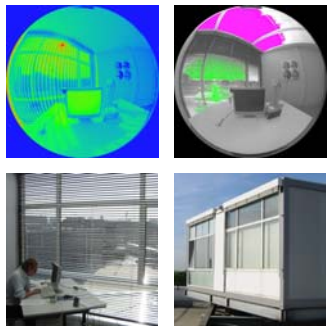
# Glare and dynamic glare evaluation



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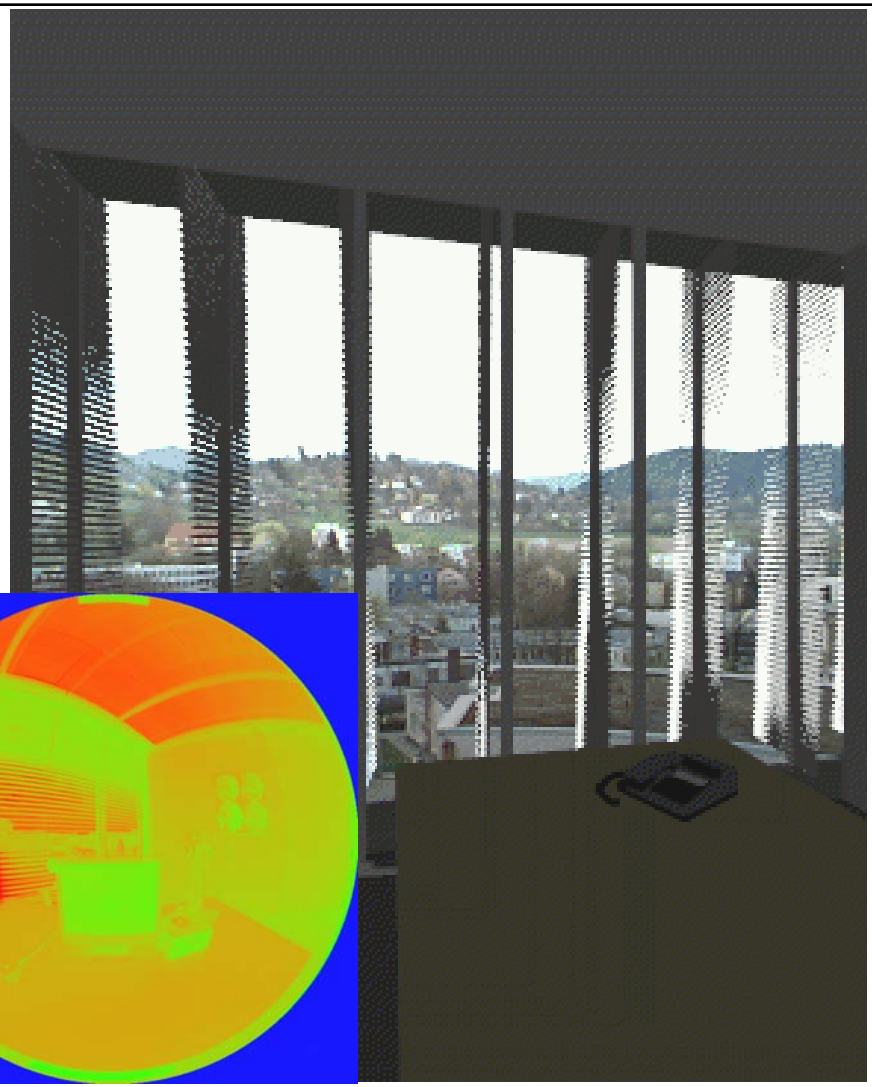
Fraunhofer Institut Solare Energiesysteme

# Use of shading devices in non residential buildings

Control strategies could be complex

Light distribution could be unusual



## Questions

**What is the impact of different shadings and controls on**

**⇒ perceived glare ?**

**Is it possible to optimise control strategies for shadings, that**

**⇒ The users are satisfied (high visual comfort) and**

**⇒ the energy demand (heating, cooling and lighting) is low?**

## Problem

**Impact of shading position on energy and comfort is large**
**Evaluation of static daylight simulation not sufficient**

## Objective

**Provide a dynamic daylighting simulation method for evaluating the daylight glare**

# Content

- Methodology of user assessments
- Window luminance as glare measure
- Validation of the static DGP
- Methodology of dynamic glare evaluation
- Validation and exemplary results
- Conclusions

# Methodology

**Two identical test rooms**

**Test room**

**Reference room**

**Questionnaire**

**Measurements : Luminance camera Illuminances**

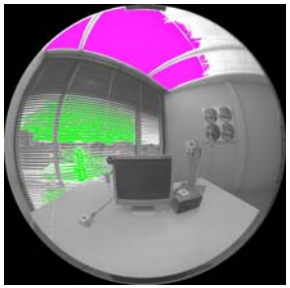
**User analysis**

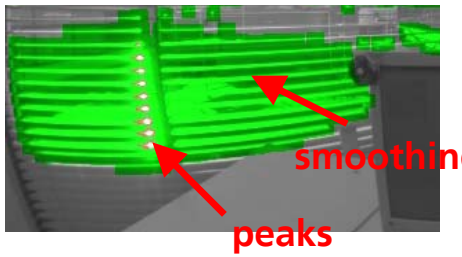
**Image processing**

**correlations**

# Evalglare:

**main features:**






**new feature**

- glare source detection
- task luminance threshold
- peak extraction, smoothing
- modified position index
- calculation of glare indexes

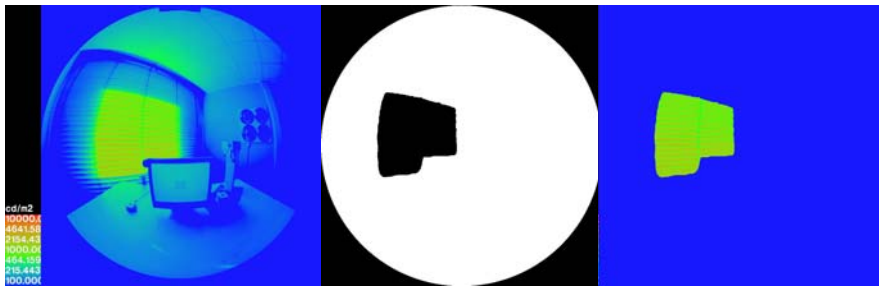
if no fish-eye lens is available (measurements)

- the vertical illuminance can be used from an external sensor and put into evalglare

-> Picture: Only for Glare source detection

# Calculation of window luminance: masking

masking



evalglare

Average L

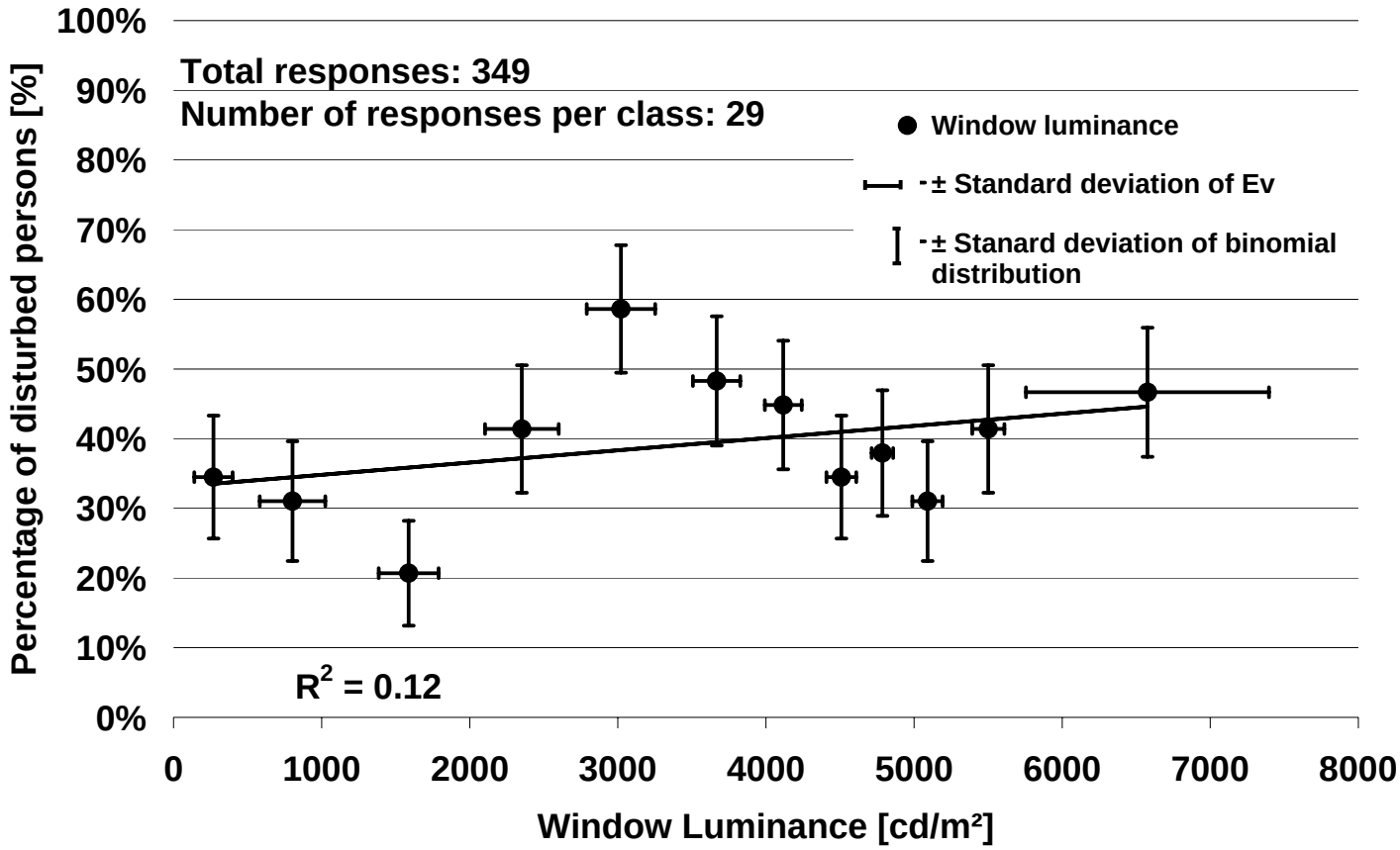
# Window luminance – no correlation with user perception of glare

Large scatter

No dependency

low correlation

$R^2$=0.12



# Daylight glare probability DGP: high correlation

Strong correlation

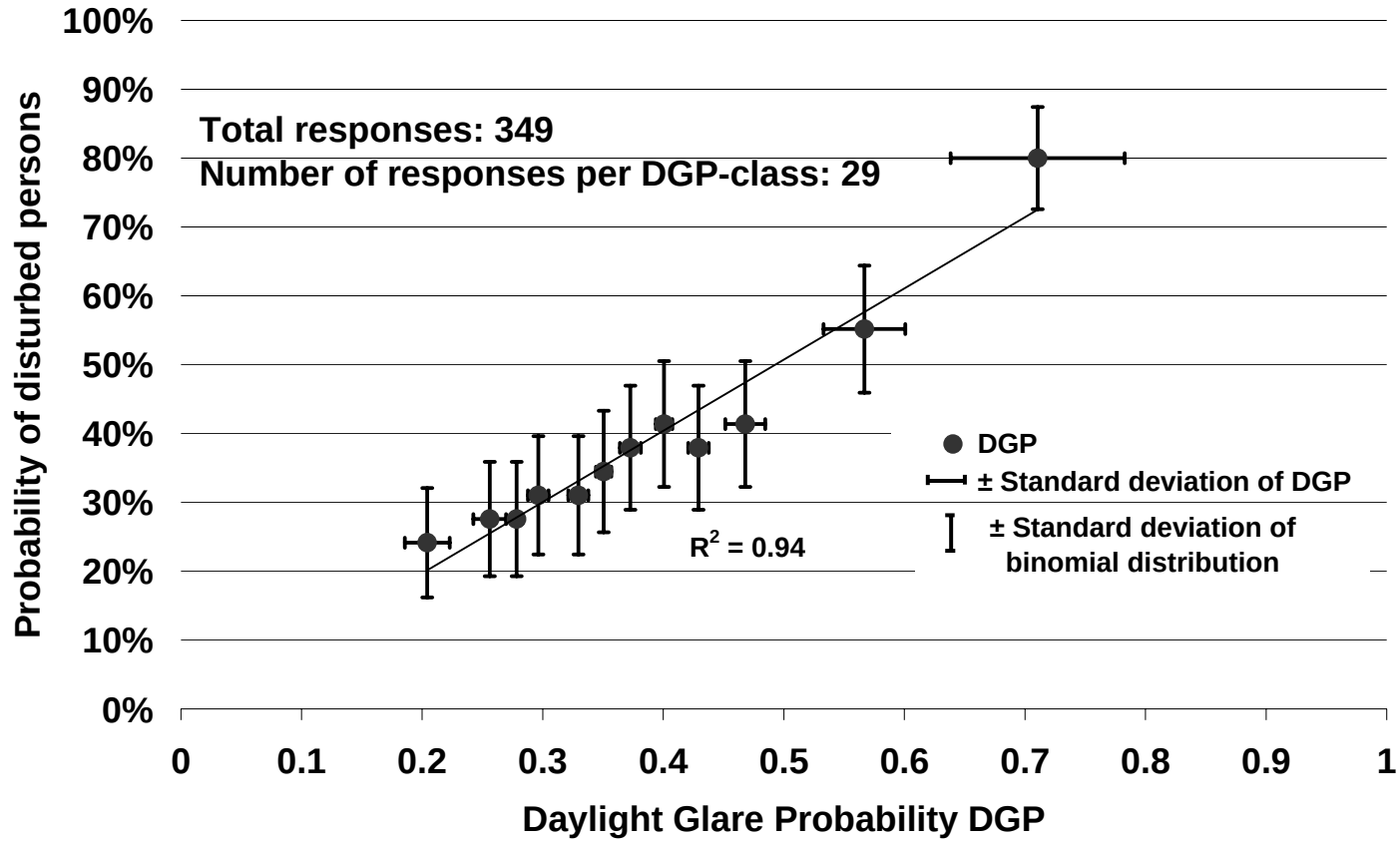
$R^2=0.94$

Logistic regression:

$p=3.44\ 10^{-8}$

Model fit:

F=35.3773 with df = 1 and $p=2.7110^{-9}$

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# New glare rating
# Daylight glare probability DGP

$$DGP = c_1 \cdot E_v + c_2 \cdot \log(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{a_1} \cdot P_i^2}) + c_3$$

**Combination of the vertical eye illuminance with modified glare index formula**

| | | |
|---|---|---|
| $E_v$: | vertical Eye illuminance [lux] | $c_1 = 5.87 \cdot 10^{-5}$ |
| $L_s$: | Luminance of source [cd/m²] | $c_2 = 9.18 \cdot 10^{-2}$ |
| $\omega_s$: | solid angle of source [-] | $c_3 = 0.16$ |
| $P$: | Position index [-] | $a_1 = 1.87$ |

# Validation of the dgp -model

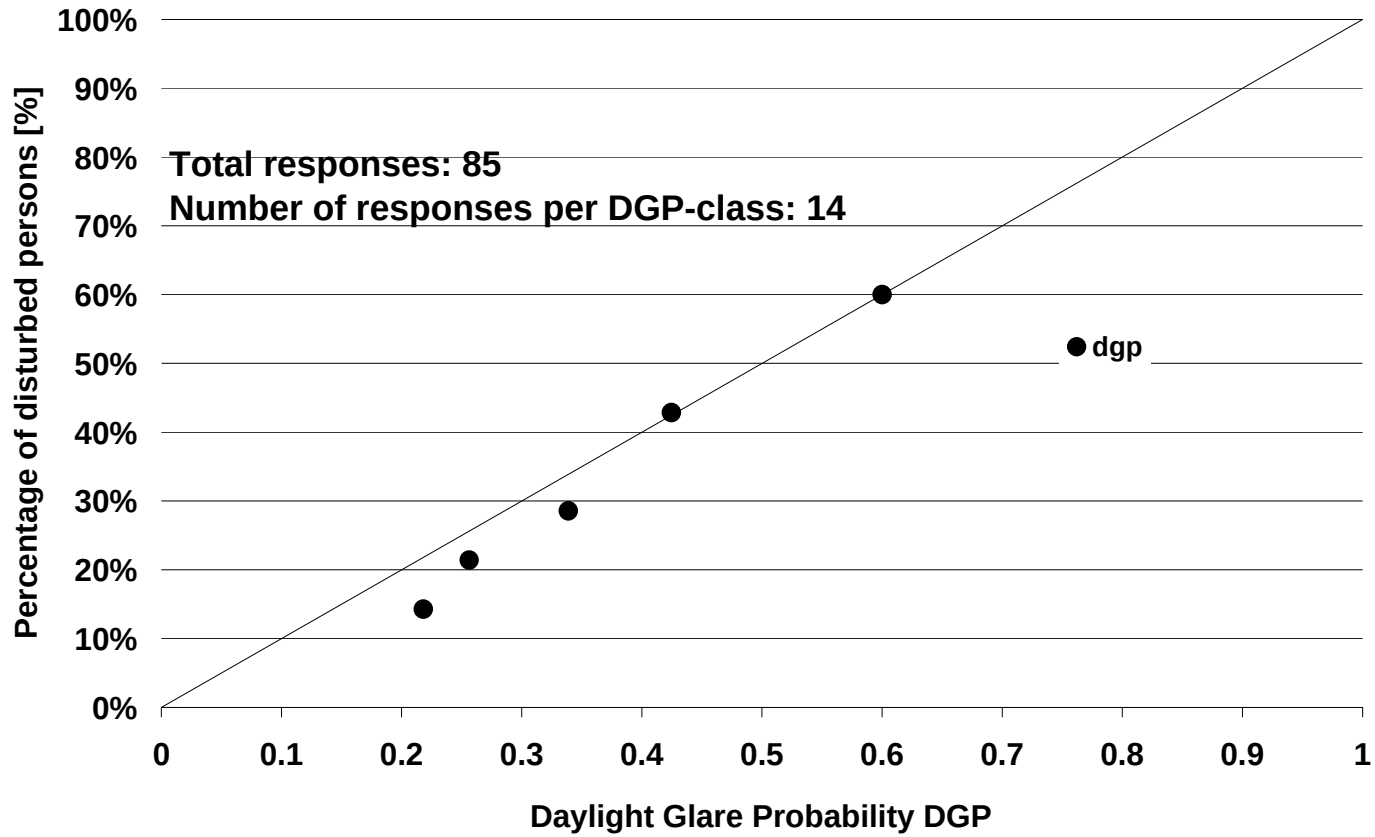
Logistic regression gives

p=0.000498

and an overall model fit

F=14.822, p= 0.0001181

-> strong dependecy



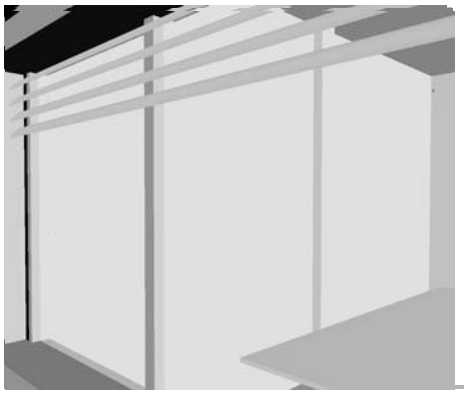
# Conclusions static glare evaluation

- window luminance show no correlation with user perception for the performed assessments
- New DGP formula shows high correlations
- further work: Other aspects have to be taken into account:

  -view contact
  -age
  -low light levels

# Simulation Approach

## Dynamic Daylight Simulation for shadings



- **Daylight simulation of shading devices is time consuming**
- **Exact and instantaneous simulation actually impossible**
- **To evaluate control strategies, various shading positions must be investigated**

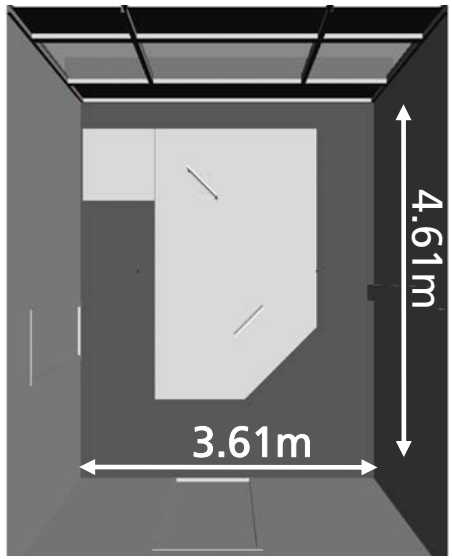
**Approach:**

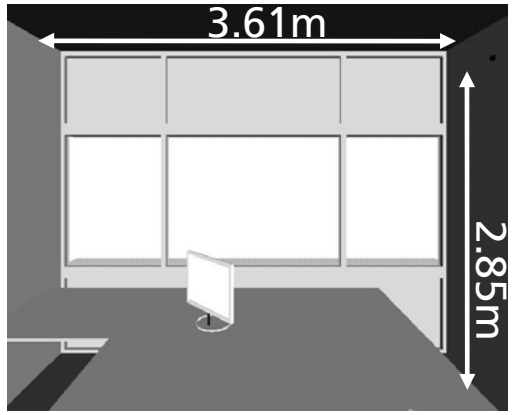
⇒ **Pre-calculate all possible shading positions**

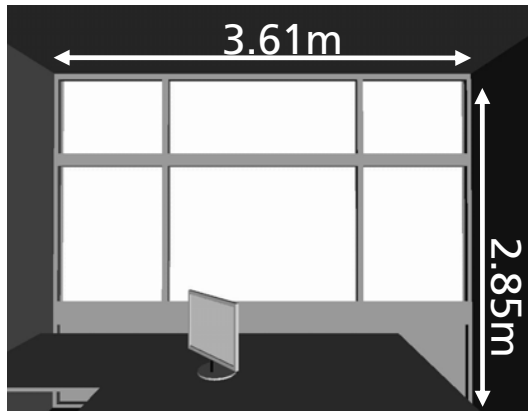
⇒ **Dynamic simulation using daylight coefficient method: RADIANCE and Daysim**

**Model set up:**

Typical single office space
with band and
large glazed facade



# Model set up:
## Shading devices

- **Grey venetian blinds ($\rho_{diff}$ Refl. 52%, $\rho_{spec}$ 15%) completely lowered**
  **for validation: 15° slat angle position**

- **Roller blind ($\tau_{tot}$=0.04,$\tau_{dir}$=0.01,$\rho$=0.42) completely lowered**

# Methods

- **Reference method:**
  **hour by hour calculation of a 180° fish-eye view picture**
  **evaluation of the picture by evalglare**

- **DGPs, based only on vertical eye illuminance**

- **Enhanced simplified calculation method**

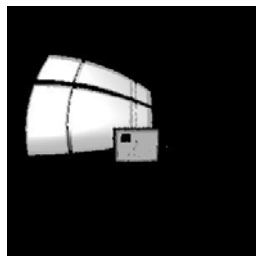
# Simplified methods

**DGPs**

$$DGPs = 6.22 \cdot 10^{-5} \cdot E_v + 0.184$$

**Enhanced simplified**

$$DGP = \underbrace{c_1 \cdot E_v}_{\text{Term 1}} + \underbrace{c_2 \cdot \log\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{c_4} \cdot P_i^2}\right)}_{\text{Term 2}} + c_3$$

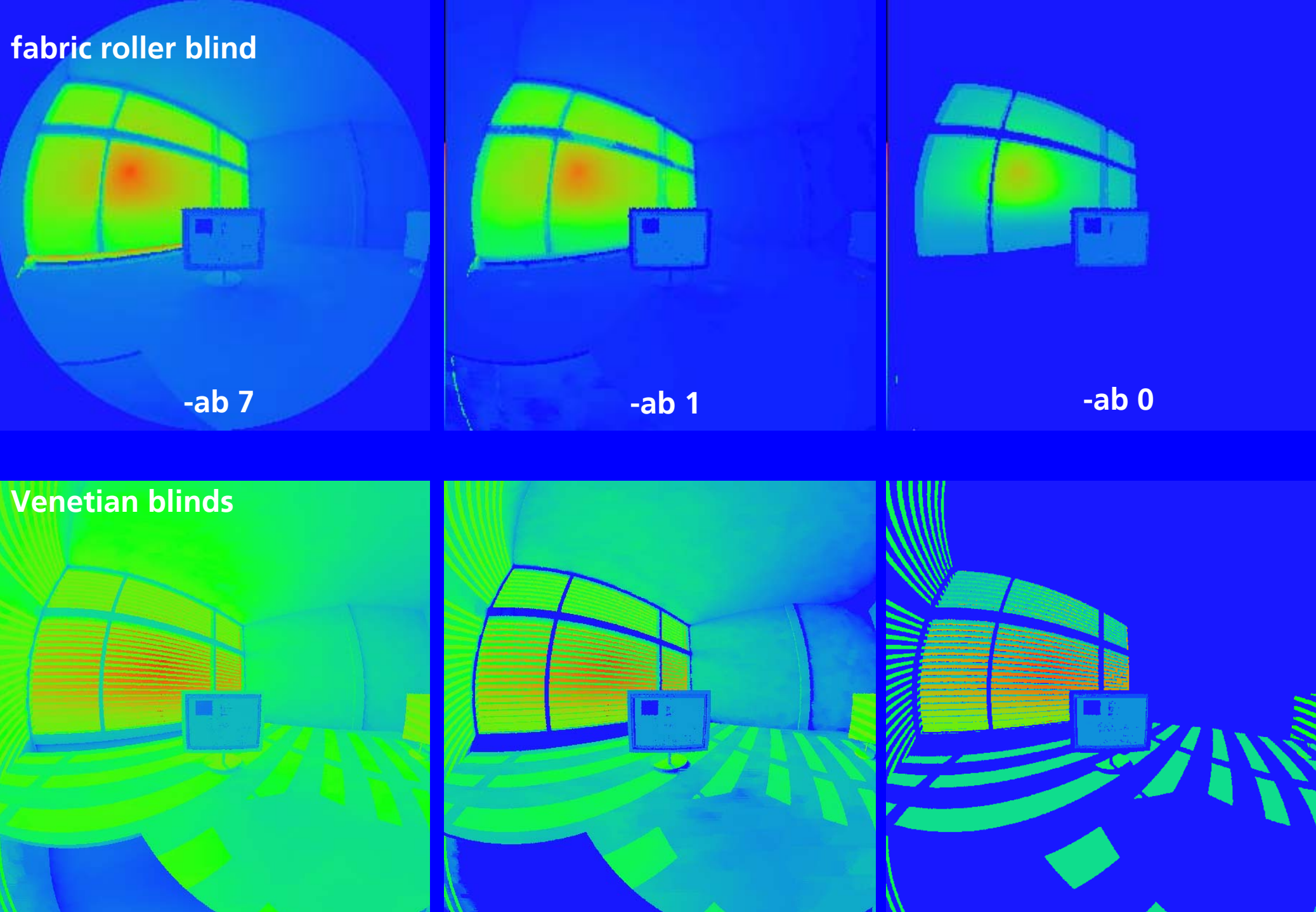
**DAYSIM** → **hourly $E_v$** +  **evalglare** → **DGP**

**„fast picture“**

# Questions

**How fast can we calculate a picture?**

1. **How many ambient bounces (-ab parameter) are necessary to get reasonable results?**
2. **Size of the picture**

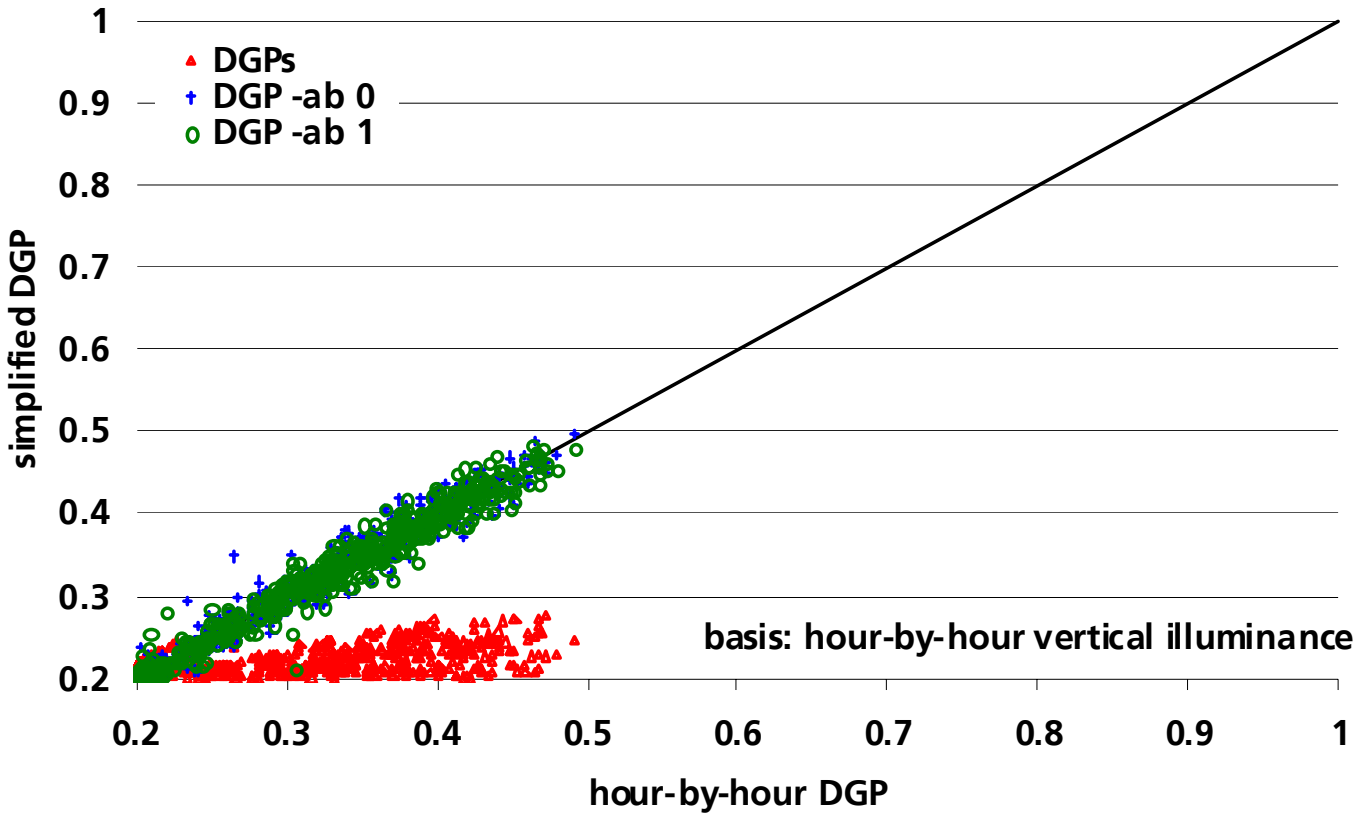

fabric roller blind
-ab 7
-ab 1
-ab 0
Venetian blinds

# Validation results fabric roller blind

Good correlation for enhanced methods

Small difference for –ab

DGPs large error

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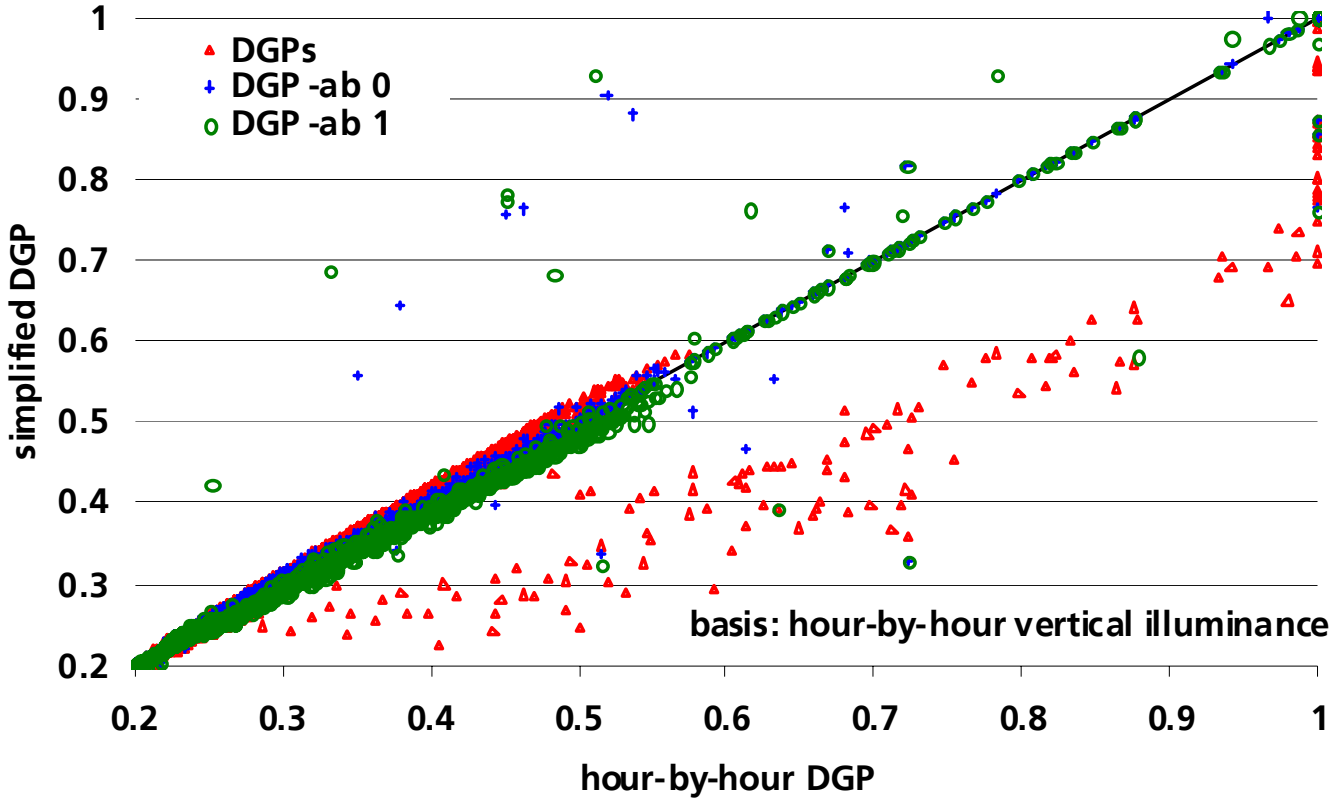
# Validation results venetian blinds

Good correlation for enhanced methods

Small difference for –ab

underestimation by DGPs



# Summary error

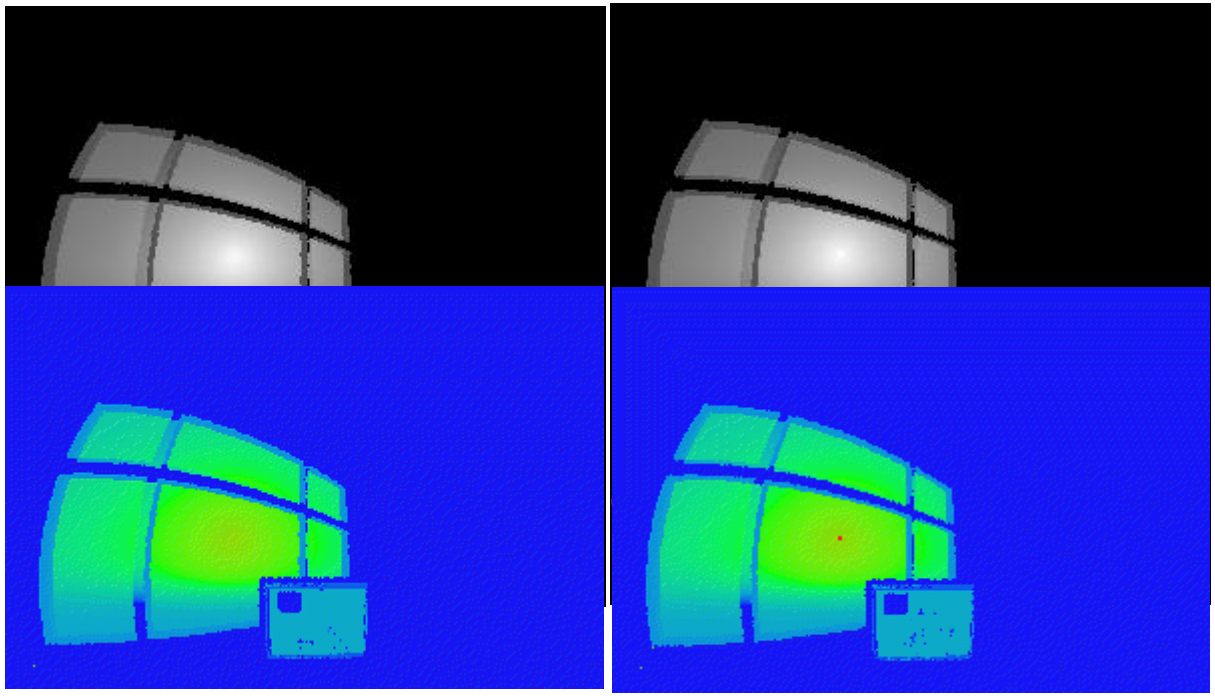
| Input data | method | | fabric roller blinds rMBE [%] | fabric roller blinds rRMSE [%] | Venetian blinds (15°) rMBE [%] | Venetian blinds (15°) rRMSE [%] |
|---|---|---|---|---|---|---|
| hour-by-hour | simplif. | DGPs | 1.4% | 15.7% | 1.8% | 8.0% |
| | enh. simpl. | DGP -ab 0 | -1.0% | 2.8% | 0.0% | 4.9% |
| | enh. simpl. | DGP -ab 1 | 1.0% | 2.7% | -1.8% | 4.3% |

$$rRSME = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{DGP_i - DGP_{es,i}}{DGP_i}\right)^2}$$

$$rMBE = \frac{1}{N}\sum_{i=1}^{N}\frac{DGP_i - DGP_{es,i}}{DGP_i}$$

# Setting “right” image resolution

Find the difference!



Same oct,
same radiance version
only different computers

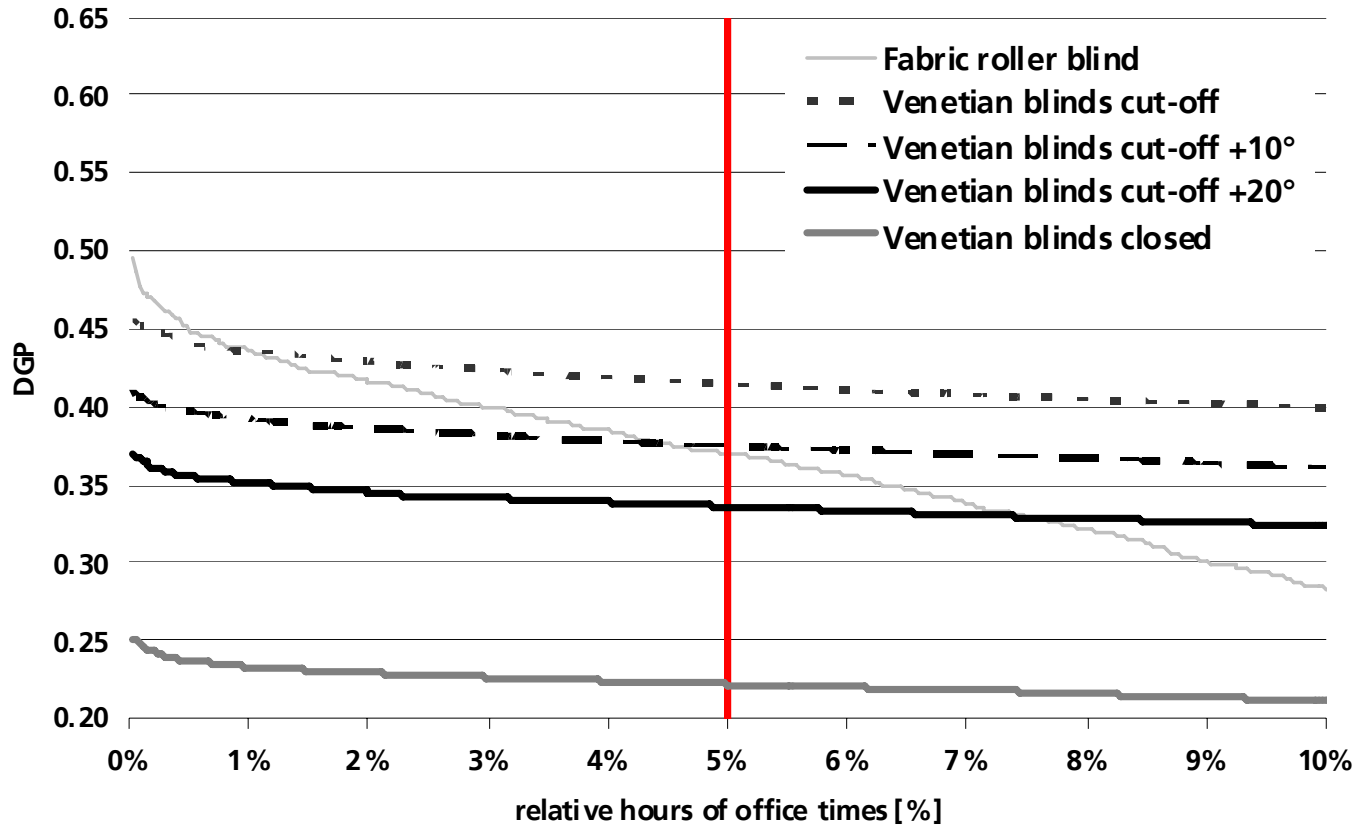
Big difference regarding glare evaluation: peak sampling!

-> Image resolution must be large enough

# Results – Overall comparison of systems and controls
# Frequency distribution

Quick comparison possible between variants

But how to rate?



# Results – Overall comparison of systems and controls

| Variant | Max DGP value in 95 % office time | Mean DGP value in 5% office time |
|---|---|---|
| Fabric roller blind | 0.37 | 0.41 |
| Venetian blinds cut-off | 0.41 | 0.43 |
| Venetian blinds cut-off +10° | 0.38 | 0.39 |
| Venetian blinds cut-off +20° | 0.34 | 0.35 |
| Venetian blinds closed | 0.22 | 0.23 |

**Idea for classification Restriction of Max 95% value and Mean 5% value?**

**Limits from user assessments?**

| | number of cases | mean value | root mean square deviation | standard error | 95%-confidence interval lower limit | upper limit |
|---|---|---|---|---|---|---|
| imperceptible | 103 | 0.333 | 0.098 | 0.010 | 0.314 | 0.352 |
| perceptible | 109 | 0.377 | 0.112 | 0.011 | 0.356 | 0.398 |
| disturbing | 103 | 0.419 | 0.148 | 0.015 | 0.390 | 0.448 |
| intolerable | 34 | 0.527 | 0.181 | 0.031 | 0.464 | 0.590 |
| total | 349 | 0.391 | 0.139 | 0.007 | 0.376 | 0.406 |

# Conclusions and outlook

- DGP is validated
- enhanced dynamic method is validated against reference
- -ab 0 for “fast picture” mostly sufficient
- take care of picture size!

Outlook

- DGP extension for age, view contact (ongoing projects)
- set up of shading classification based on DGP (ongoing project)
- Integration of dynamic glare calculation into DAYSIM foreseen

**Thank you for your attention!!**

**p.s.: evalglare can be downloaded here:**

**http://www.ise.fhg.de/radiance**