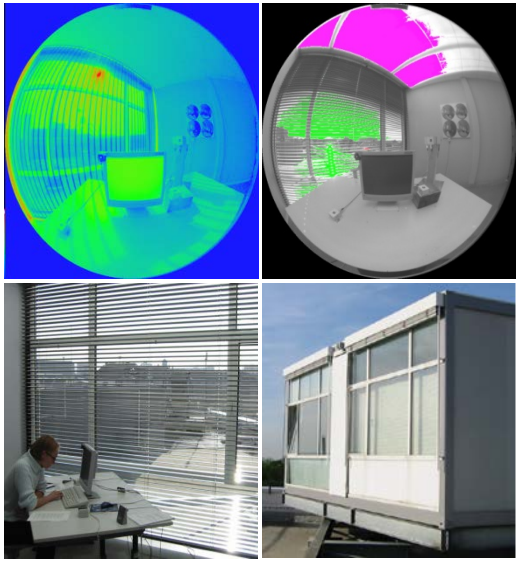
Glare analysis and metrics

Introduction into daylight glare evaluation

Introduction into evalglare and exercises



Jan Wienold,

Fraunhofer-Institut für
Solare Energiesysteme ISE

Fraunhofer
ISE

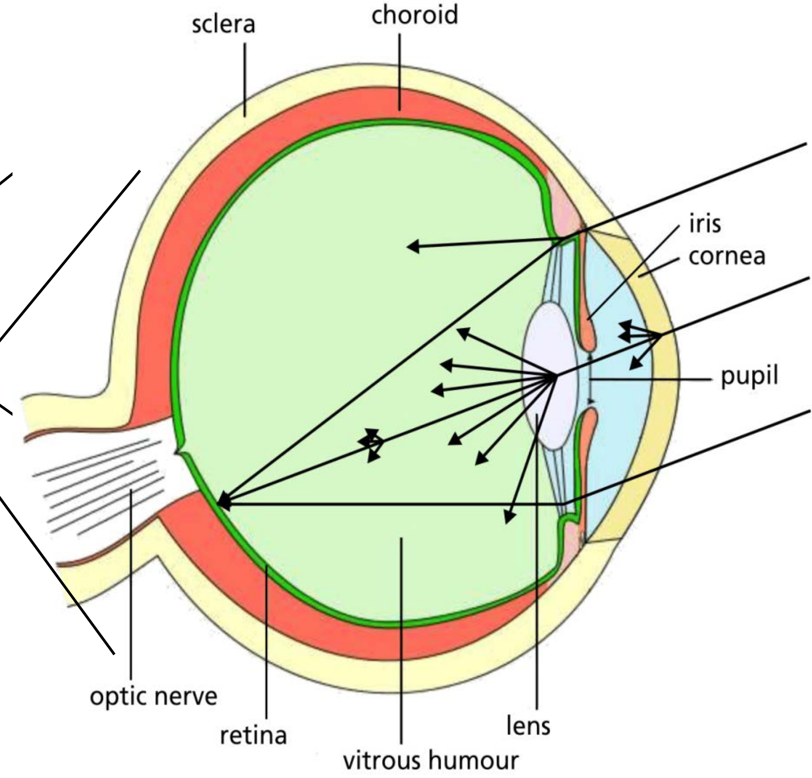
Content

- Introduction
- Existing glare metrics
- Methodology to evaluate glare metrics
- Evaluation of existing glare metrics
- The daylight glare probability DGP
- Low light correction of the DGP
- Age influence on the DGP
- Evalglare - introduction


Elias Canetti
Die Blendung
Roman
Elias Canetti
Die Blendung
Source: www.readme.c

Glare can be divided into

- Reflex glare
- Disability glare
- Discomfort glare



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

Content

- Introduction
- Existing glare metrics
- Methodology to evaluate glare metrics
- Evaluation of existing glare metrics
- The daylight glare probability DGP
- Low light correction of the DGP
- Age influence on the DGP
- Evalglare - introduction

Daylight glare metrics – up to now

Principal structure of existing complex glare formulas:

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

Developed under artificial lighting conditions

Not under daylight

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

How reliable are these discomfort glare formulas?

Fraunhofer ISE

Daylight glare metrics – Daylight glare index DGI

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

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

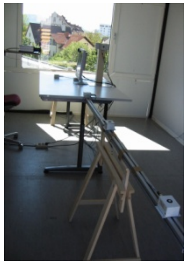
L_s: Luminance of source
ω_s: Solid angle of source
L_b: Background luminance $\Rightarrow$ adaptation luminance
P: Position index

Developed with less than 10 subjects

Content

- Introduction
- Existing glare metrics
- Methodology to evaluate glare metrics
- Evaluation of existing glare metrics
- The daylight glare probability DGP
- Low light correction of the DGP
- Age influence on the DGP
- Evalglare - introduction

Methodology
user assessment



Two identical test rooms

Test room	Instrumentation room
Questionnaire	Measurements : Luminance camera Illuminances
User analysis	Image processing

correlations

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

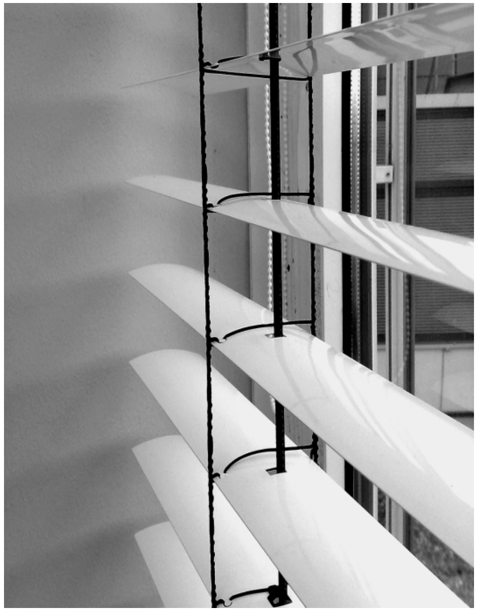
74 subjects, more than 110h tests, about 50 days

349 different situations

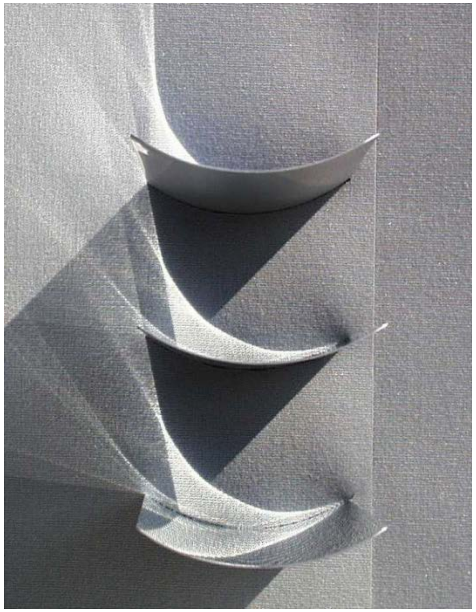
Fraunhofer ISE

Tested three shading devices

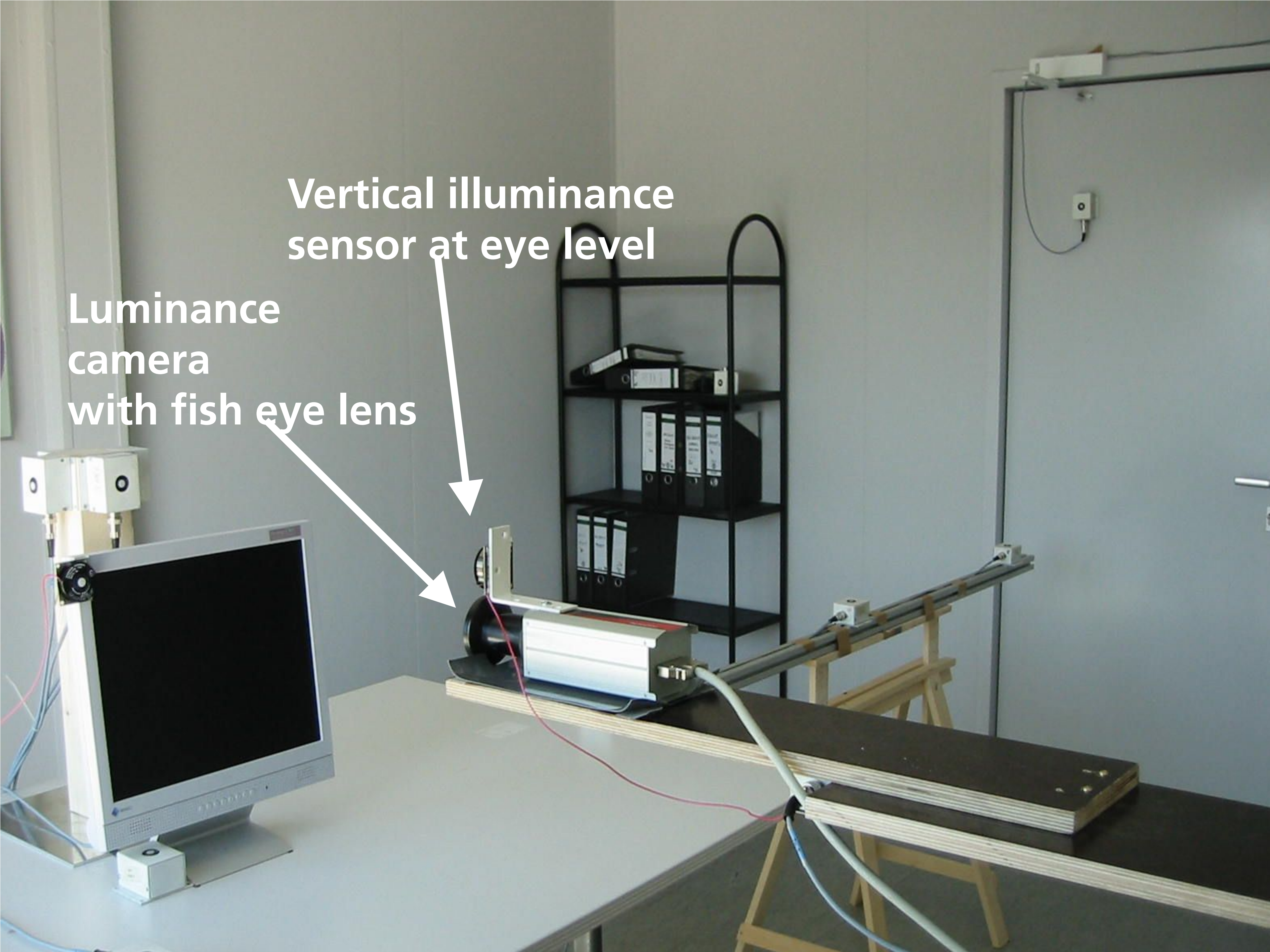
White Venetian blinds
80mm, convex, ρ=.84
D (sunny), DK (sunny)



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

Content

- Introduction
- Existing glare metrics
- Methodology to evaluate glare metrics
- Evaluation of existing glare metrics
- The daylight glare probability DGP
- Low light correction of the DGP
- Age influence on the DGP
- Evalglare - introduction

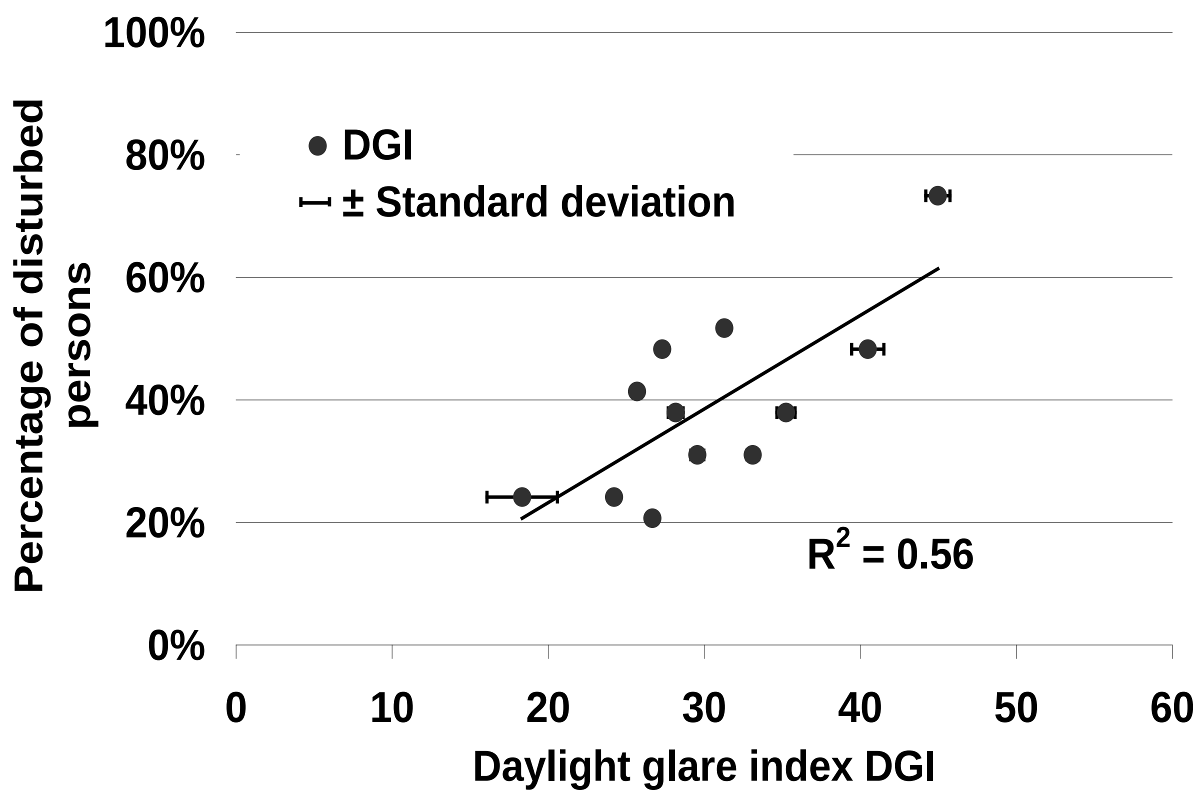
Evaluation of existing glare metrics

- All metrics are compared to the percentage of persons disturbed

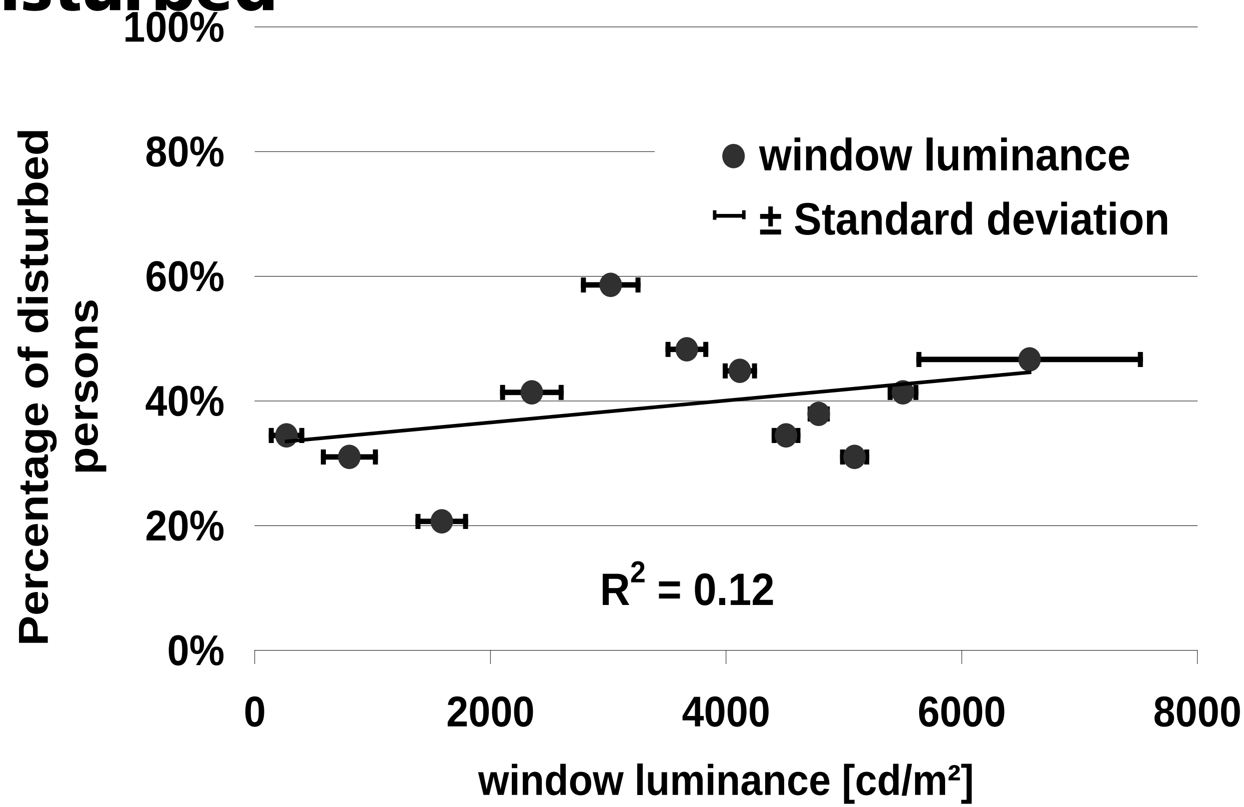
Result: Daylight glare index versus percentage of persons disturbed

Large scatter

Weak correlation



Result: Average window luminance versus percentage of persons disturbed



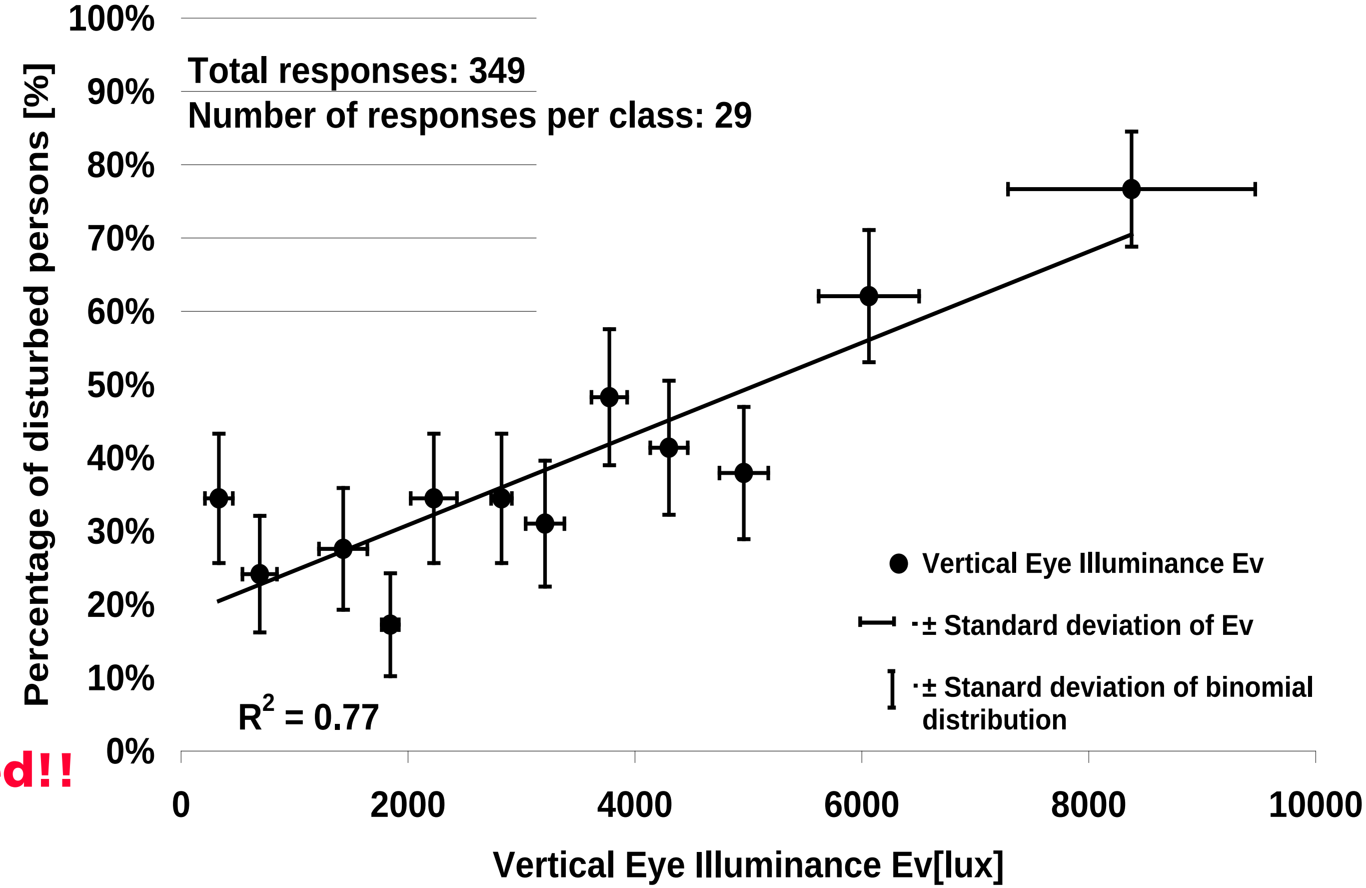
Large scatter

No dependency

no correlation

Fraunhofer ISE

Result: vertical eye illuminance versus percentage of persons disturbed



reasonable correlation

But no peaks can be considered!!

Fraunhofer ISE

Content

- Introduction
- Existing glare metrics
- Methodology to evaluate glare metrics
- Evaluation of existing glare metrics
- The daylight glare probability DGP
- Low light correction of the DGP
- Age influence on the DGP
- Evalglare - introduction

Idea for the development of the DGP

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

and (!!)

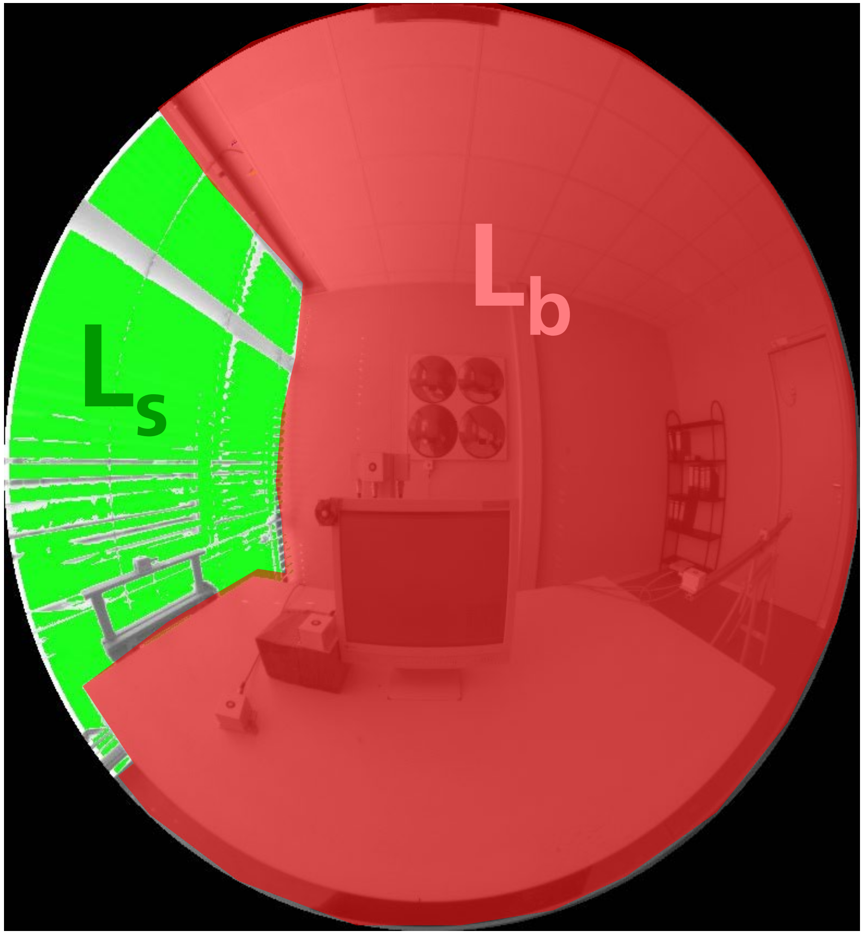
Parts of CIE-glare index (or UGR)

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

L_s	Luminance of source
ω_s Ω_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

Fraunhofer ISE

Daylight glare probability DGP

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

Combination of the vertical eye illuminance with modified glare index formula

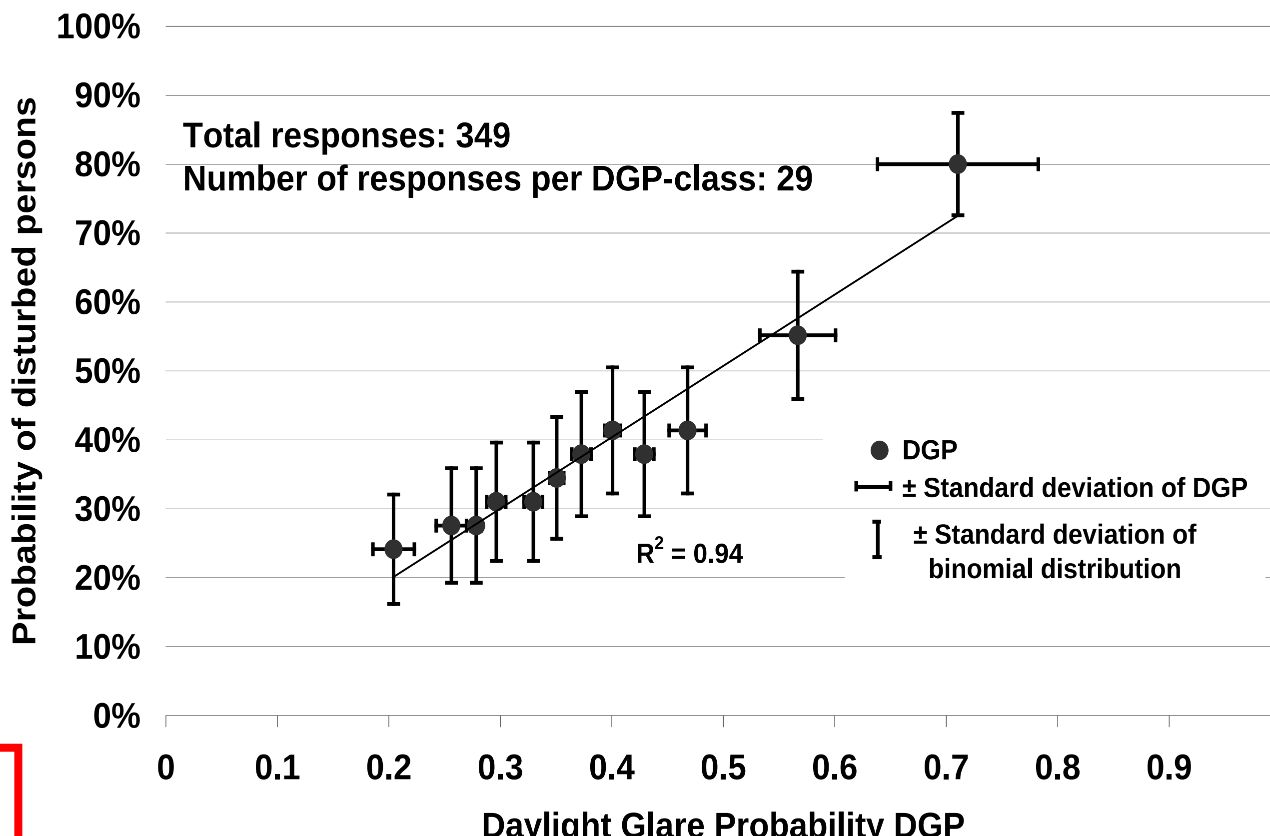
E_v:	vertical Eye illuminance [lux]	$c_1 = 5.87 \cdot 10^{-5}$
L_s:	Luminance of source [cd/m²]	$c_2 = 9.18 \cdot 10^{-2}$
ω_s:	solid angle of source [-]	$c_3 = 0.16$
P:	Position index [-]	$a_1 = 1.87$

Correlation between DGP and probability of persons disturbed

Strong correlation

Logistic regression:

$p=3.44\ 10^{-8}$
$\Rightarrow$Much stronger than for all other metrics



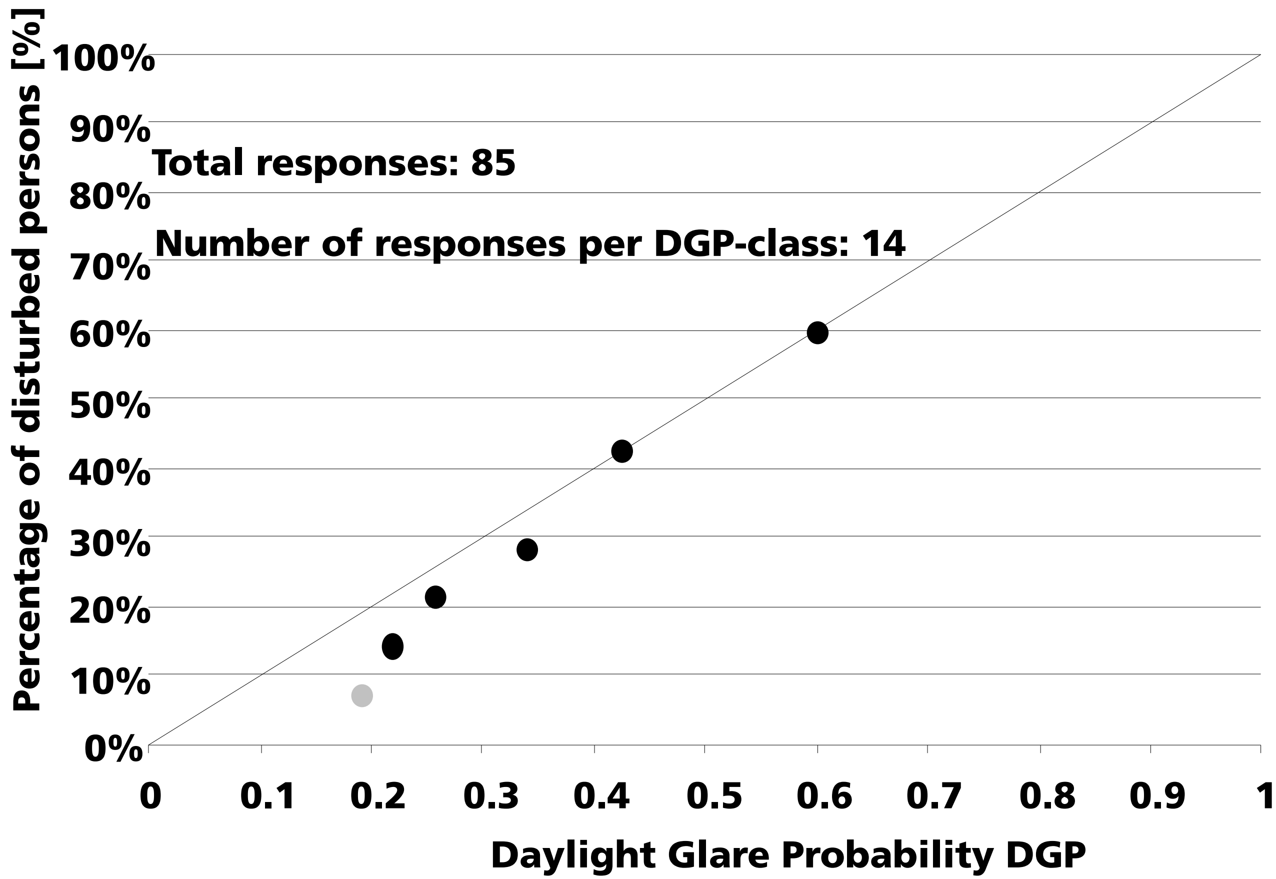
Valid for
DGP $\geq$ 0.2
$E_v \geq$ 380 lux

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)



Fraunhofer ISE

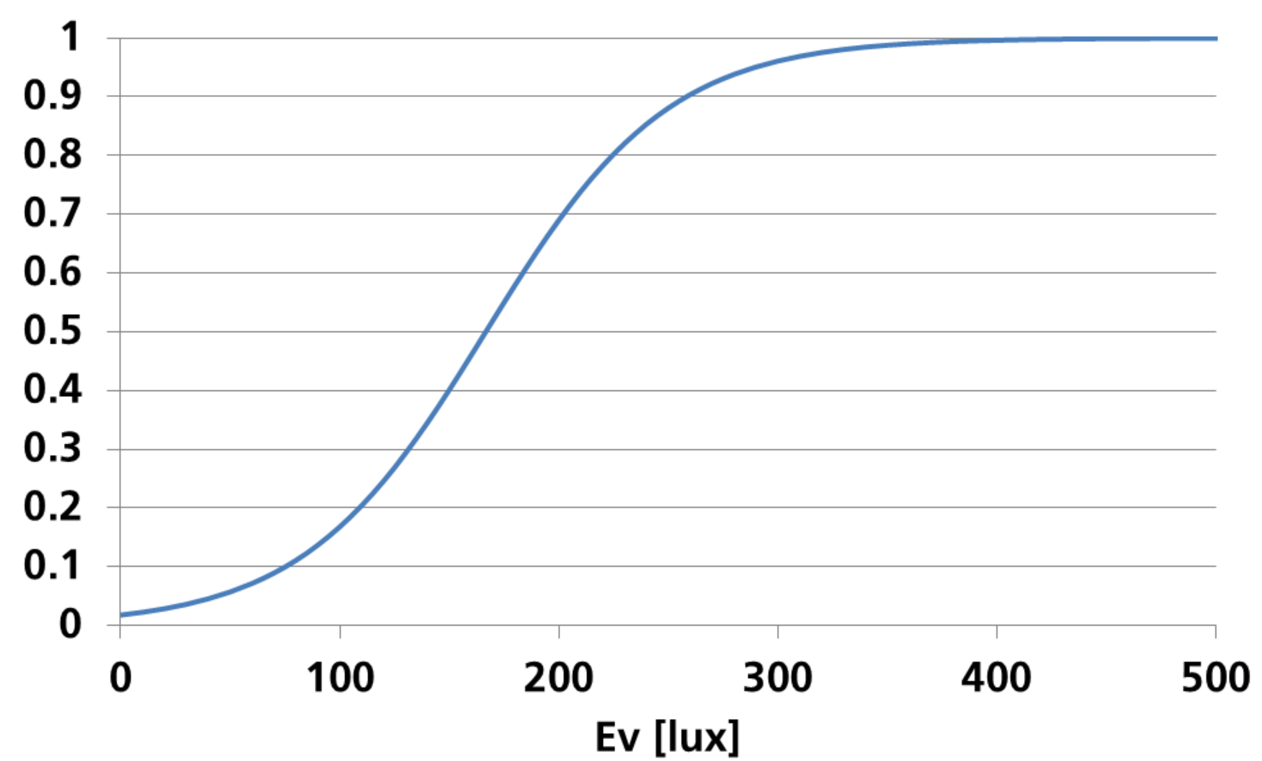
Low light correction

- 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

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

Fraunhofer ISE

Low light correction



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

Age influence

- User assessments with 3 age groups
  15 test persons in age group 20-30
  15 test persons in age group 50-60
  15 test persons in age group 60-70

- parallel study in 9 office buildings à 15 offices each (done by University Karlsruhe)
- we found a (weak) improvement of the correlation between user perception and DGP when age is applied to equation
- This was confirmed by the office study (better improvement than in the lab study)

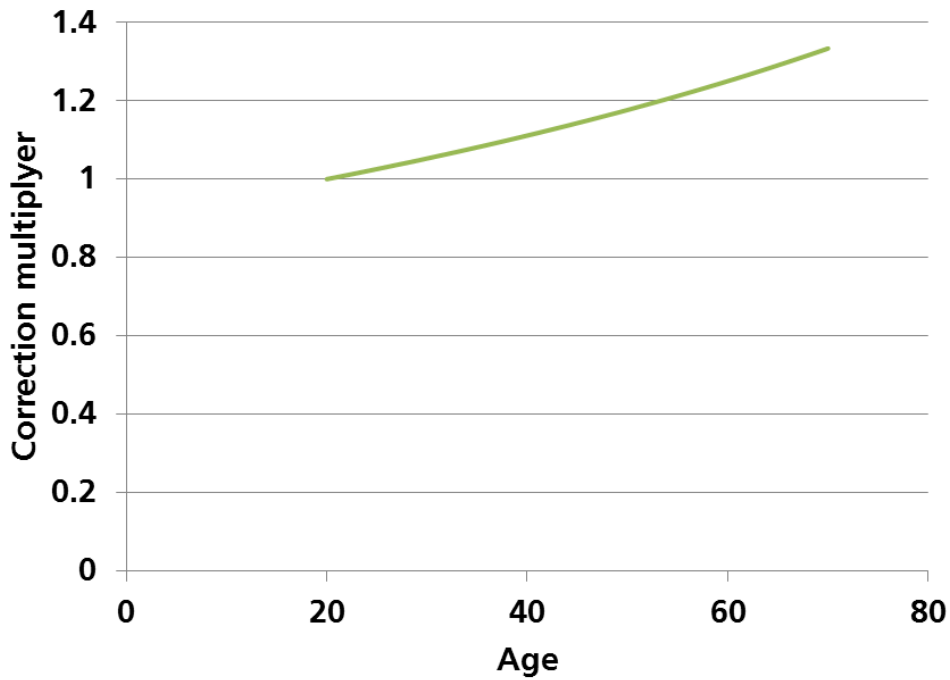
Fraunhofer ISE

Field study: 9 buildings in Germany

16 offices in each building

Age influence

- Following correction showed best correlation:



$$DGP\_age = \frac{DGP}{(1.1 - 0.5 * \frac{age}{100})}$$

- evalglare implementation: New option: -a *age*
- default: age=20, factor =1

Fraunhofer ISE

Results of the test room studies

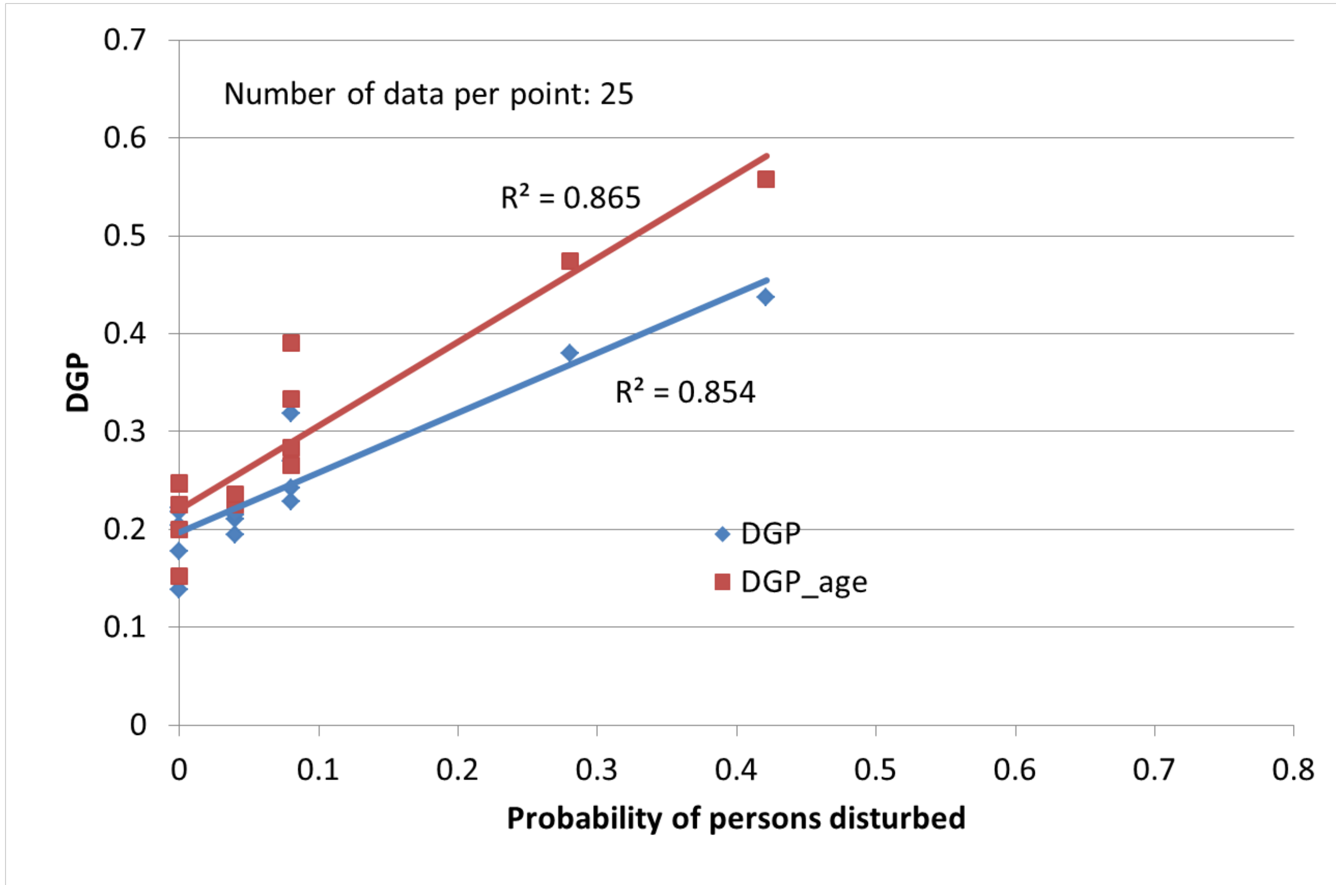
Each point represent 25 data

Improvement of the correlation is small

0.854 -> 0.865

But

- Statistically significant
- Later proven by field study



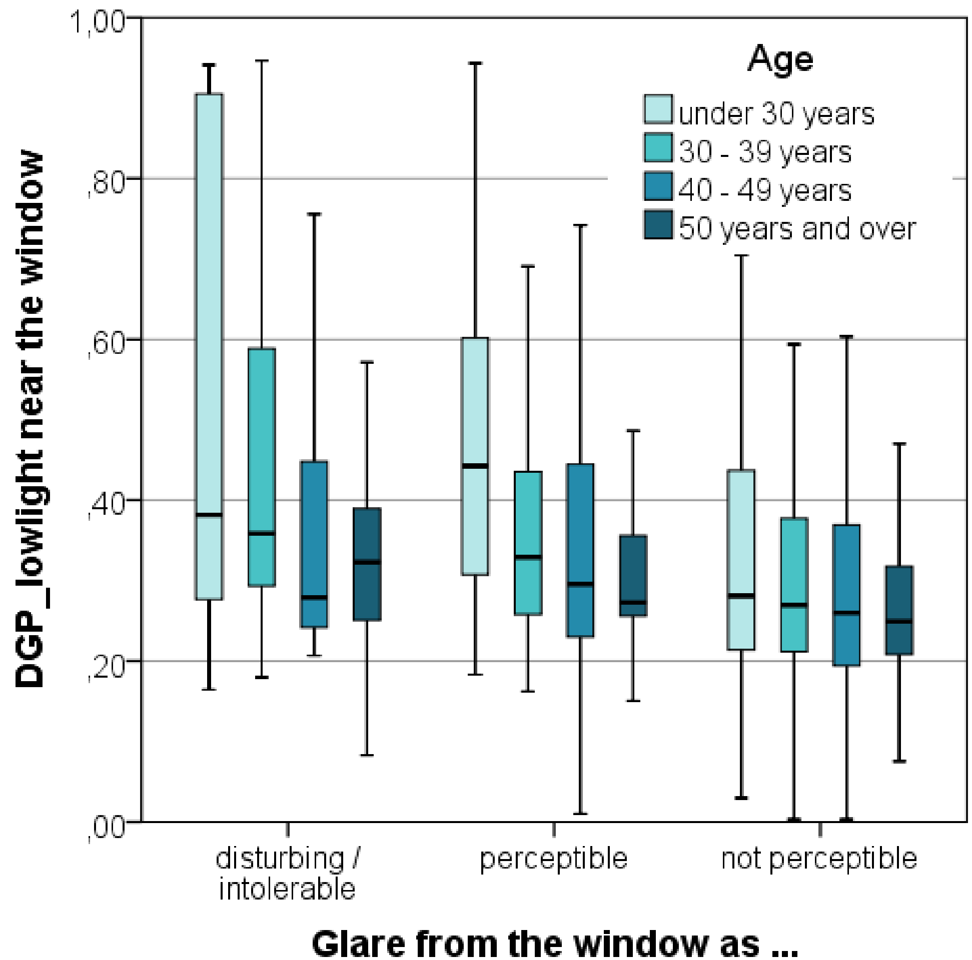
Fraunhofer ISE

Daylight Glare Probability DGP and Age

- Younger subjects accept higher DGP-values than older subjects, improvement by Age-correction

- Linear regression-model, unbalanced panel for $DGP_{lowlight}$
- R^2=0.259
- F=284.0, sample N=824

- RE-model, unbalanced panel for $DGP_{lowlight, viewratio, age}$
- R^2=0.270
- F=274.7, sample N=751



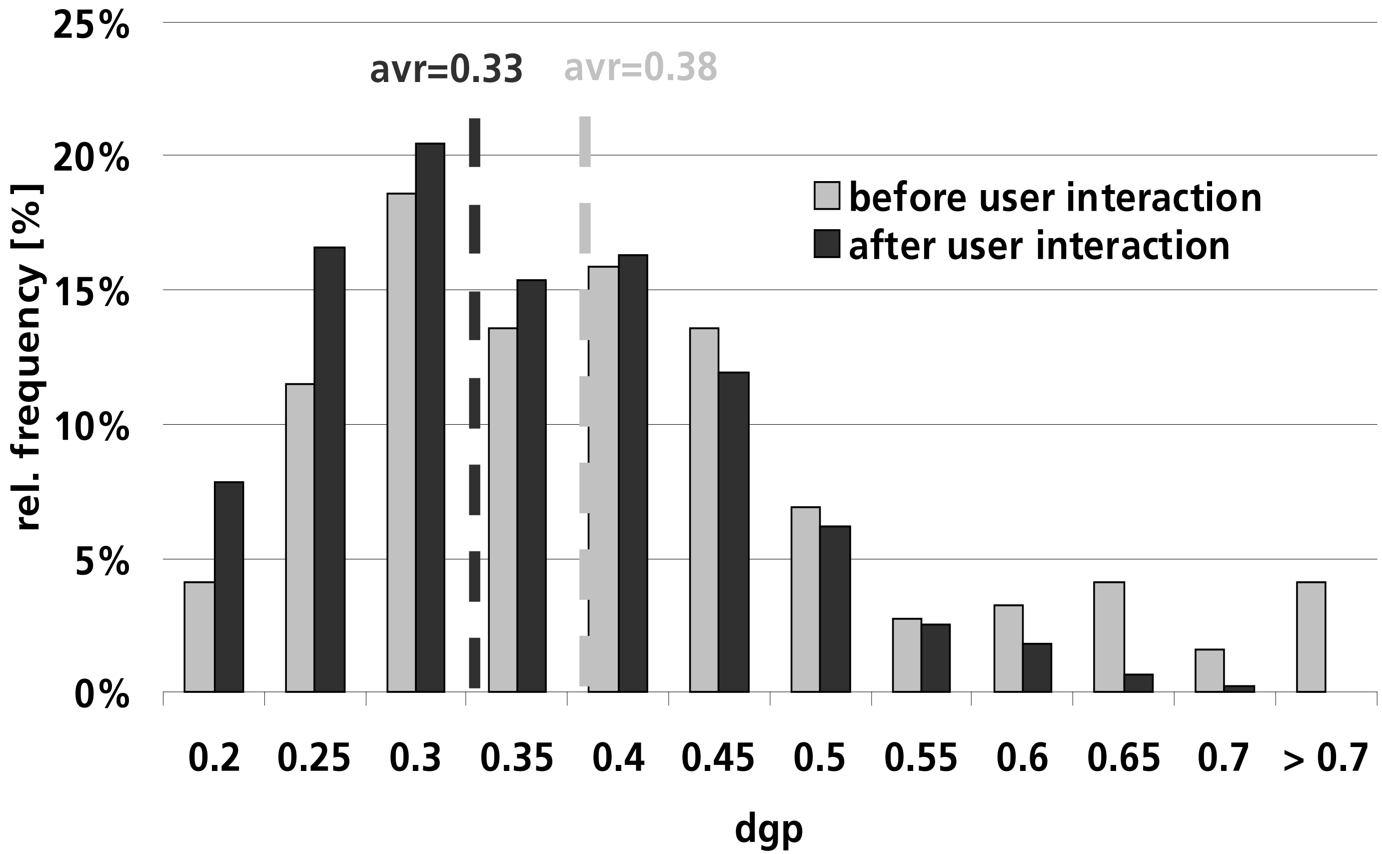
Evaluation of existing models and development of the DGP - conclusions

- 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
- Tool for the glare evaluation developed **evalglare**

DGP – Ranges?

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

Acceptance of glare



Fraunhofer ISE

Evaluation of annual data

Idea:

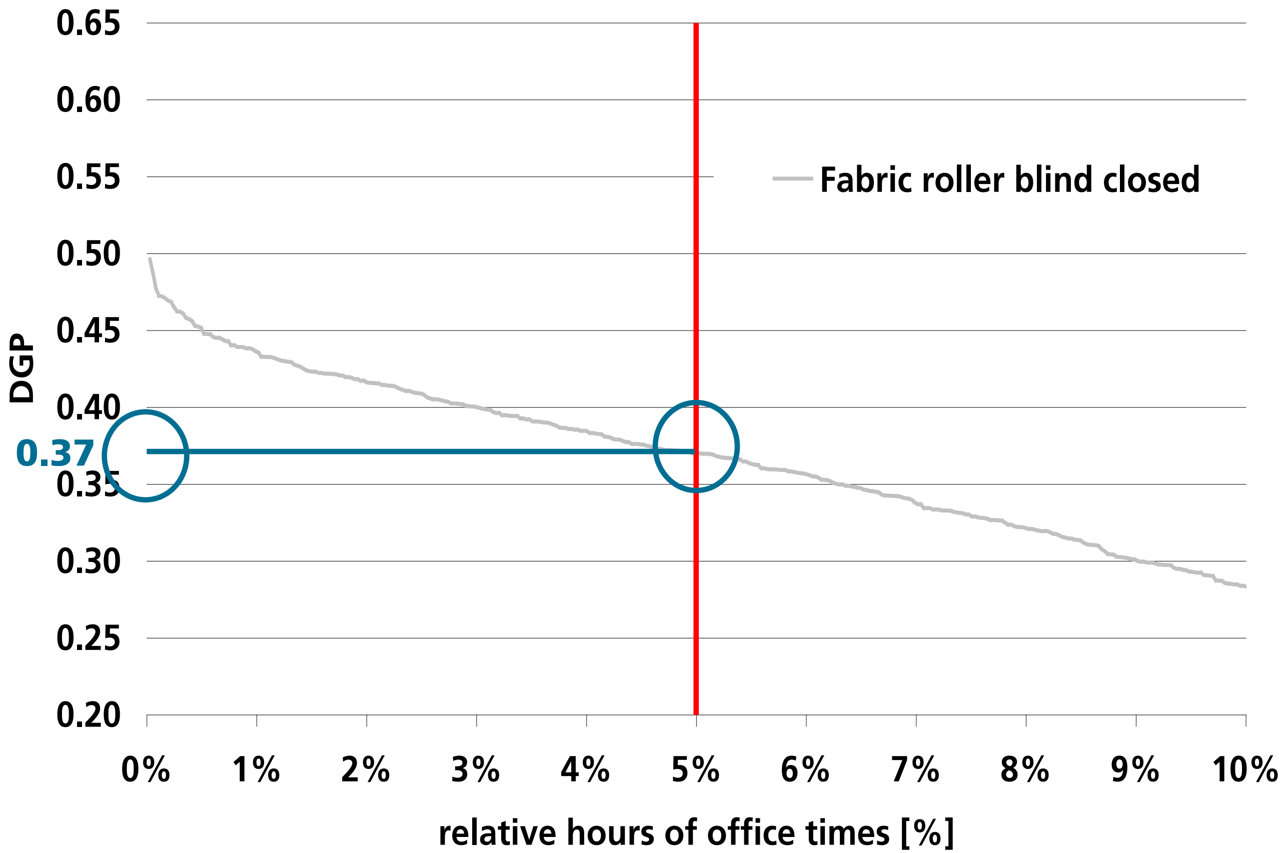
Use similar method than for thermal comfort [EN 15251, 2007]

$\Rightarrow$ Define three categories, in those a certain amount of users are satisfied

$\Rightarrow$ Here: Usage of glare categories from questionnaire

$\Rightarrow$ A 5% exceedance is allowed

Evaluation of annual data



Fraunhofer ISE

Basis for the categories: Results of the user assessments
Descriptive one-way ANOVA analysis (ANalysis Of VAriance)

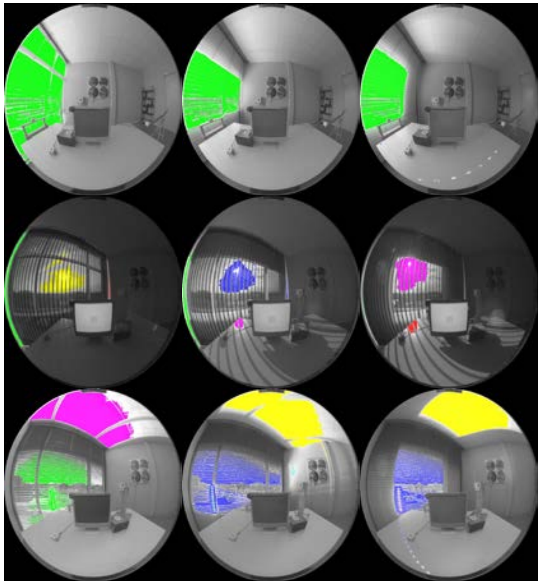
Glare rating	DGP avg	95%-confidence interval lower limit	upper limit
imperceptible	0.33	0.314	0.352
perceptible	0.38	0.356	0.398
disturbing	0.42	0.39	0.448
intolerable	0.53	0.464	0.59
avg	0.39	0.314	0.352

Suggestion of glare - classes

	A best class 95 % of office-time glare weaker than “imperceptible”	B good class 95 % of office-time glare weaker than “perceptible ”	C reasonable class 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

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:

Vertical Illuminance

DGP

UGR

DGI

VCP

CGI

Luminance of all glare sources

Solid angle of all glare sources

Per glare source (only with –d available):

Position (x,y, position index)

Size (solid angle)

Luminance

Task, background and maximum luminance

Direct illuminance

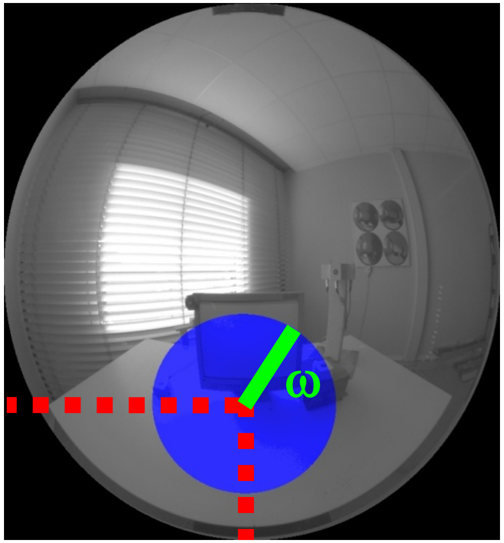
Direction vector

Evalglare

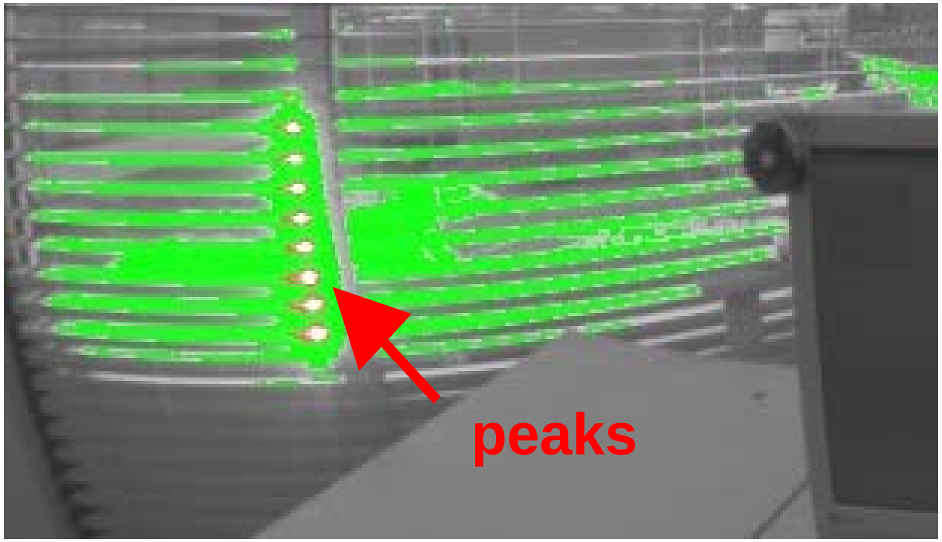
Primary goal : Detection of glare sources, calculation of glare indices

Important features:

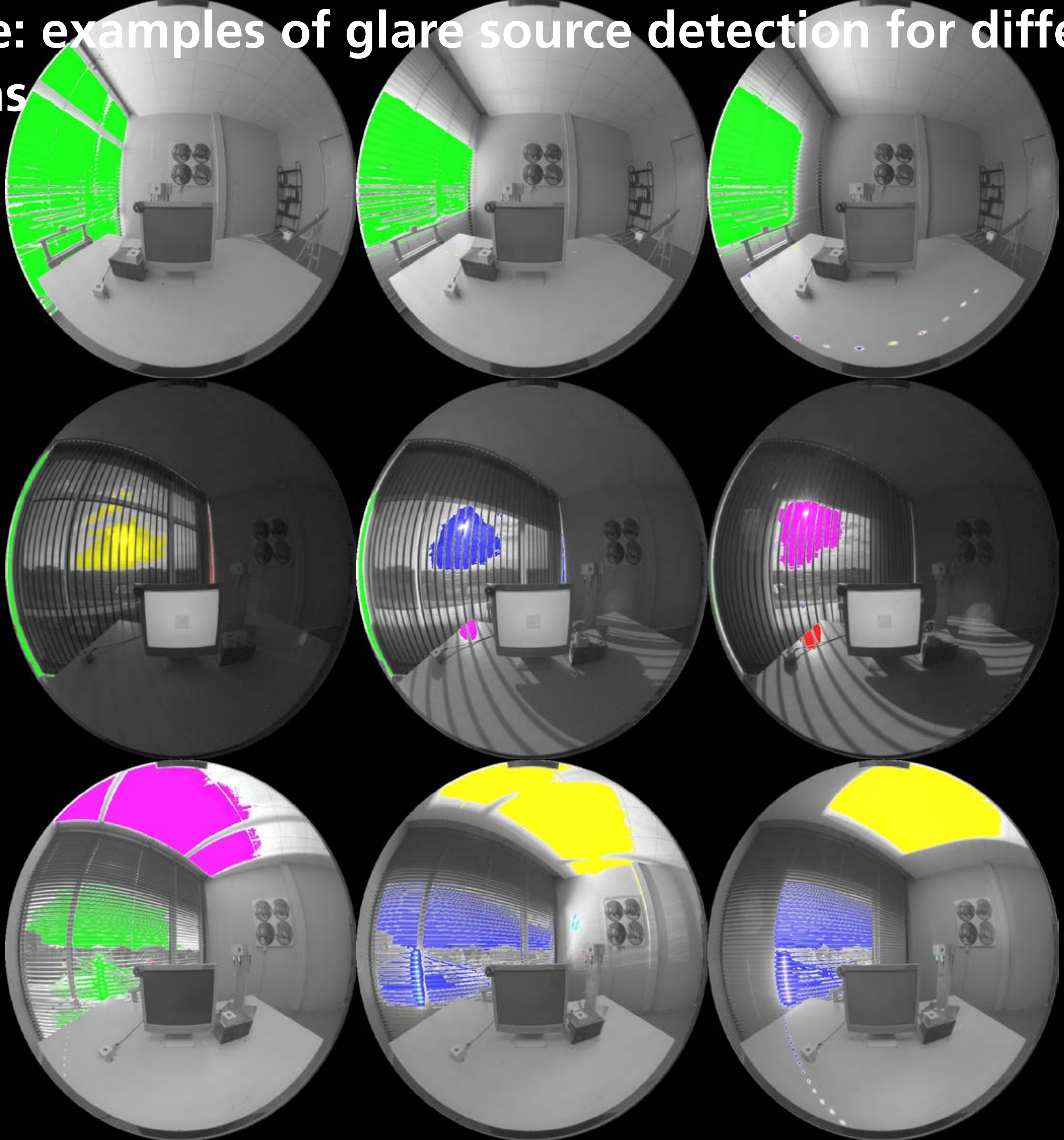
Task area detection mode (–t):
xy position of centre of task
opening angle ω of task



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

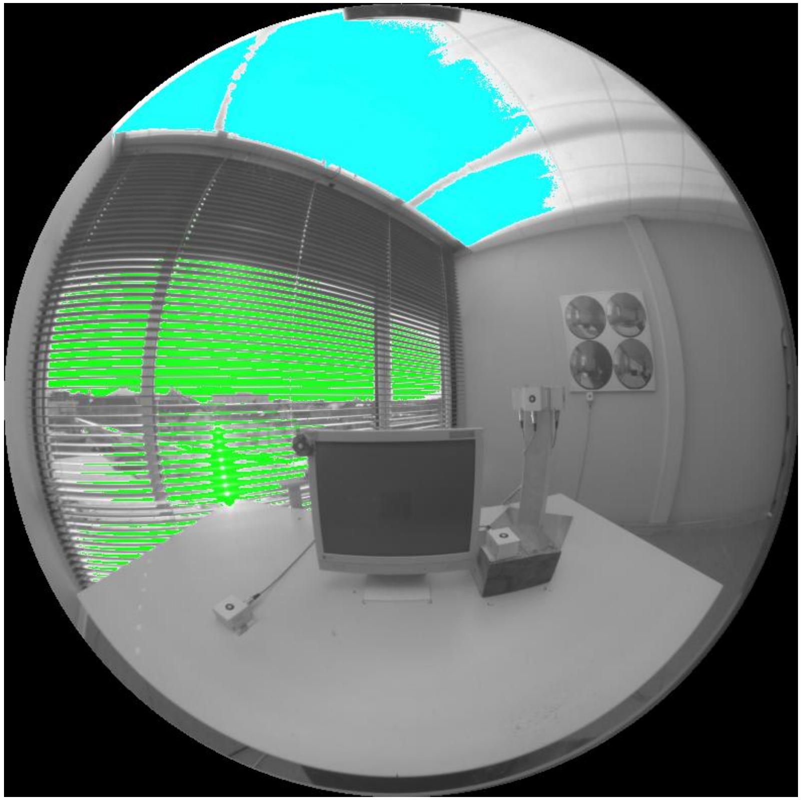


evalglare: examples of glare source detection for different situations



Influence of the –r parameter

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

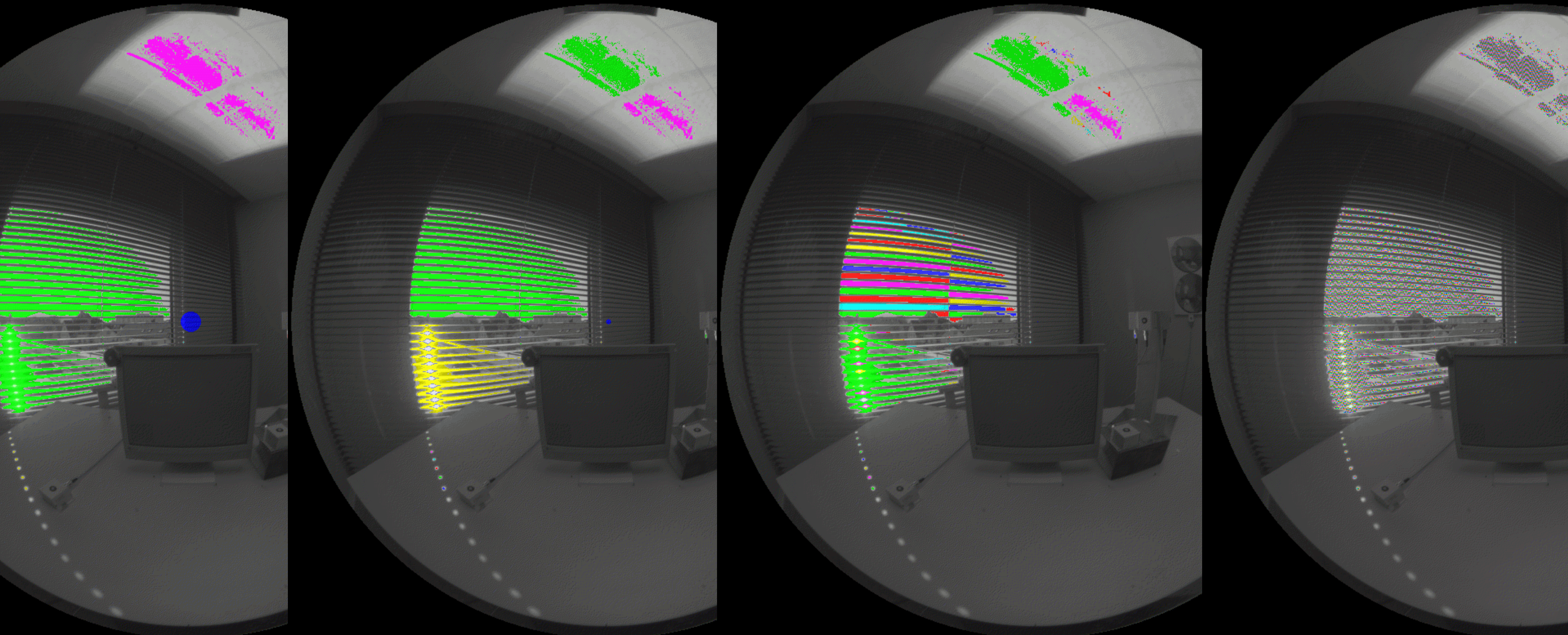


Merging of "glare areas" to a glare source – How large should be a glare source?

Influence of the –r parameter

Fraunhofer ISE

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

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

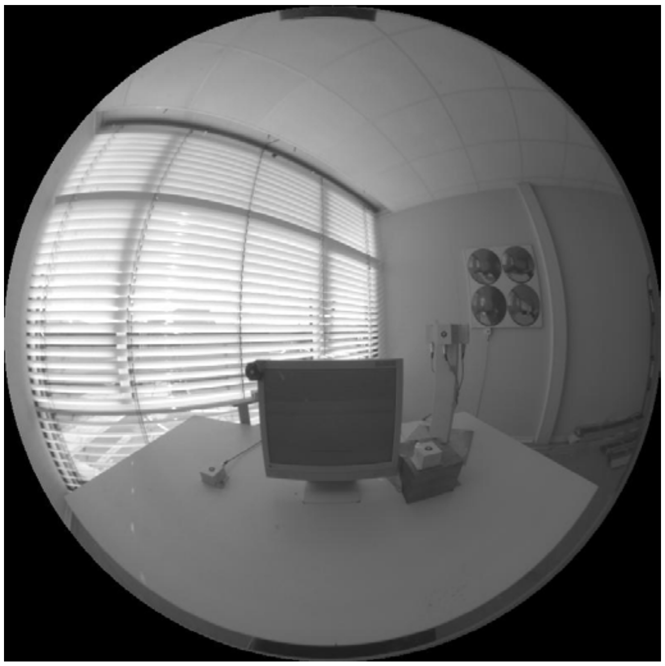
Known problems with 0.9x versions

- 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!!

Fraunhofer ISE

Example



Reality:

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

e.g. use

pcompos -s 1 testpic.pic 0 0

-> same image

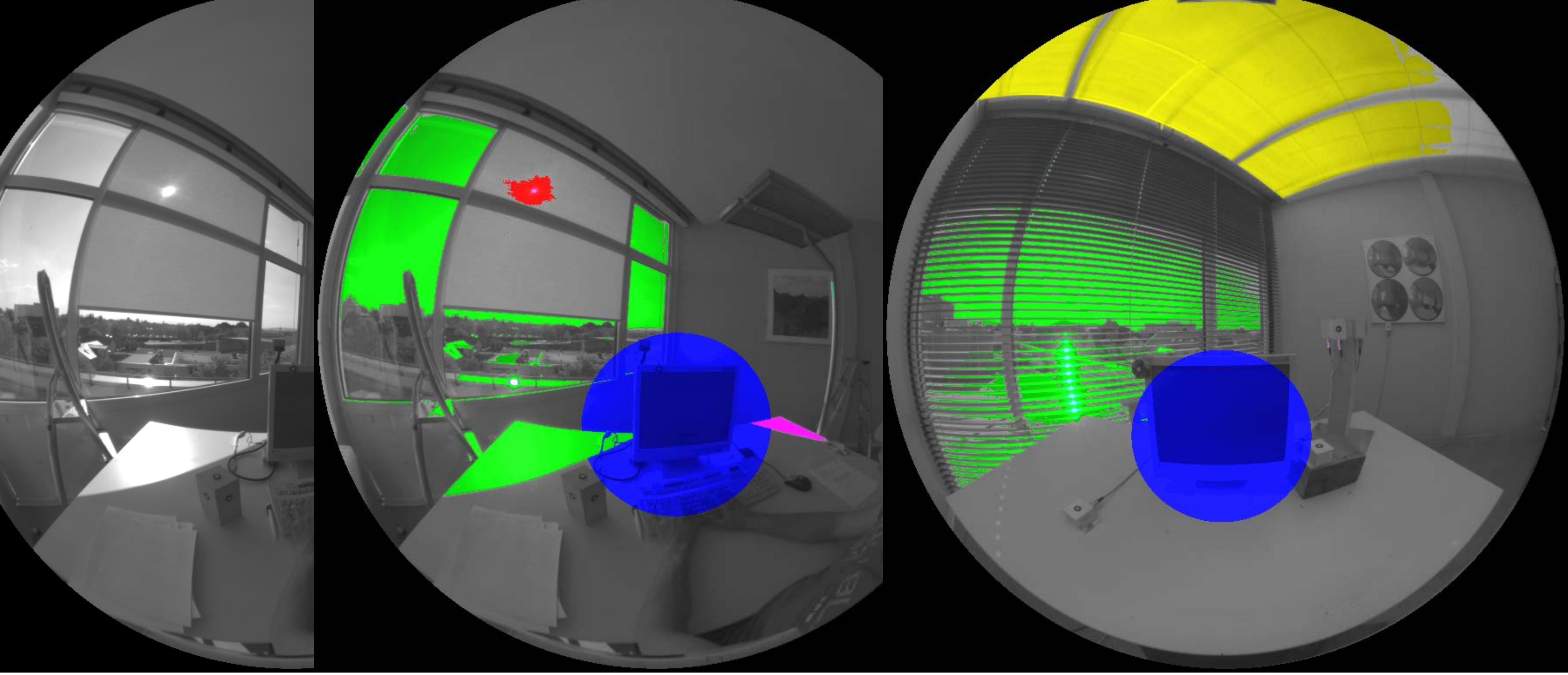
-> tab added to the view option string in header

-> indicating invalid view

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

Result when providing wrong hdr-header:

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



Version 1.11 is available here:

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

Thanks for your attention!!