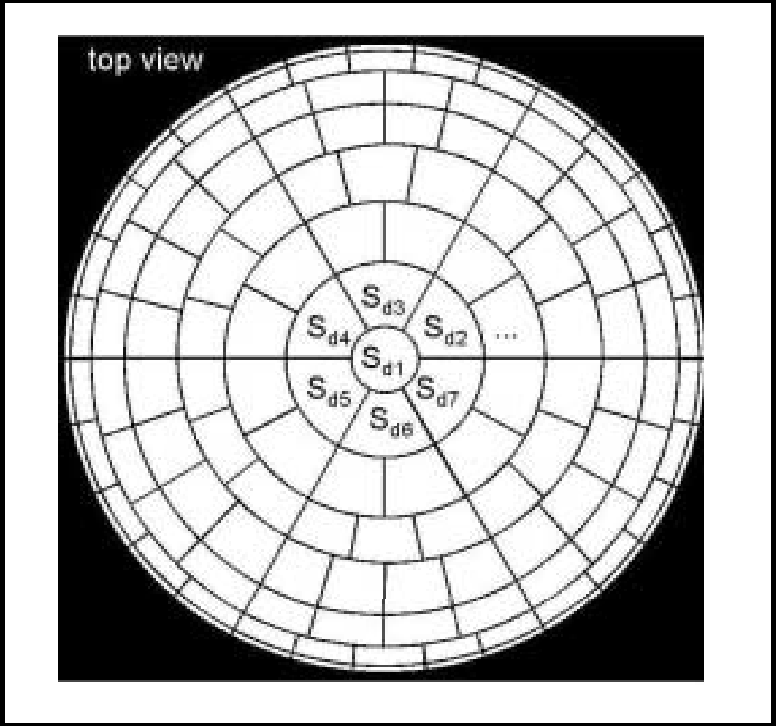


Daylight Coefficients: "same accuracy as standard Radiance"

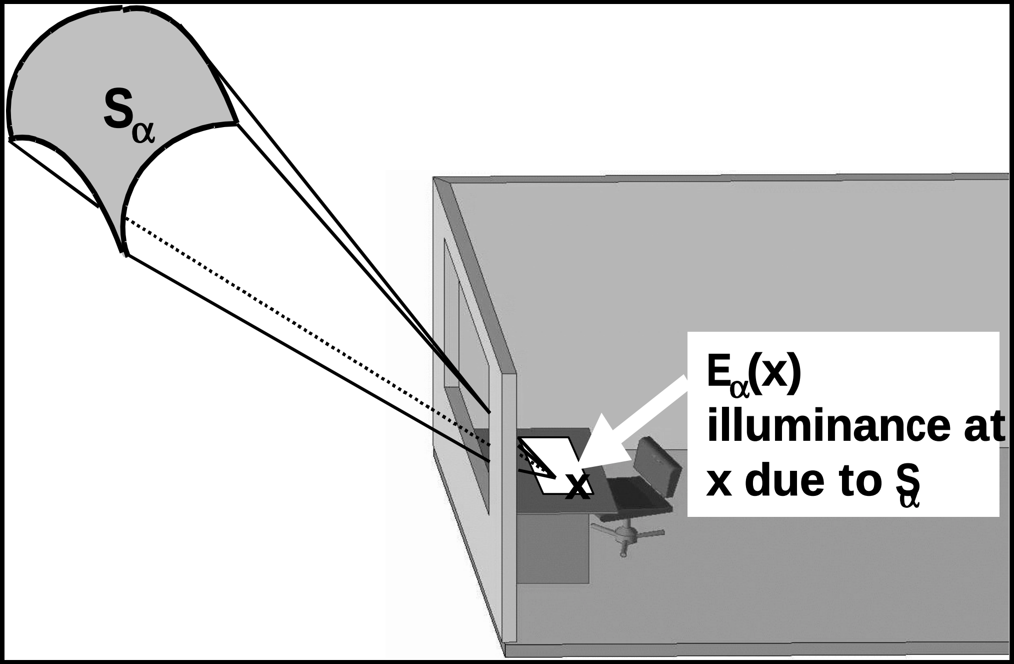
(Radiance materials: "plastic", "metal", "glass")

Daylight Coefficients

(1) Division of the Celestial Hemisphere



(2)Calculate Daylight Coefficients



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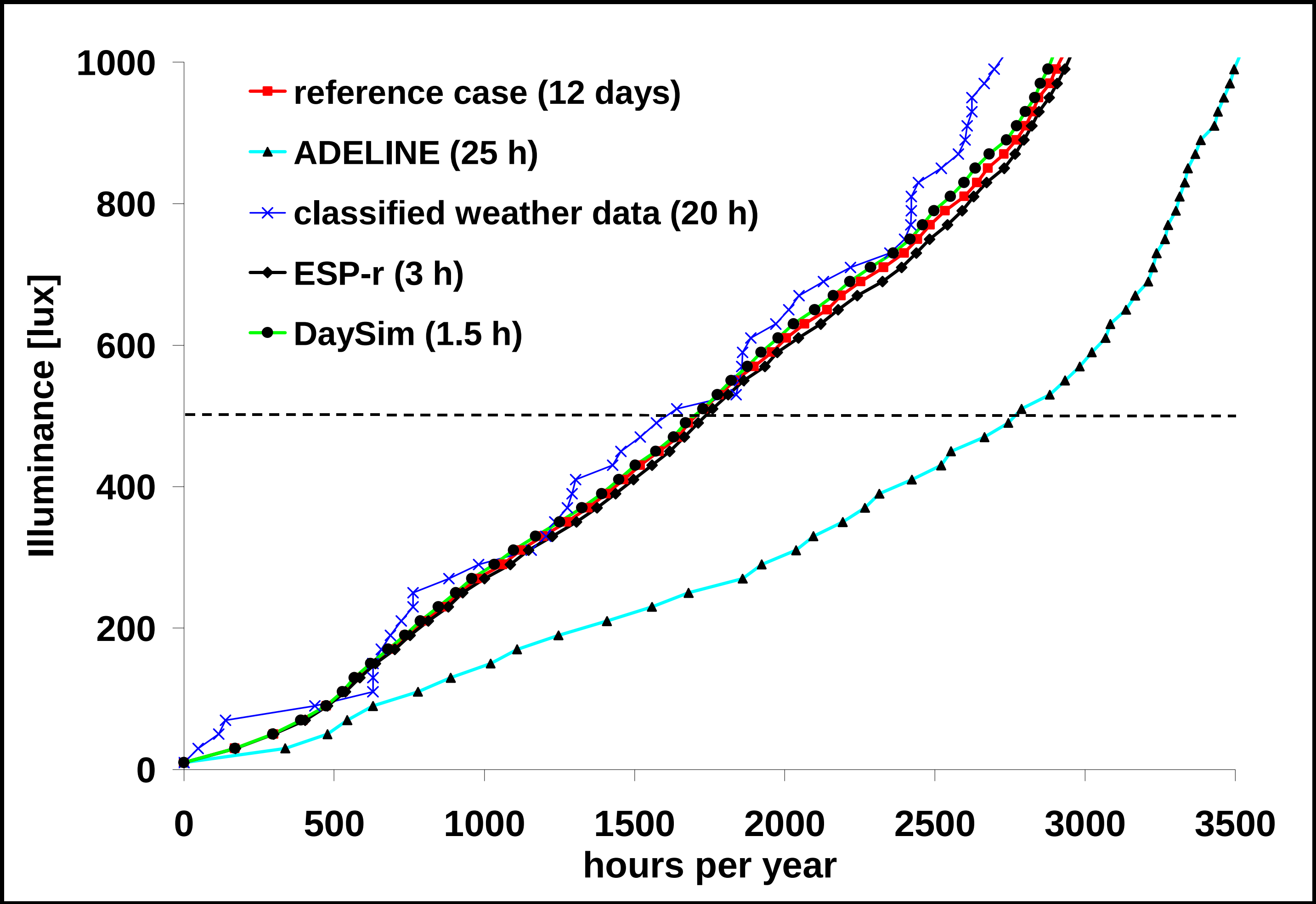
Previous Radiance Validation Studies

Energy & Buildings

Reinhart & Herkel 2000



Daylight Coefficients were the fastest & most accurate dynamic method.

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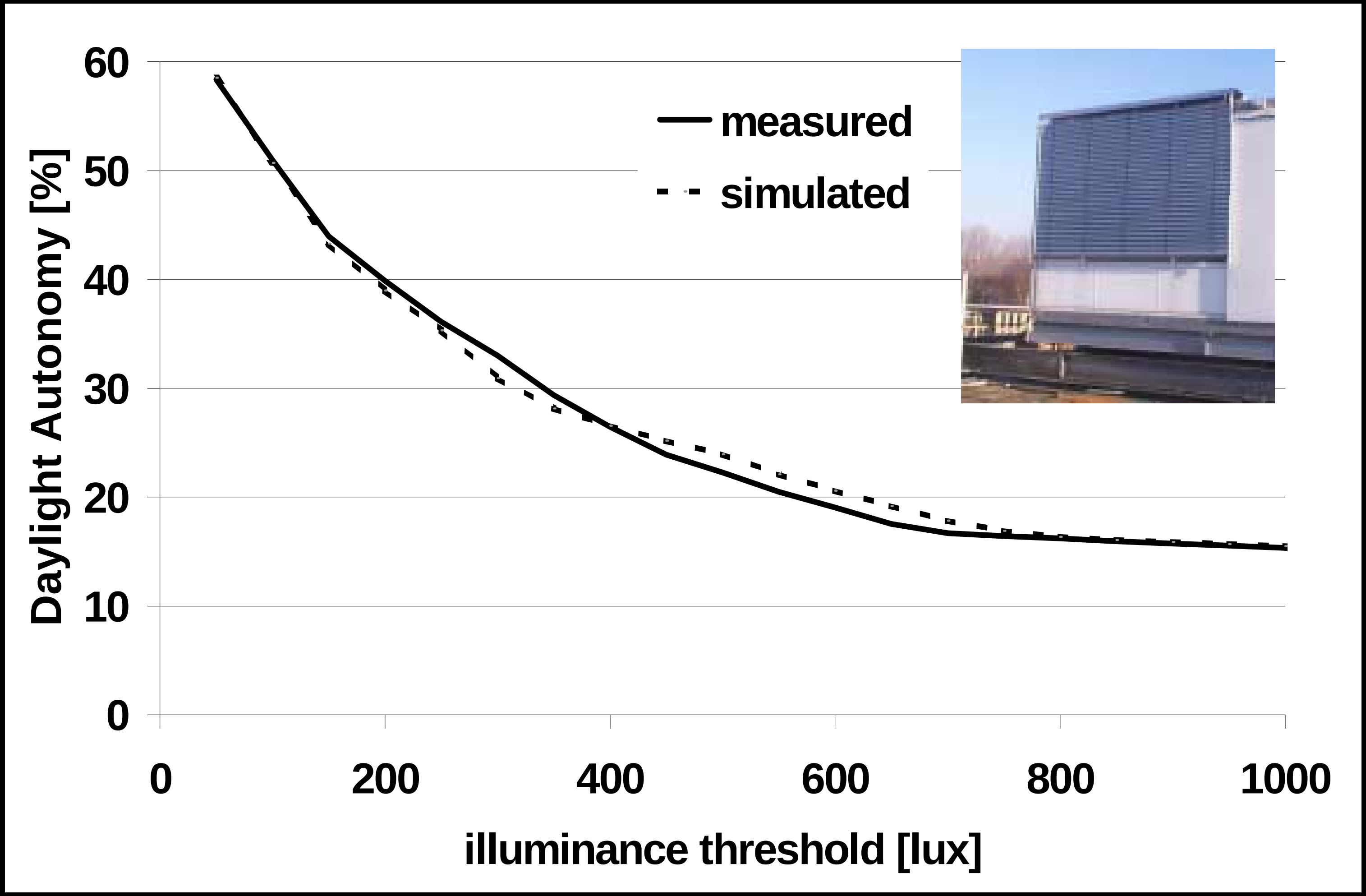
Previous Radiance Validation Studies

Energy & Buildings
Reinhart, Walkenhorst 2001



Radiance & Perez & Daylight Coefficients – venetian blinds

(Radiance materials: “plastic”, “metal”, “glass”)

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Conclusion from Previous Studies

- The combination Perez/Radiance/Daylight Coefficients is capable of accurately modeling the short time step development of indoor illuminances due to daylight for complex geometries and "plastic", "metal", and "glass" type materials.

- Good accuracy corresponds to a MBE ~10% and a RMSE of ~25%. The simulation errors for the sky model and the raytracing algorithm are of the same order of magnitude.

- Simulations of ceiling sensors tend to be less accurate (MBE ~20%, RMSE 30%) as they require detailed modeling of surrounding buildings and ground.

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Validation Study: Objectives

- to increase the number of validated Radiance material modifiers to include translucent glazings,
- present a general methodology of how to derive a Radiance material model of a translucent panel based on goniophotometer and integrating sphere measurements, and
- to validate the resulting Radiance model in a full scale test room.

Kalwall Validation: Methodology

- Goniophotometer & Integrating Sphere Measurements
- Development of a Radiance model
- Test-room measurements
- Radiance/Perez validation

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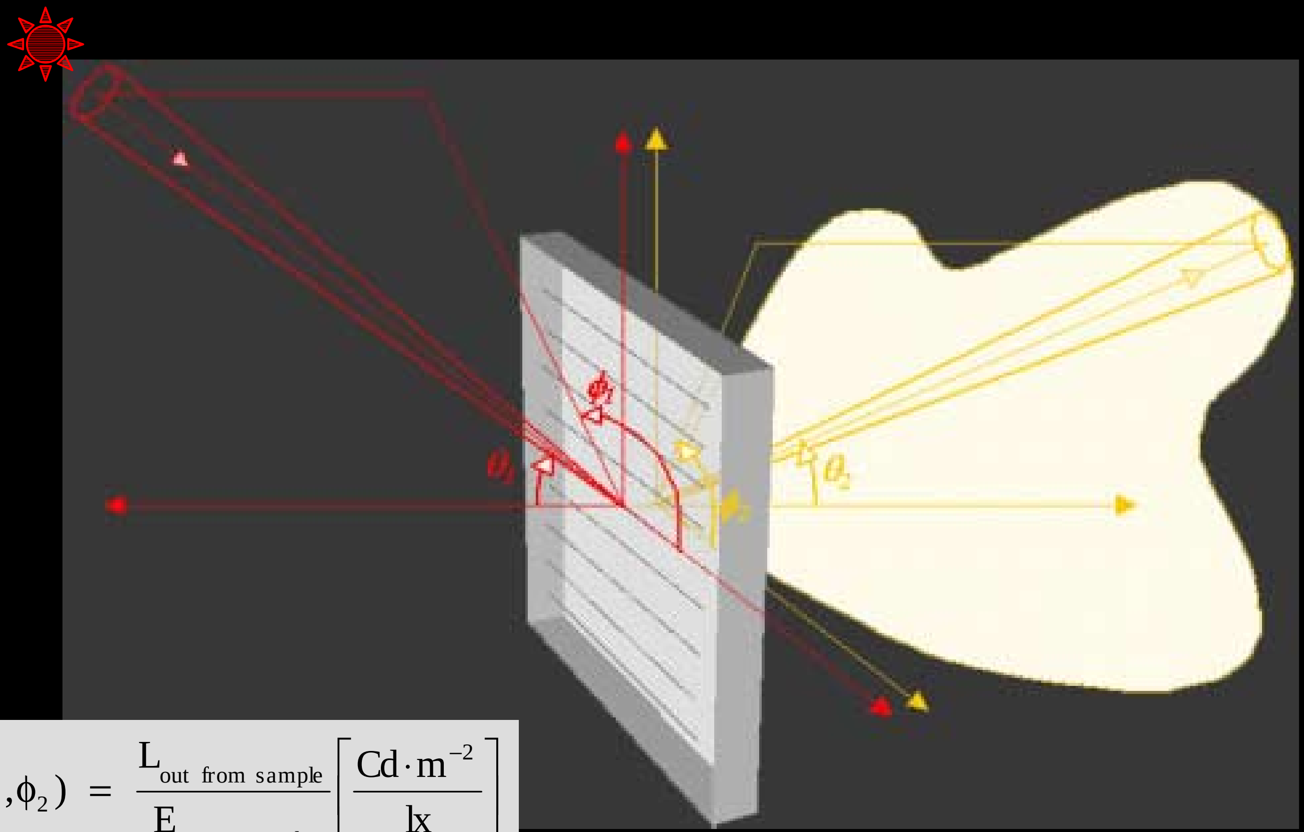
Goniophotometer measurements

Light redirecting systems assessment

- BRDF or BTDF = light distribution after reflection or transmission, for each incident direction



$$\mathrm{BT(R)DF}\ (\theta_1,\phi_1,\theta_2,\phi_2) = \frac{L_{\text{out from sample}}}{E_{\text{inc on sample}}} \left[\frac{\mathrm{Cd}\cdot\mathrm{m}^{-2}}{\mathrm{lx}}\right]$$

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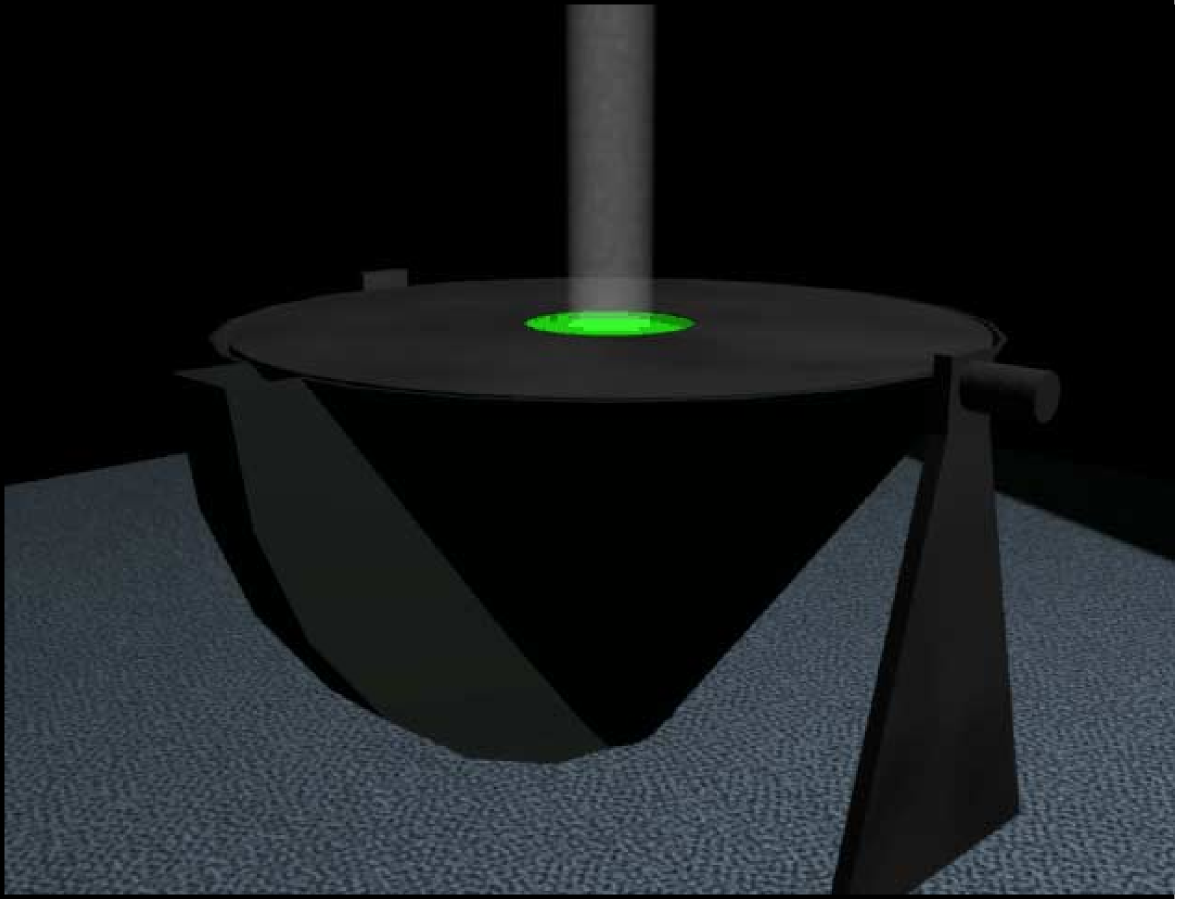
EPFL bidirectional goniophotometer

- Functioning principle: Transmission



courtesy of M. Andersen

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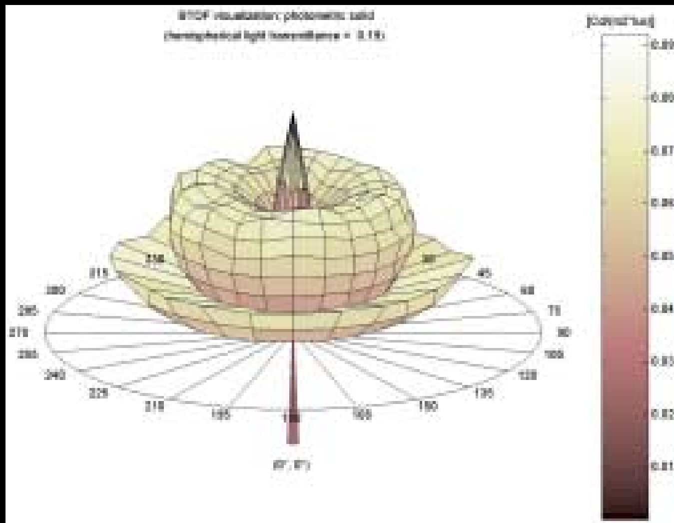
The Sample

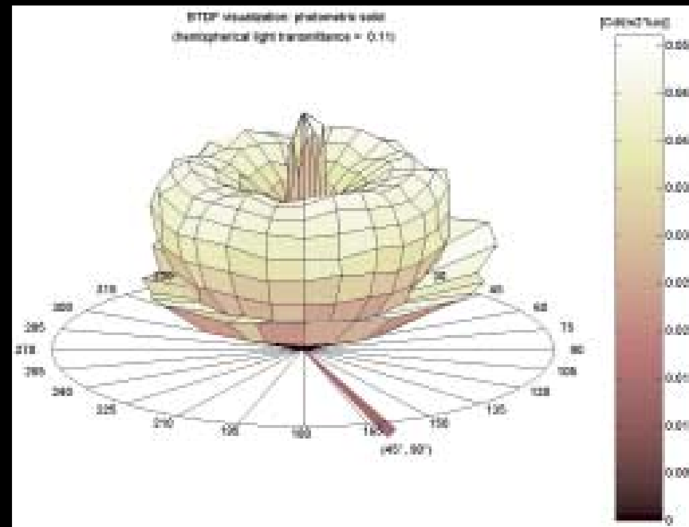
exterior

Interior

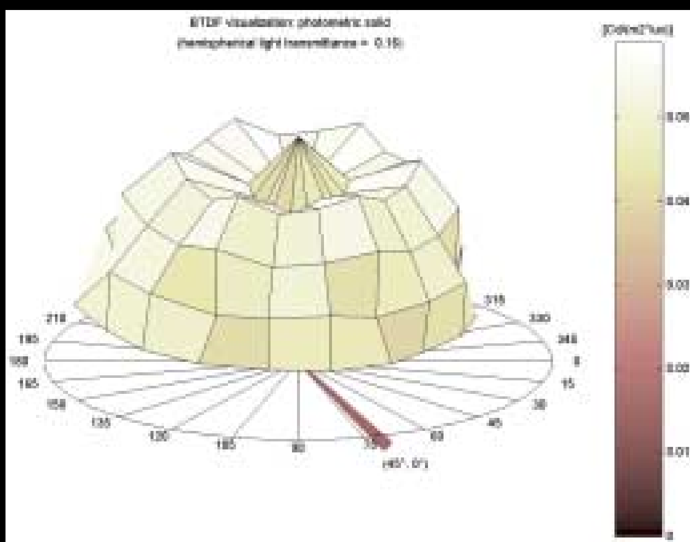
Goniophotometer Measurements I



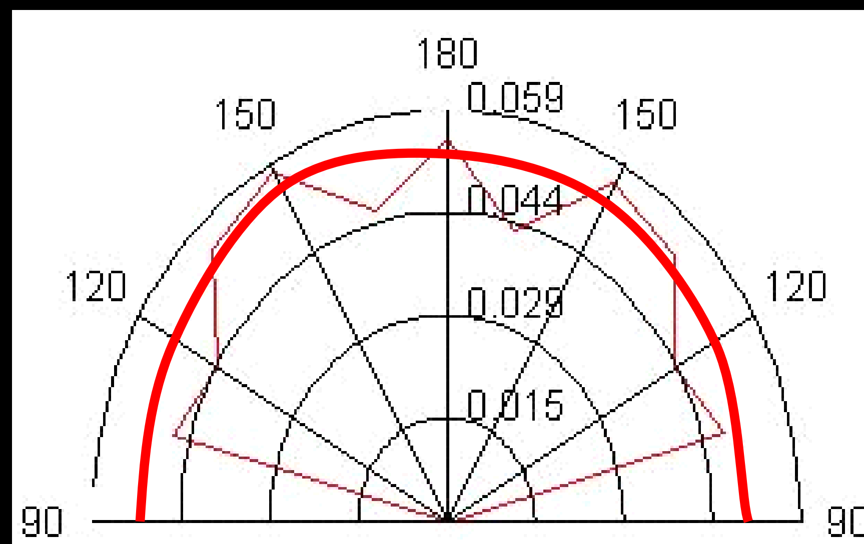
BTDF along $\theta_{incident}$=0º, $\phi_{incident}$ =0º, Ø = 150 mm



BTDF along 45º, 90º, Ø = 150 mm



BTDF along 45º, 0º, Ø = 280 mm



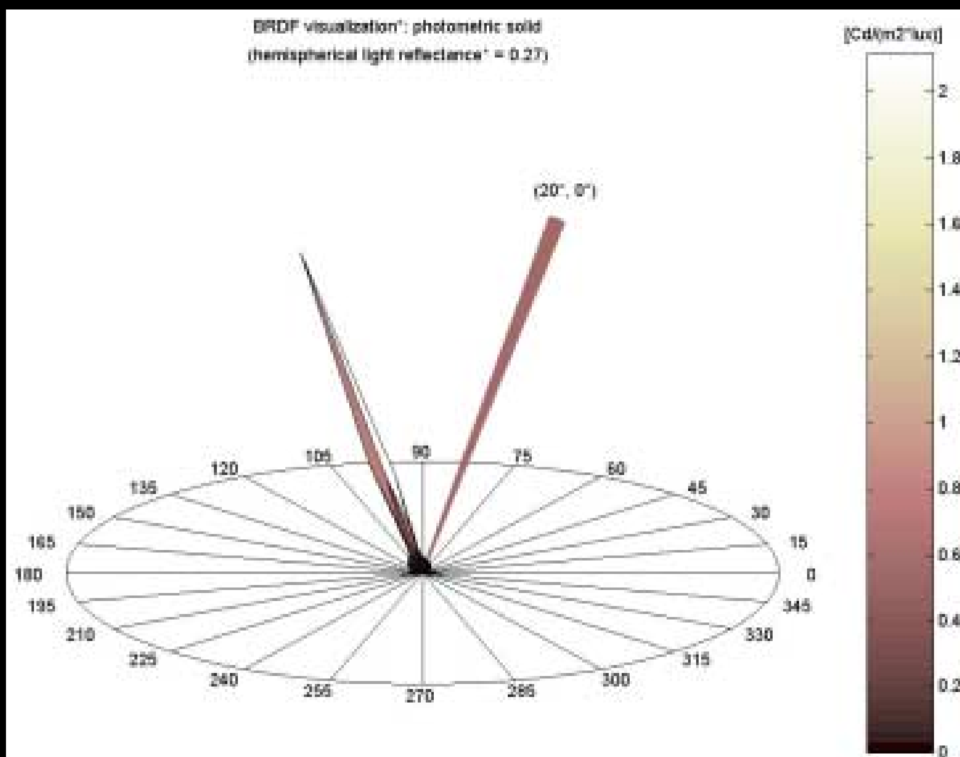
BTDF along 45º, 0º (section view), Ø = 280 mm

- **two diaphragm sizes used: 150mm and 280mm (tradeoff between edge effects and signal to noise ratio)**

Goniophotometer Measurements II

Approximation: The system is rotationally invariant (no variation with either the incident or the emerging azimuth angles).

The spatial heterogeneity in diffusion being due to the framing and size of the analyzed sample as well as to the limitations of the experimental equipment, the system can reasonably be considered as a good diffuser.



BRDF along 20°, 0°, Ø = 150 mm

BRDF:

mean diffuse refl. 21%

specular refl. 8%

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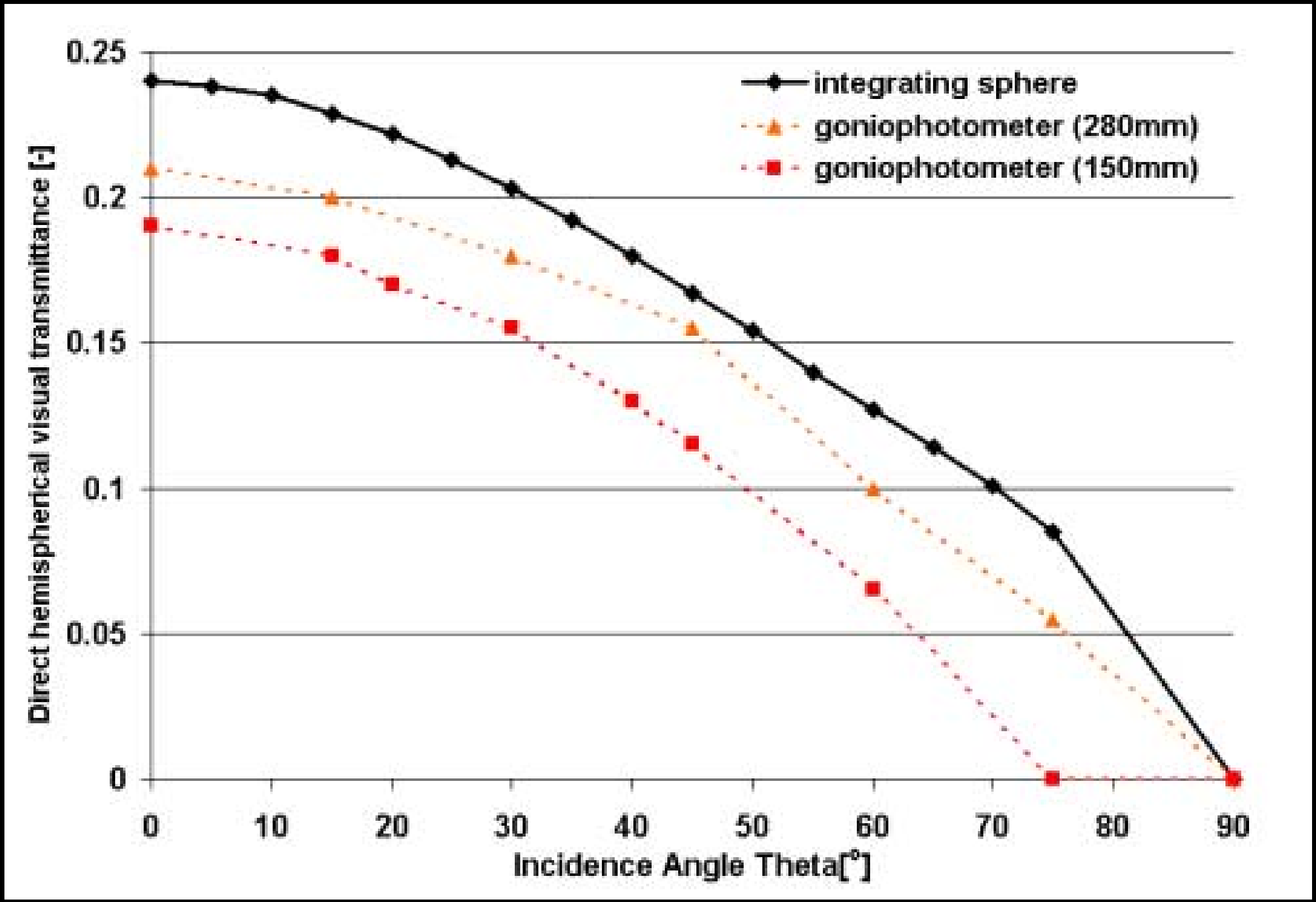
Direct hemispherical Transmittance



- an ideal diffuser would have a constant function.
- direct normal hemispherical transmittance 24%

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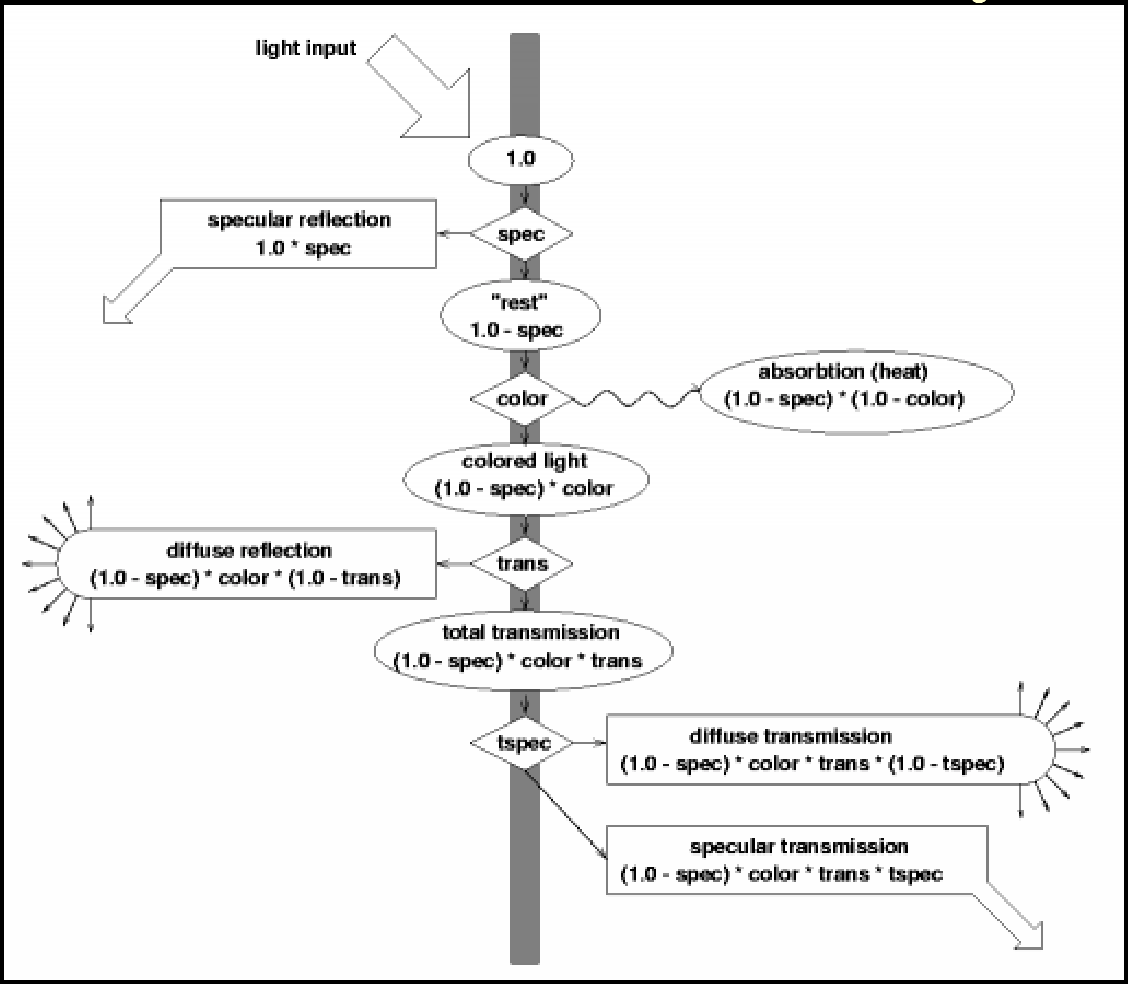
“trans”and “transdata”

Website - Georg Mischler



- “trans” describes an ideal diffuser.
- “transdata” allows to specify an angle dependant transmittance. **Caveat:** The function file onlies apply to direct sunlight and not to diffuse daylight.

$trans_{24\%}$

```
# RADIANCE "trans" model of a translucent panel assuming
# only direct normal hemispherical transmittance is available
# R_d = C_r = C_g = C_b = 0.21 = diffuse reflectance
# R_s = A_4 =0.08 = specular reflectance
# S_r = 0.0 = surface roughness
# T_d = 0.24 = direct normal diffuse hemispherical transmittance
# T_s = 0 = transmitted specularity (ideal diffuser)
# A_7 = T_s/(T_d+T_s) = 0
# A_6 = (T_d+T_s)/(R_d+T_d+T_s) = 0.5333
# A_5 = S_r = 0
# A_1 = A_2 =A_3 = R_d/((1-R_s)*(1-A_6)) = 0.48913
# S_t = A_6*A_7*(1-A_1)*A4 = 0
# resulting Radiance material:
void trans PANEL
0
0
7 0.48913 0.48913 0.48913 0.08 0  0.5333 0
# A1      A2      A3      A4   A5 A6     A7
```

trans$_{16\%}$

\# RADIANCE “trans” model of a translucent panel assuming
\# only direct normal hemispherical transmittance is available
\# R_d = C_r = C_g = C_b = 0.21 = diffuse reflectance
\# R_s = A_4 =0.08 = specular reflectance
\# S_r = 0.0 = surface roughness
\# T_d = 0.16 = diffuse – diffuse transmittance
\# T_s = 0 = transmitted specularity (ideal diffuser)
\# …
void trans PANEL
0
0
7 0.40446 0.40446 0.40446 0.08 0 0.435635 0
\# A1 A2 A3 A4 A5 A6 A7

“transdata”

```
void transdata PANEL
4 noop refl.dat rang.cal rang
0
6 0.40446 0.40446 0.40446 0.08 0.435635 1
```

refl.dat

```
##### HEADER #####
# one-dimensional data array
1
# irregularly spaced axis:
# two zeros – number of divisions – division values
0 0 17
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 90
##### Body #####
# Data values:
0.471279687
0.467352356
0.46146136
0.449679368
0.43593371
0.418260722
0.398624068
0.377023749
0.353459765
0.327931838
0.302404466
0.274913151
0.249385501
0.223857851
0.198330201
0.166911556
0
```

rang.cal

```
{ Compute incident angle in degrees (from either side) }
rang(dx,dy,dz) = 180/PI*Acos(abs(Nx*dx+Ny*dy+Nz*dz));
```

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Validation Measurements

NRC Daylighting Lab

"hedge" with black cloth

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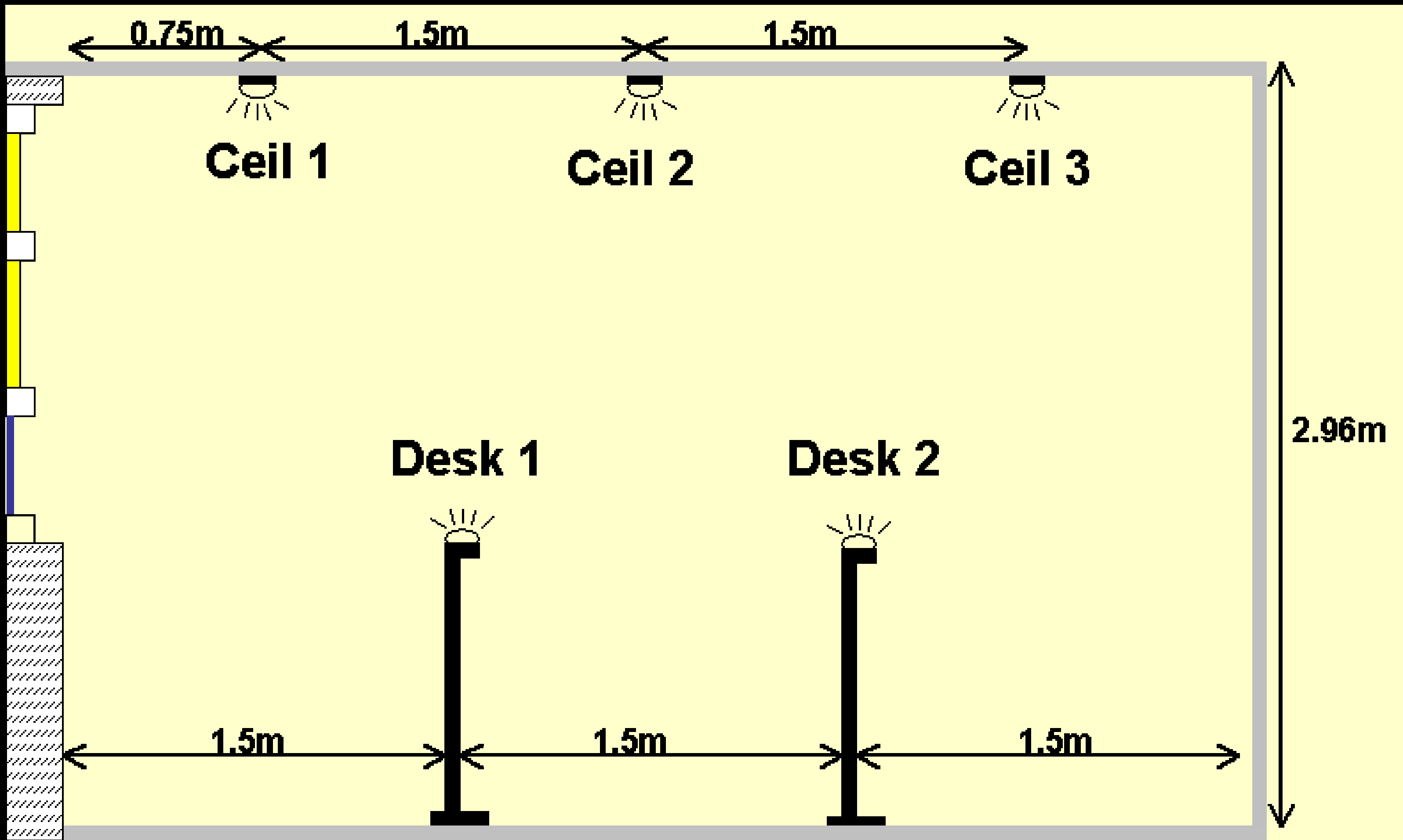
Validation Measurements



5 indoor illuminance sensors, 1 façade illuminance sensor, direct and diffuse irradiance… 19 days… 30 sec measurement interval… >120,000 illuminance measurements

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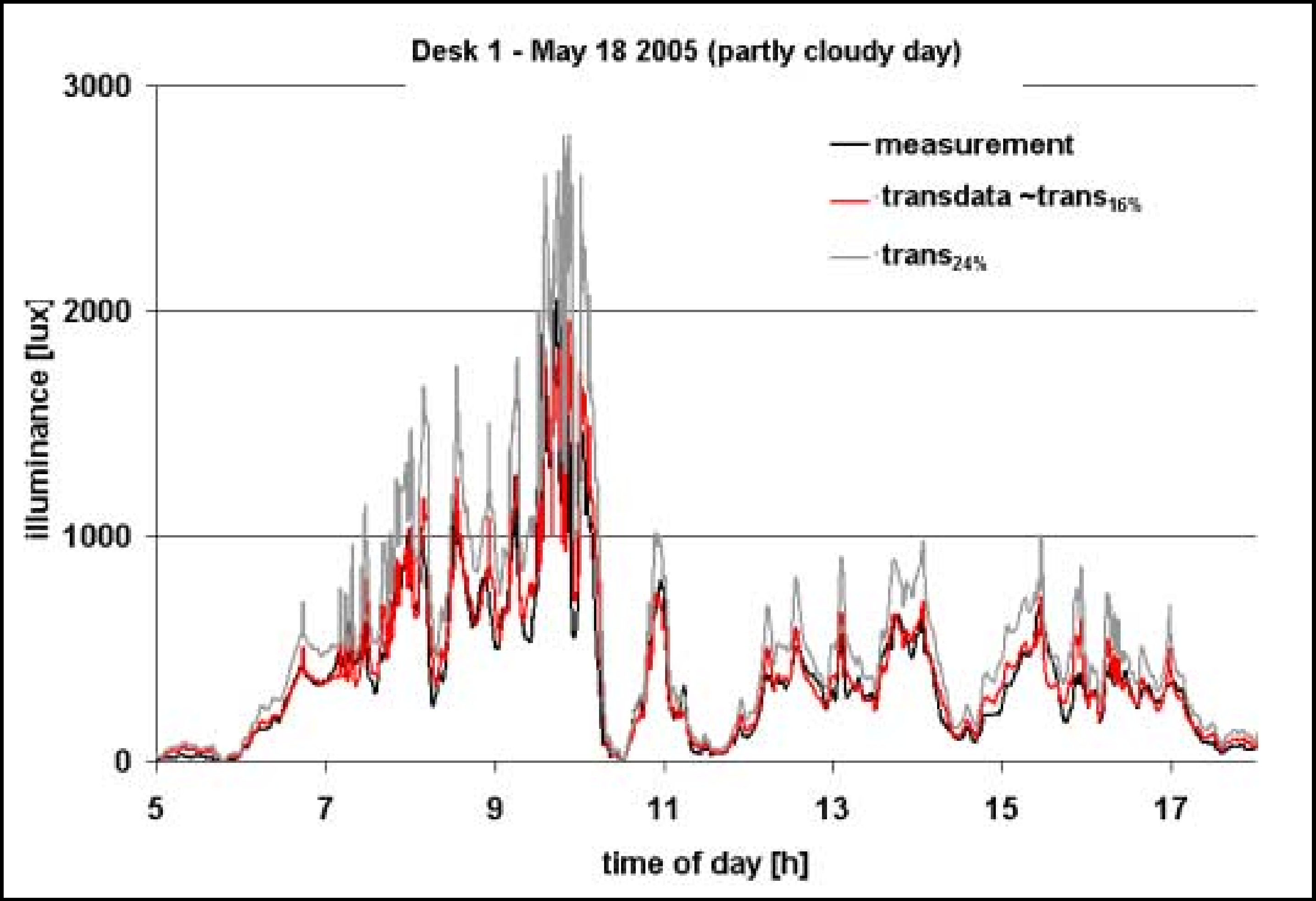
Partly Cloudy Day



- excellent agreement
- "$trans_{16\%}$" and "transdata" model nearly identical

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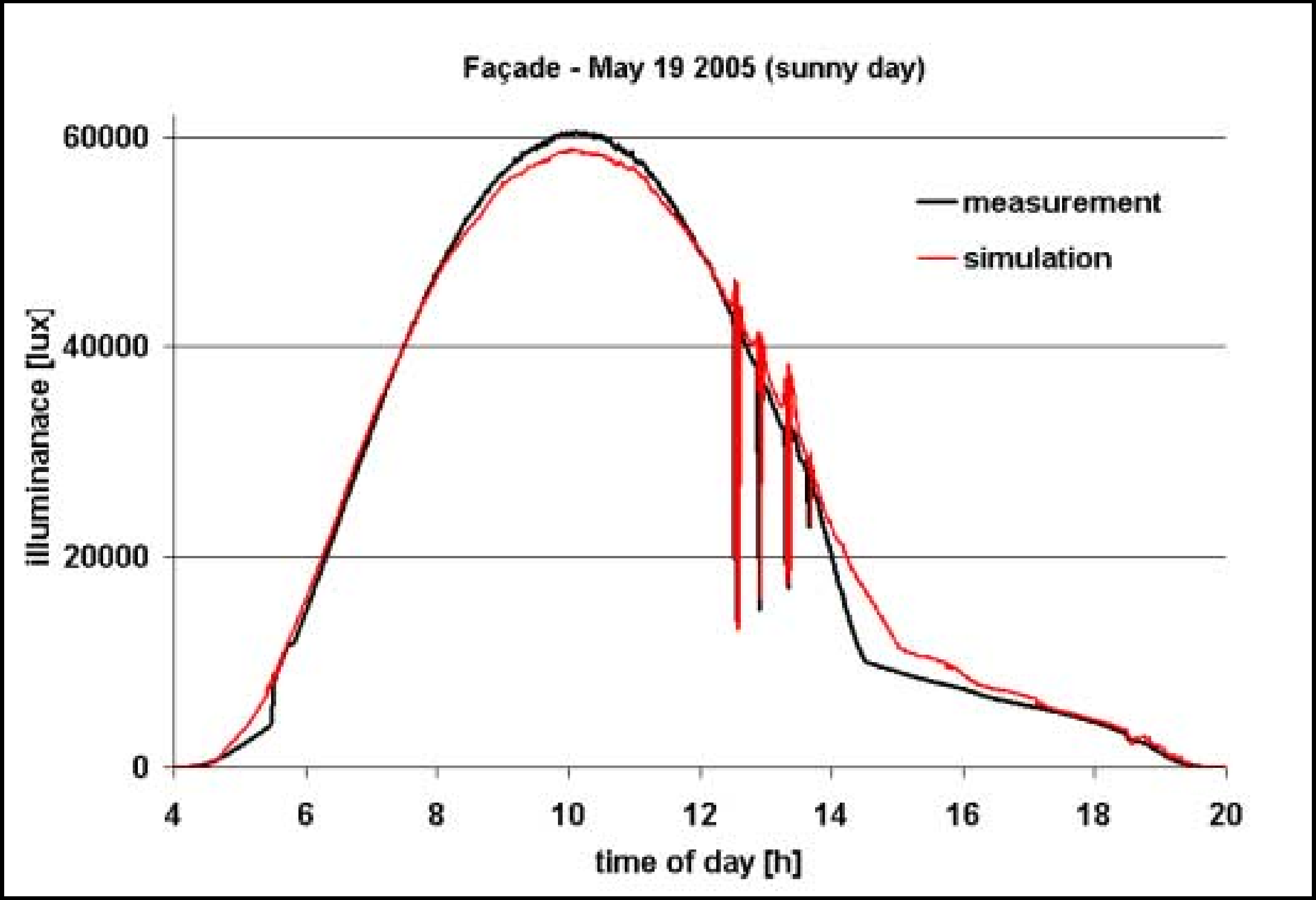
Sunny Day - Outside



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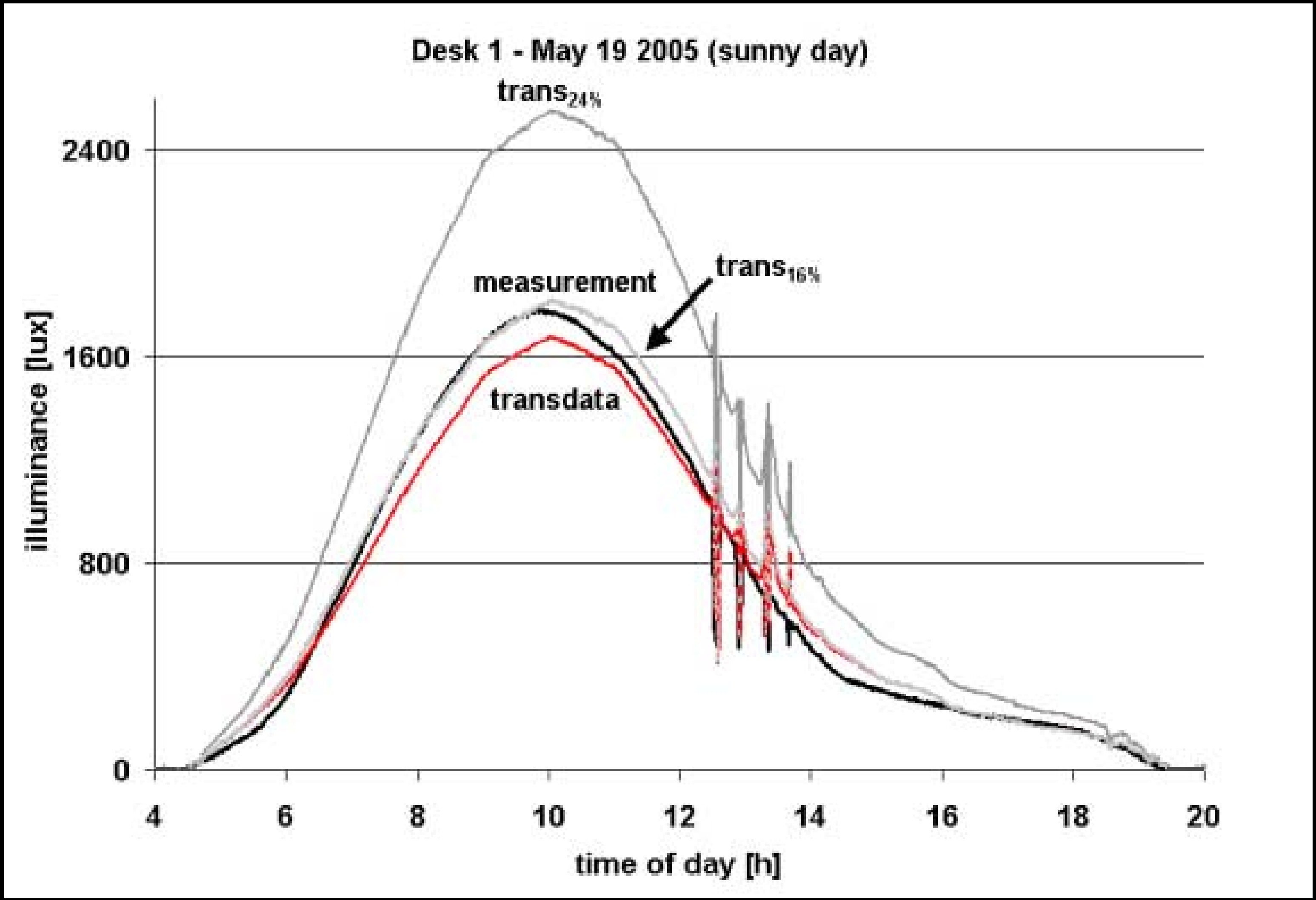
Sunny Day - Inside



- “transdata” & “$trans_{16\%}$”better than “$trans_{24\%}$”

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MBE & RMSE

sensor		$trans_{24\%}$	$trans_{16\%}$	transdata
DESK1	MBE [%]	49.5	7.5	3.5
	RMSE [%]	52.4	14.6	14.3
CEIL1	MBE [%]	57.7	12.7	8.9
	RMSE [%]	60.9	19.2	18.6

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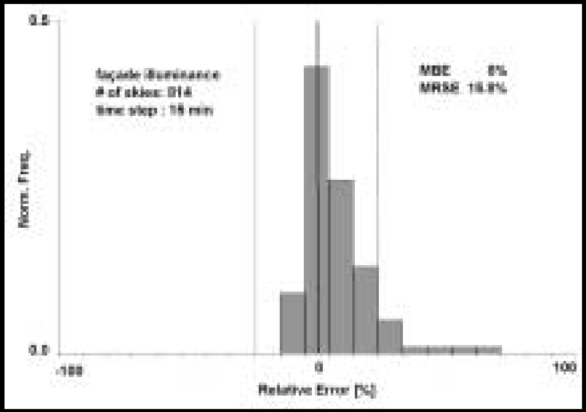
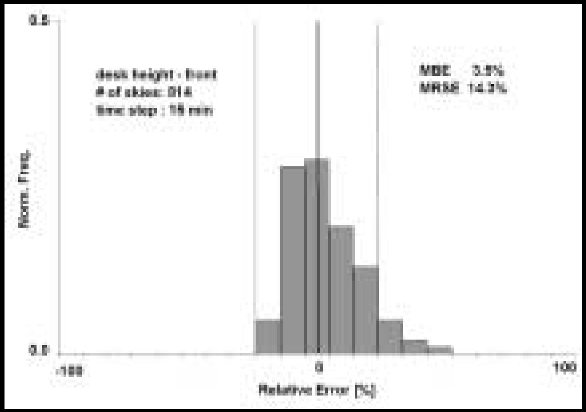
Error Distribution Spectra
Radiance & Perez

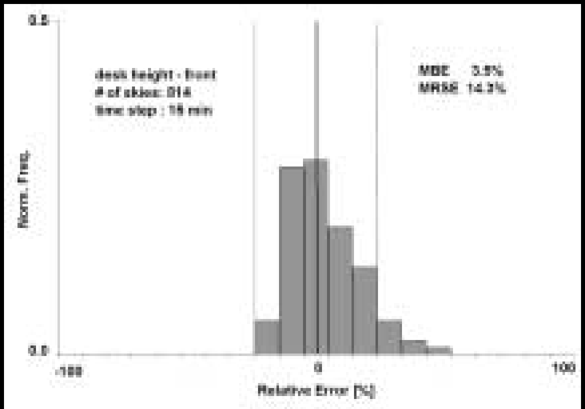
Facade



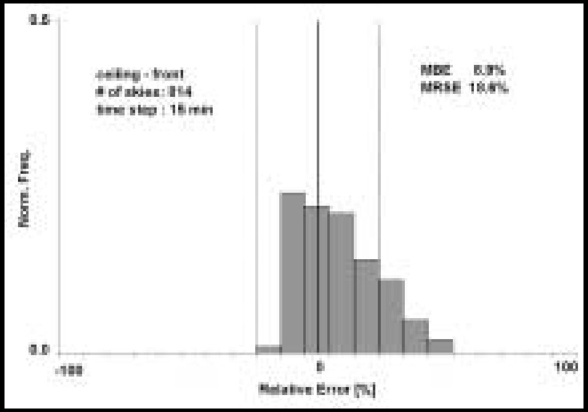
Desk 1



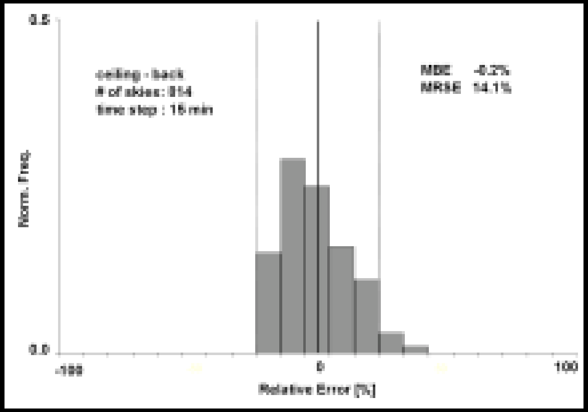
Desk 2



Ceil 1



Ceil 3



76% to 86% of simulations lie in 20% error band

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Practical Considerations:

How significant is a 20% error?

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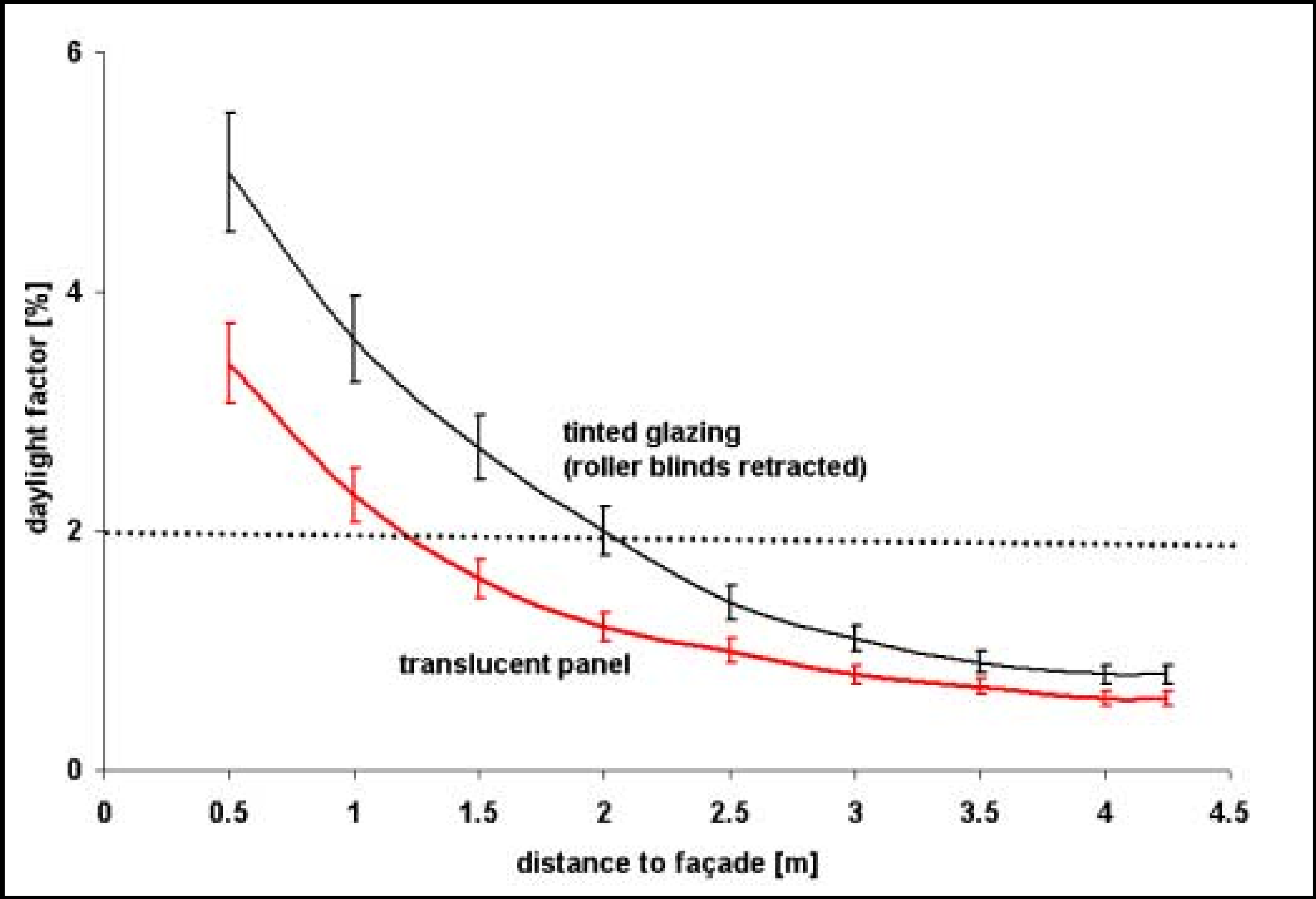
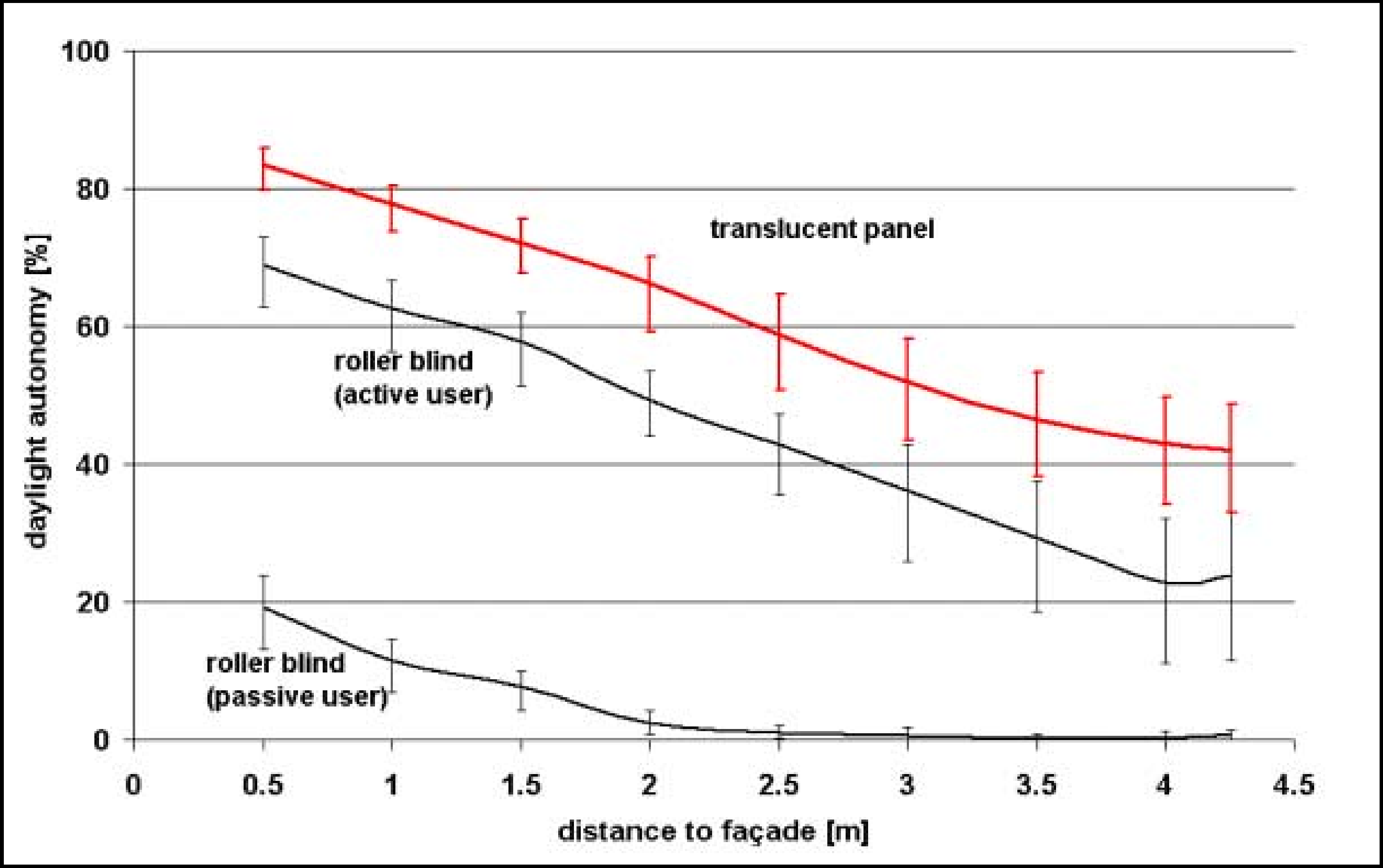
Practical Considerations: Daylight Factor (10% error)



- 10% since no sky error
- Apply LEED analysis

Practical Considerations: Daylight Autonomy (20% error)



Ottawa… Mo-Fr. 8.30 to 4.30… 450 lux min. ill…

Different results than DF analysis.

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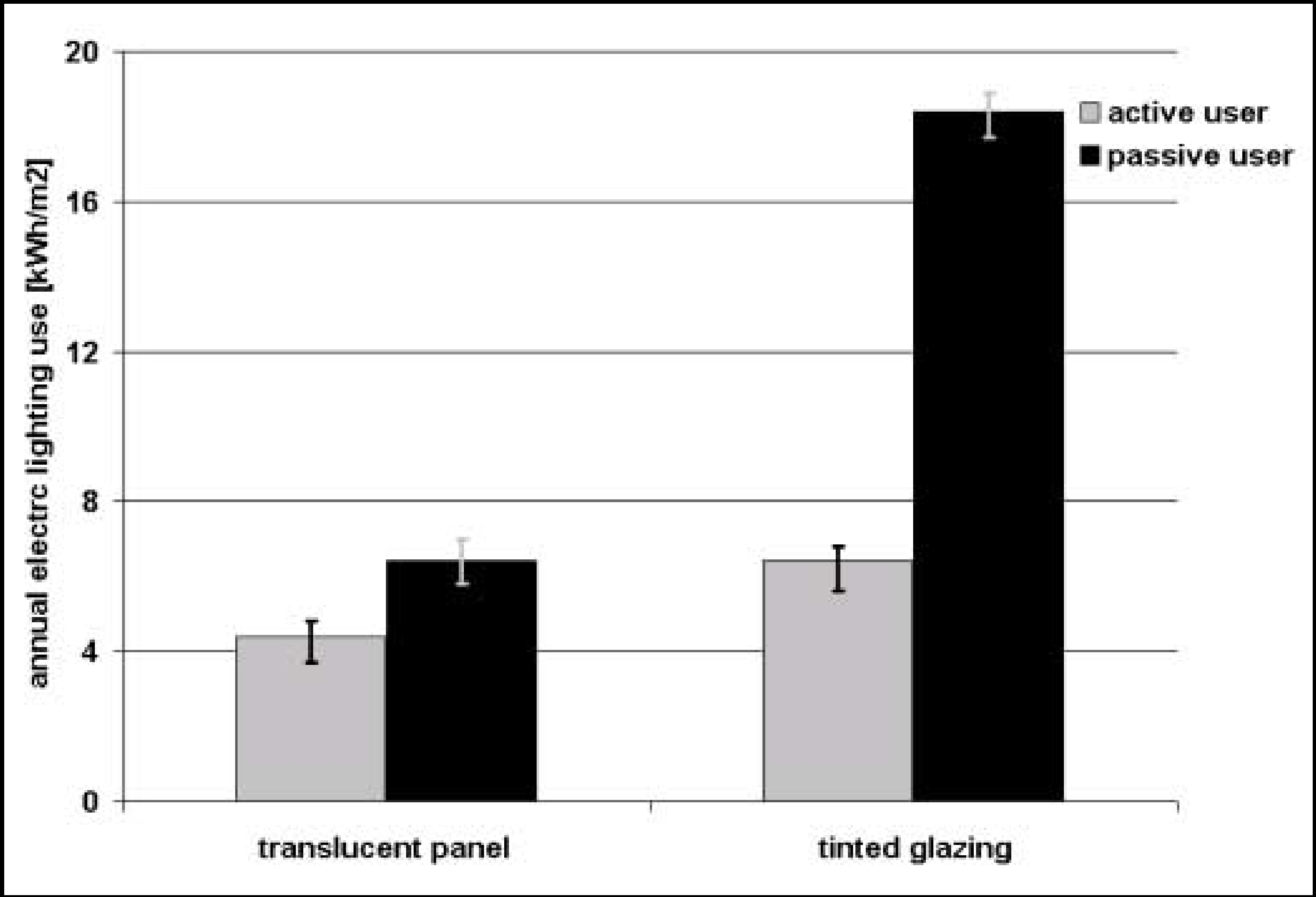
Practical Considerations: Electric Lighting Use (20% error)



- Ottawa… Mo-Fr. 8.30 to 4.30… 450 lux min. ill… ideally photocell control
- translucent panel always lower than tinted glazing with roller blinds.

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Conclusion

- We now have a validated Radiance model of a translucent material (more to follow).

- Accuracy as good as in earlier studies for “glass”, “plastic”, and “metal”.

- Method developed can be used for other materials and products such as a photocell.

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