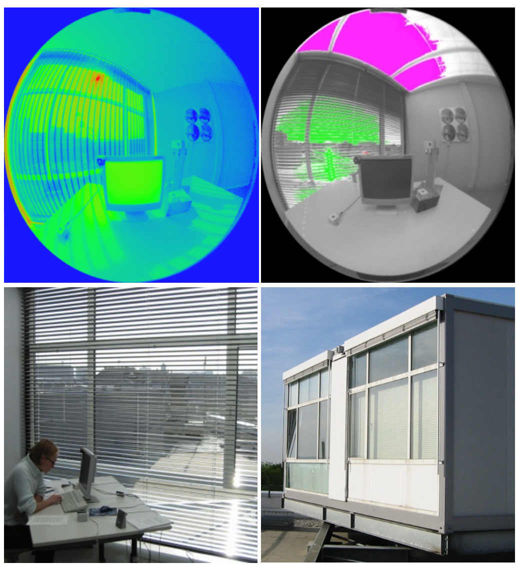
# Daylight Glare analysis and metrics

Introduction into daylight glare evaluation

Introduction into evalglare

Comparison evalglare - findglare



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# Content

- Introduction – What is glare?
- Existing glare metrics
- User assessments to evaluate glare metrics
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- Importance of glare source detection: Task area
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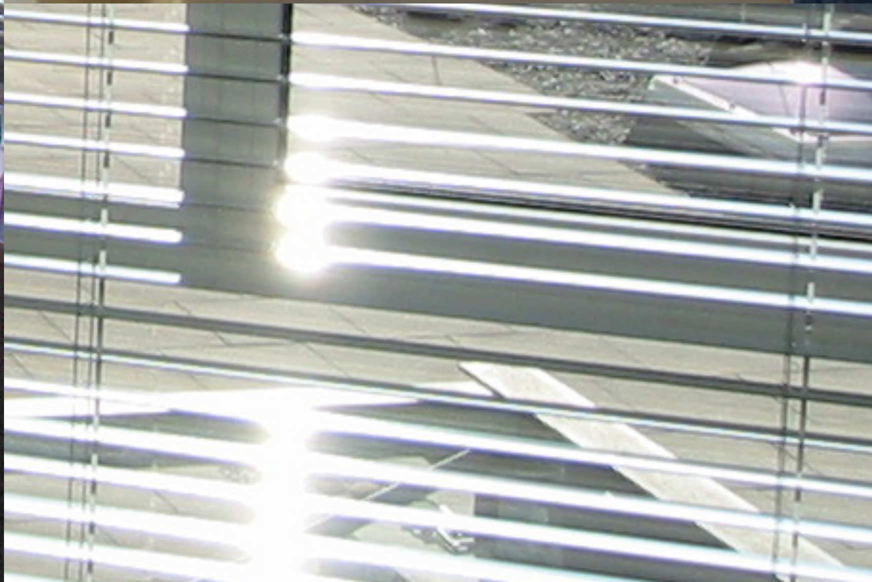
# What is glare : Visual (dis)comfort

## Visual comfort has different dimensions

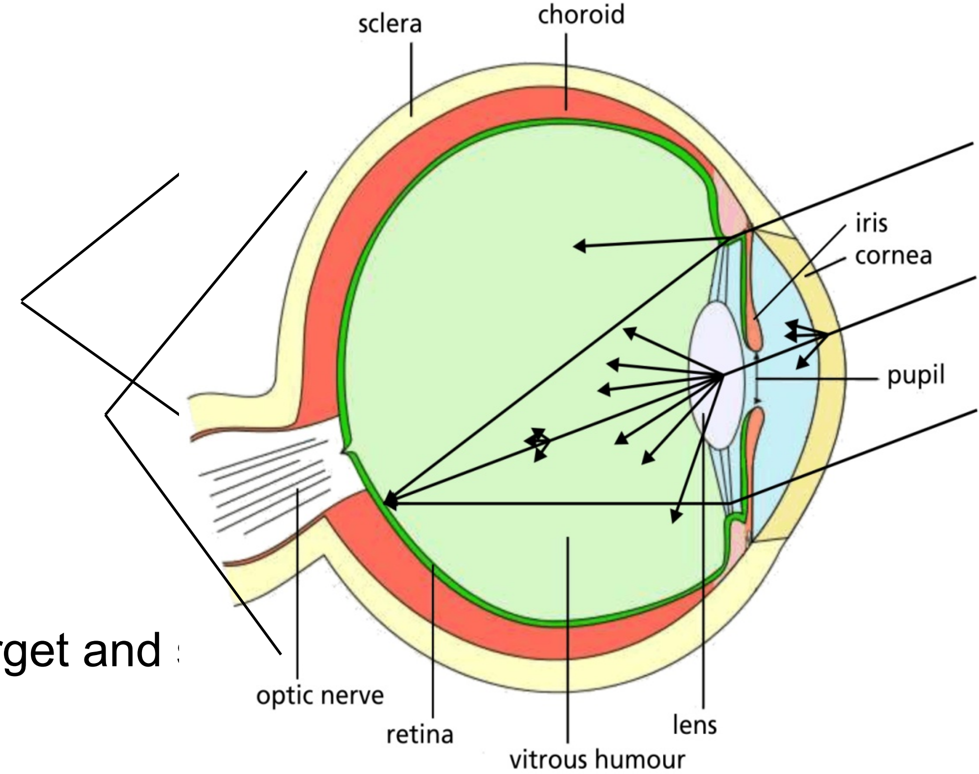
- Daylight availability
- Readability of computer screens
- View to exterior
- contrast in the field of view
- color
- glare


Source: www.readme.cc



# Glare can be divided into

- Reflex glare
- Disability glare
- Discomfort glare
- Contrast glare between visual target and :



# Discomfort glare

- Discomfort = Subjective rating
- In most cases below disability glare
- Possible scaling:
  - imperceptible
  - perceptible
  - disturbing
  - intolerable

⇒ Indirect consequences (headaches, getting fatigue), often not direct measurable

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# Daylight glare metrics – up to now

Principal structure of existing complex glare formulas:

$$G = f\left(\frac{L_s^{a_1} \cdot \omega_s^{a_2}}{L_b^{a_3} \cdot P^{a_4}}\right)$$

$L_s$: Luminance of source
$\omega_s$: Solid angle of source
$L_b$: Background luminance ⇒ adaptation
$P$: Position index

**Developed under artificial lighting conditions**

**Not under daylight**

**How reliable are these discomfort glare formulas?**

# Daylight glare metrics – Daylight glare index DGI

$$G = f\left(\frac{L_s^{a_1} \cdot \omega_s^{a_2}}{L_b^{a_3} \cdot P^{a_4}}\right)$$

$$DGI = 10 \log_{10} 0.48 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07\, \omega_s^{0.5}\, L_s}$$

$L_s$: Luminance of source
$\omega_s$: Solid angle of source
$L_b$: Background luminance ⇒ adaptation luminance
P: Position index

**Developed with less than 10 subjects**

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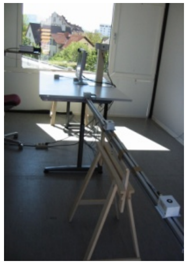
# Methodology
# user assessment

Two identical test rooms

Test room

Instrumentation room



Questionnaire

Measurements :
Luminance camera
Illuminances

User analysis

Image processing

correlations

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## User Assessments: 2 sites (D,DK), 3 window sizes, 3 shadings

74 subjects, more than 110h tests, about 50 days

349 different situations

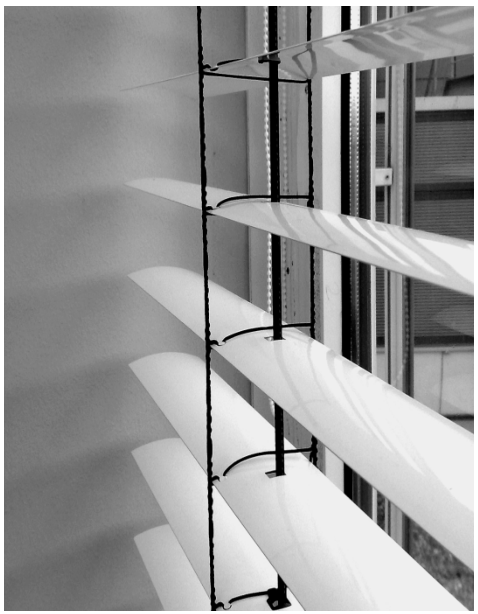
# Discomfort glare

## Important boundary conditions for user assessments

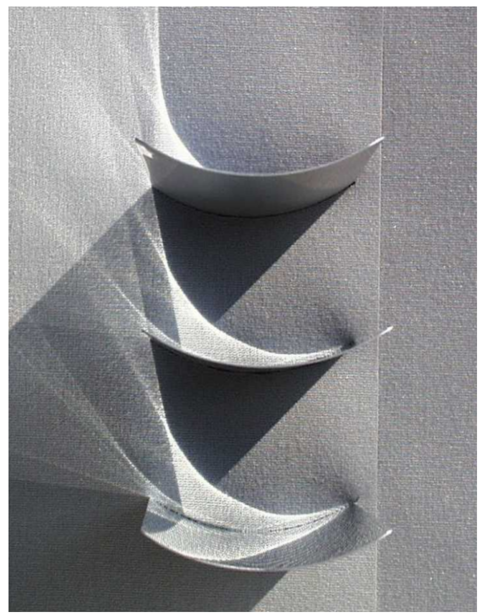
- The important influence factors have to be varied
- For glare: the amount of light and the size of a light source are definitely important factors for the glare evaluation
- Without varying them, their influence cannot be studied

# Tested three shading devices

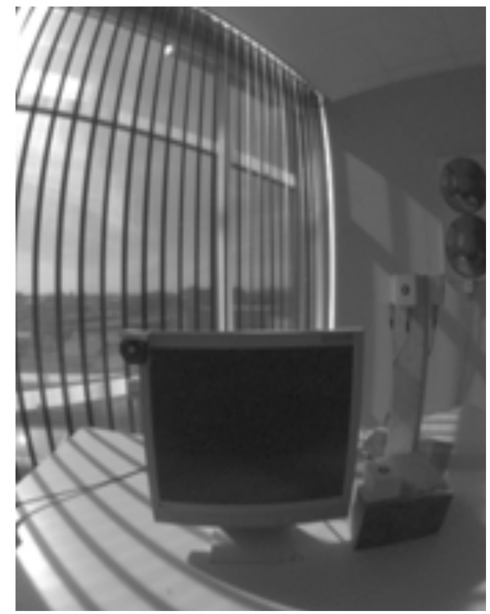
White Venetian blinds
80mm, convex, ρ=.84
D (sunny), DK (sunny)

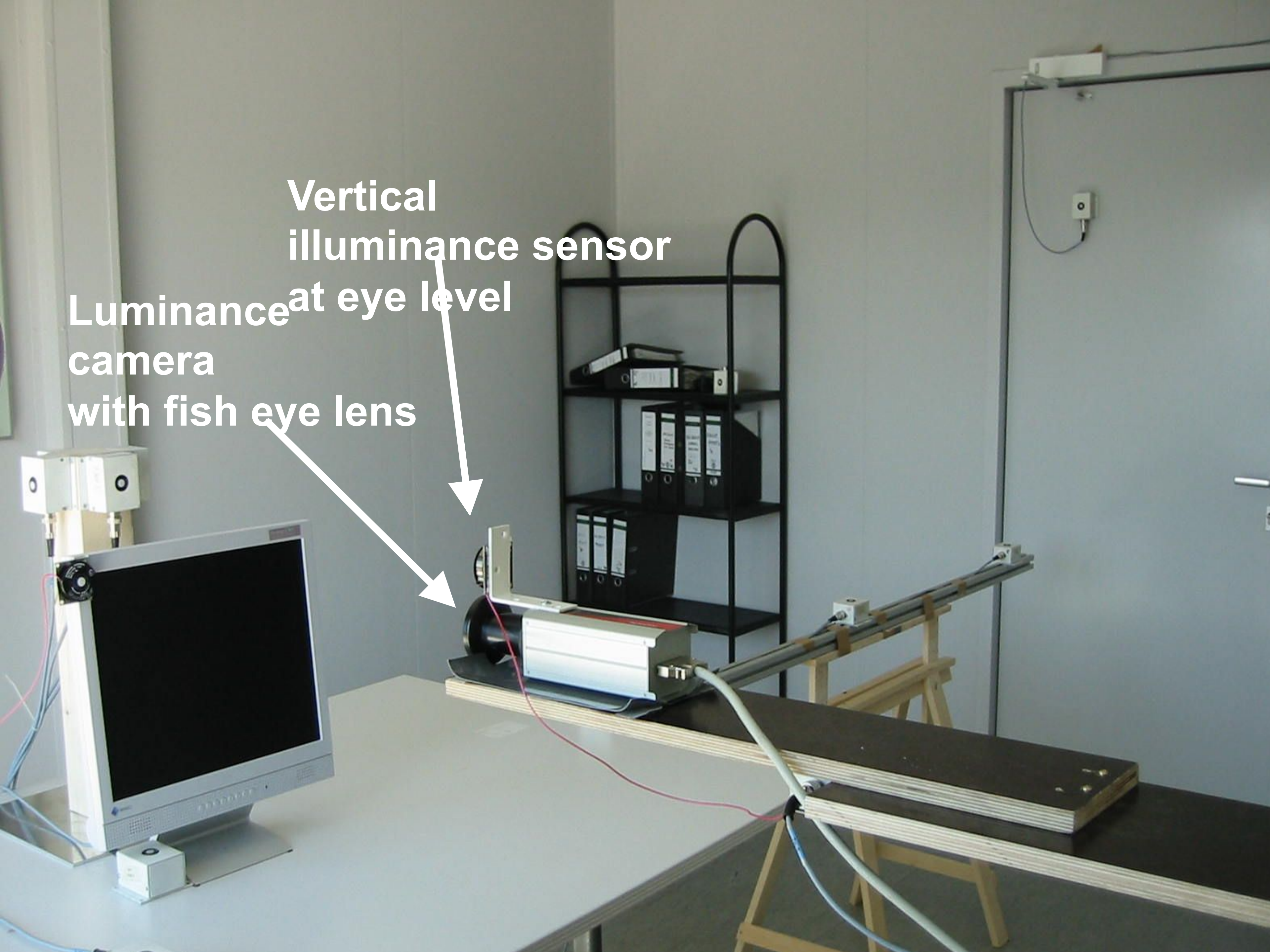


Specular Venetian blinds
80mm, concave, ρ=.95
D (sunny) ,DK (cloudy)



Vertical foil lamellas
τ=0.02
D (sunny)




Vertical
illuminance sensor
at eye level
Luminance
camera
with fish eye lens

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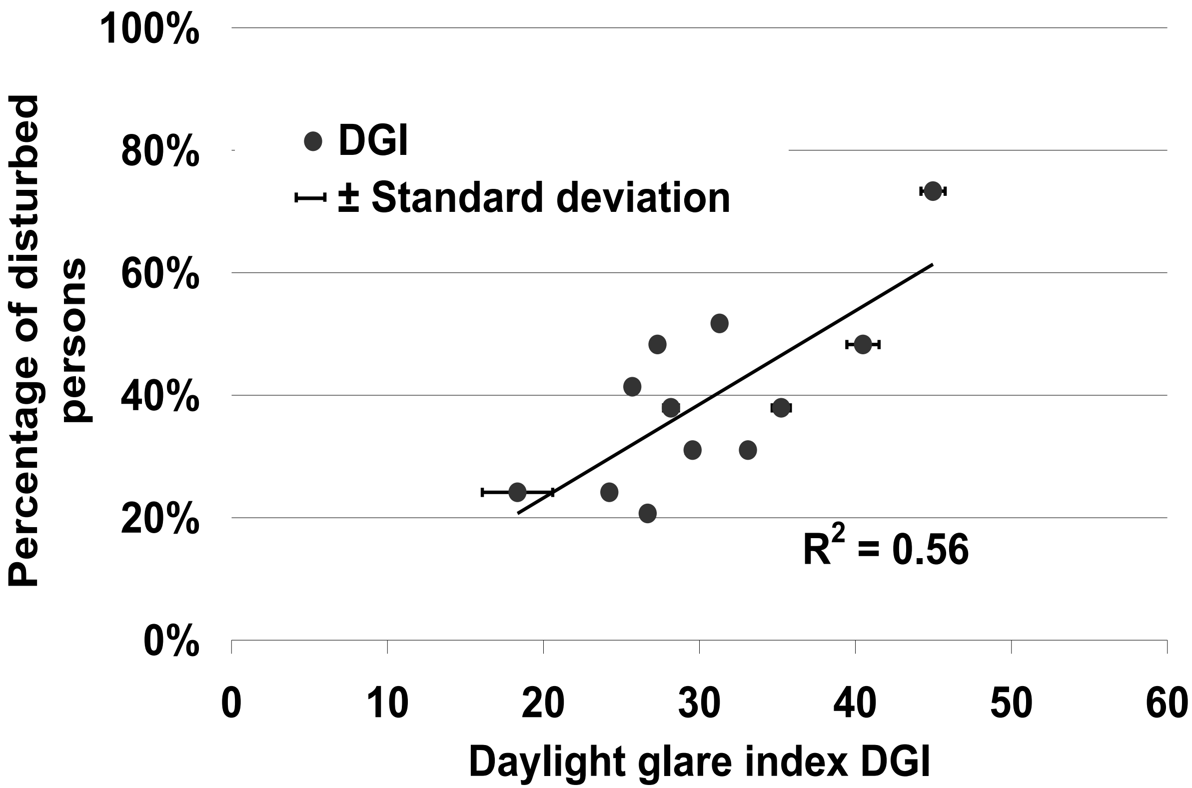
# Evaluation of existing glare metrics

- All metrics are compared to the percentage of persons disturbed

# Result: Daylight glare index versus percentage of persons disturbed

Large scatter

Weak correlation

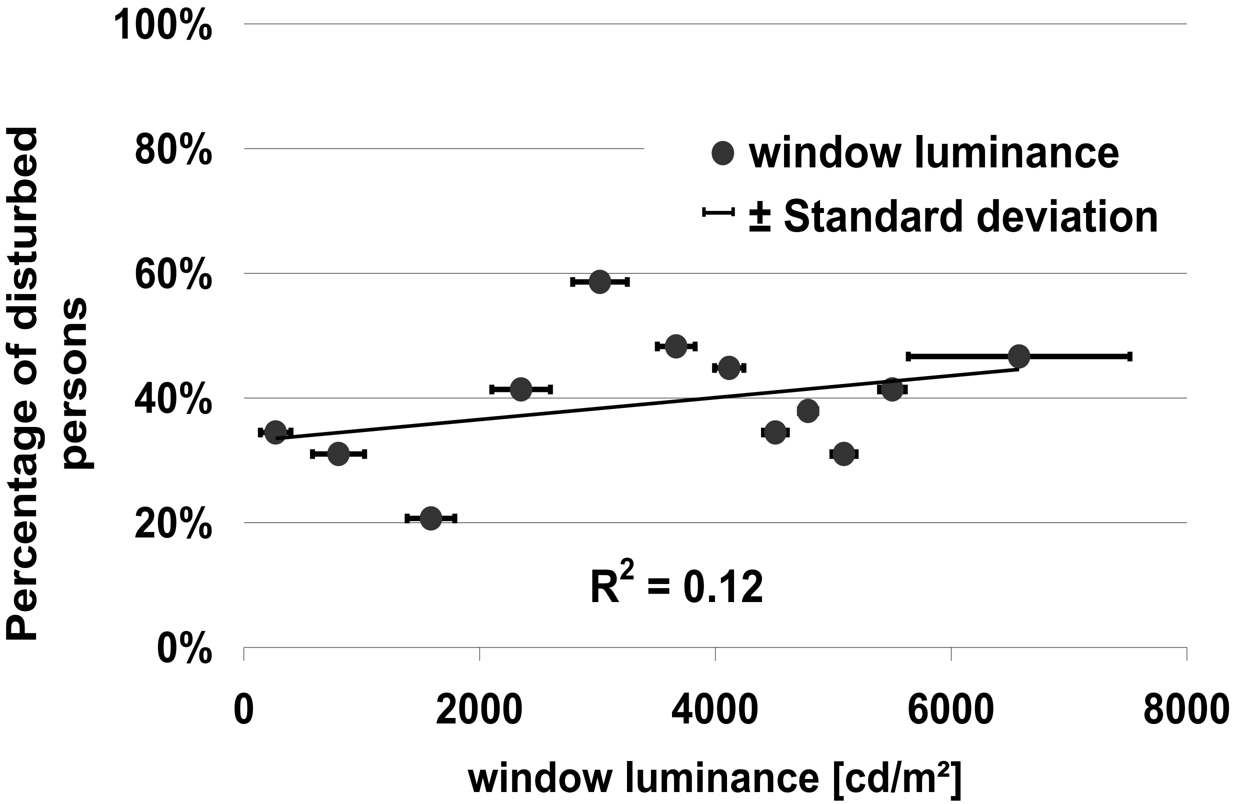


# Result: Average window luminance versus percentage of persons disturbed

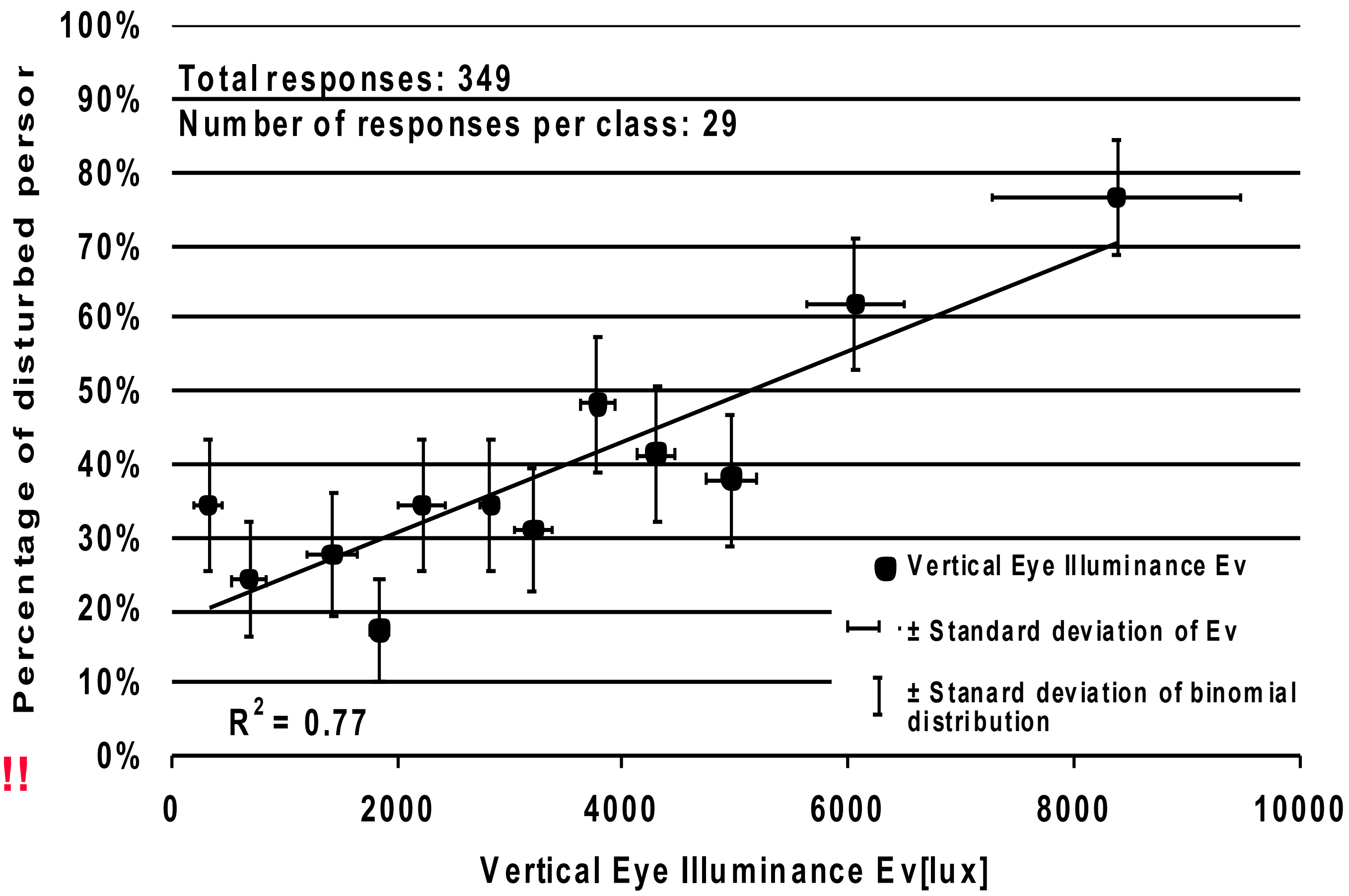
Large scatter

No dependency

no correlation



# Result: vertical eye illuminance versus percentage of persons disturbed




**reasonable correlation**

**But no peaks can be considered!!**

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## Idea for the development of the DGP

Use recent findings (Knoop, Osterhaus): Vertical Eye illuminance

**and (!!)**

Parts of CIE-glare index (or UGR)

$$CGI = 8 \log_{10} 2 \cdot \frac{\left[1 + \frac{E_d}{500}\right]}{E_d + E_i} \cdot \sum_{i=1}^{n} \frac{L_s^2 \omega_s}{P^2}$$

| | |
|---|---|
| $L_s$ | Luminance of source |
| $\omega_s$ $\Omega_s$ | Solid angle of source |
| $L_b$ | Background luminance of source |
| P | Position index |
| $E_d$ | Direct vertical illuminance |
| $E_i$ | Indirect vertical illuminance |

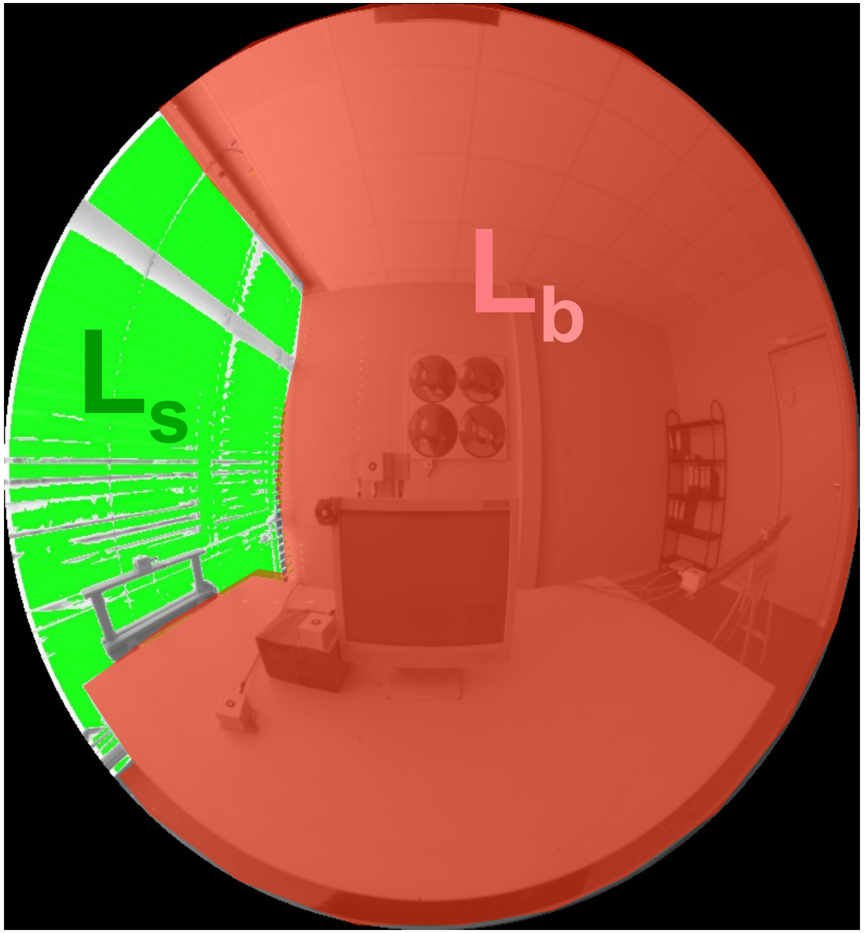
# Adaptation level in equation?

$$G = f\left(\frac{L_s^{a_1} \cdot \omega_s^{a_2}}{L_b^{a_3} \cdot P^{a_4}}\right)$$

**Large glare source**

**$L_b$?**

**Better correlations when using $E_v$**



# 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]

$L_s$: Luminance of source [cd/m²]

$\omega_s$: solid angle of source [-]

$P$: Position index [-]

$c_1 = 5.87 \cdot 10^{-5}$

$c_2 = 9.18 \cdot 10^{-2}$

$c_3 = 0.16$

$a_1 = 1.87$

# Correlation between DGP and probability of persons disturbed

Strong correlation

Logistic regression:

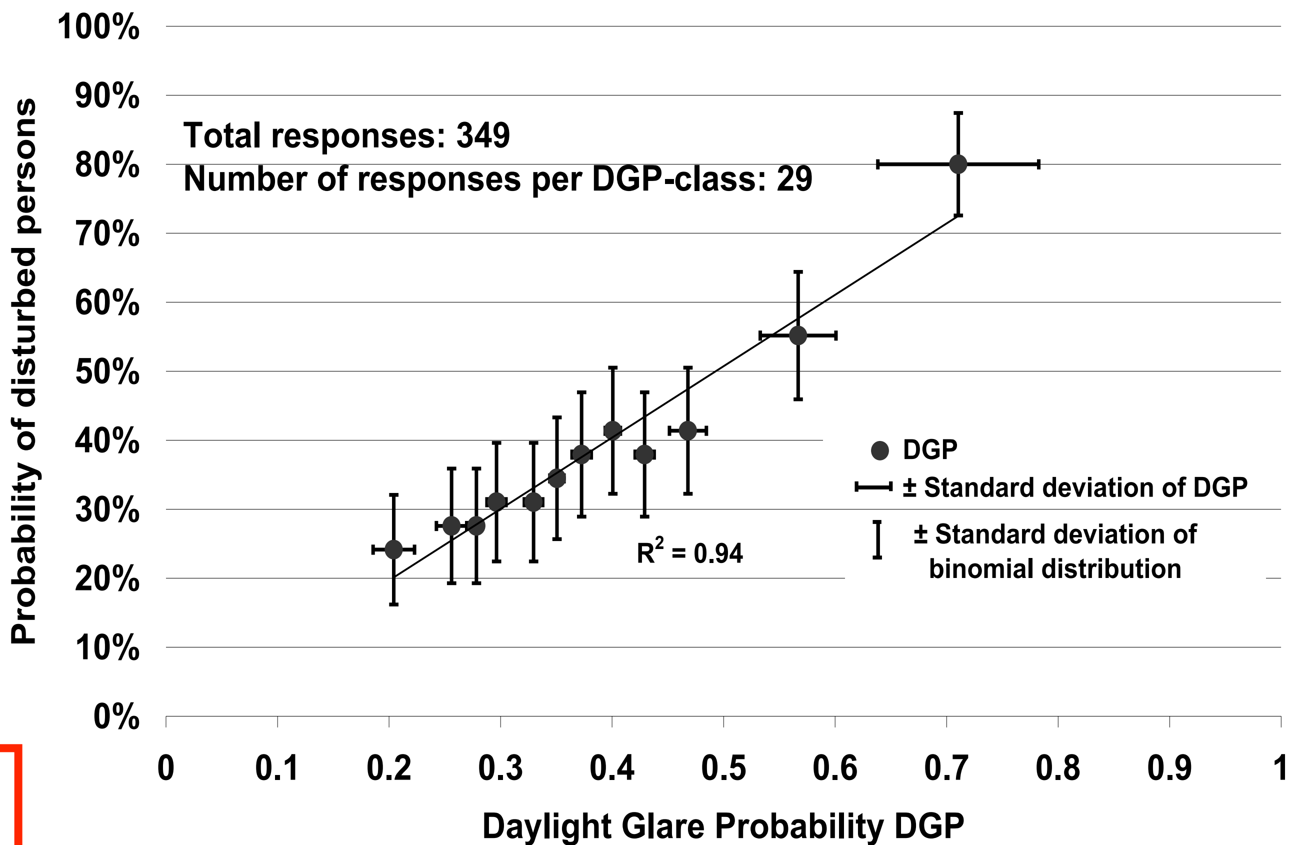
$p=3.44\ 10^{-8}$

⇒Much stronger than for all other metrics

Valid for

$DGP \geq 0.2$

$E_v \geq 380$ lux

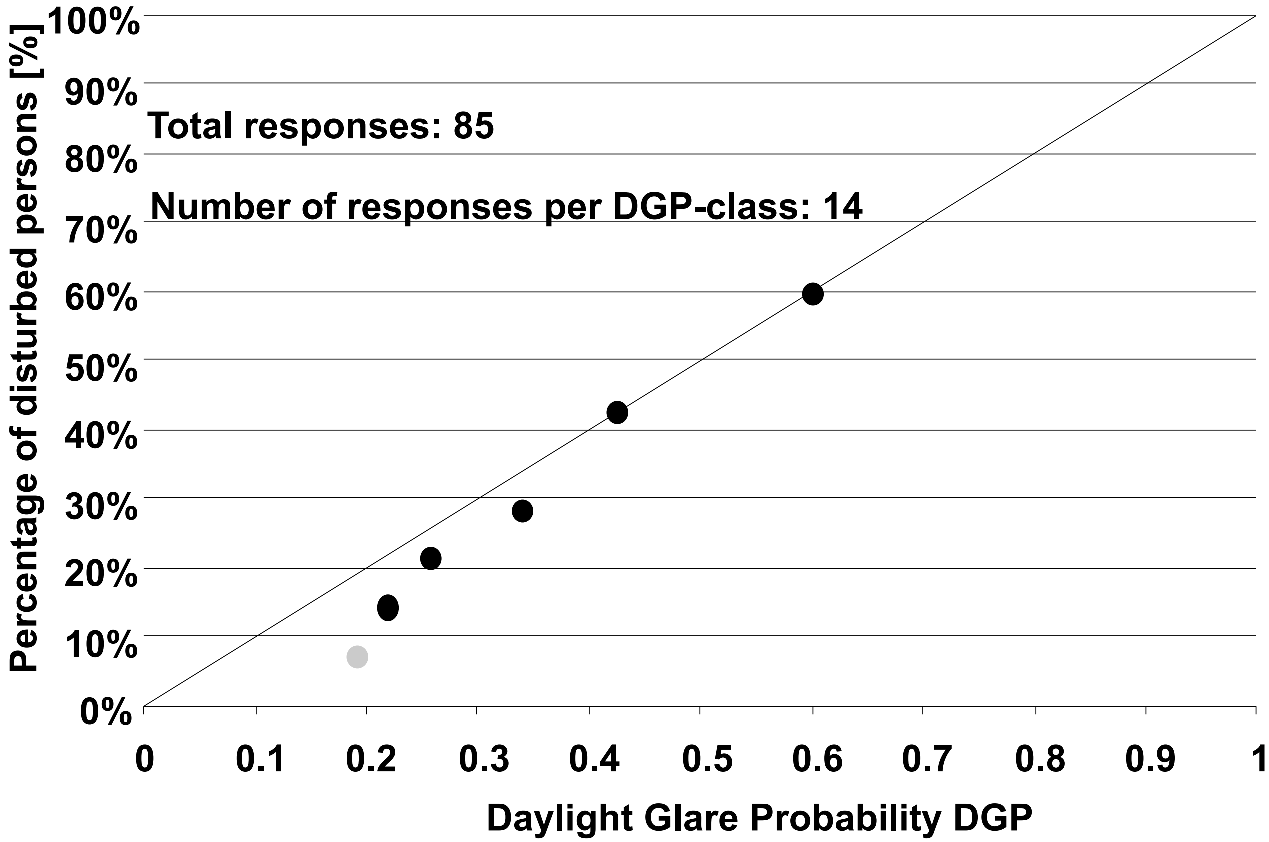


# Validation of the DGP model against additional data

Additional data from 28 new subjects:

6 for vertical foil system (D) and

22 for specular blinds (DK)



# Low light correction

- Problem: DGP is not defined for values smaller than 0.2 or
  Ev < 320 lux!!

- correction factor for “low light” scenes

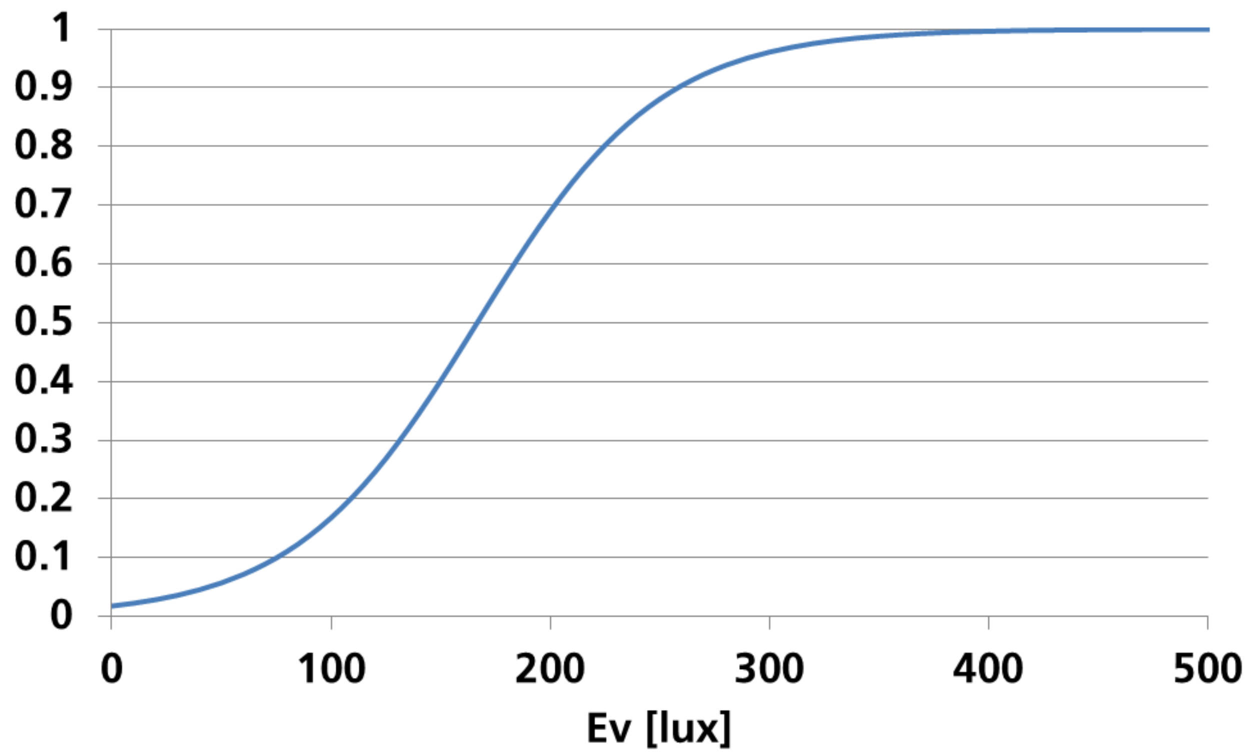
- advantage: existing DGP equation is not changed, but usability range extended

- based on user assessments

- s-Curve between 0-300 lux Ev

$$DGP\_lowlight = DGP \frac{e^{0.024*E_V - 4}}{1 + e^{0.024*E_V - 4}}$$

# Low light correction




$$DGP\_lowlight = DGP \frac{e^{0.024 * E_V - 4}}{1 + e^{0.024 * E_V - 4}}$$

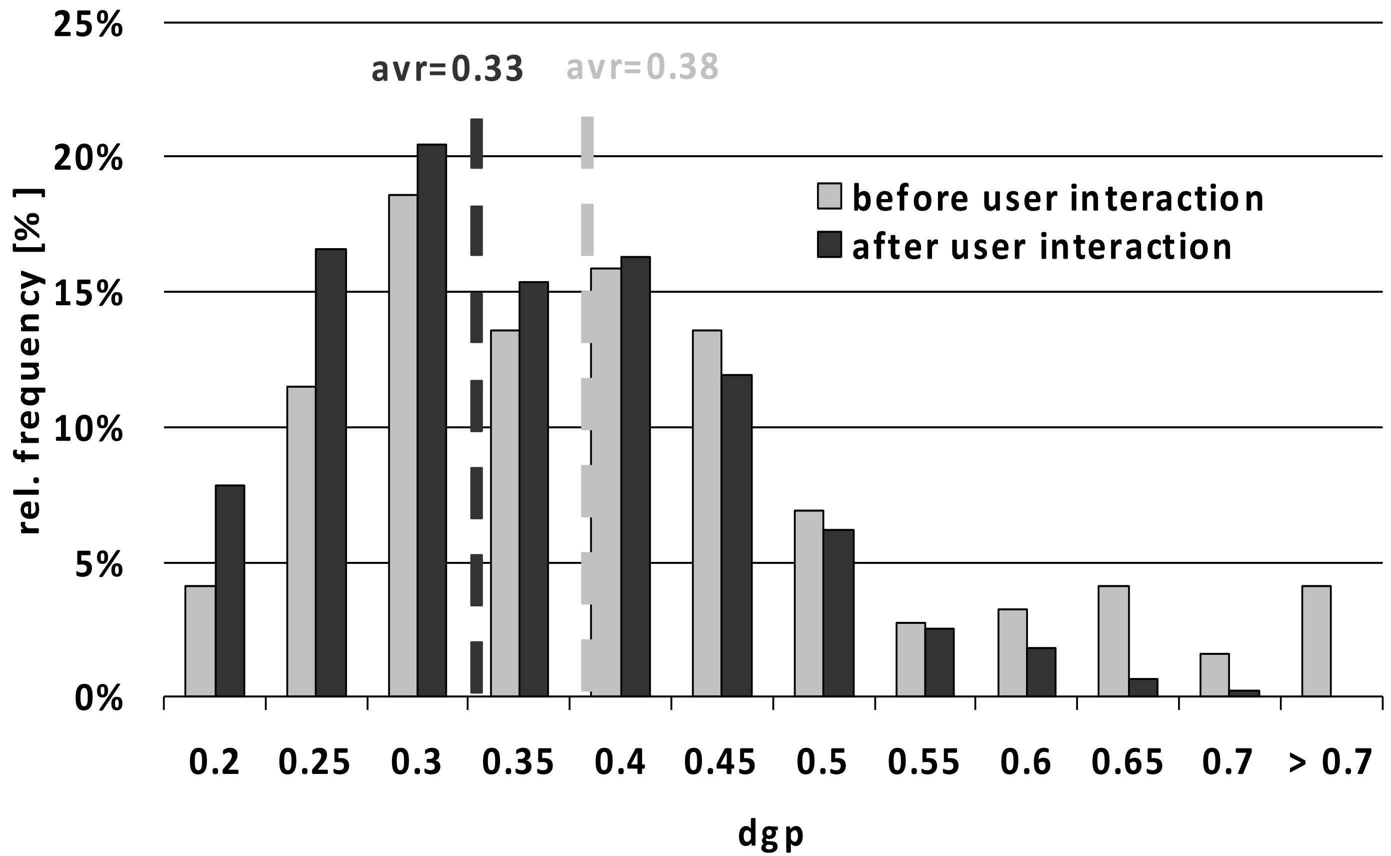
# Evaluation of existing models and development of the DGP - conclusions

- Existing discomfort glare formulas show low correlations with user assessments
- Especially windows luminance and indices based on it show low correlation
- DGP - improves the correlation
- DGP validated in a follow up study and field study

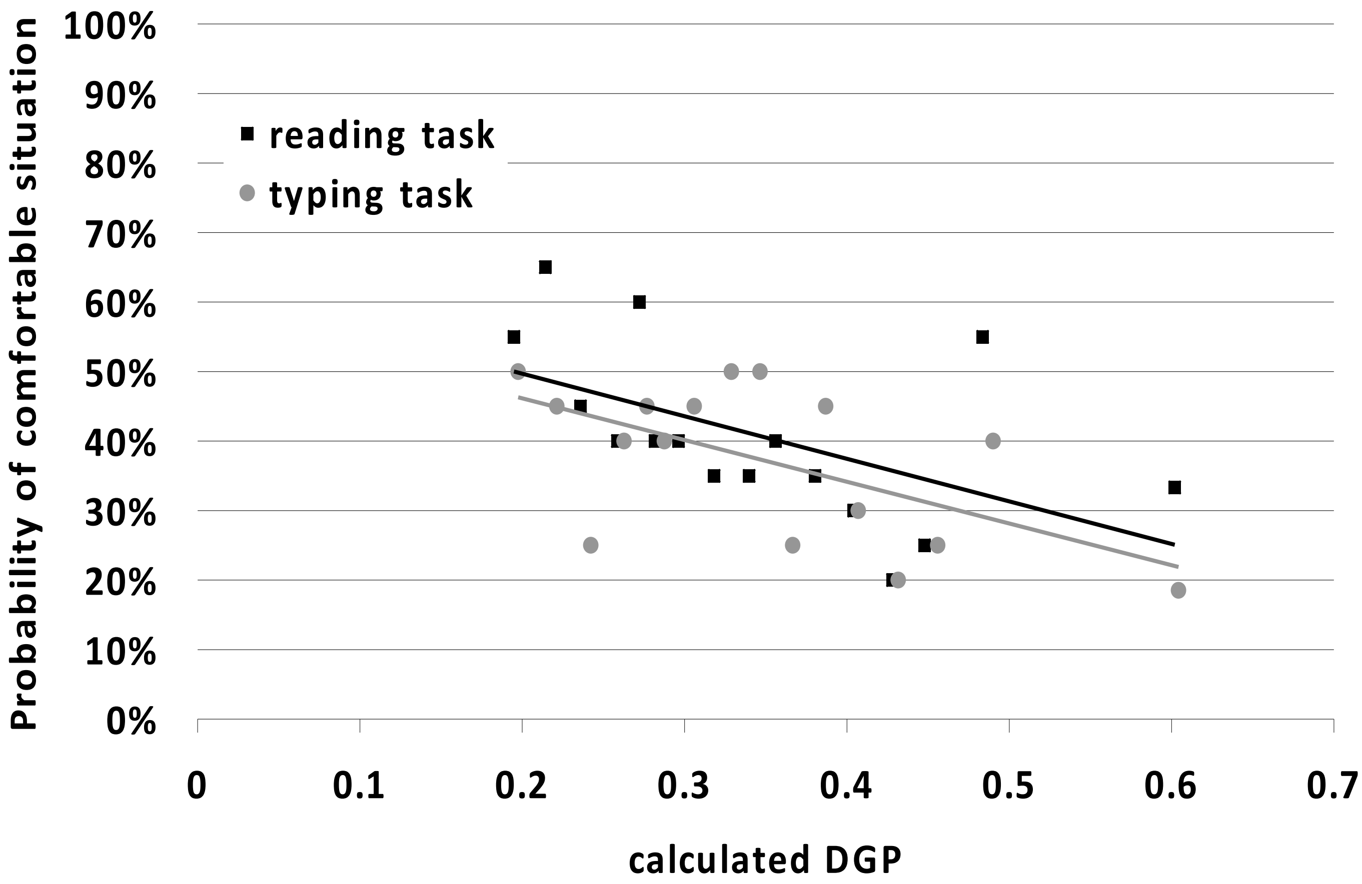
# DGP – Ranges?

- What is preferred by the users?
- What is accepted?
- How to evaluate the data climate based?

# Acceptance of glare



# Influence of glare on overall visual comfort perception



# How to evaluate glare on annual basis?
(dynamically, climate based)

For planning purpose:

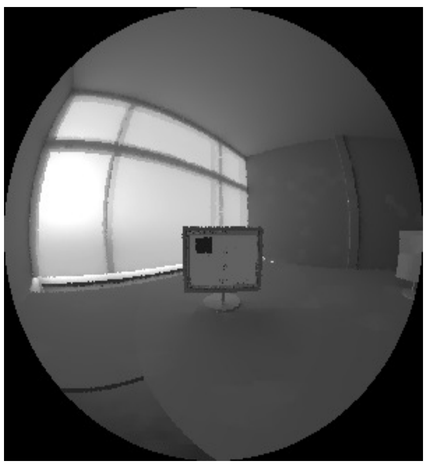
⇒ A fast and reliable calculation method is needed

⇒ A comprehensive evaluation method is needed

# What possibilities do we have to evaluate glare dynamically?

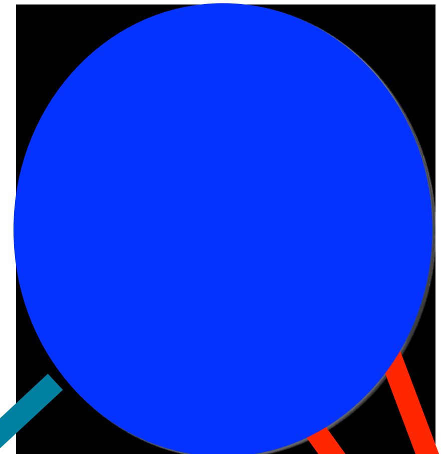
Hour by hour calculation:

Radiance reference method



Time consuming!

evalglare



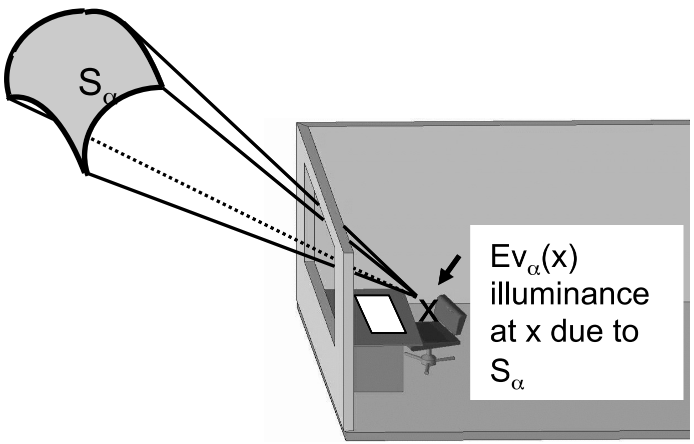
$$E_{vert} = \sum_i L_i \cdot \omega_i \cdot \cos(\theta_i)$$

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

# What possibilities do we have to evaluate glare dynamically?

Simplified method:

Calculating the vertical eye illuminance by the use of daylight coefficient method




Daysim

Hourly $E_v$

But no pictures!

Ignore peak glare sources!

$$DGPs = c_1 \cdot E_v + c_3$$

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

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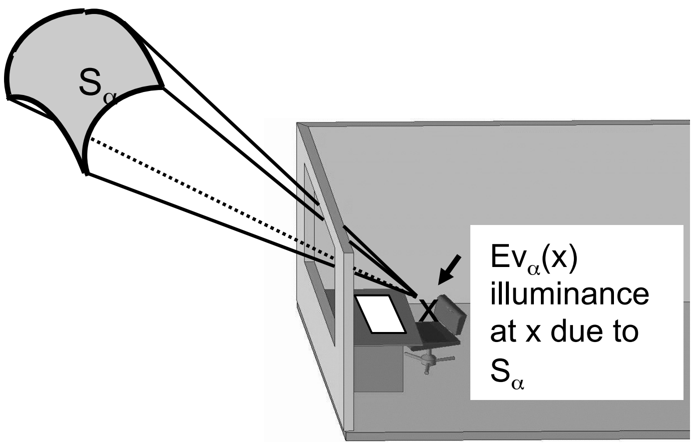
# ~~What possibilities do we have to evaluate glare dynamically?~~

Enhanced simplified method:

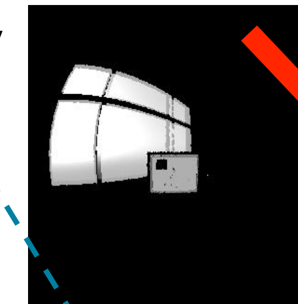
Calculating the vertical eye illuminance by the use of daylight coefficient method



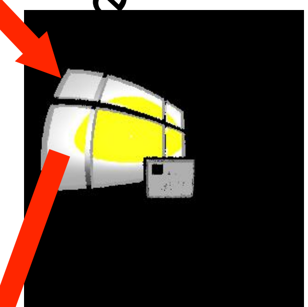

Daysim

Hourly $E_v$

Calculation of a simplified picture



evalglare



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

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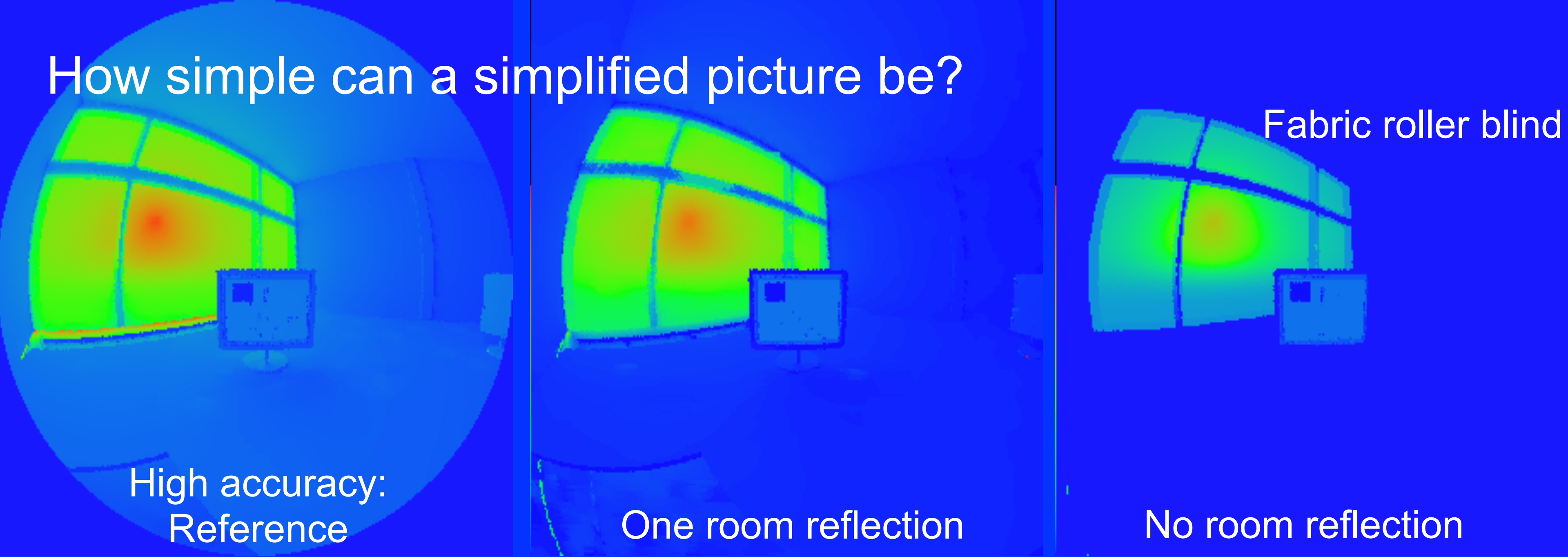
# How simple can a simplified picture be?



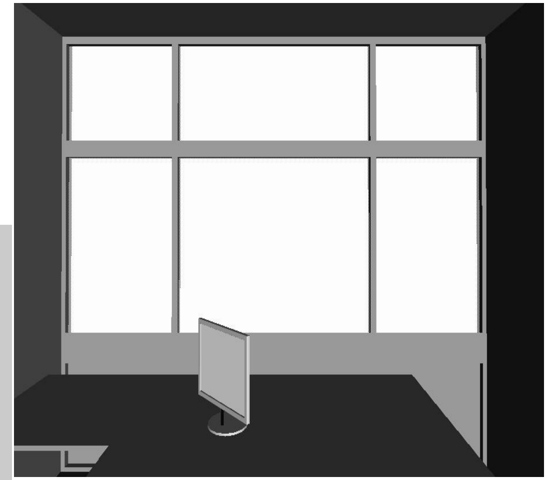
# Example room models

Single space office

1. Band window façade
2. Fully glazed façade with parapet

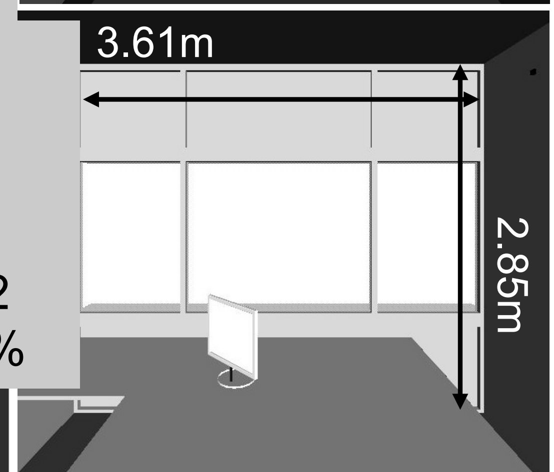
Two shading devices

1. Fabric roller blinds
2. Silver Venetian blinds



Fabric roller blinds:

grey-alu




Venetian Blinds:
80 mm convex slats
slat distance 72 mm
Fixed slat angle 15°
silver color $\rho_{vis}$ = 0.52
specular reflection 5%

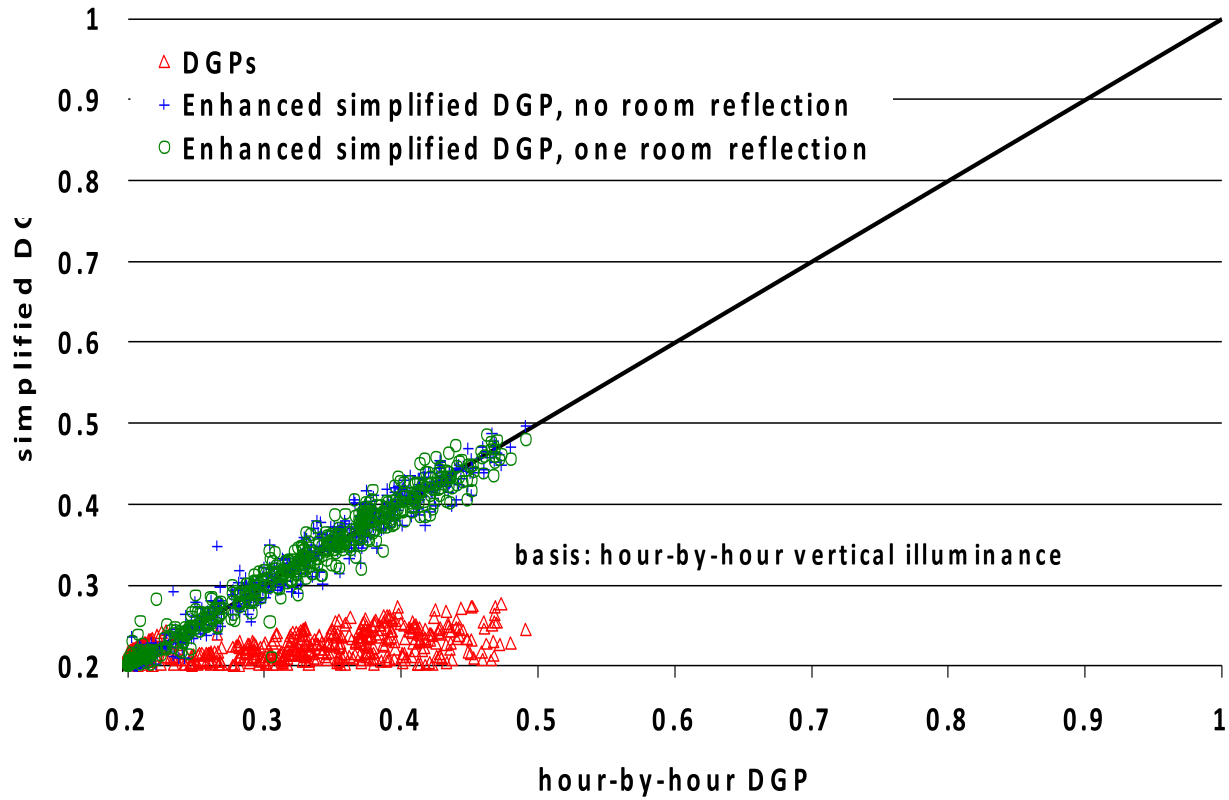
# Validation results

## fabric roller blind

Good correlation for enhanced methods

Small difference for using room reflection calculation

DGPs large error

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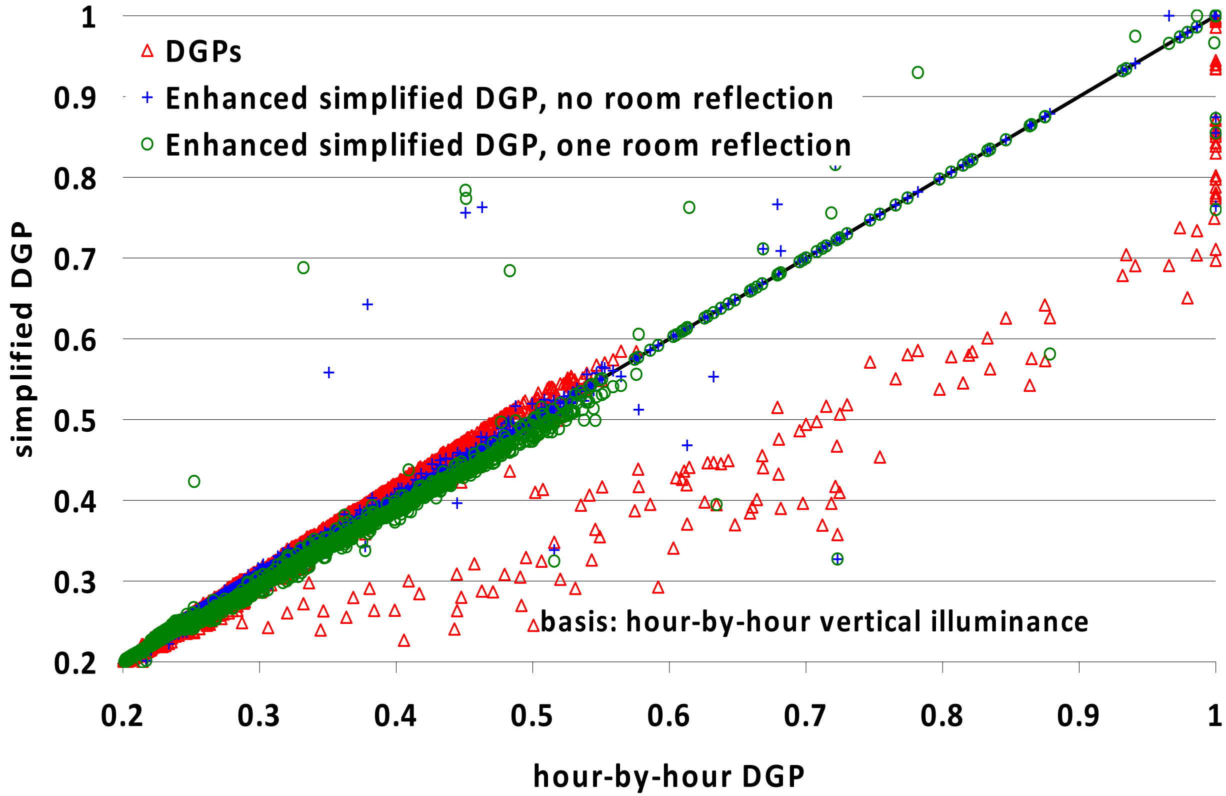
# Validation results
# venetian blinds

Good correlation for enhanced methods

Small difference for using room reflection calculation

underestimation by DGPs



# Summary error

| Method | | fabric roller blind rRMSE [% ] | Venetian blind rRMSE [% ] |
|---|---|---|---|
| simplified | DGPs | 15.7% | 8.0% |
| enhanced simplified | DGP no refl. | 2.8% | 4.9% |
| enhanced simplified | DGP one refl. | 2.7% | 4.3% |

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

# Evaluation of annual data

Idea:

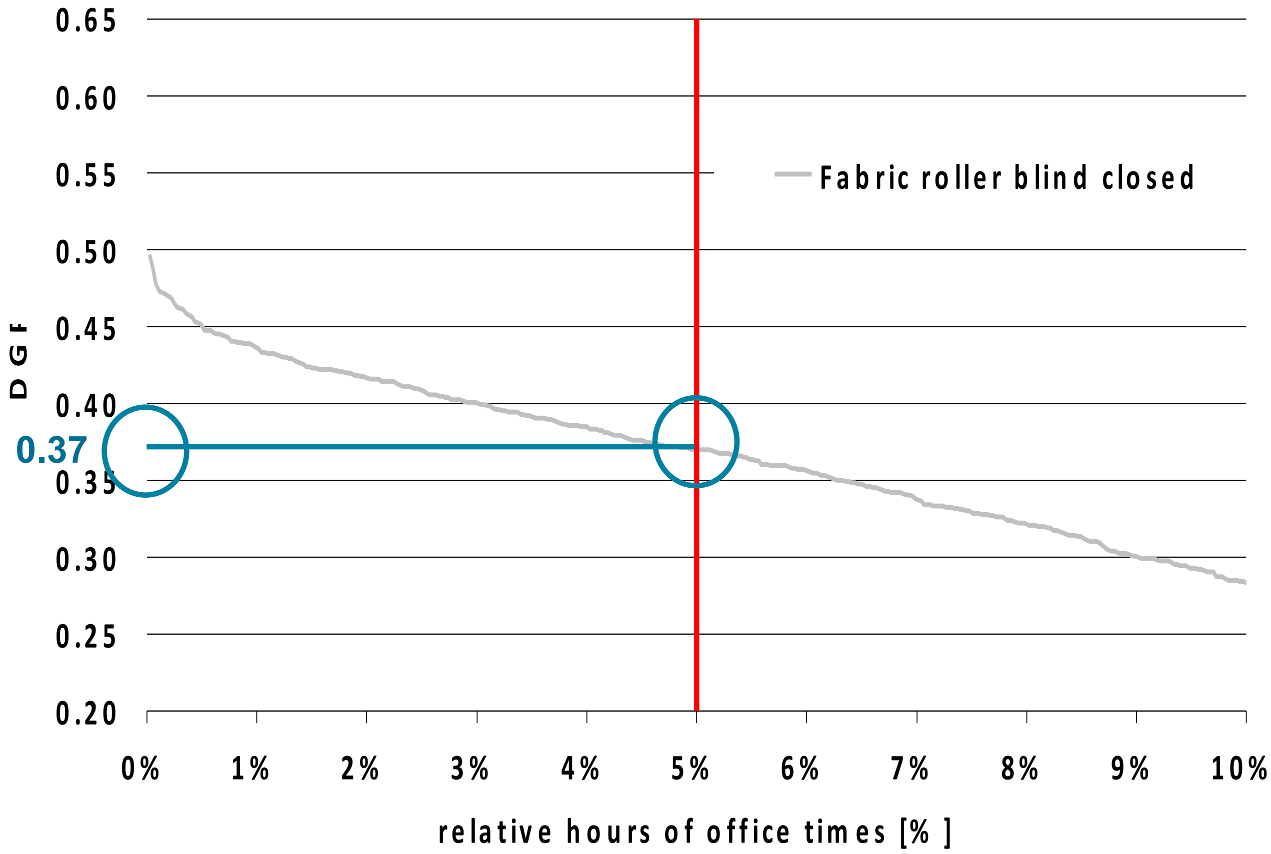
Use similar method than for thermal comfort [EN 15251, 2007]

⇒ Define three categories, in those a certain amount of users are satisfied

⇒ Here: Usage of glare categories from questionnaire

⇒ A 5% exceedance is allowed

# Evaluation of annual data



# Basis for the categories: Results of the user assessments

Descriptive one-way ANOVA analysis (ANalysis Of Variance)

| Glare rating | DGP avg | 95% -confidence interval lower limit | upper limit |
|---|---|---|---|
| imperceptible | 0.33 | 0.314 | 0.352 |
| perceptible | 0.38 | 0.356 | 0.398 |
| disturbing | 0.42 | 0.39 | 0.448 |
| intolerable | 0.53 | 0.464 | 0.59 |
| avg | 0.39 | 0.314 | 0.352 |

# Suggestion of glare - classes

| | A<br>best class<br>95 % of office-time glare weaker than "imperceptible" | B<br>good class<br>95 % of office-time glare weaker than "perceptible " | C<br>reasonable class<br>95 % of office-time glare weaker than "disturbing" |
|---|---|---|---|
| DGP limit | ≤ 0.35 | ≤ 0.40 | ≤ 0.45 |
| Average DGP limit within 5 % band | 0.38 | 0.42 | 0.53 |

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# findglare – evalglare : radiance based tools

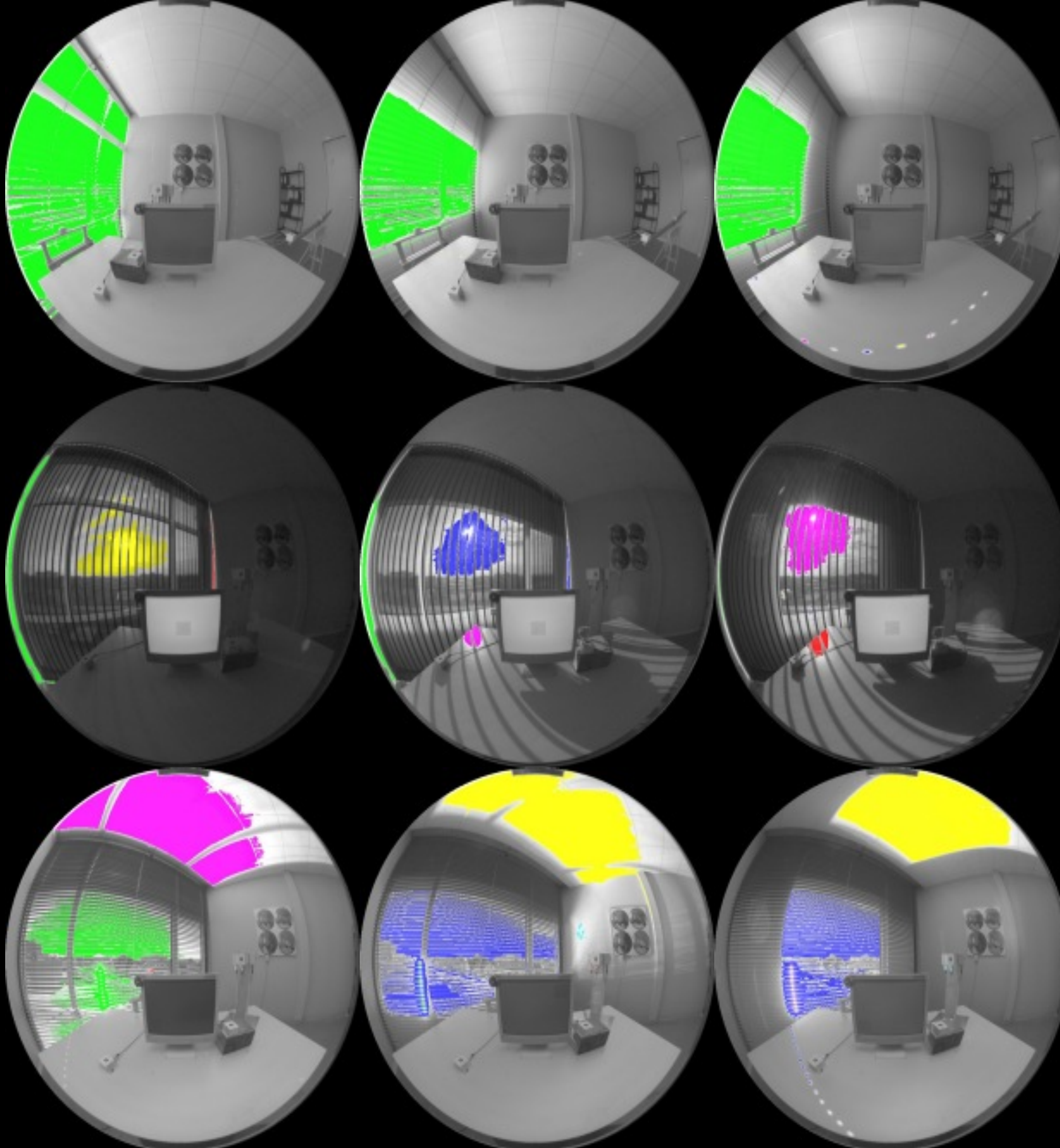
Main differences between findglare and evalglare

- findglare is much faster
- evalglare can use a task driven detection algorithm
- DGP can be calculated only in evalglare up to now
- Some special features are included in evalglare only (e.g. provision of externally measure Ev, field of view cut, colored output of the glare source pixels…)

# findglare – evalglare : radiance based tools

Glare detection – What is a glare source???? :

- findglare: all sections of the image, which luminance are  x-times larger than average luminance of the image, is treated as a glare source (default value =7) . Problem: if the glare source gets large, probably nothing is detected!



# Detection of glare sources

What is a glare source? (In the view of a program)

⇒ reliable algorithm to detect a “glare source” in a scene

⇒ should be valid for any kind of visual environment

I) Average luminance of the whole scene:
Every pixel larger than x-times of the av. luminance is treated as glare source (RADIANCE default=7)

Main disadvantages:

⇒ In bright scenes, only few zones are detected

⇒ Does not take into account, that the overall amount of light at the eye (=vertical illuminance) is a main glare parameter

# Detection of glare sources

II) Fixed value threshold (e.g. 2000cd/m²) :

Disadvantages:

⇒ Does not take into account adaptation level

⇒ Works only in limited scenes properly

III) Calculate "task luminance" and treat all pixels higher than x-times of the task luminance as glare source

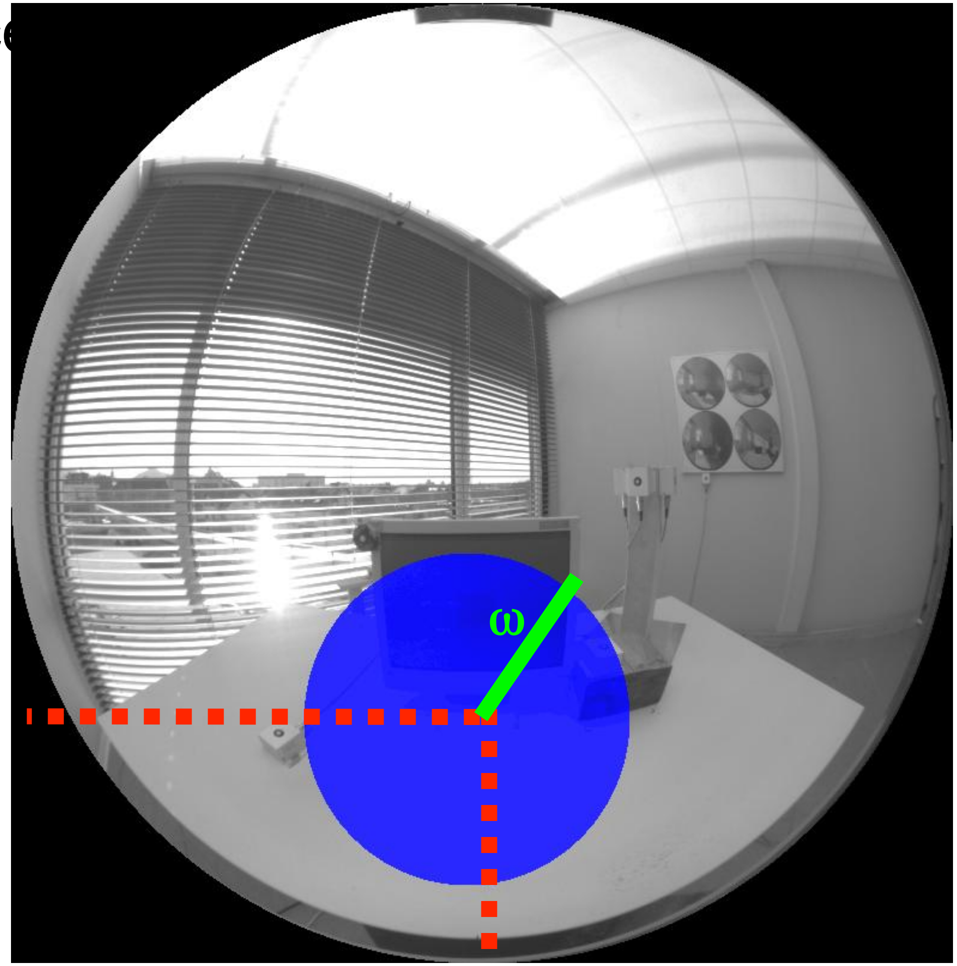
Depending on the "size" of the task, the adaptation level is taken into account

Disadvantage: Knowledge of task location needed

All three methods are implemented into evalglare

# Detection of glare sources

Define task luminance
as threshold for glare sourc




Two parameters have to be provided:

1. *x y* position of picture (centre of task)
2. opening angle ω of task

-t *x y ω* : task mode without colouring

**-T** *x y ω* : task mode with colouring

# findglare – evalglare : radiance based tools

Glare detection:

- evalglare: all three methods are included, but:

# findglare – evalglare : radiance based tools

Importance of task area detection - example:

- 433 images from user assessments
- in 193 cases the user voted disturbing or intolerable
- "default 7x" algorithm detected 130 situations with glare
- BUT: only 95 cases (59%) when the users voted noticeable glare or more, in 33 cases (20%) when the users voted disturbing or more
- Especially large glare sources (e.g. fully glazed face with blinds) are not detected, because the influence very much the average luminance of the image.

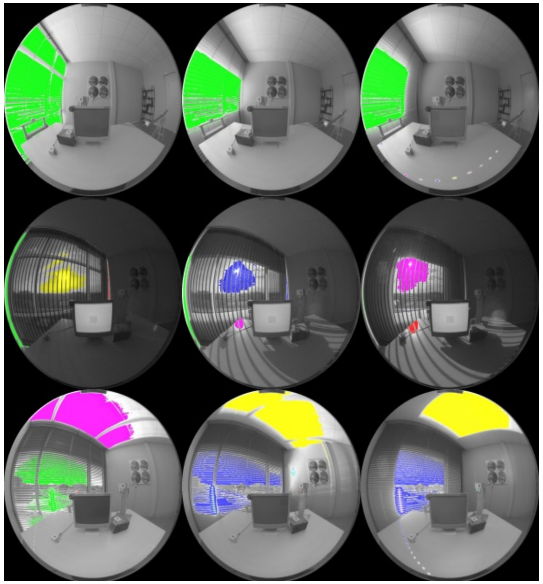
# findglare – evalglare : radiance based tools

Glare detection:

- It is strongly recommended to use the task-area method!!!

# Evalglare
# A Radiance based tool for glare evaluation

Introduction



- Command line based tool to evaluate glare within a given image, mainly daylit scenes.

  Usage (independent on operating system):

  evalglare [options] hdr   (hdr can be piped also)

- Software needs only the executable file

- Output to “standard output” -> flexible

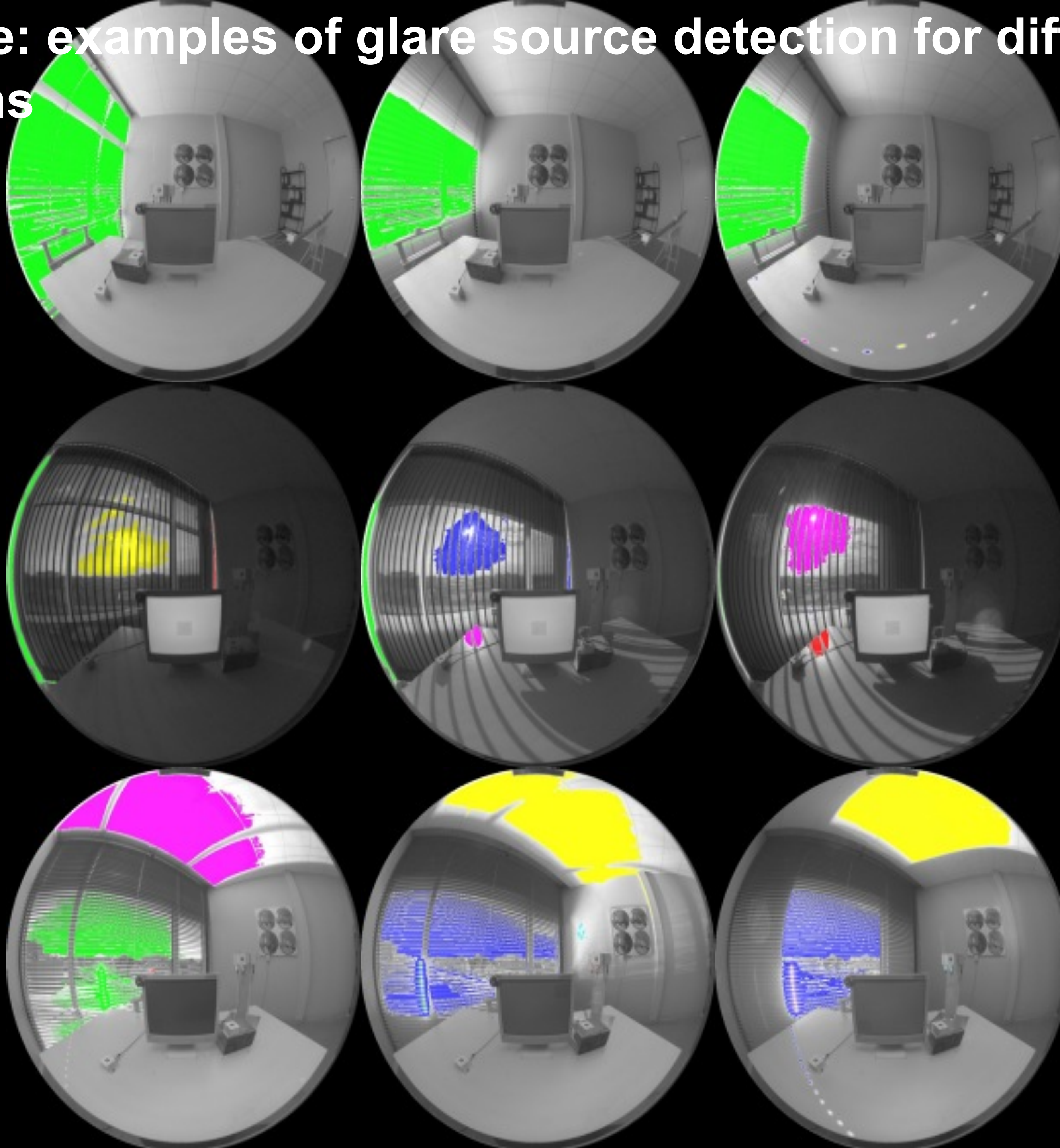
# Evalglare

**Primary goal : Detection of glare sources, calculation of glare indices**

**Calculated values:**

| **In total:** | **Per glare source (only with –d available):** |
|---|---|
| Vertical Illuminance | Position (x,y, position index) |
| DGP | Size (solid angle) |
| UGR | Luminance |
| DGI | Task, background and maximum luminance |
| VCP | Direct illuminance |
| CGI | Direction vector |
| Luminance of all glare sources | |
| Solid angle of all glare sources | |
| Disability glare, CIE, Stiles-Holladay | |

# evalglare: examples of glare source detection for different situations



# Detection of glare sources

Which parameter must be set for the detection modes?

-b *value*

Value > 100 : Fixed luminance value detection mode is enabled

e.g. –b 2000 : Every pixel showing a luminance larger than 2000 cd/m$^2$ is treated as a glare source pixel

-> Try out with your image (use b=500, b=2000, b=5000) and visualize!

# Detection of glare sources

Which parameter must be set for the detection modes?

-b *value*

Value ≤ 100 *and neither* –t *nor* –T are used :

Average luminance detection mode is enabled

e.g. –b 5 : Every pixel showing a luminance larger than 5 times of the average luminance of the full image is treated as a glare source pixel

-> Try out with b=0, b=2 and b=10 with your image and visualize!

# Detection of glare sources

Which parameter must be set for the detection modes?

-b *value*

Value $\leq$ 100 *and either* –t *or* –T are used :

Task luminance detection mode is enabled

e.g. –b 5 –T 300 300 0.5

: Every pixel showing a luminance larger than 5 times of the average luminance of the task area is treated as a glare source pixel

-> Try out two different task positions and sizes with your image and visualize!

# Detection of glare sources

But important to know:

Using task area mode does not change viewing direction!!!

No influence on position index!! (not yet, need?)

# Position index is used in most glare metrics

Principal structure of glare metrics:

$$G = f\left(\frac{L_s^{a_1} \cdot \omega_s^{a_2}}{L_b^{a_3} \cdot P^{a_4}}\right)$$

| | |
|---|---|
| $L_s$: | Luminance of source |
| $\omega_s$: | Solid angle of source |
| $L_b$: | Background luminance ⇒ adaptation |
| P: | Position index |

# Position index is used in most glare metrics

$L_s$ : source luminance

$L_b$ : background luminance

$\Omega_s$: Modified solid angle

$\omega_s$: solid angle of source

P: Guth position index

$E_d$: direct vertical illuminance

$E_i$: indirect vertical illuminance

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

$$DGI = \frac{2}{3}(GI + 14) \qquad GI = 10\,log_{10}\, 0.48 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07\,\omega_s^{0.5}\, L_s}$$

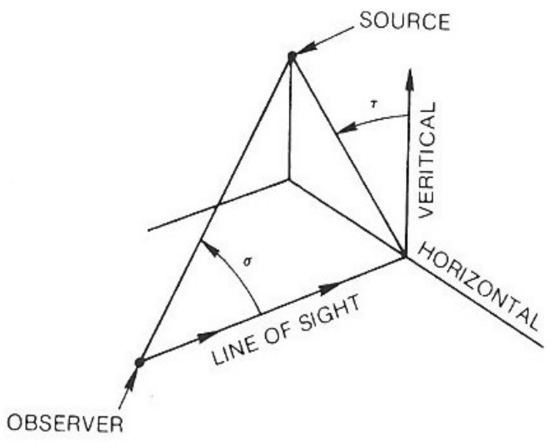
$$CGI = 8\,log_{10}\, 2 \cdot \frac{\left[1 + \frac{E_d}{500}\right]}{E_d + E_i} \cdot \sum_{i=1}^{n} \frac{L_s^2\, \omega_s}{P^2}$$

$$UGR = 8\,log_{10}\, \frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \frac{L_s^2\, \omega_s}{P^2}$$

## Calculation of existing glare

## formulas

IES position index




$$\ln P = [35.2 - 0.31889\tau - 1.22e^{-2\tau/9}]10^{-3}\sigma + [21 + 0.26667\tau - 0.002963\tau^2]10^{-5}\sigma^2$$

$\tau$ : angle from vertical plane containing sourceand line of sight

$\sigma$ : angle between line of sight and line from observer to source

Only defined above view direction!

# Position index below line of sight:

Model from Toshie Iwata 1997
Expressed by Prof. Einhorn

$$P = 1 + 0.8 * R / D \qquad \{R < 0.6D\}$$

$$P = 1 + 1.2 * R / D \qquad \{R >= 0.6D\}$$

$$R = \sqrt{H^2 + Y^2}$$

D : distance eye - to plane of source in view direction

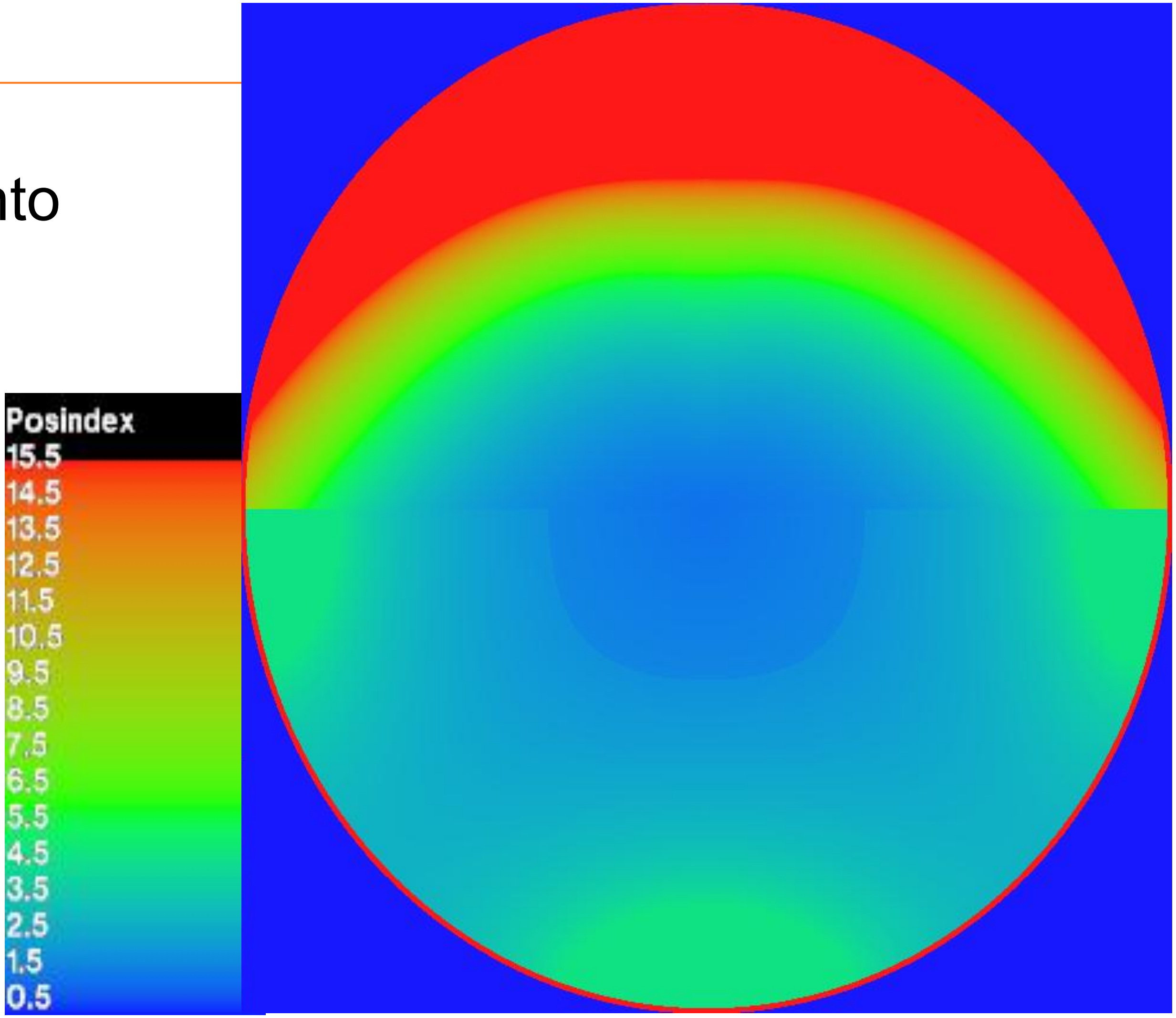
H : Vertical distance between source and view direction

Y : Horizontal distance between source and view direction

# Position index

implementation into evalglare

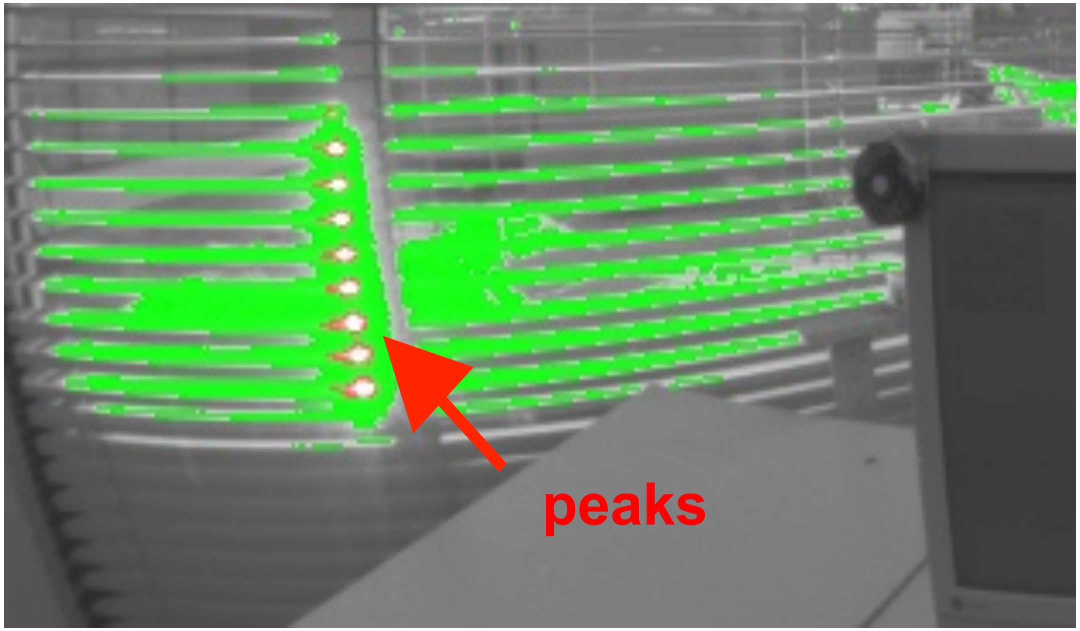
View direction is always in centre of picture!!



# Evalglare

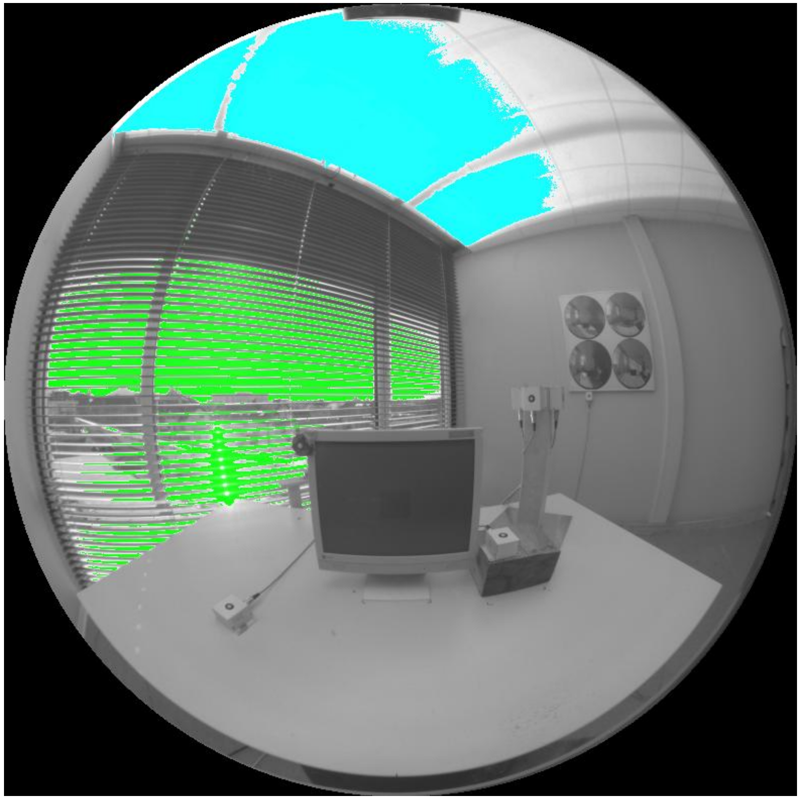
## Spot extraction

Spot extraction (-y) (nowadays default)
"Peaks" of very high luminances can
be extracted to an extra glare source



# Glare source detection algorithm: Merging of pixels to a glare source (gs)

Which pixels should be counted to which glare source?



# Detection of gs Algorithm

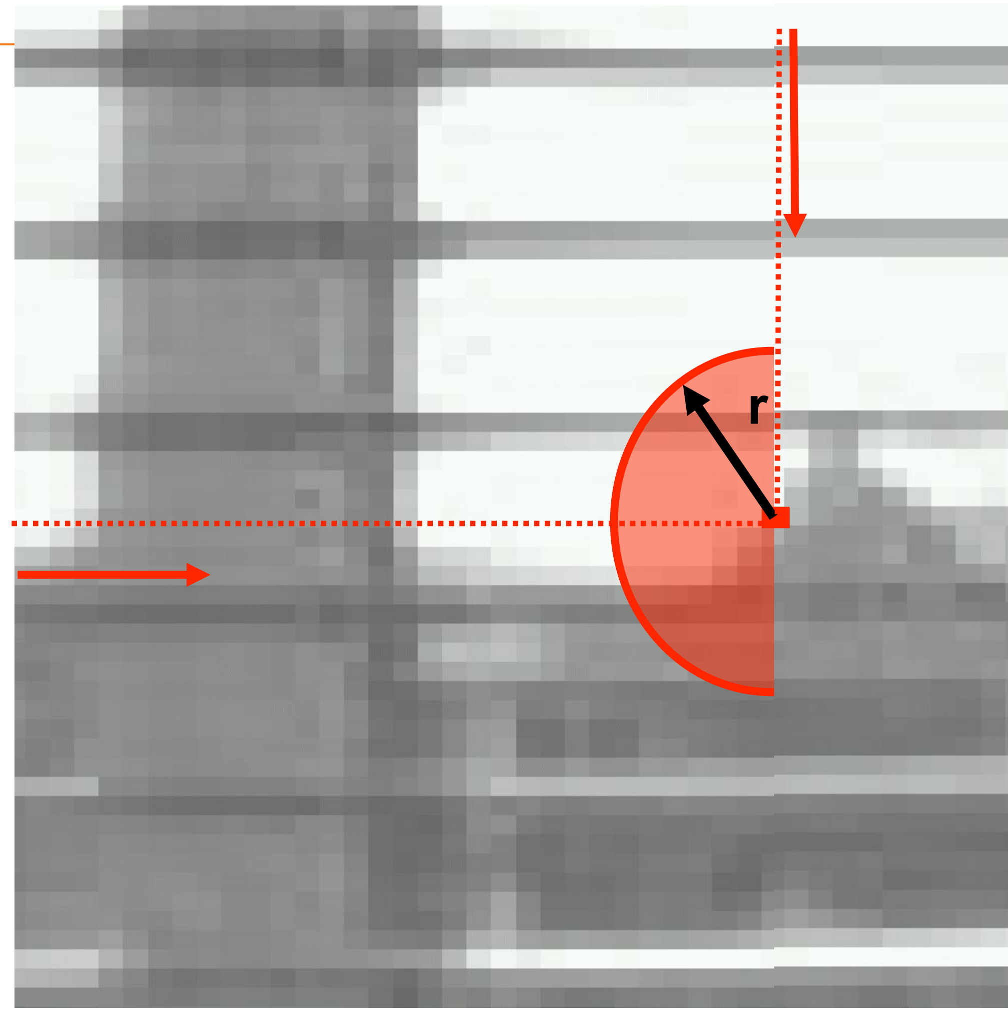
## r-parameter

First scan of picture pixel by pixel

If $L_{pixel}$ > threshold (task luminance) then

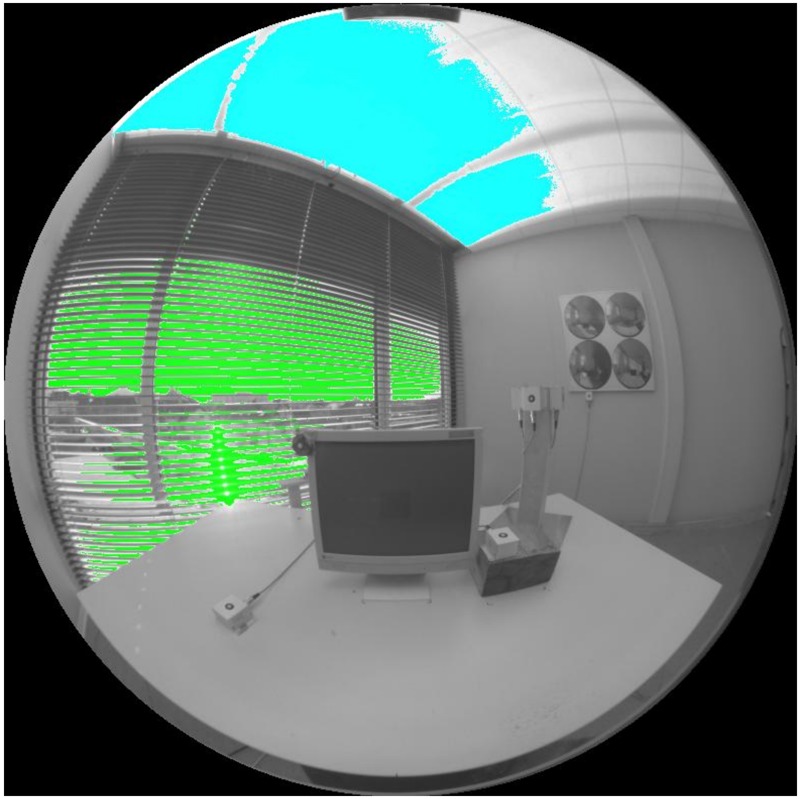
Search for other pixels in the nearby (r provides as $\omega$ as parameter)

Add pixel to gs (luminance, position)



# Influence of the –r parameter

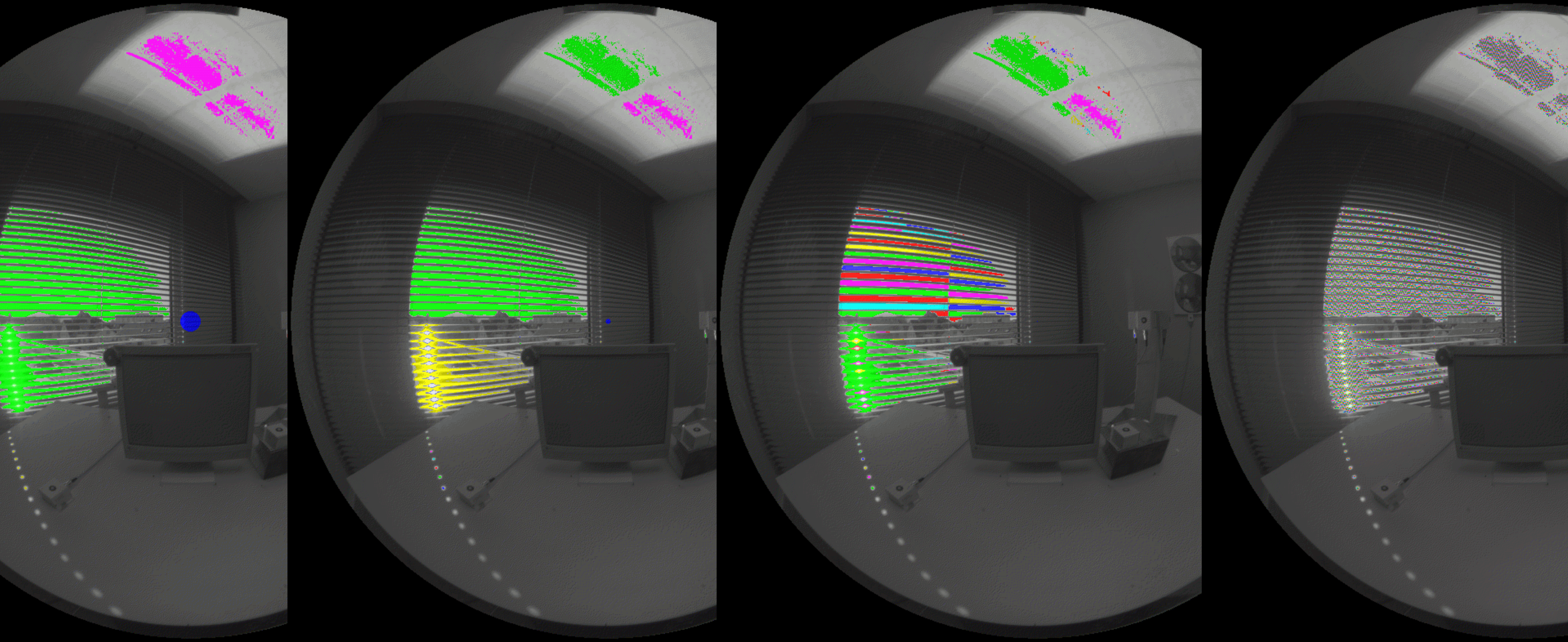
-r is a search diameter, for combining glare pixels to a glare source



Merging of “glare areas” to a glare source – How large should be a glare source?

Influence of the –r parameter

R=0.2 (default) | R=0.05 | R=0.015 | R=0.001



DGP 0.6277 | 0.6274 | 0.6286 | 0.67

-> Try out different search radius with your image and visualize!

# The evalglare checking picture ( –c *hdrfile*)

Up to now:

- Each found glare source gets a certain color.
- In total 6 colors, the 7th glare source gets the first color again.
- Just a visualization of the glare sources – no information about importance

- The color might lead the user think of a significance, but there is none (yet)

# What to do if you don‘t have a fish-eye image?

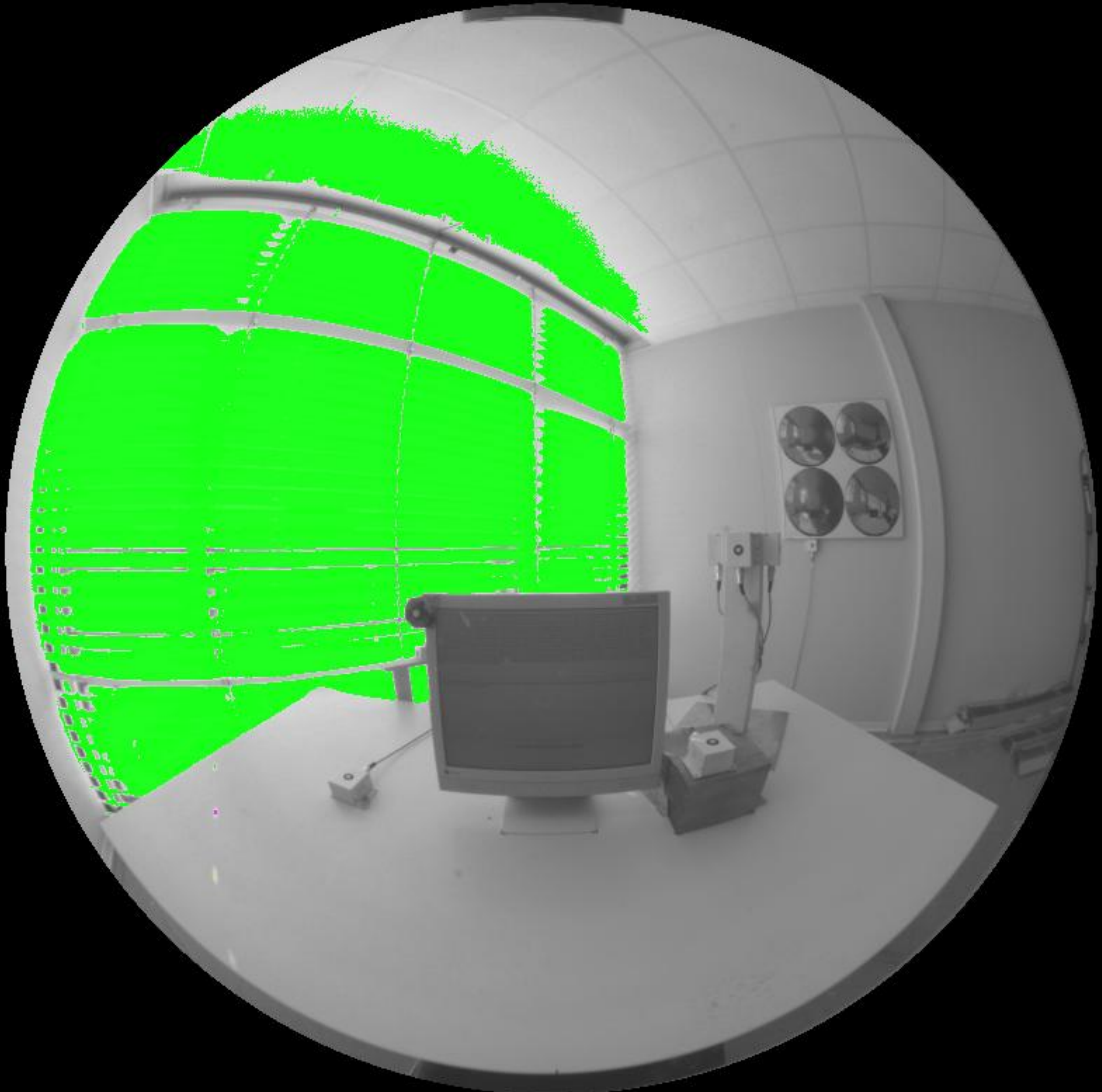
- measure the vertical eye illuminance separately to be accurate
- try to catch the main light sources in the image
- use:

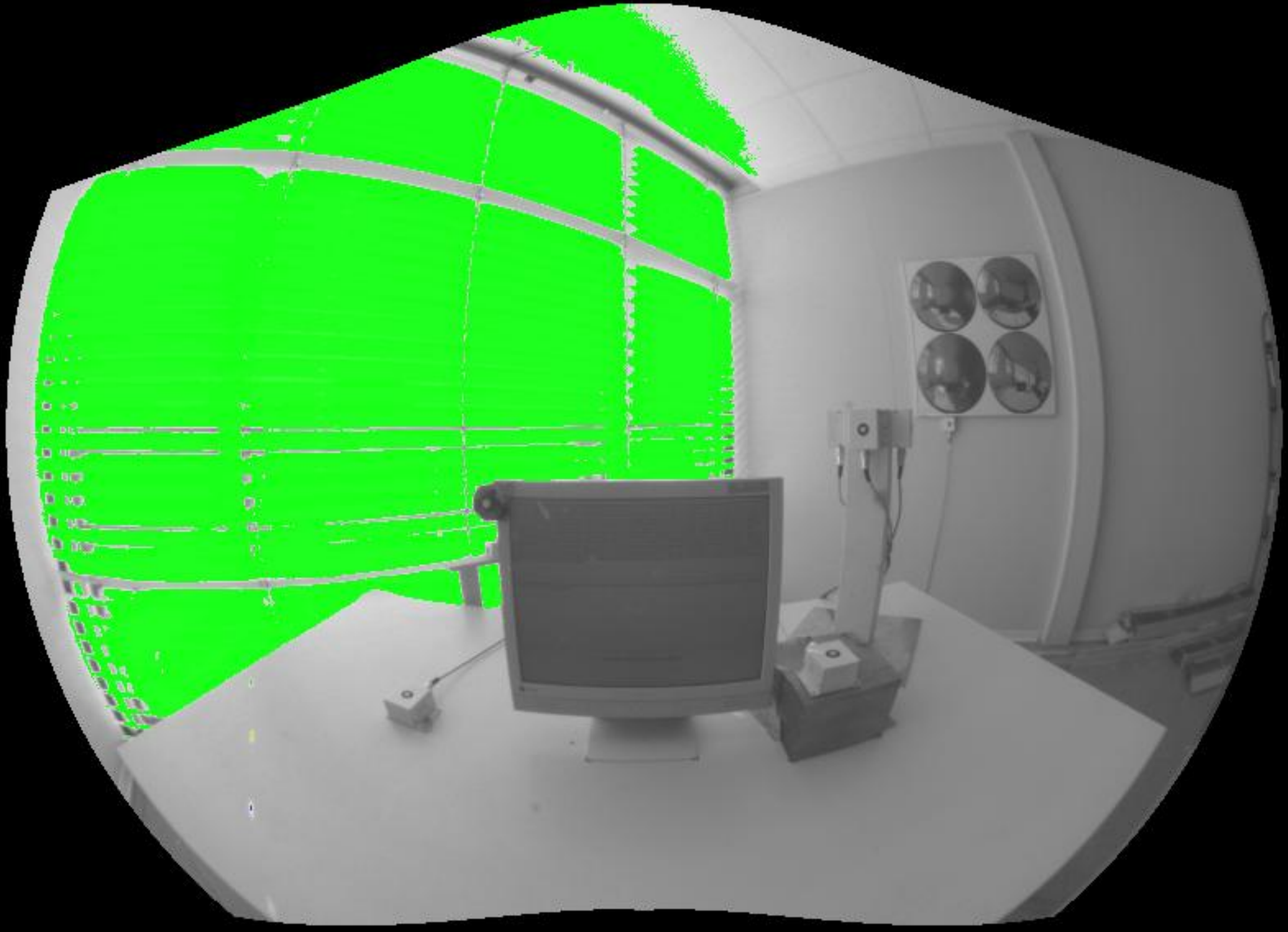
evalglare –i Ev *hdrfile*

The –i option enables to provide external illuminance values

# Cutting field of view based on Guth

- based on paper of Guth 1958:
  Light and Comfort, Industrial Medicine and Surgery, November 1958
- activated by option -G *type*,
  *type*=1: total field of view,
  *type*=2: field of view seen by both eyes





# Detailed output –d

- detailed information about the glare sources
- size(solid angle), position(x,y), Position index, direction vector, task luminance, Edir caused by glare source

```
2 No pixels x-pos y-pos L_s Omega_s Posindx L_b L_t E_vert Edir Max_Lum Sigma xdir ydir zdir
1 8.000000 363.125138 313.125297 746381308.068426 0.0000923477 2.948167 38.383377 11560.269531 61866.158167 61745.573231 746381312.000000 0.000000 -0.000111 -0.952052 0.305936
2 391.000000 442.571127 450.737313 753082.817802 0.0047627966 1.020995 38.383377 11560.269531 61866.158167 61745.573231 746381312.000000 0.000000 -0.271428 -0.947911 -0.166709
dgp,av_lum,E_v,lum_backg,E_v_dir,dgi,ugr,vcp,cgi,lum_sources,omega_sources,Lveil: 1.000000 11560.269418 61866.158167 38.383377 61745.573231 43.038952 84.689842 0.000000 83.017189 -na
```

# Direction vector of glare sources

- angle between glare sources:
- scalar product between direction vectors gives then the cos of the angle

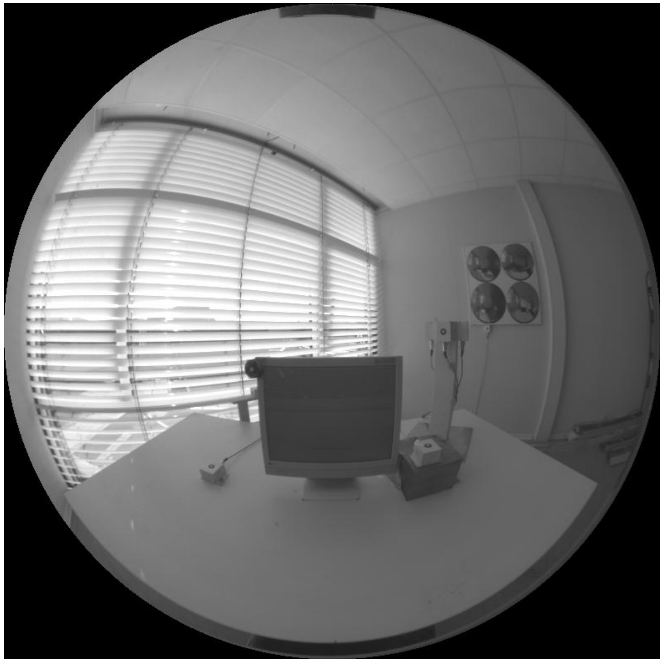
# Please use the current version!!! (v1.11)

## Known problems with 0.9x versions

- Only ONE problem…
  -> View type handling/**validity**!
  **What is an invalid view ????**
  **It's not a problem of evalglare 0.9x, it's a problem how the user is handling the hdr image!!!**
  -> missing view information
  -> Images treated by tools (like pcompos)

  Then
  RADIANCE routines treat view as invalid -> standard view is used <> fish eye!!

# Example



Reality:

Ev=6125 lux, **DGP=0.52**

e.g. use

pcompos -s 1 testpic.pic 0 0

-> same image

-> tab added to the view option string in heade

-> indicating invalid view

Apply evalglare (e.g. v0.9f)

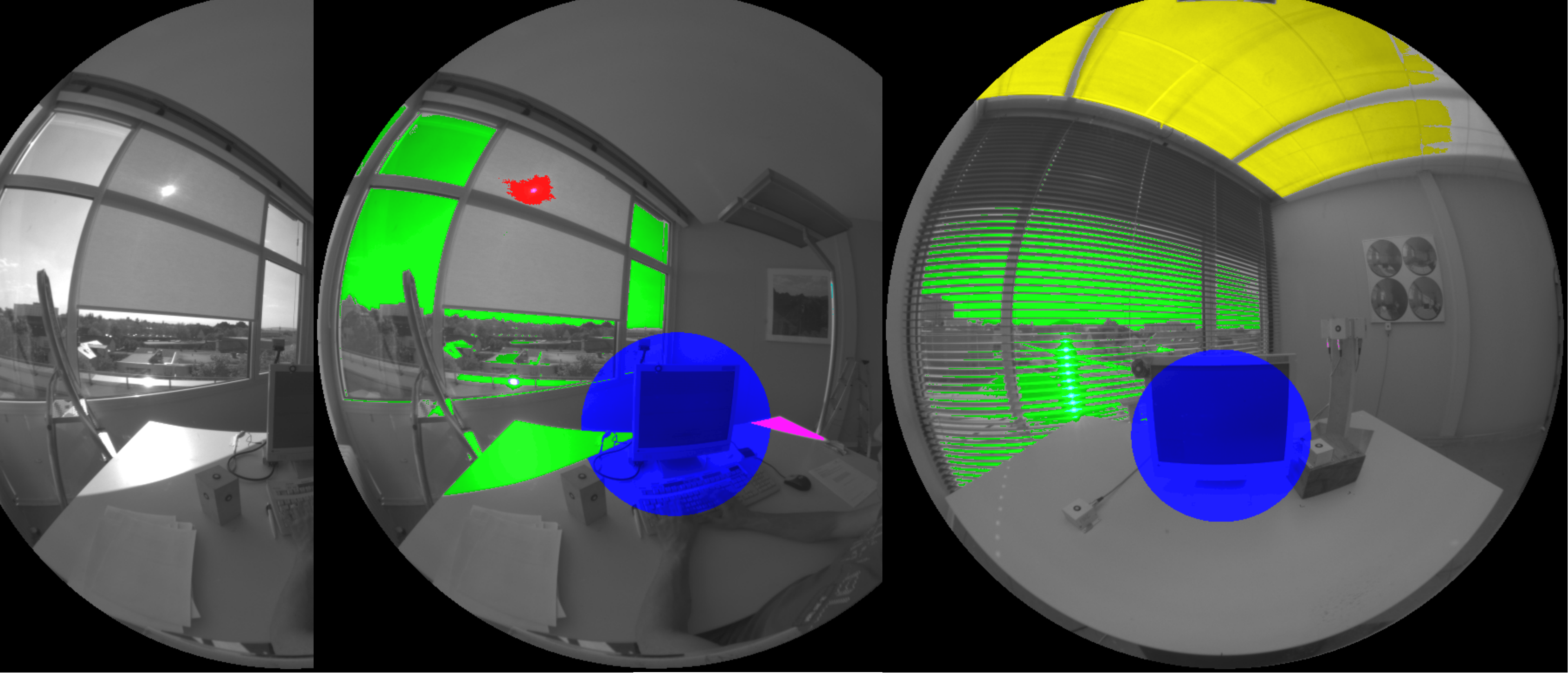
Result when providing wrong hdr-header:

Ev=780 lux, **DGP =0.23** !!!!!!!!!

# Conclusion

Evalglare and findglare are powerful tools to evaluate glare scenes

But: Be aware about the scene and detection parameters!!!!



**Version 1.11 is available here:**

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

# Thanks for your attention!!

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