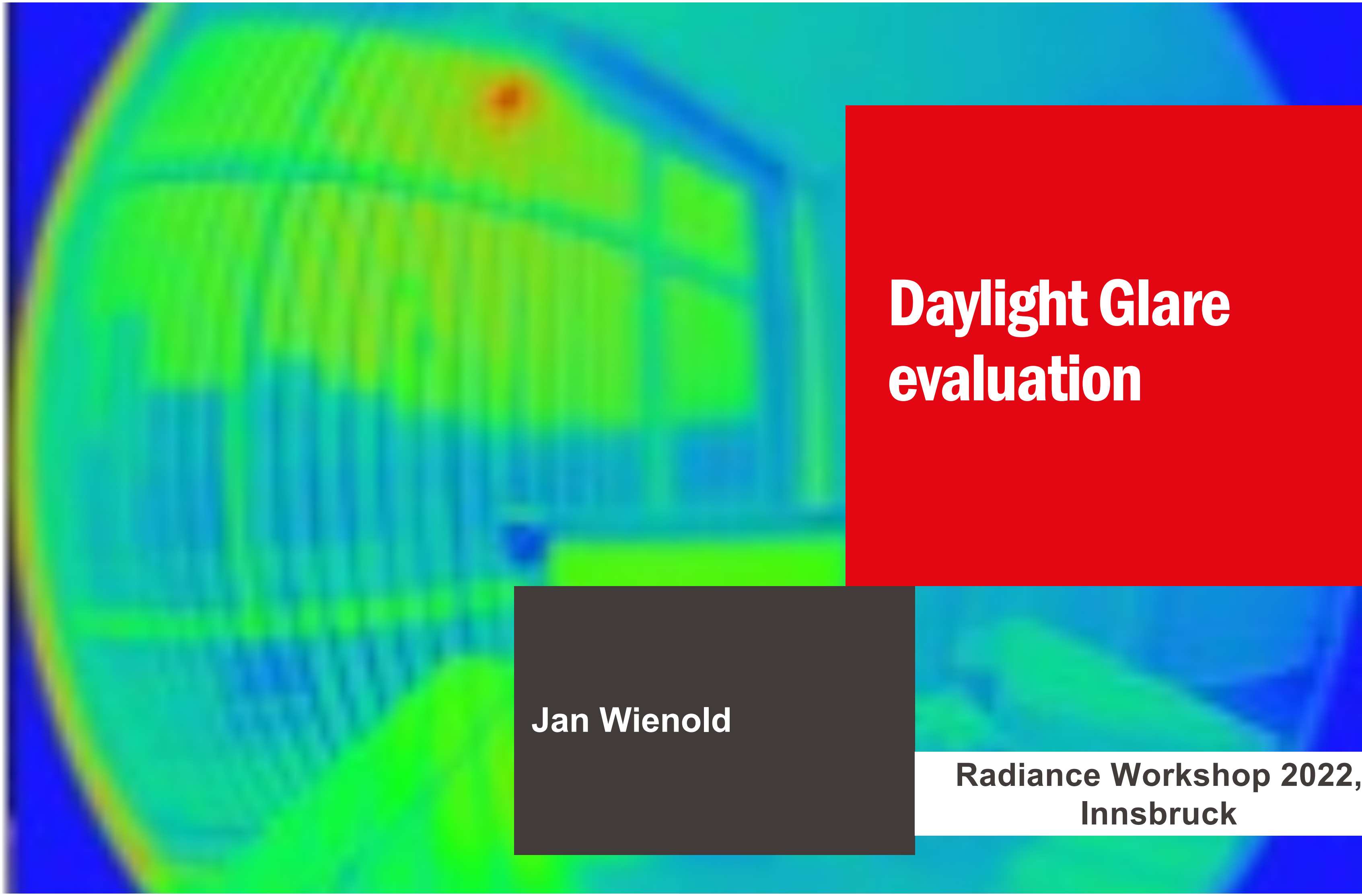

Daylight Glare evaluation

Jan Wienold

Radiance Workshop 2022, Innsbruck

LIPID
Laboratory of Integrated Performance in design

EPFL

Content

- What is glare?
- User assessments to evaluate glare metrics
- Evaluation of existing glare metrics – cross-validation study
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Glare

CIE Definition of glare:
"*Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts*"

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Glare

CIE Definition of glare:
"*Condition of vision in which there is **discomfort** or **a reduction in the ability to see details or objects**, caused by an unsuitable distribution or range of luminance, or by extreme contrasts*"

⇢ Discomfort > ***discomfort glare***

or

⇢ Impairing the visual task > ***disability glare***

Glare

CIE Definition of glare:
"*Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an* ***unsuitable distribution or range of luminance****, or by* ***extreme contrasts***"

Caused by

⇢ Unsuitable distribution or range of luminance > ***saturation glare***

⇢ Extreme contrast > ***contrast glare***

Glare

“saturation glare”

-> no saturation of receptors! misleading expression

new expression needed, but not yet decided

Glare

Can be subdivided into 3 main categories:

1. Reflections or veiling glare -> Legibility of computer screens

2. Disability glare: impairs the vision, but not necessarily causing discomfort

3. Discomfort glare: Glare that causes discomfort without necessarily impairing the vision of objects

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Legibility of computer screens / displays

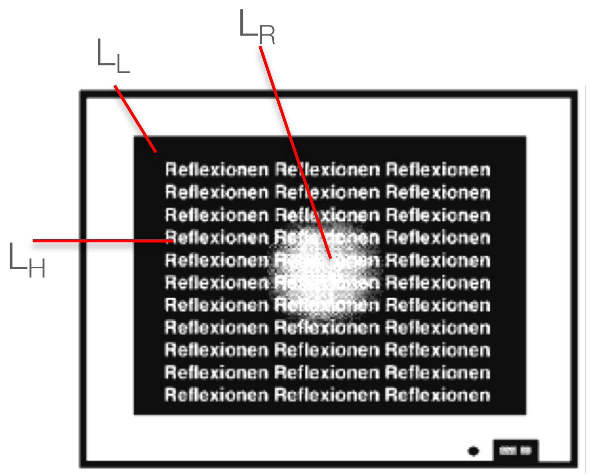
- Legibility -> Contrast

- Contrast (ratio):

$$CR = \frac{L_H}{L_L}$$

- Visible Contrast (ratio)

$$CR = \frac{L_H + L_R}{L_L + L_R}$$



Reflections on displays

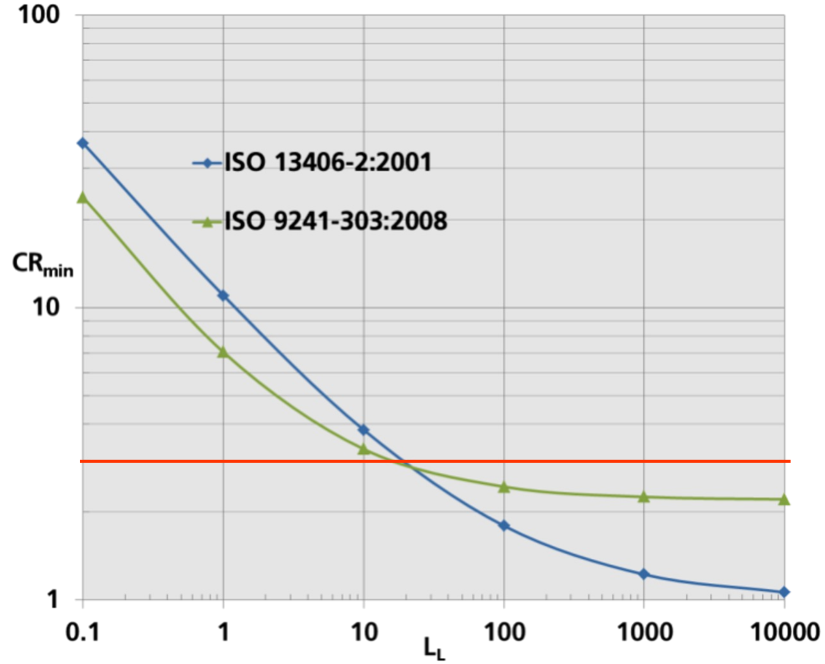
Existing model ISO 9241-303:2011

$$CR_{\min} = K_{age}.(2.2 + 4.84 \cdot L_L^{-0.65})$$

Contrast is a function of Low state Luminance

Low state : How black is the black....

In office environments a visible contrast of 4 is mostly sufficient



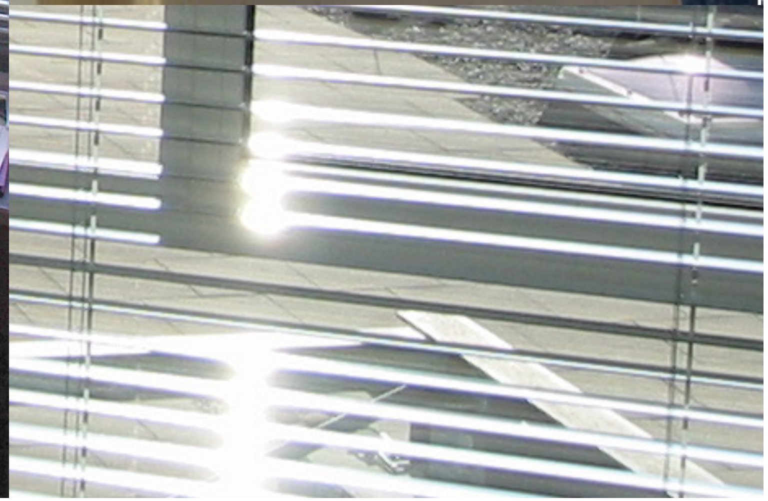
Reflections on displays

Modeling challenge:

Where to get the correct reflection properties, especially when anti-reflective coatings are applied?? (BRDF)

Disability glare

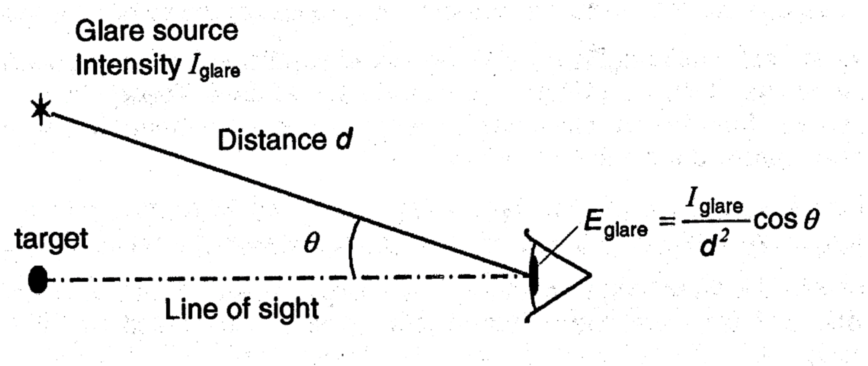
Source: www.readme.cc



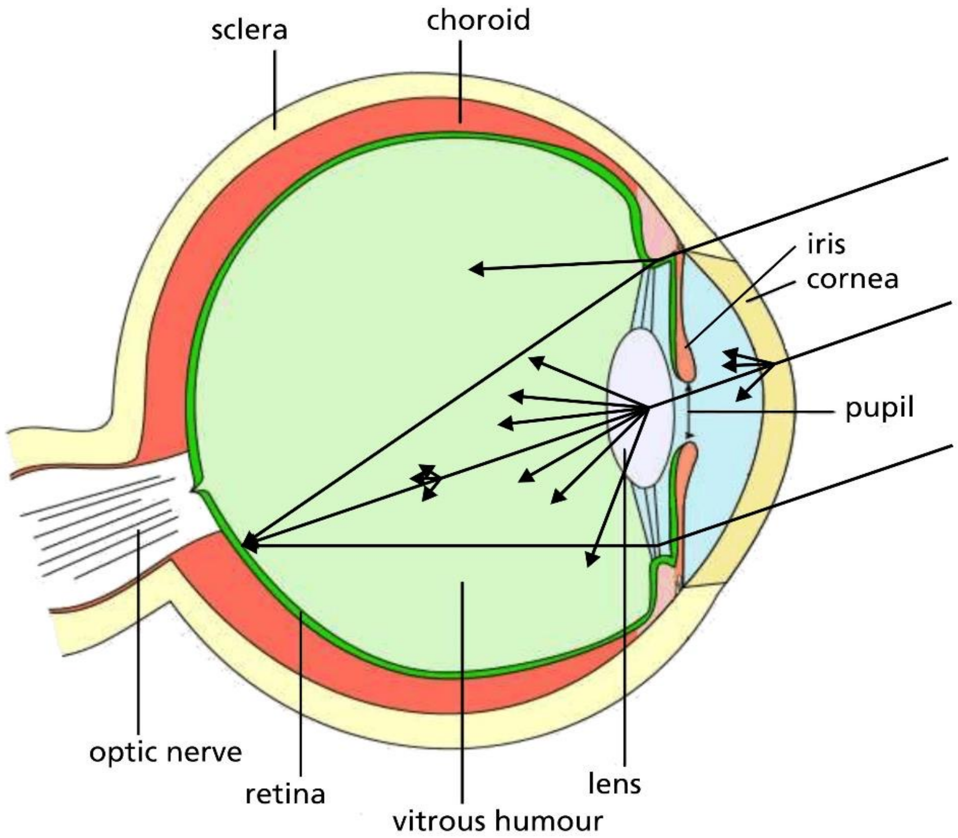
Disability glare

Quantification (CIE) :

Equation from Stiles- Holladay



$$\frac{L_{veil}}{E_{glare}} = \frac{10}{\theta^2}$$



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Disability glare

BUT: Unclear if applicable for high adaptations levels (daylight situations)!

Studies needed

Stiles-Holladay equation is implemented in evalglare

Discomfort glare

- Discomfort = Subjective rating
- In most cases below disability glare
- Indirect consequences (headaches, getting fatigue), often not direct measurable

How to quantify?

Daylight glare metrics – up to end of last century

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
ω_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?

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Daylight glare metrics – Daylight glare index DGI

$$G = f\left(\frac{L_s^{a_1} \cdot \omega_s^{a_2}}{L_b^{a_3} \cdot P^{a_4}}\right) \qquad DGI = 10\log_{10} 0.48 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07\,\omega_s^{0.5}\, L_s}$$

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

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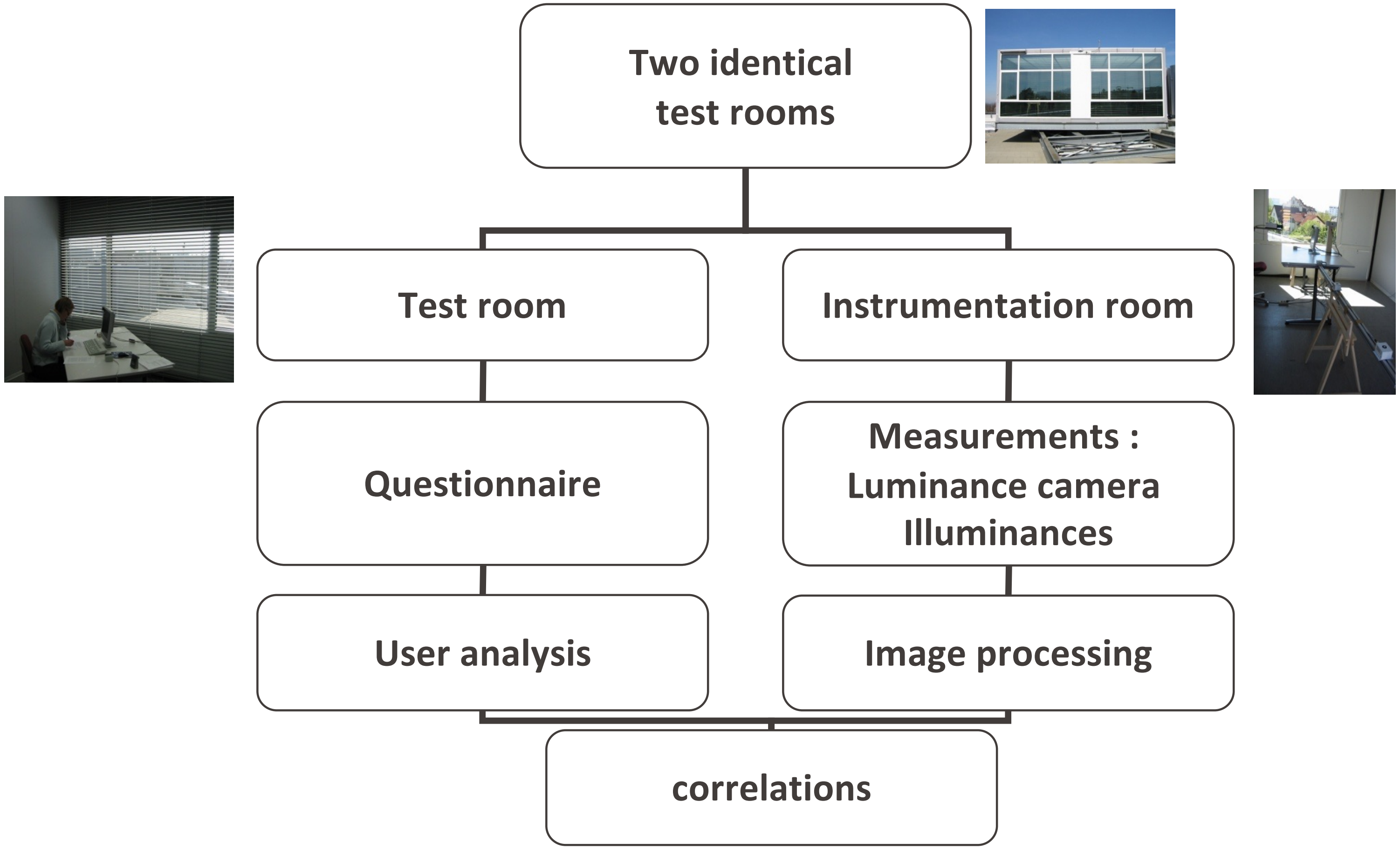
Methodology
user assessment



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

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Discomfort glare

Important boundary conditions for user assessments

- The important influence factors have to be varied
- Co-founding factors should be avoided or kept constant
- 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

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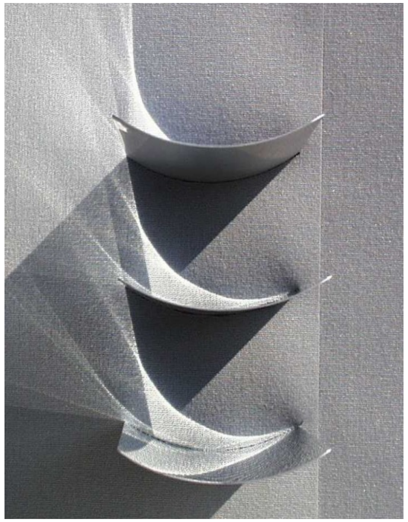
Tested three shading devices

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)

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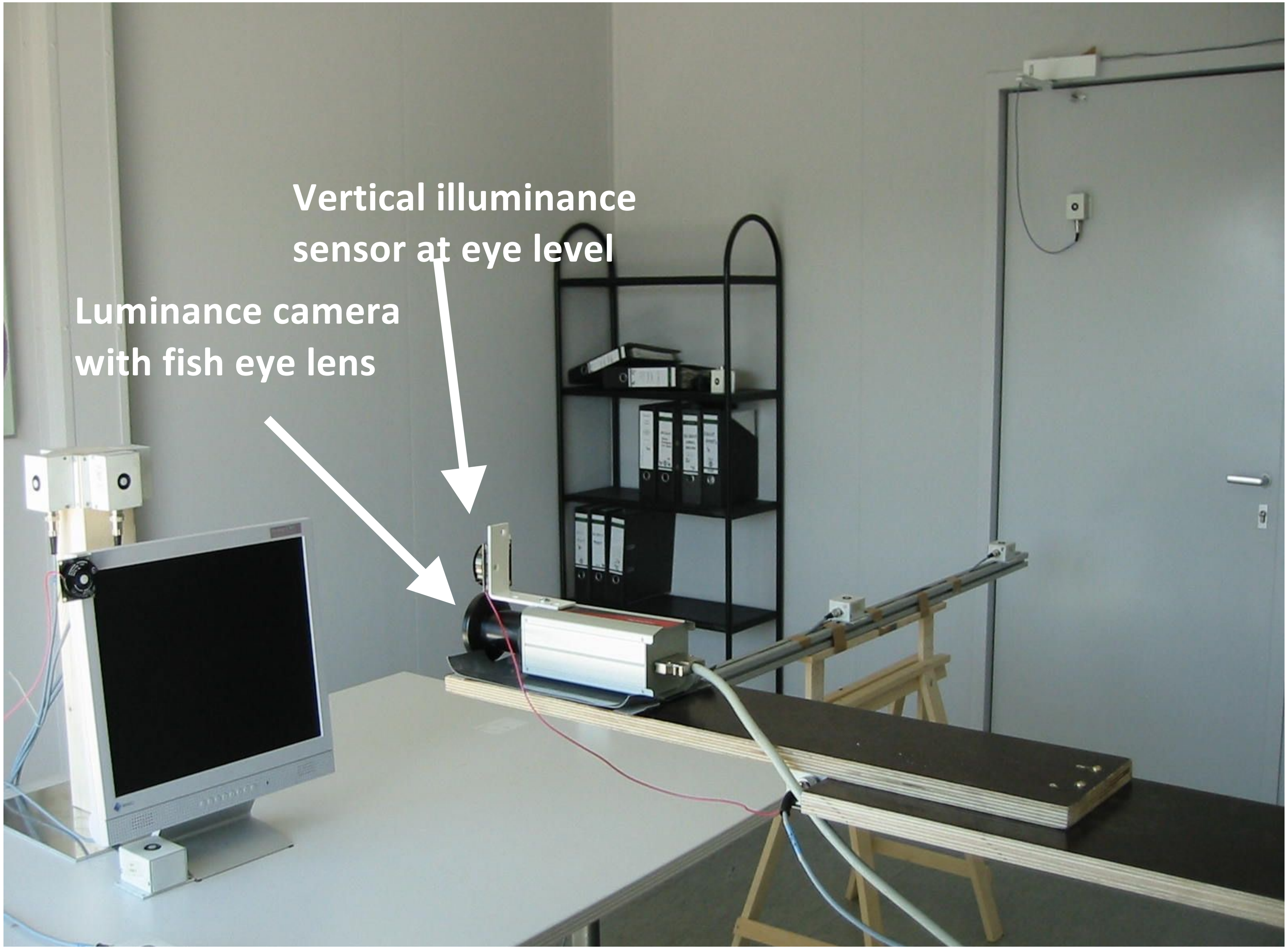
Vertical illuminance
sensor at eye level
Luminance camera
with fish eye lens

Idea for the development of the DGP

Use 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

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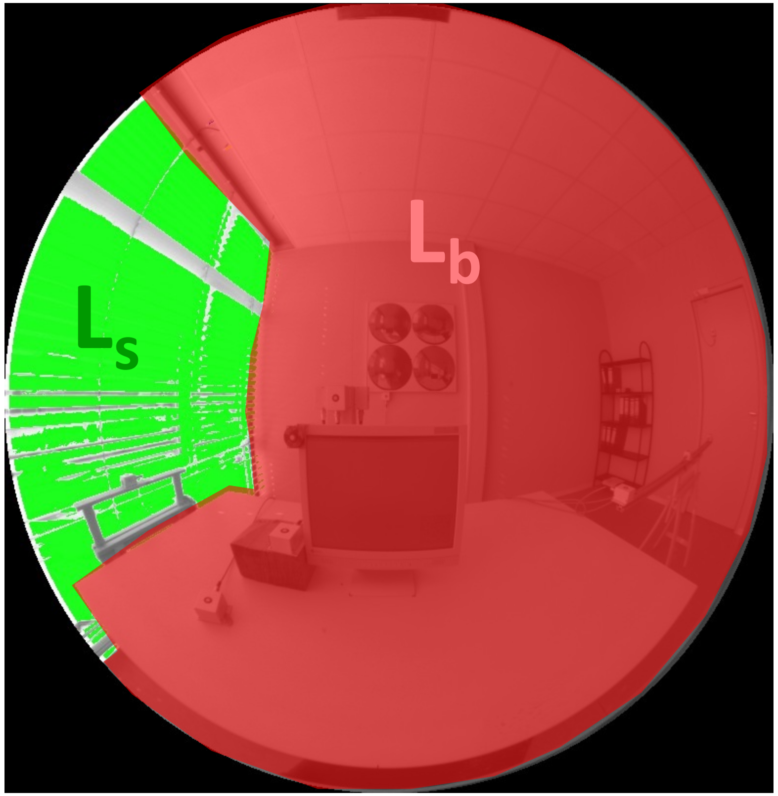
Adaptation level in equation?

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

Large glare source

L_b?

Better correlations when using E_v



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Discomfort glare metrics for daylight

Daylight Glare Probability DGP, adopted in EN17037, EN12464 and EN14501

Combination of the vertical eye illuminance and a modified glare index equation

Saturation effect **Contrast effect**

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

E_v: vertical Eye illuminance [lux]

L_s: Luminance of source [cd/m²]

ω_s: solid angle of source [-]

P: Position index [-]

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

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

$c_3 = 0.16$

$a_1 = 1.87$

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Cross-validation and robustness of daylight glare metrics

7 studies, 4 continents, 6 countries

All studies are lab-studies, office-like test rooms.

1160 data-points,

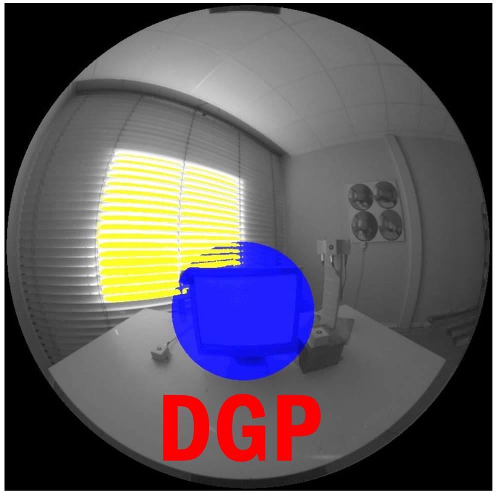
801 non-development data-points

Wienold J., Iwata T., Sarey Khanie M., Erell E., Kraftan E., Rodriguez R. G., Garreton J. Y., Tzempelikos T., Konstantzos I., Christoffersen J., Kuhn T. E., Andersen M.

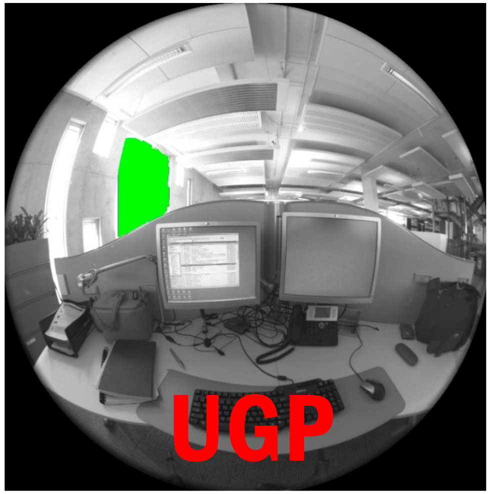
Motivation

Several studies published, stating that existing glare metrics do not perform well

Suggesting new metrics, based on their "own" dataset



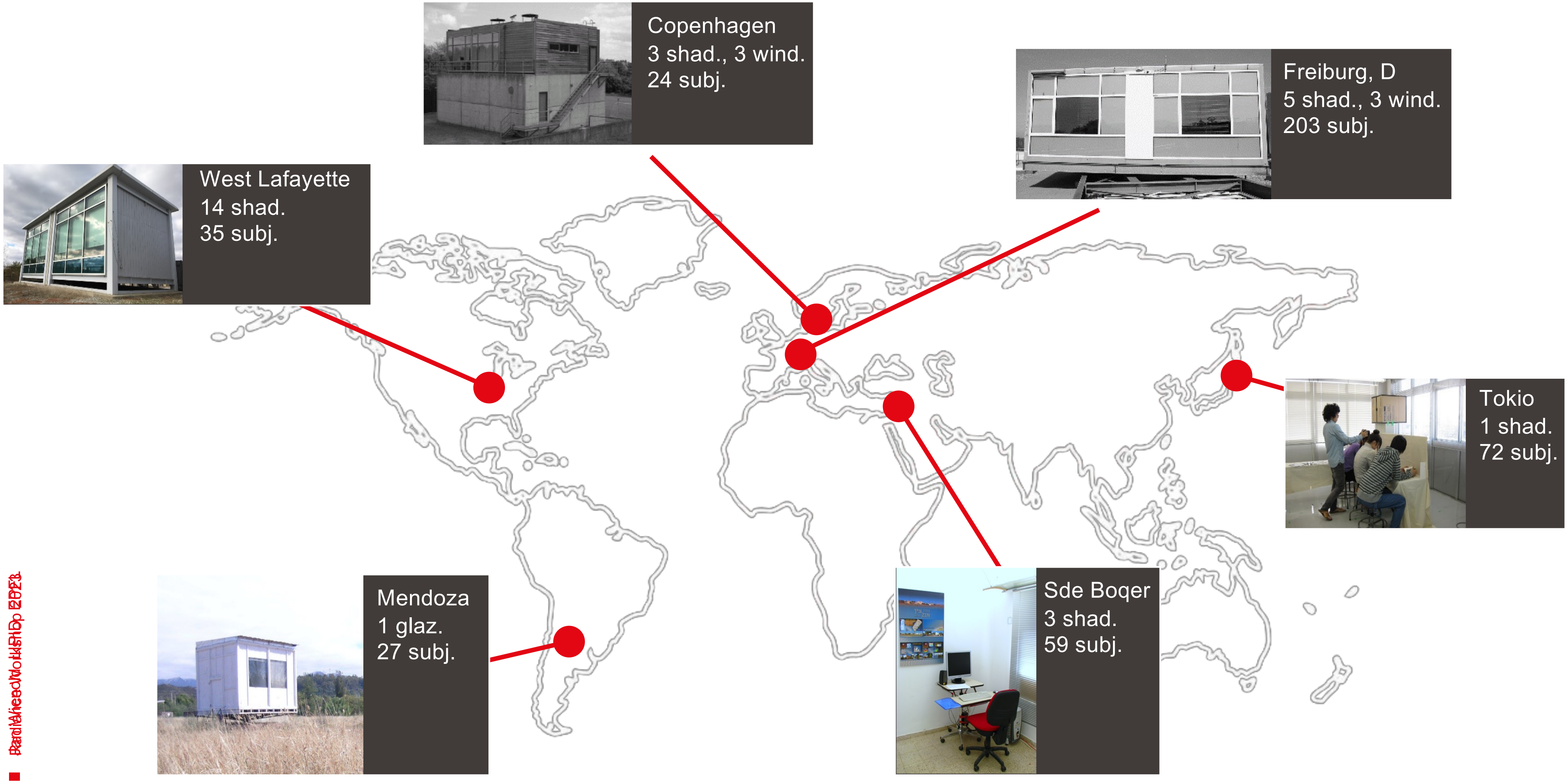
Wienold et. al.
Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras , Energy and Buildings, 2006



Hirning et. al.
Discomfort glare in open plan green buildings,
Energy and Buildings, 2014

Van den Wymelenberg et. al.
Evaluating a New Suite of Luminance-Based Design Metrics for Predicting Human Visual Comfort in Offices with Daylight, Leukos 2015

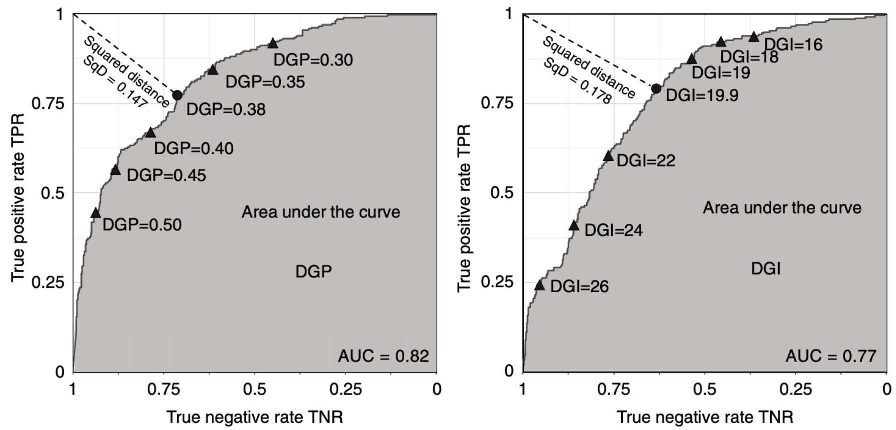
Experimental data

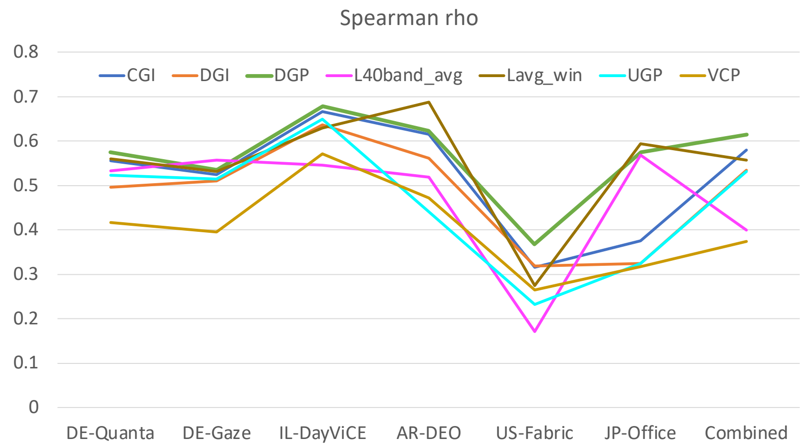


Results: DGP most robust and best performing glare metric

- Several independent statistical tests applied
- Performance and robustness evaluated

Metric		Performance Ranking			Robustness Ranking			
	total	overall	Spearman	Avg SqD	overall	Max SqD	Variation borderl.	Test failing
DGP	**1**	**1**	1	1	**1**	1	1	1
E_v	**2**	**3**	4	3	**2**	3	5	2
$PGSV_{sat}$	**2**	**2**	4	2	**3**	2	9	2
L_{avg}	**4**	**3**	2	5	**5**	6	12	4
L_{pos_avg}	**5**	**5**	6	4	**4**	9	6	6
PGSV	**6**	**7**	9	6	**7**	7	14	4
CGI	**7**	**8**	10	9	**8**	14	4	10
L_{avg_win}	**7**	**5**	3	7	**11**	4	22	8
DGI	**9**	**12**	15	10	**6**	11	3	10
DGI_{mod}	**10**	**10**	11	11	**9**	19	2	10
E_{dir}	**10**	**9**	12	8	**10**	5	21	6
L_{med}	**12**	**10**	8	14	**17**	22	13	8
PGL	**13**	**13**	14	12	**15**	13	16	13
UGR	**14**	**16**	18	16	**13**	15	7	18
L_{40band_avg}	**14**	**15**	16	15	**14**	17	11	13
UGR_{exp}	**16**	**20**	20	18	**12**	8	10	17
UGP	**17**	**18**	18	17	**15**	16	8	18
L_{std_win}	**18**	**14**	7	20	**21**	21	20	13
L_{med_win}	**19**	**16**	13	21	**20**	20	18	13
VCP	**20**	**18**	22	13	**19**	10	19	20
GSV	**21**	**22**	21	19	**18**	12	15	21
L_{med_lowerv}	**22**	**21**	17	22	**22**	18	17	21





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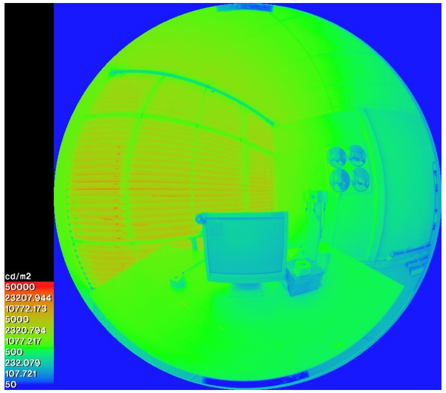
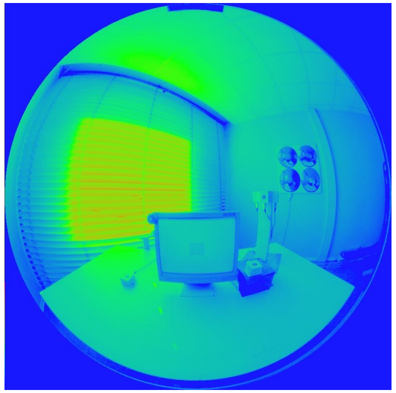
Discussion: Contrast based metrics



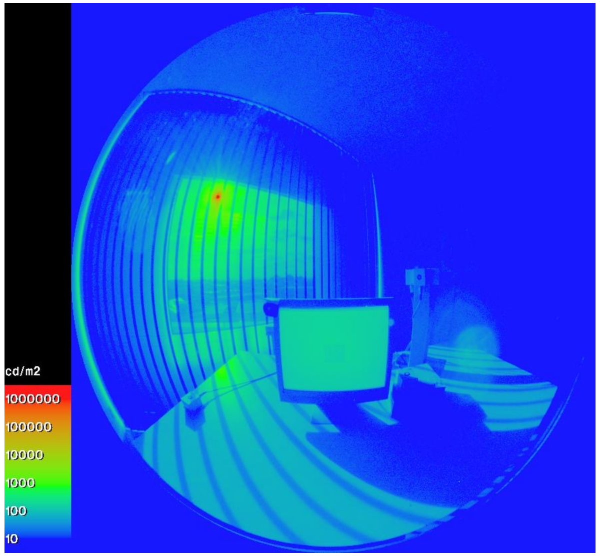


CGI, DGI, DGI_{mod}, UGR, UGP, UGR_{exp}, VCP

		Average	Ratio of persons	Saturation effect based metrics		Contrast based metrics		
Window Size	Cases	Window Luminance [cd/m^2]	disturbed by glare	E_v [lux]	DGP [-]	DGI [-]	CGI [-]	UGP [-]
Small	42	3032	29%	2494	0.29	20.5	29.7	0.85
Large	43	2815	49%	4468	0.43	17.8	29.3	0.76

Failing if saturation effect is dominant !!!

Discussion: Saturation effect based metrics



E_v, DGPs, E_{dir}, L_{avg}, L_{avg_pos}, $PGSV_{sat}$

Failing if contrast effect is dominant !!!
(e.g. low transmittance glazing like EC or fabrics and sun in field of view)

Conclusion:
DGPs not applicable when a peak luminance is in the field of view
(as specified also in the original publication…)

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Evaluation of existing models - conclusions

- DGP works reasonably for a wide range of situations (ρ_{avg}=0.57, average (binary) glare prediction rate 70-75%) Main limitation are situations in dim environments where visible sky luminance might cause glare
- Other metrics might work well in specific situations
- Especially windows luminance and indices based on it show low correlation
- DGP_s , E_v or L_{avg} fail to predict contrast glare (e.g. sun visible through EC or fabric shading) and should be applied only in cases where no peak luminance can be expected

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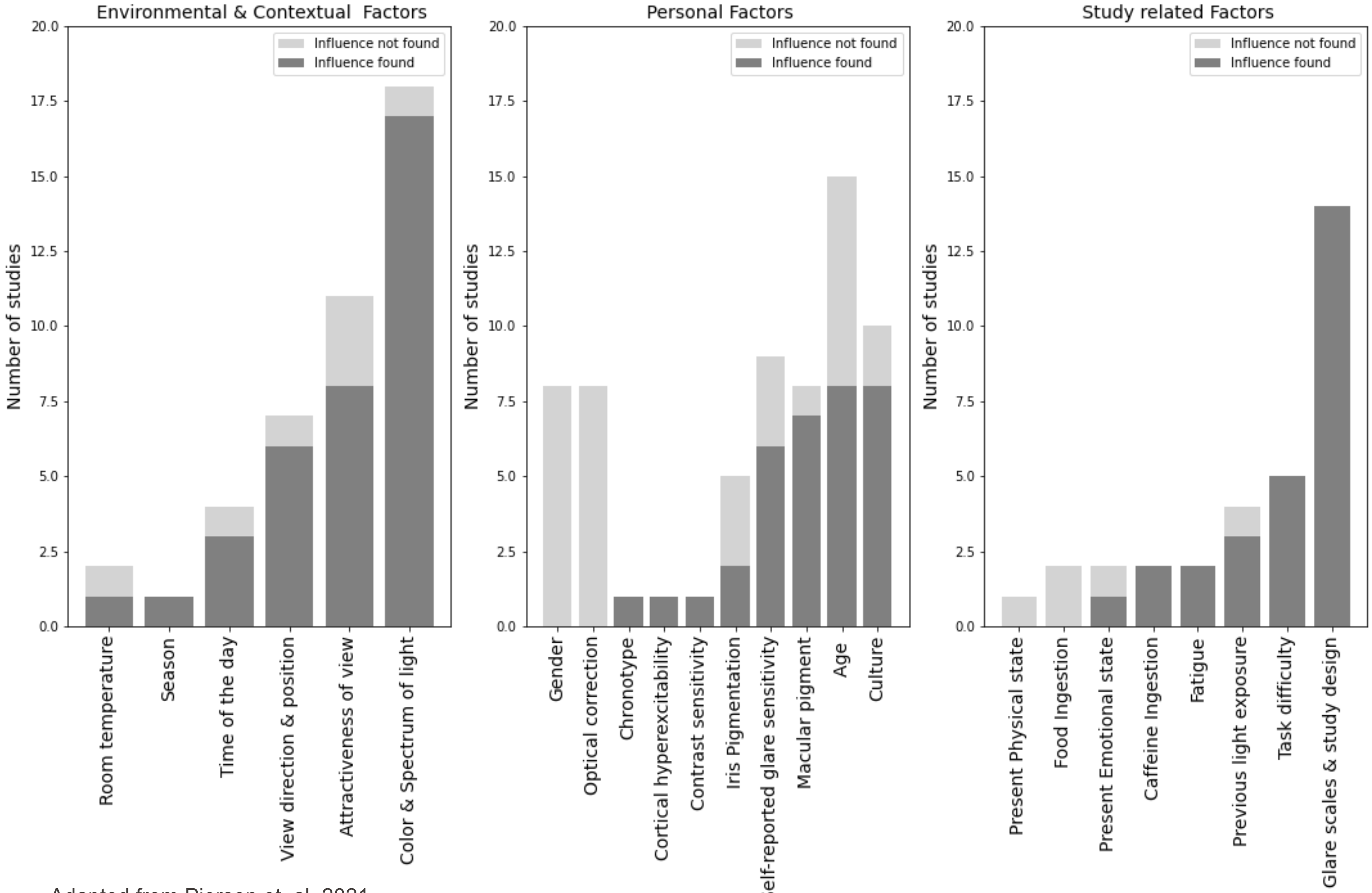
Current research

- Determine influence factors on discomfort glare
- Increase amount of “glare data” world-wide to improve glare metrics
- Expand validity od DGP for low light situations

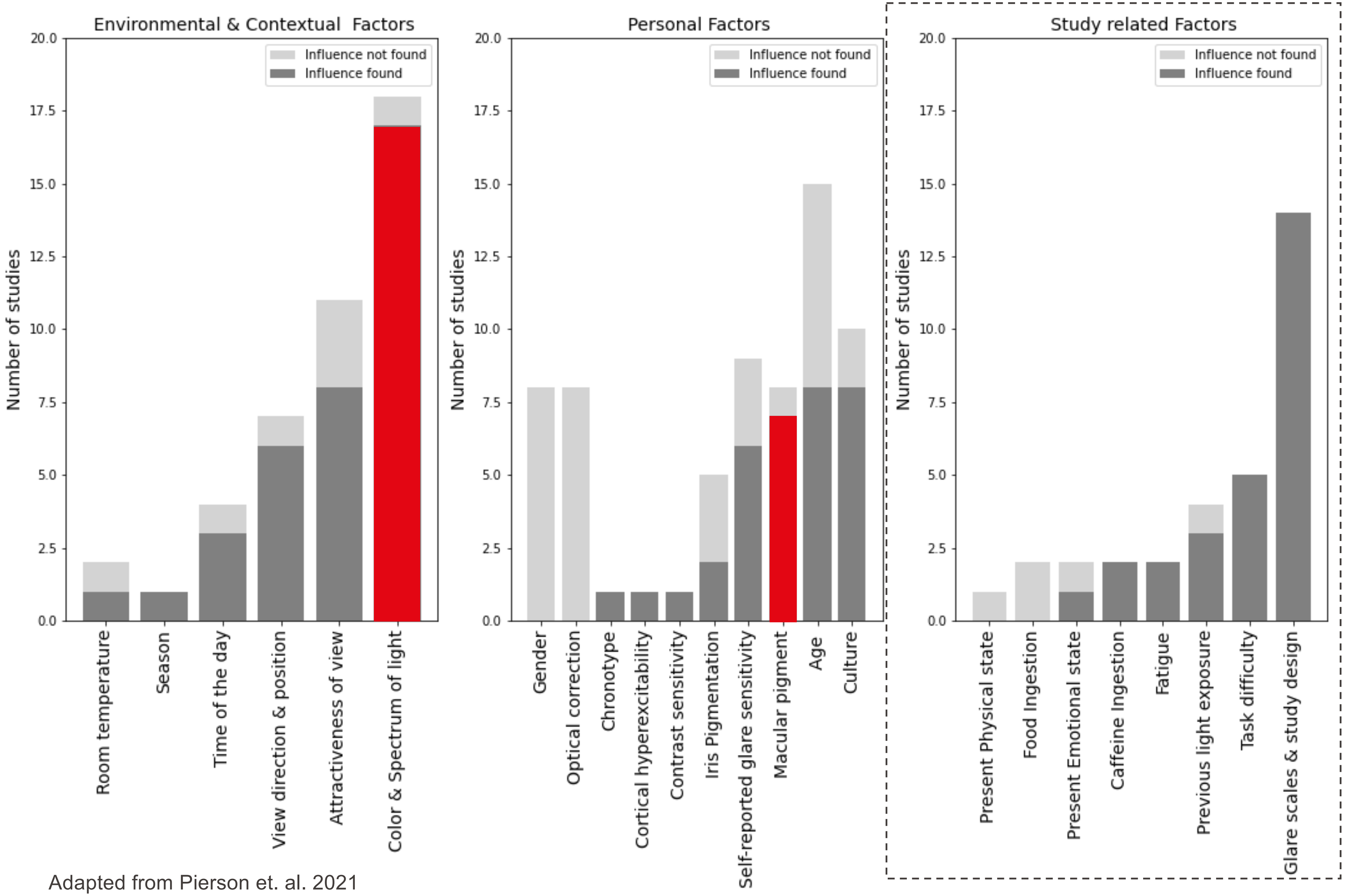
Influence factors on discomfort glare

- Although metrics work reasonably well, the responses between subjects under similar conditions are varying strong – other influence factors than the "typical ones" expected

- Literature review of Pierson et al.
  "Review of Factors Influencing Discomfort Glare Perception from Daylight", LEUKOS, 2018, 14(3), pp. 111–148



Adapted from Pierson et. al. 2021



Adapted from Pierson et. al. 2021

Research questions addressed by PhD thesis of Sneha Jain 2023*

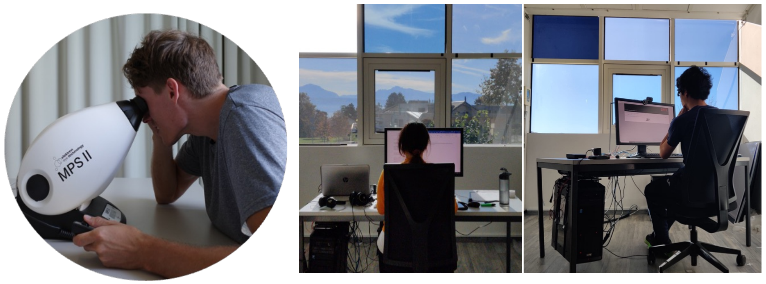
Ocular Characteristics	Environmental Characteristics
Is there an influence of macular pigments on discomfort glare from daylight?	Is there an influence of the color of daylight on discomfort glare from daylight?

* S. Jain, *Discomfort glare from daylight: Influence of transmitted color and the eye's macular pigment*, EPFL, 2023

Experiments

Ocular Characteristics

Is there an influence of macular pigments on discomfort glare from daylight?



MPOD and glare measurements in neutral and blue glazing (N=55)

Environmental Characteristics

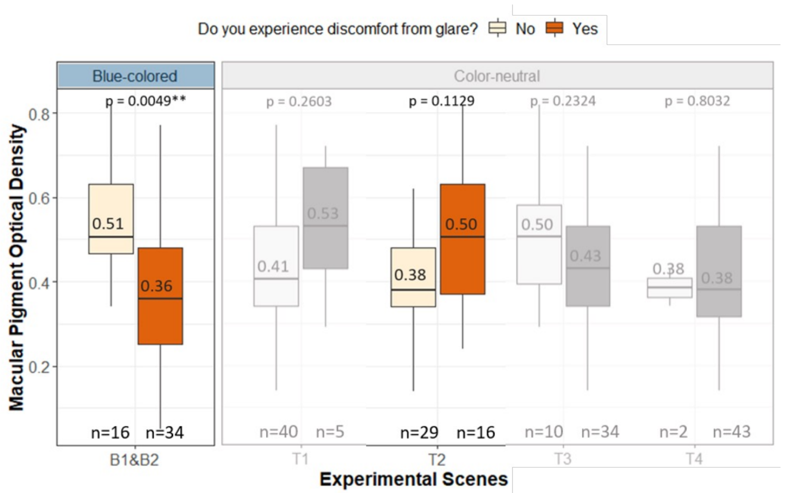
Is there an influence of the color of daylight on discomfort glare from daylight?

Glare measurements in Red, Green, Blue and neutral glazing (N=55)

Results

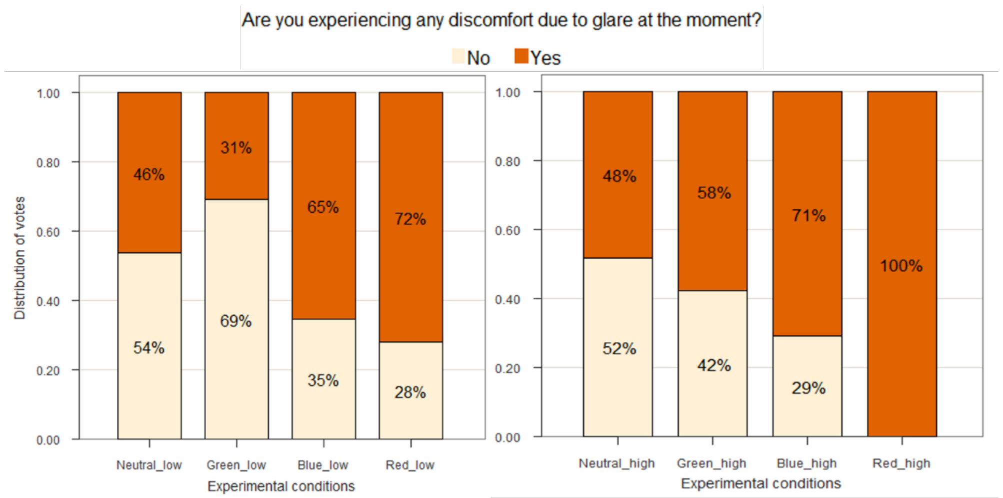
Ocular Characteristics

Is there an influence of macular pigments on discomfort glare from daylight?



Environmental Characteristics

Is there an influence of the color of daylight on discomfort glare from daylight?



Conclusions

Ocular Characteristics	**Environmental Characteristics**
Is there an influence of macular pigments on discomfort glare from daylight?	Is there an influence of the color of daylight on discomfort glare from daylight?

No influence of macular pigment on glare in neutral daylit conditions but strong influence under blue-colored glare source.

Strong influence of color of daylight transmitted through colored glazing on discomfort glare.

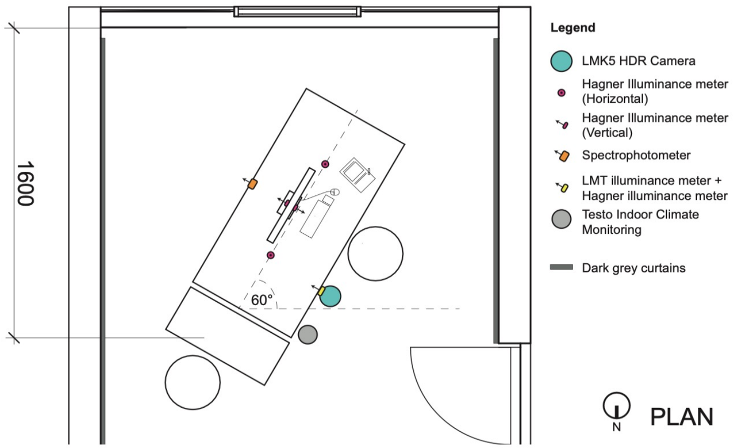
Key findings

- No influence of MPOD in neutral indoor daylit scenarios with typically off-fovea light source.
- Red glazing is most disturbing, closely followed by blue glazing in creating discomfort glare.
- Color-neutral as well as the green glazing are more comfortable ones.
- **V(λ)** is not suitable to characterize luminance under brightly lit colored daylight conditions.
- Spectral weighting in glare models need modifications for such conditions.
- Smart glazing technology should be developed to have neutral tints for better glare protection.

DGP – Range extension to dim daylit scenarios PhD thesis of Geraldine Quek (2022)*

Two experiments under dim lighting conditions conducted:

1. Single office layout



(a) Floor plan

(b) Experiment setup

* G. Quek, *Visual comfort without borders: Extending daylight glare prediction to dim daylit environments*, EPFL, 2022

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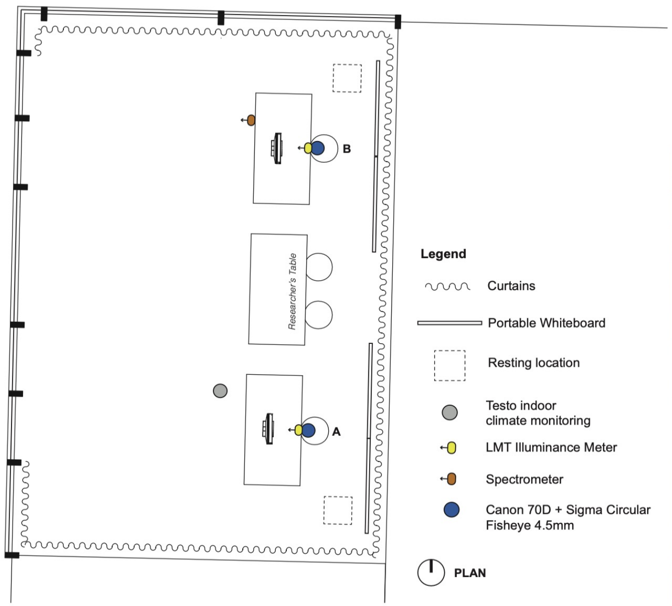
DGP – Range extension to dim daylit scenarios
PhD thesis of Geraldine Quek (2022)*

Two experiments under dim lighting conditions conducted:

2. Open plan office layout



(a) Floor plan

(b) Experiment setup

* G. Quek, *Visual comfort without borders: Extending daylight glare prediction to dim daylit environments*, EPFL, 2022

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DGP – Range extension to dim daylit scenarios

Revision of DGP can be expected in 2024

Change to a logistic function to mathematically limit value between 0-1.

Basic concept of hybrid metric with two terms for saturation and contrast will be kept.

Well balanced experimental data will be used to expand the model, also to expand DGP to extreme high ranges.

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Content

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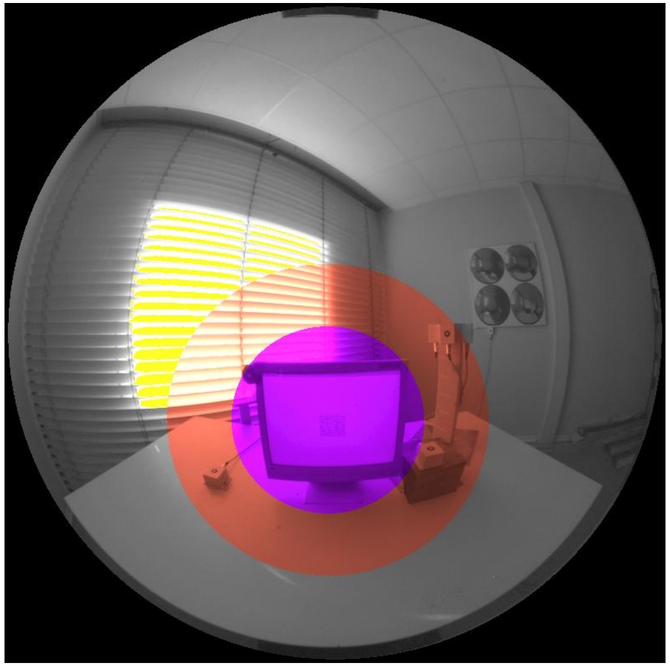
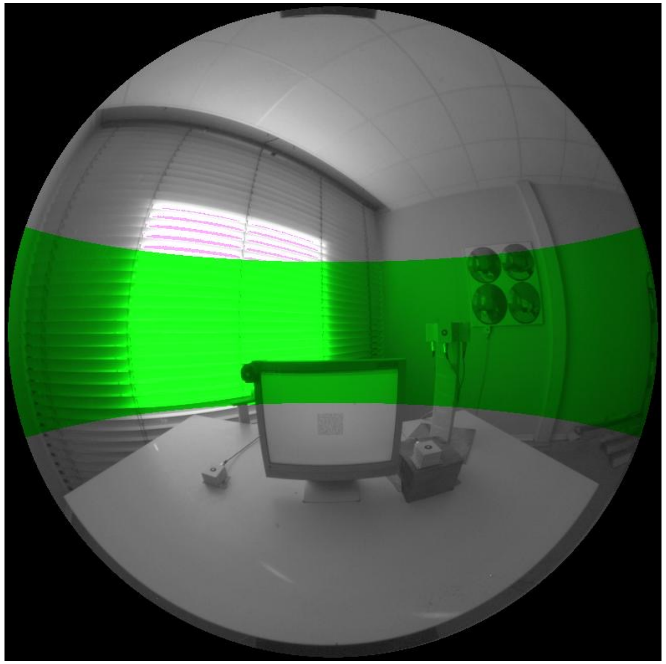
How to evaluate glare – intro into evalglare





What is evalglare ?

It is a (command-line) tool for performing a glare analysis of an Radiance-based HDR scene
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

Core features:

- detects glare sources in HDR images
- calculates solid angles from pixels/glare sources
- calculates vertical illuminance from image
- calculates various glare metrics (DGP, UGR, VCP, DGI, CGI…)
- detailed output of calculated values of glare sources

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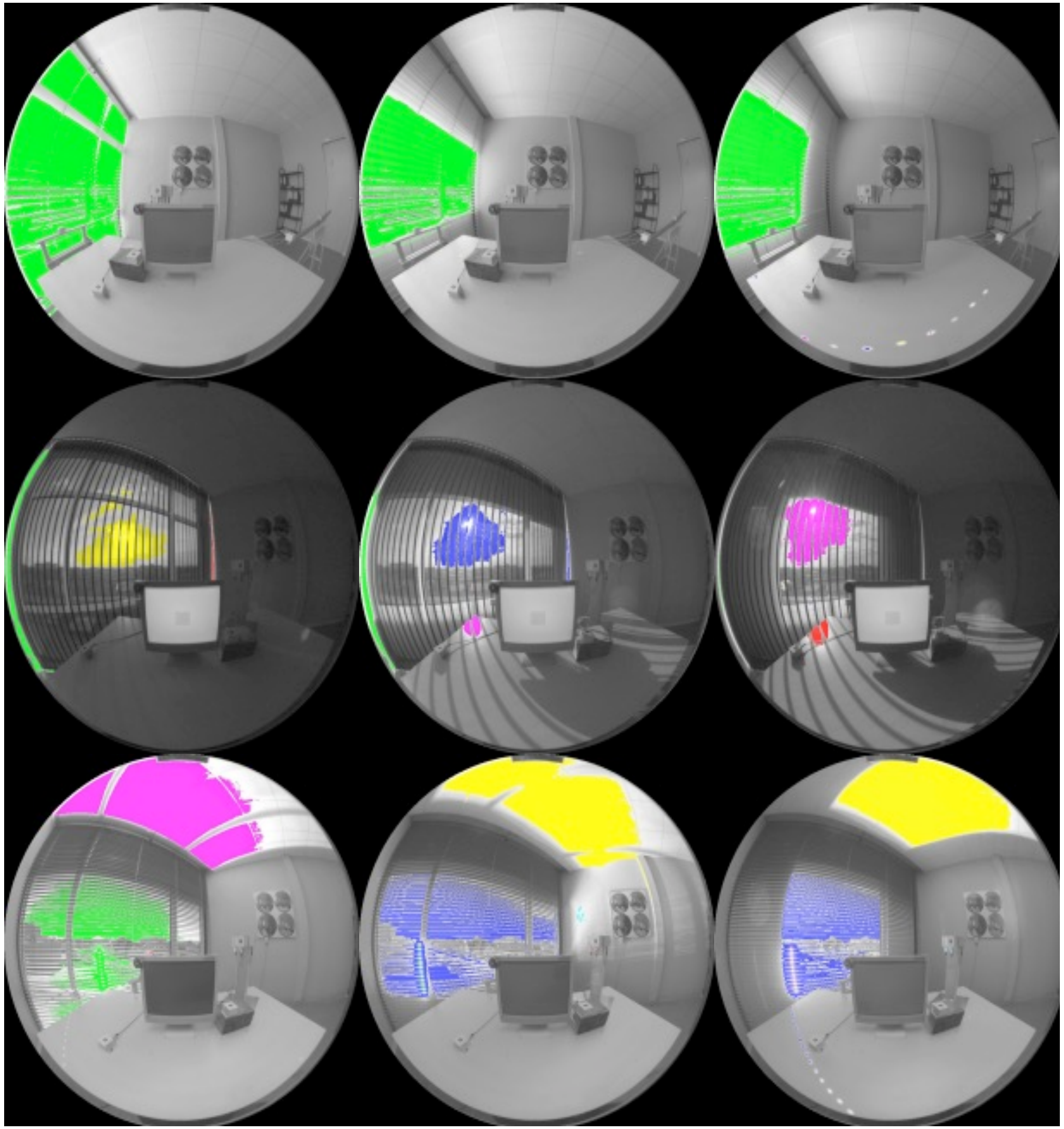
evalglare

Additional features:

- cut the field of view
- (simple) statistical analysis of the image or parts of the image (mean, median, 95 percentile, 75 percentile, standard deviation)
- Zonal evaluation (two circular zones possible, horizontal band)
- Masking between 2 images to evaluate the masked area

What is a glare source ?



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What is a glare source ?

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

Objectives:

⇒ 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

What is a glare source ?

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

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/m² is treated as a glare source pixel
Default setting!!

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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

Detection of glare sources

Which parameter must be set for the detection modes?

-b *value*

Value ≤ 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

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

No influence on position index!!

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Detection of glare sources
Define task luminance as threshold for glare source

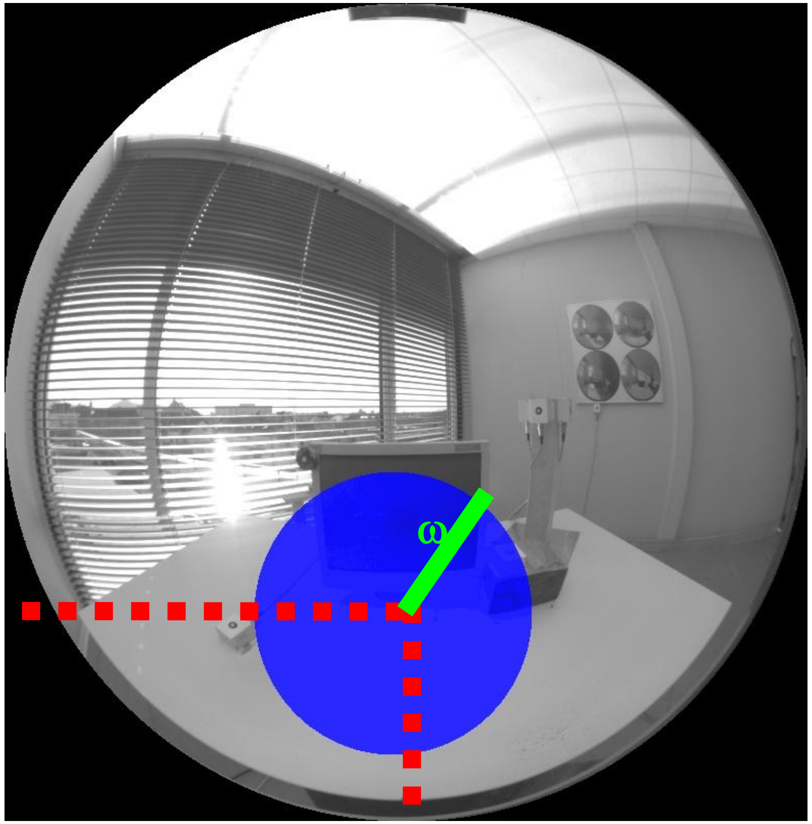
Two parameters have to be provided:

1. *x y* position of picture (centre of task)

2. opening angle w of task

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

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



But….

This is what is implemented in evalglare since 2005, based on the (limited) experiments at Fraunhofer from 2003-2005.

Study from C. Pierson investigated existing GS-detection methods:
Pierson C., Wienold J., Bodart M., *Daylight discomfort glare evaluation with evalglare: Influence of parameters and methods on the accuracy of discomfort glare prediction*, Buildings, 8 (8), art. no. 94,2018, DOI: 10.3390/buildings8080094
After that publication, the fixed threshold of 2000 cd/m^2 is default in evlglare.

In real it is not trivial to answer the question “what is a glare source”.

Some insights from ongoing research:

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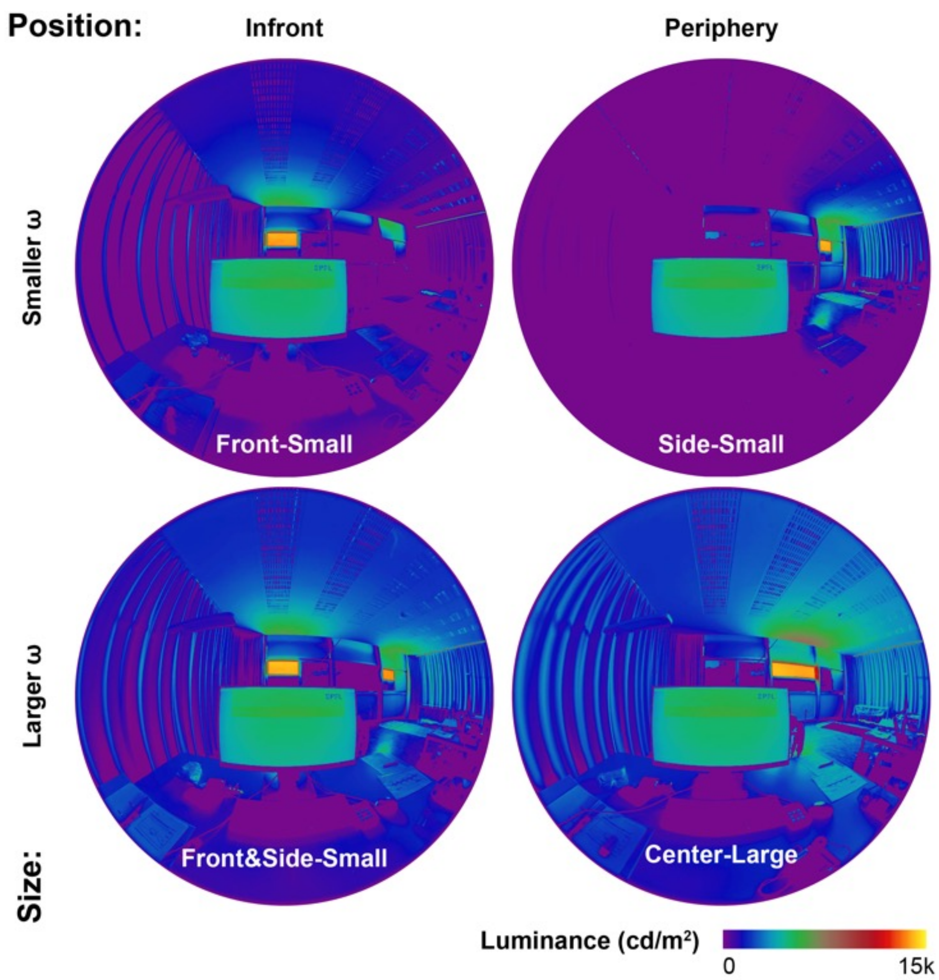
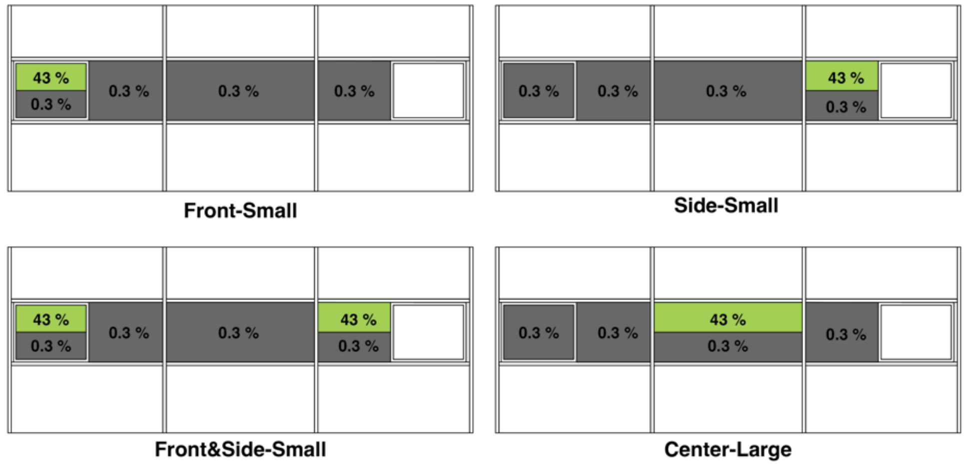
Previous study from G. Quek



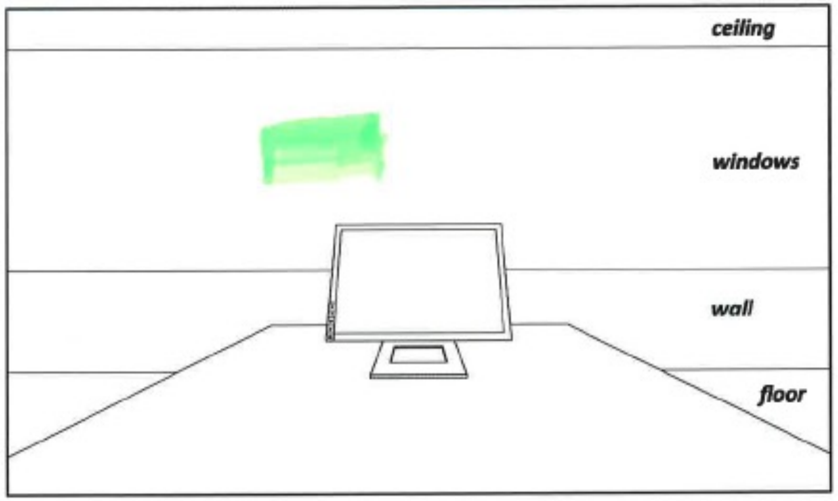


- 1 x 3M™Envision Diffuser Film 3735-60 (63% T_{vis})
- 2 x LEE 299 1.2 Neutral density window films (6.6% T_{vis})
- Attached on x no. of Perspex PMMA-XT (92% T_{vis})

*Labels are from Participant A's perspective

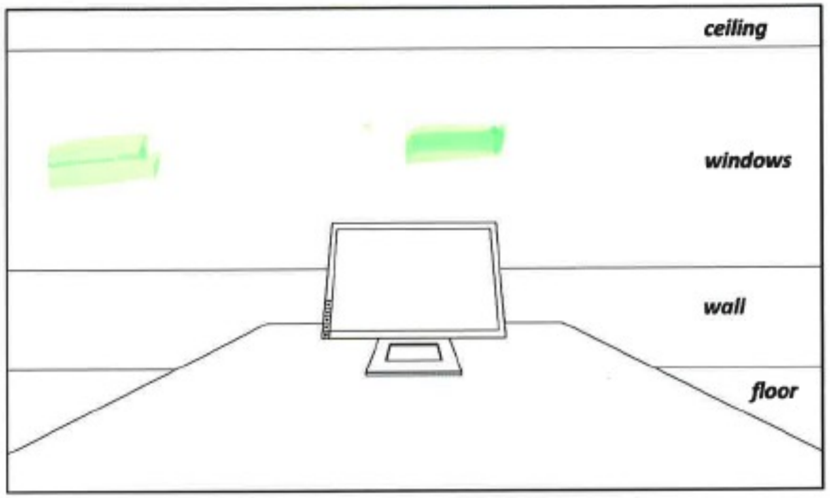
Previous study- Marking of perceived glare sources

If you experience any uncomfortable glare at the moment, please color the cause(s) or source(s) of glare on the diagram below. If not, leave it blank.



Definition: Glare is the sensation of visual discomfort caused by differences between light and dark areas, or by excessive brightness in your field of view.

If you experience any uncomfortable glare at the moment, please color the cause(s) or source(s) of glare on the diagram below. If not, leave it blank.



Definition: Glare is the sensation of visual discomfort caused by differences between light and dark areas, or by excessive brightness in your field of view.

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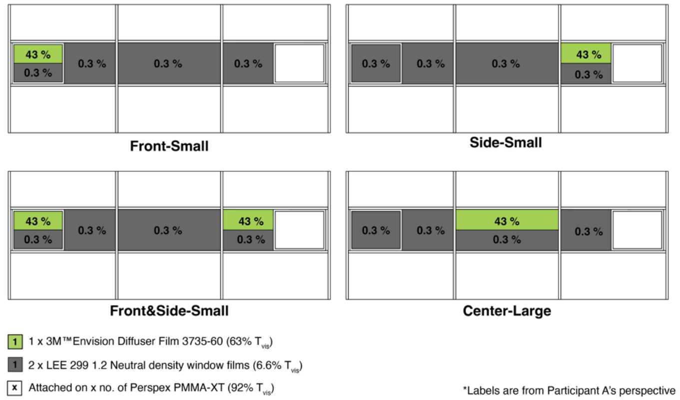
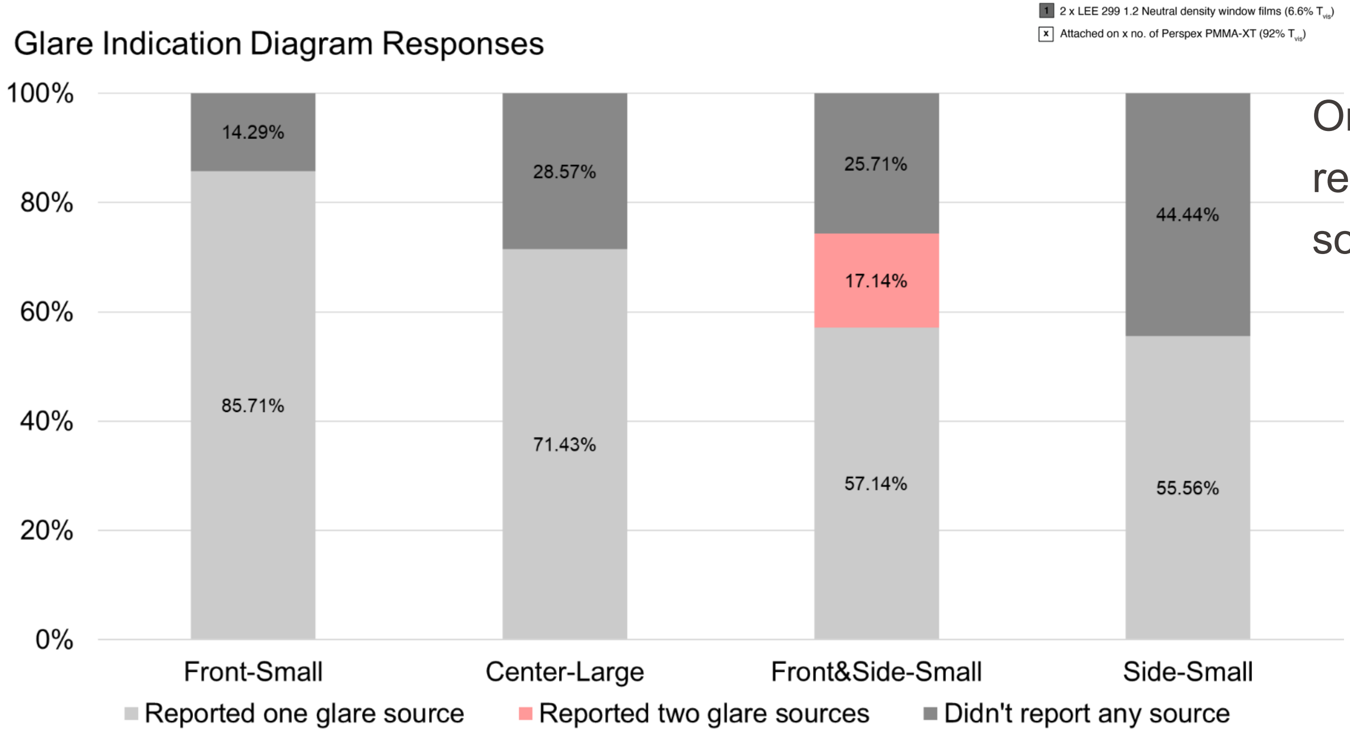
Previous study- Result





Only 17% of the test persons rereported a second glare source…

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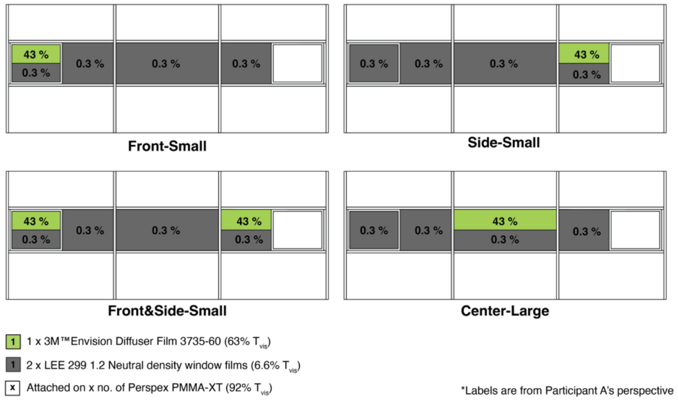
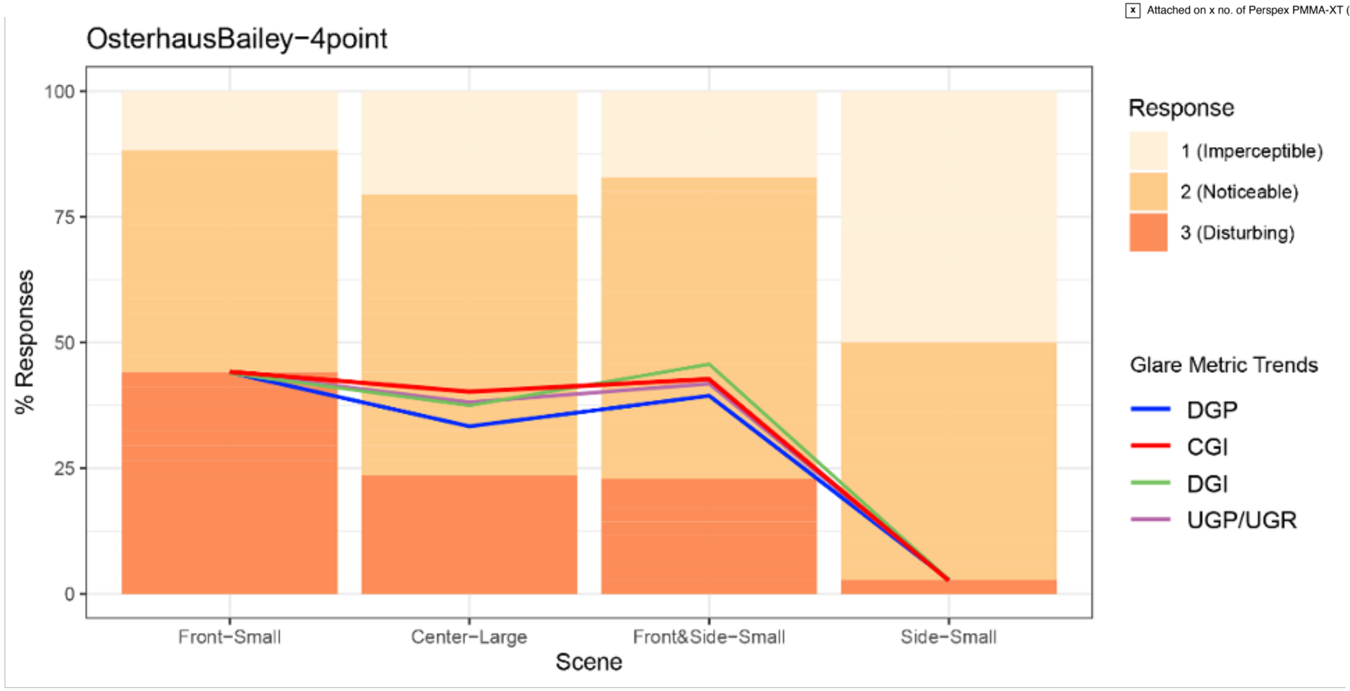
Previous study- Result





Second “glare source” does not increase glare perception

-> Second glare source does not act as glare source but contributes to the adaptation level only

-> perceptual model to detect “real” glare sources is needed

Position index is used in most glare metrics

L_s : source luminance

L_b : background luminance

Ω_s: Modified solid angle

ω_s: solid angle of source

P: Guth position index

E_d: direct vertical illuminance

E_i: indirect vertical illuminance

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

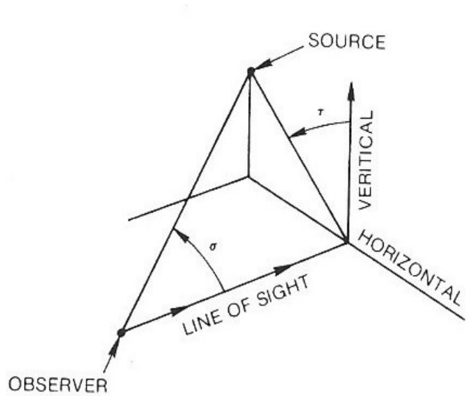
$$DGI = \frac{2}{3}(GI + 14) \qquad GI = 10 \log_{10} 0.48 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega_s^{0.8}}{L_b + 0.07\, \omega_s^{0.5} L_s}$$

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

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

Calculation of glare equations

IES position index



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

τ : angle from vertical plane containing sourceand line of sight

σ : 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

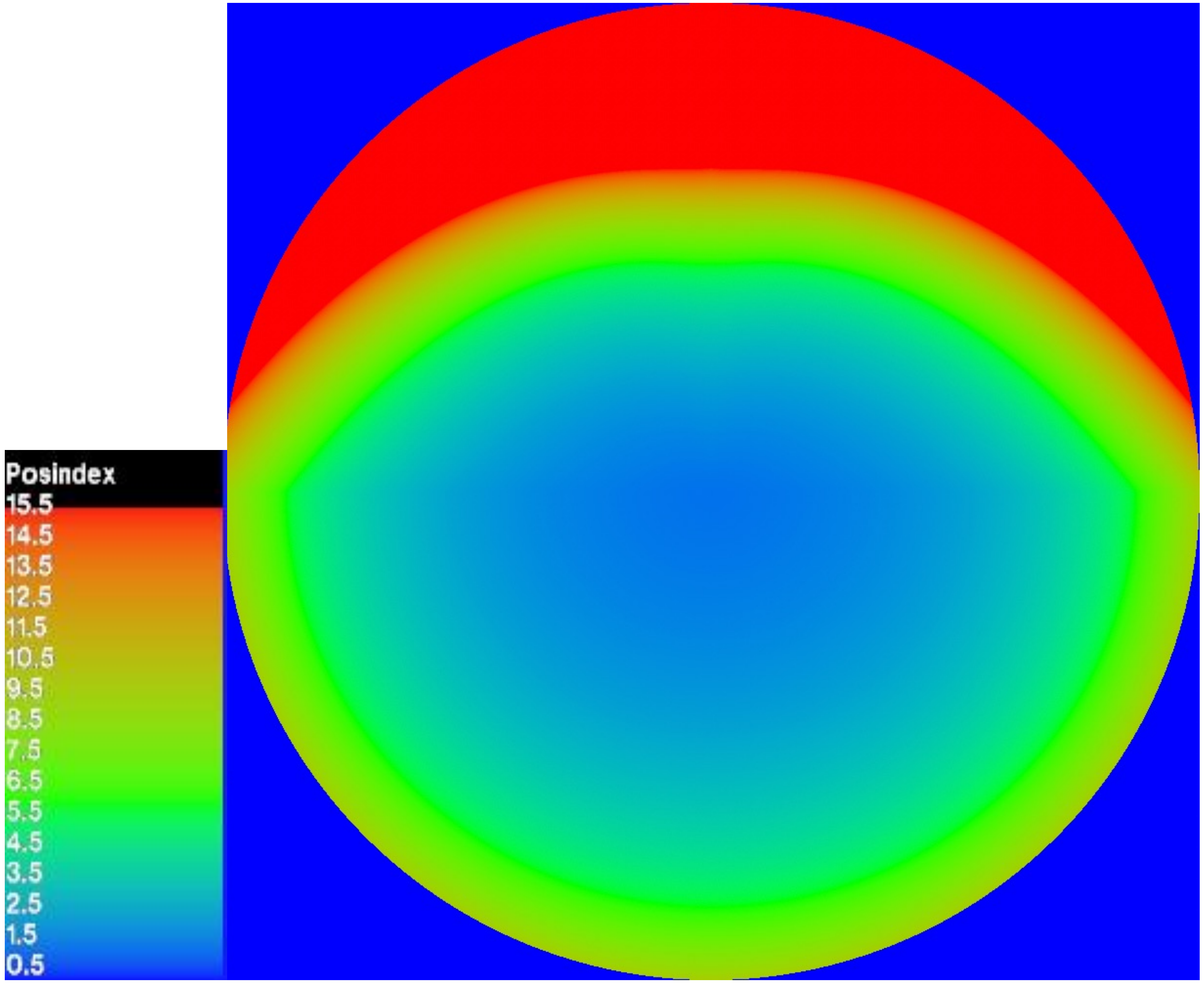
H : Vertical distance between source and view direction

Y : Horizontal distance between source and view direction

Position index

implementation in evalglare

View direction is always in centre of picture!!



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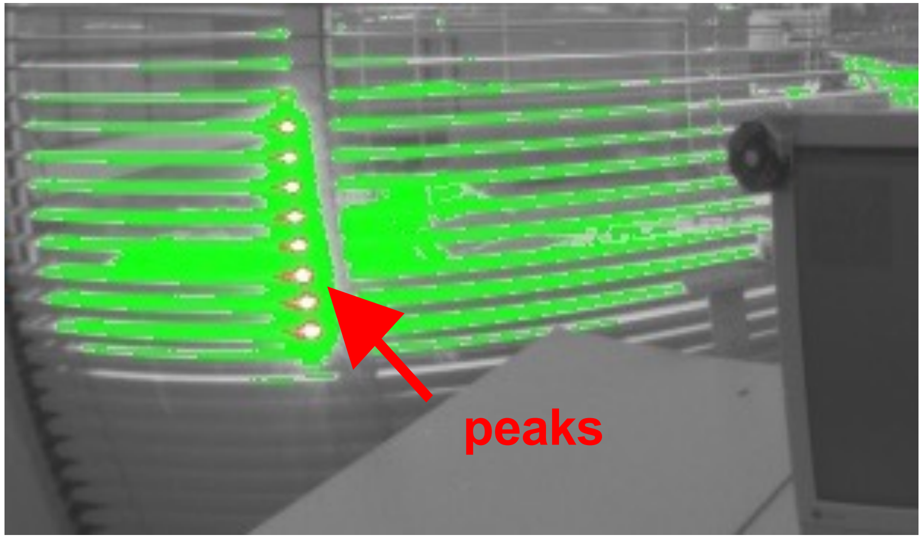
Evalglare peak extraction

Option –y (default, default threshold 50kcd/m^2)
"Peaks" of high luminances can
be extracted to an extra glare source

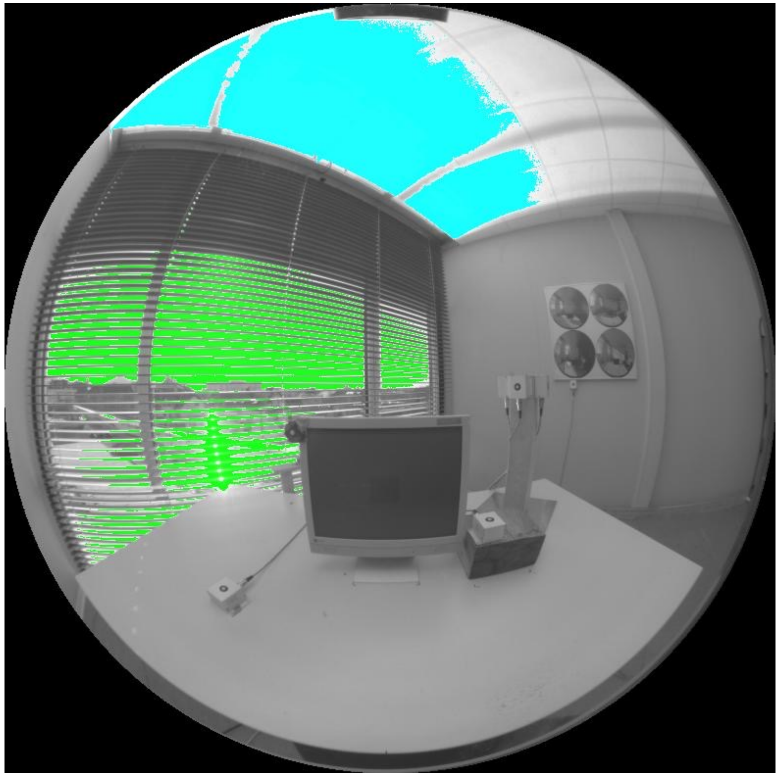
Option –Y *value*
value is used as threshold for peak extraction



Caution
All peaks are extracted to one glare source
Error in positional weighting for very distant peaks!

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

Which pixels should be counted to which glare source?



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Detection of gs Algorithm

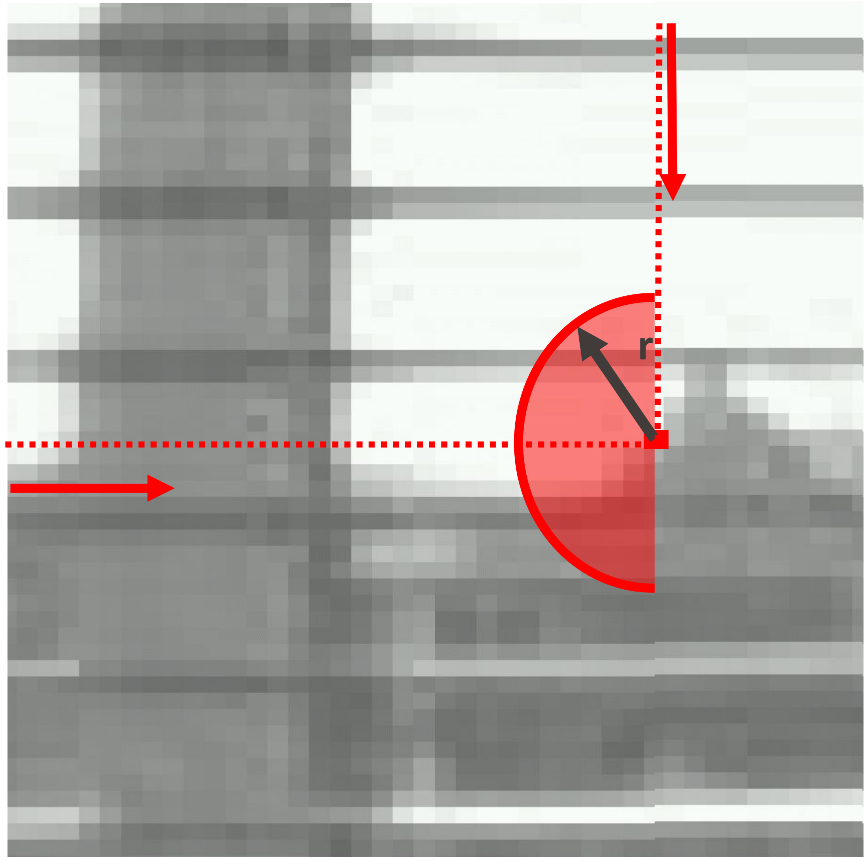
r-parameter

First scan of picture pixel by pixel

If Lpixel > threshold (task luminance) then

Search for other pixels in the nearby (r provides as ω as parameter)

Add pixel to gs (luminance, position)

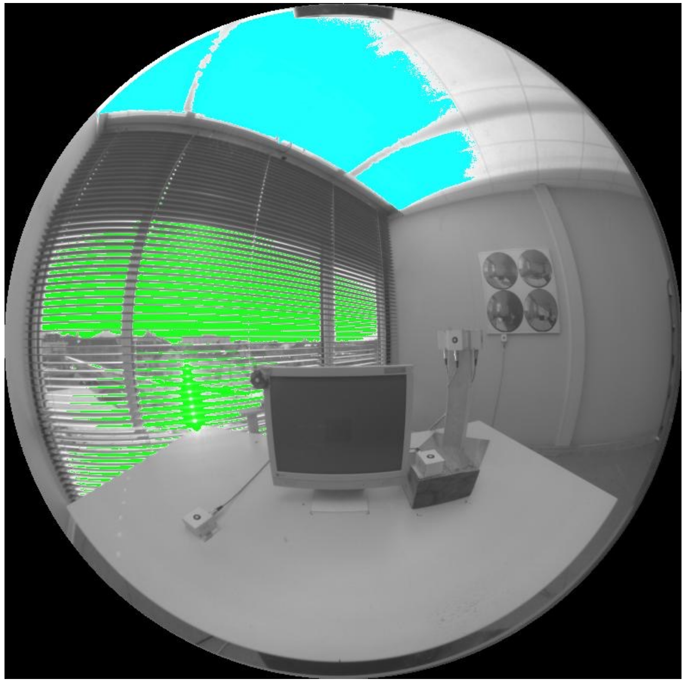


Influence of the –r parameter

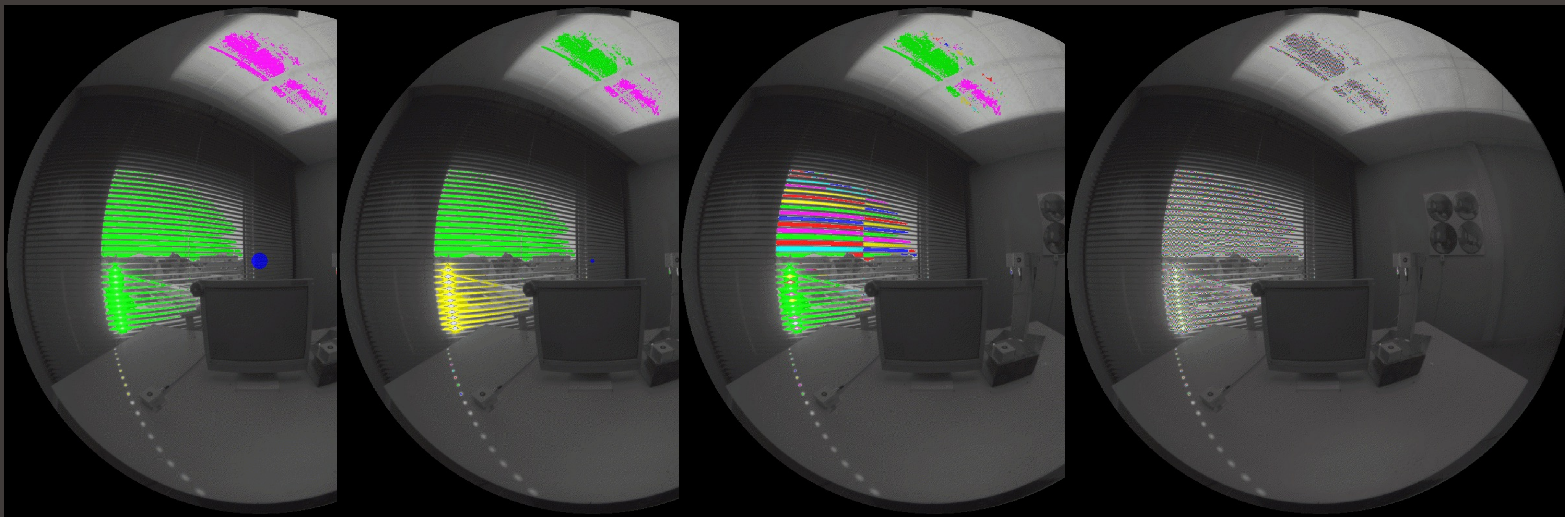
-r is a search diameter, for combining
glare pixels to a glare source

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

The influence of the r-parameter was studied in detail by M. Sarey Khanie here:

Khanie M.S., Jia Y., Wienold J., Andersen M., *A sensitivity analysis on glare detection parameters*,14th International Conference of IBPSA - Building Simulation 2015, BS 2015, Conference Proceedings, pp. 285 - 292

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)

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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

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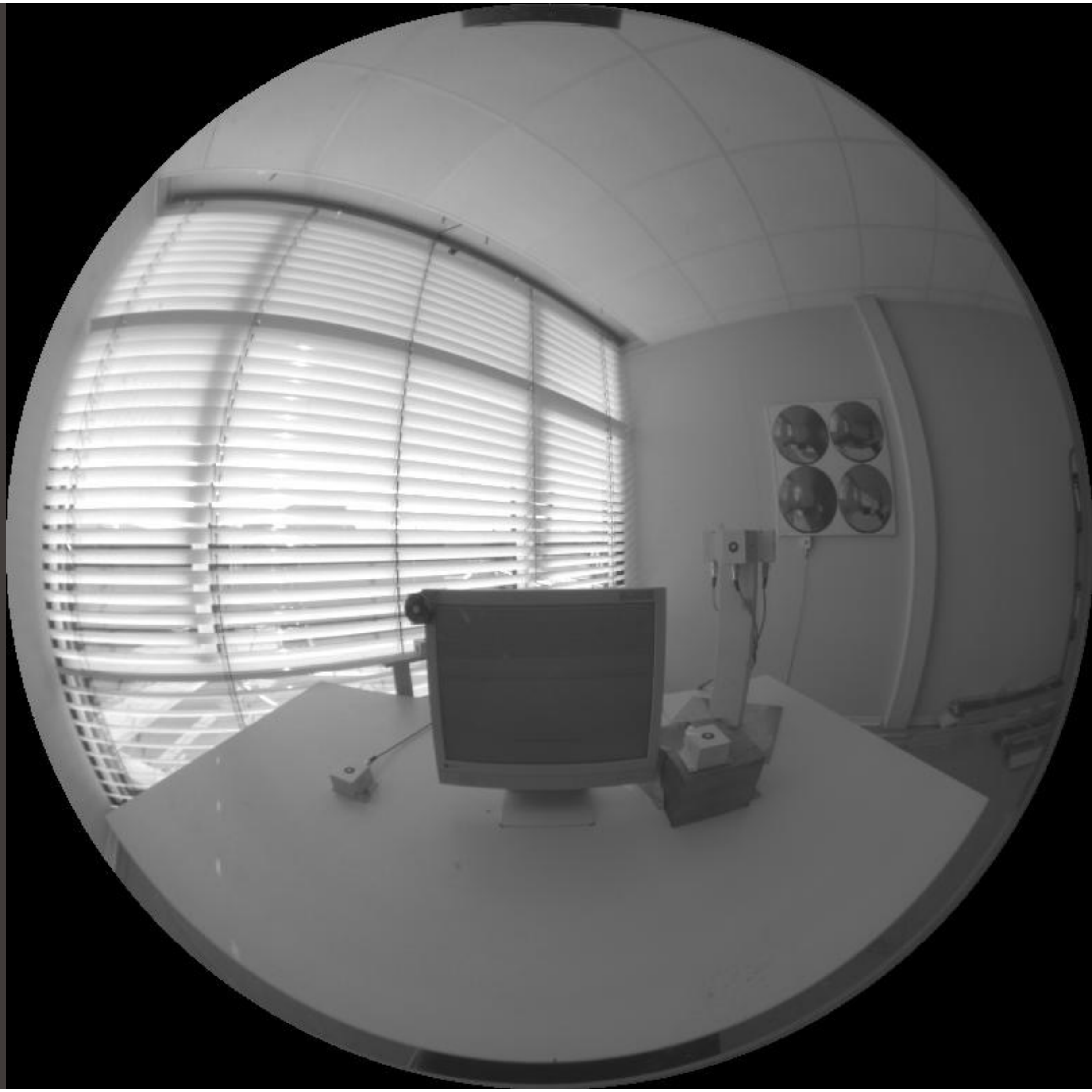
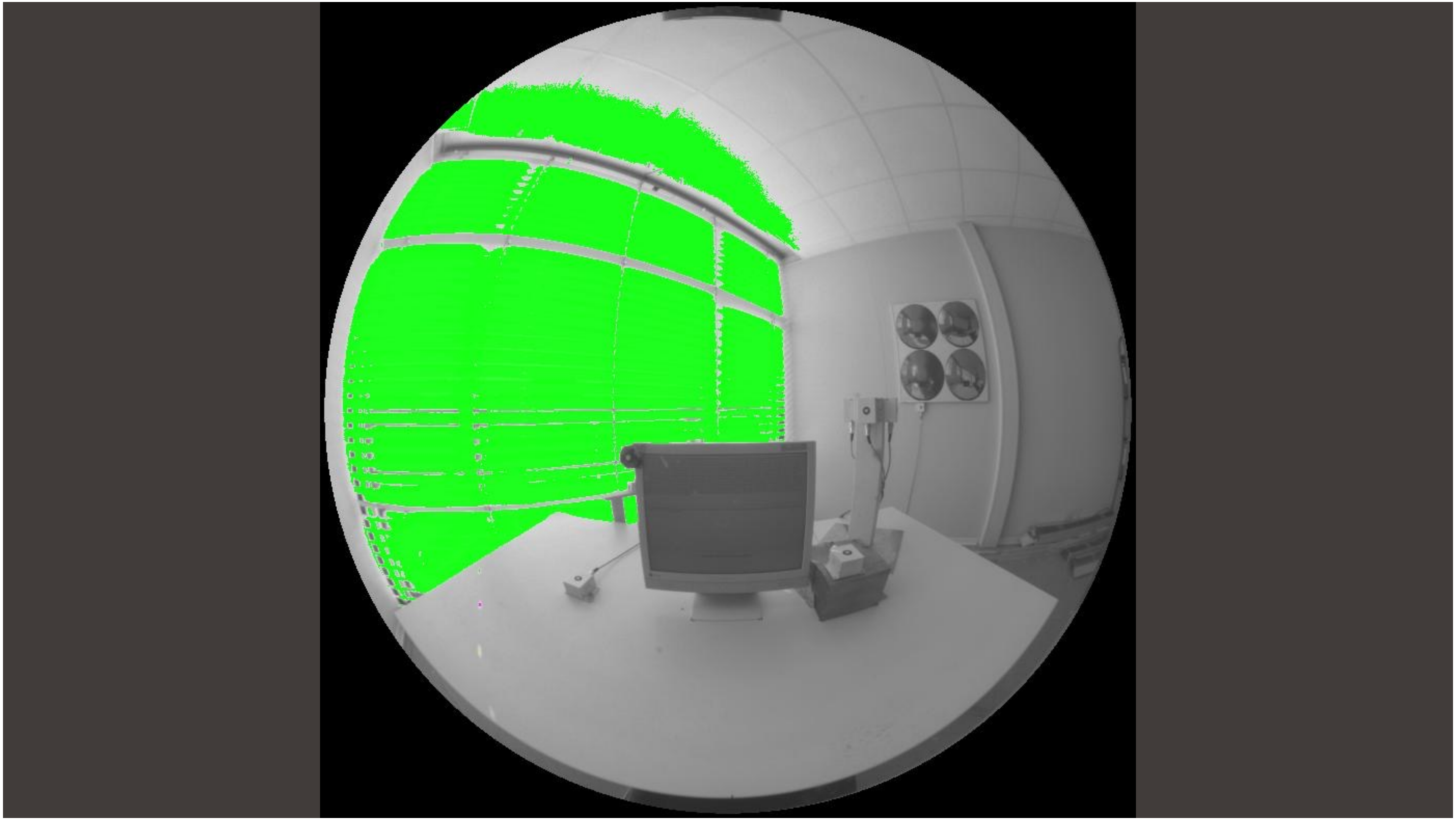
Cutting field of view based on Guth

- based on paper of Guth 1958:
  Light and Comfort, Industrial Medicine and Surgery, November 1958

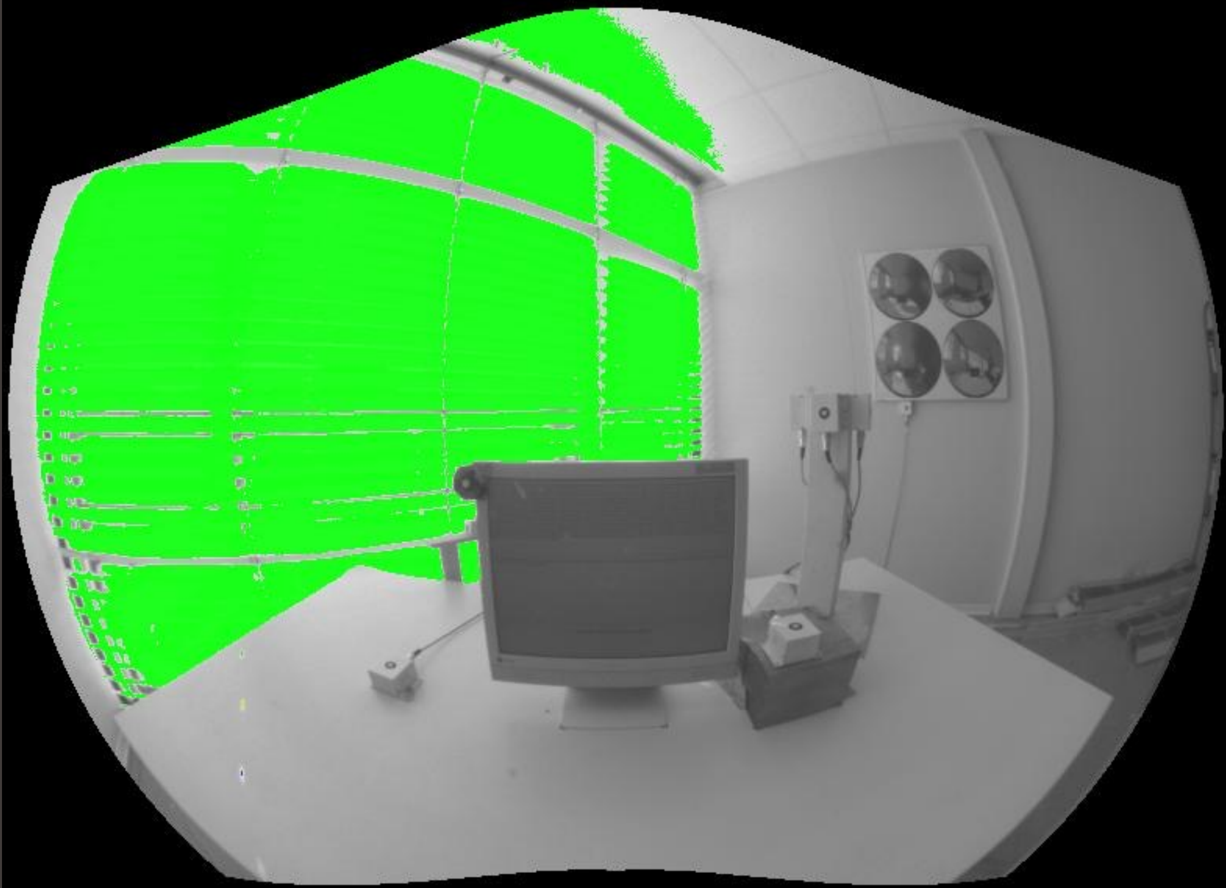
- activated by option -G *type*,
  type=1: total field of view,
  type=2: field of view seen by both eyes





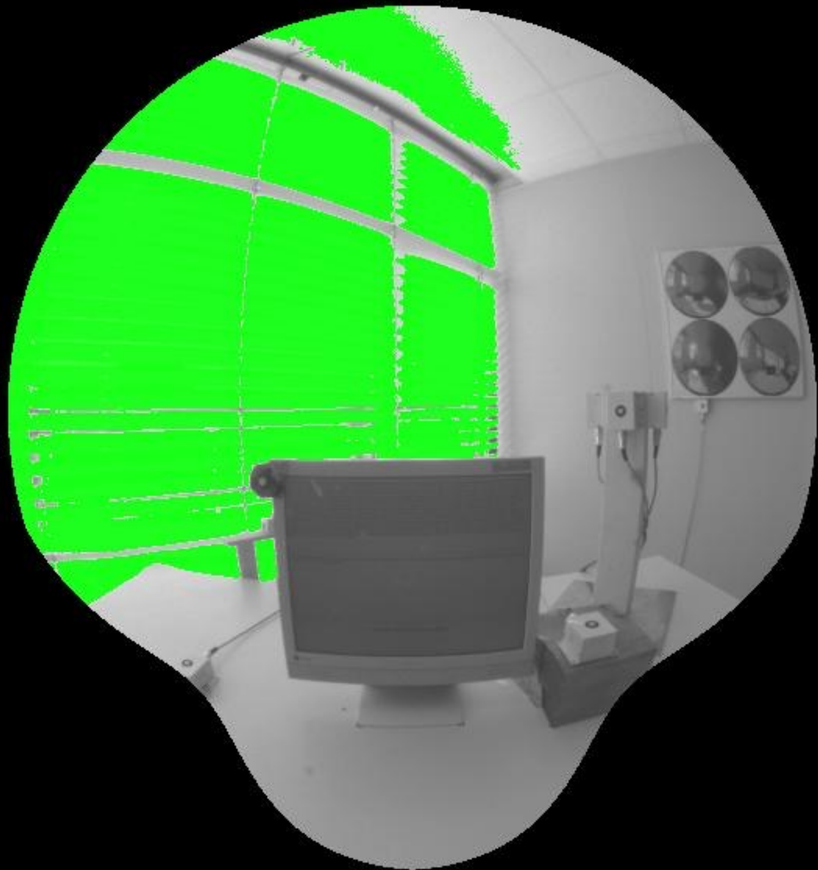
total field of view

-G 1



field of view seen by both eyes

-G 2



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 -nan 0.004855 2(

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Direction vector of glare sources

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

Horizontal band evaluation:

activated by -B angle [rad]

e.g. for ±20° from horizontal line («40°-band») -> angle=0.349

Output in separate line (first line).

Following values within the band are calculated:

band_omega solid angle of band [sr]

band_av_lum average luminance of band [cd/m²]

band_median_lum median luminance of band [cd/m²]

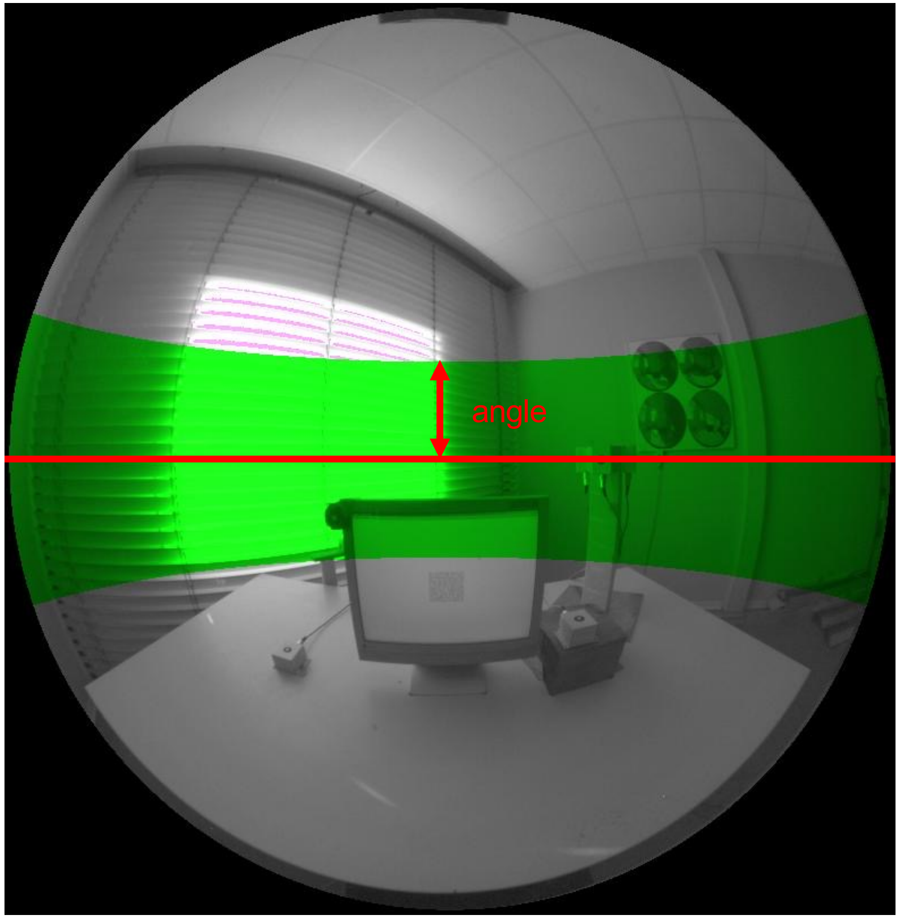
band_std_lum standard deviation of luminance,

band_perc75 75 percentile luminance of band [cd/m²]

band_perc95 95 percentile luminance of band [cd/m²]

band_min_lum minimum luminance of band [cd/m²]

band_max_lum maximum luminance of band [cd/m²]



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Zonal evaluation

Needed for examle when performing a contrast evaluation

activated by

-l xpos ypos angle : single zone

-L xpos ypos angle1 angle2 : two zones

All angles in [rad]

Zonal evaluation

activated by

-l xpos ypos angle : single zone

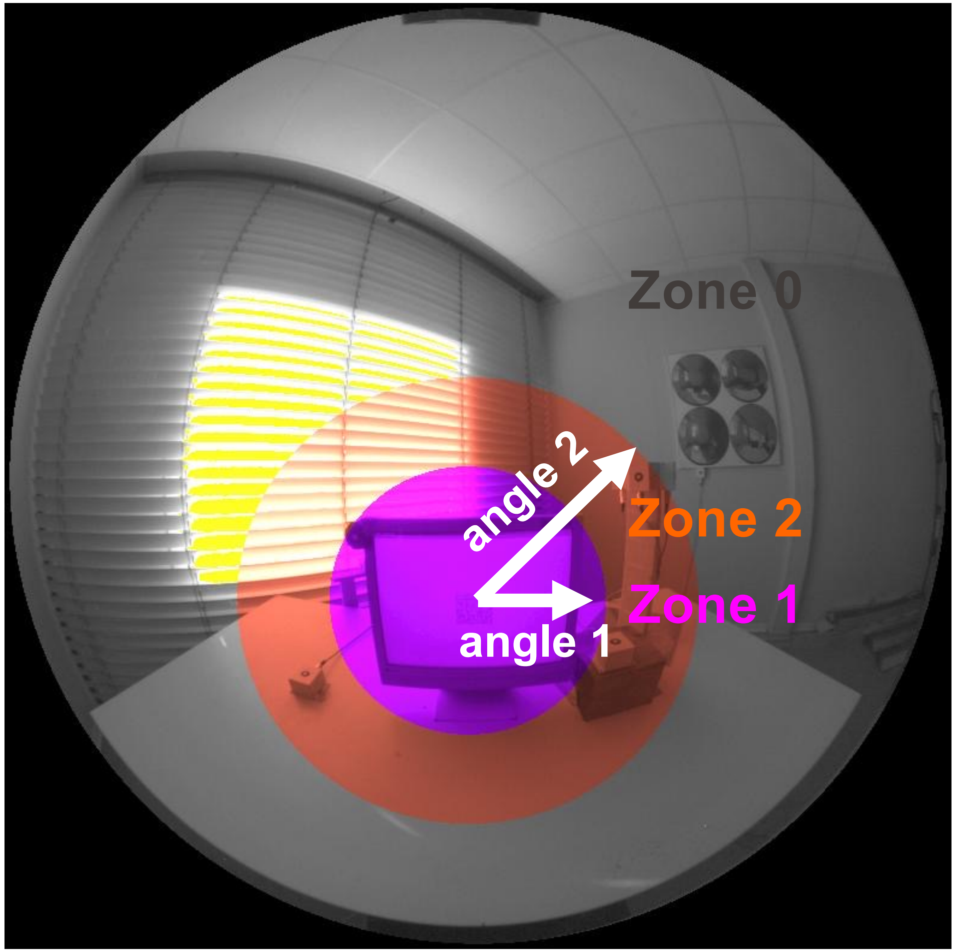
-L xpos ypos angle1 angle2 : two zones

Angles in [rad]

Output in separate lines (first lines).
Within the zones z1,z2 are calculated:

z1(2)_omega: solid angle of zone [sr]
z1(2)_av_lum: average luminance of zone [cd/m²]
z1(2)_median_lum: median luminance of zone [cd/m²]
z1(2)_std_lum: standard deviation of luminance of zone,
z1(2)_perc75: 75 percentile luminance of zone [cd/m²]
z1(2)_perc95: 95 percentile luminance of zone [cd/m²]
z1(2)_min_lum: minimum luminance of zone [cd/m²]
z1(2)_max_lum: maximum luminance of zone [cd/m²]

Let´s do an example evaluation ….



Example zonal evaluation

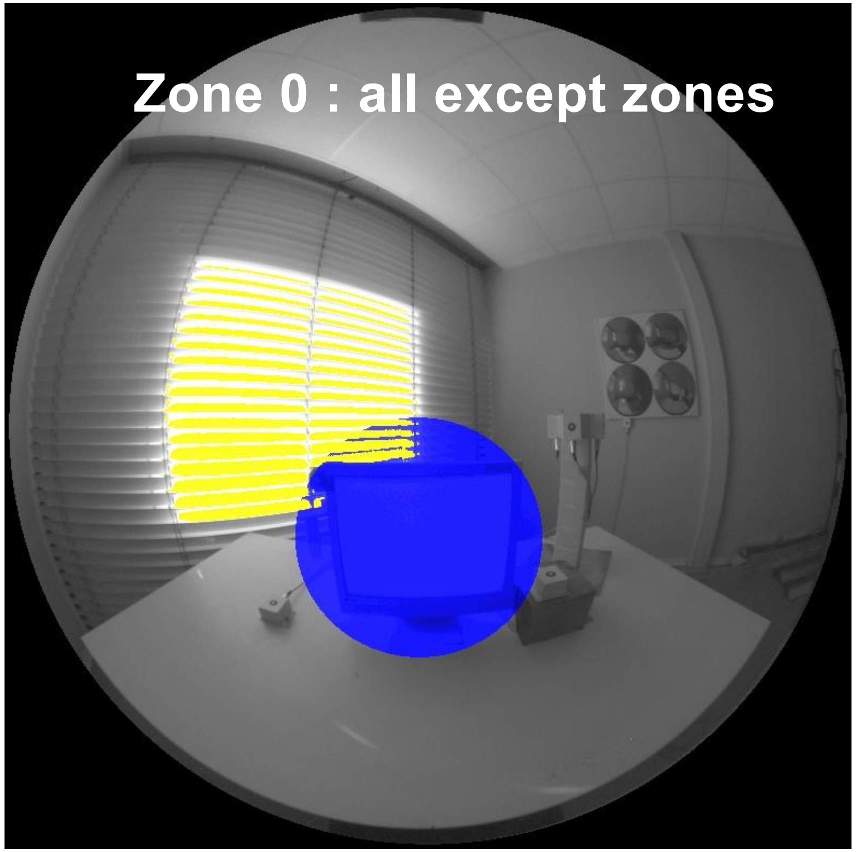
No zonal evaluation

evalglare –T 384 289 0.9 -d –c output.hdr input.hdr

Delivers one glare source:

1 No pixels x-pos y-pos L_s Omega_s Posindx L_b L_t E_vert Edir Max_Lum Sigma xdir ydir zdir Eglare_cie Lveil_cie teta glare_zone

1 22804.000000 253.726604 380.657331 1594.290752 0.3456751723 1.645702 155.048325 215.517090 983.203954 437.027954 10225.375000 32.430944 0.534143 0.047862 0.844038 437.027954 4.155182 32.430944 0



Example zonal evaluation

One zone evaluation

evalglare –t 384 289 0.9 –l 384 289 0.9 -d
–c output.hdr input.hdr

Delivers data for the zone:

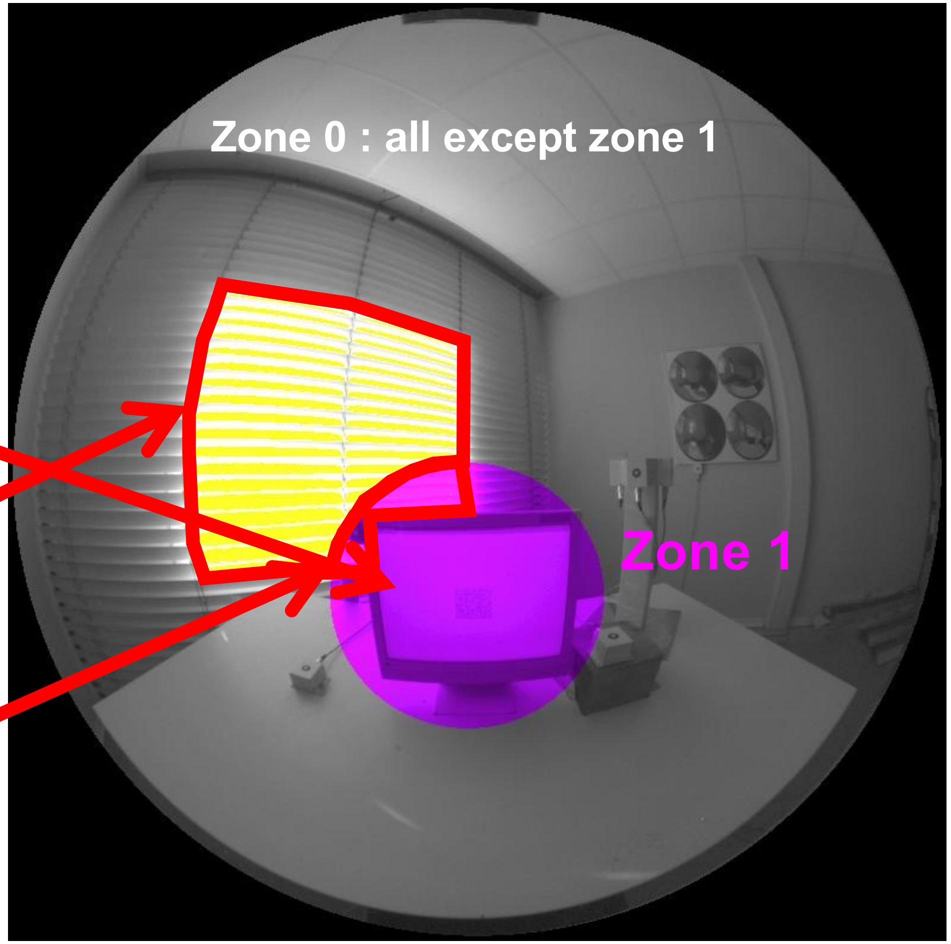
zoning z1_omega,z1_av_lum,z1_median_lum,z1_std_lum,z1_perc_75 z1_perc_95,z1_lum_min,z1_lum_max: 0.625647 215.517084 133.201172 351.694818 173.755859 1082.390623 13.678467 2533.968711

And delivers two glare sources:

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 Eglare_cie Lveil_cie teta glare_zone

1 20791.000000 244.894048 376.972908 1596.012599 0.3131968995 1.759448 155.048325 215.517090 983.203954 437.027954 10225.375000 34.597101 0.064329 0.062703 0.823165 437.027954 3.651151 34.597101 0

2 2013.000000 338.901363 416.186370 1577.686503 0.0324782728 1.194143 155.048325 215.517090 983.203954 437.027954 10225.375000 13.742772 0.218148 -0.094064 0.971372 0.000000 0.000000 13.742772 1



Example zonal evaluation

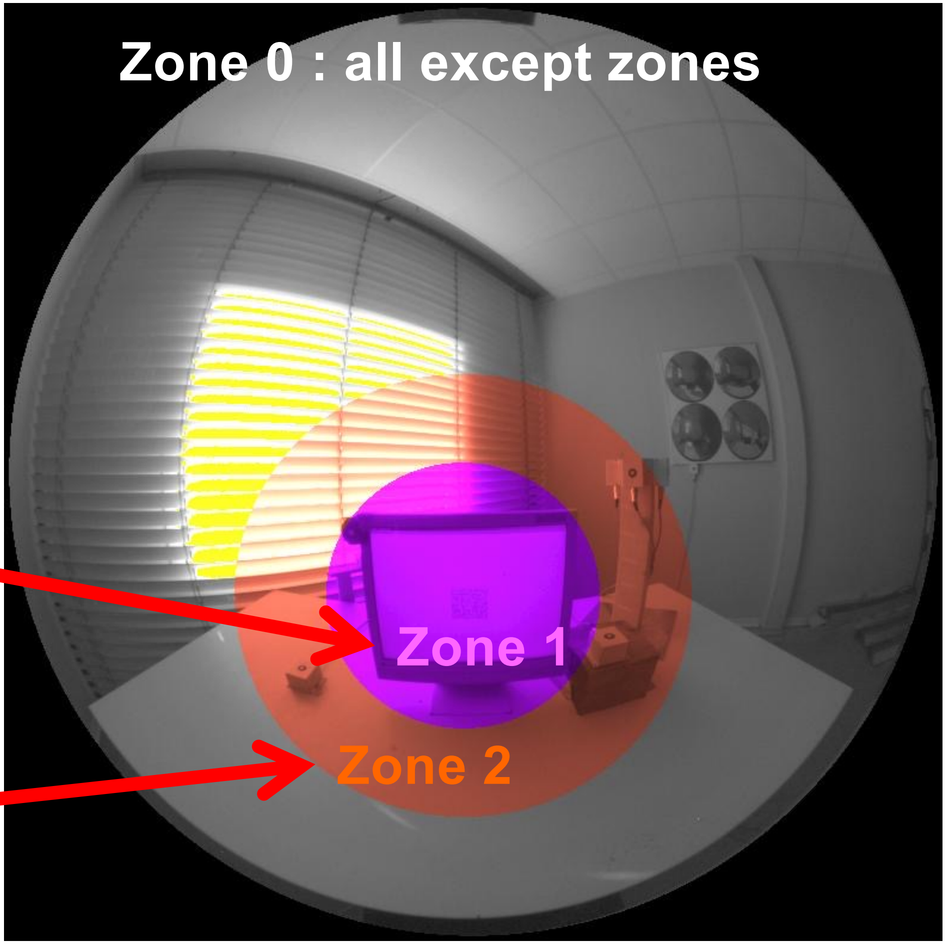
Two zones evaluation

evalglare –t 384 289 0.9 –L 384 289 0.9 1.5 -d –c output.hdr input.hdr

Delivers data for the zones:

zoning:z1_omega,z1_av_lum,z1_median_lum,z1_std_lum,z1_perc_75, z1_perc_95,z1_lum_min,z1_lum_max: 0.625647 215.517084 133.201172 351.694818 173.755859 1082.390623 13.678467 2533.968711

zoning:z2_omega,z2_av_lum,z2_median_lum,z2_std_lum,z2_perc_75,z2_perc_95,z2_lum_min,z2_lum_max: 1.060242 397.341643 109.427734 559.723433 304.160156 1717.281290 13.591064 4933.687511



Example zonal evaluation

Two zones evaluation

evalglare –t 384 289 0.9 –L384 289 0.9 1.5 -d
–c output.hdr input.hdr

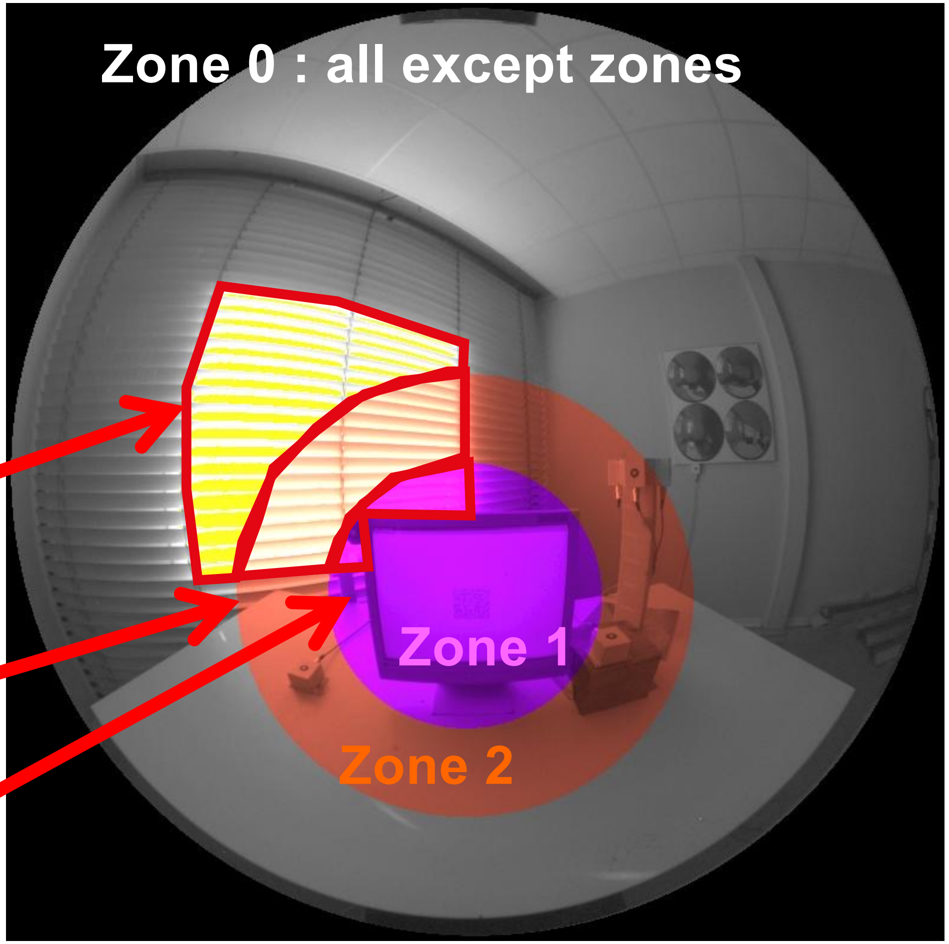
Delivers three glare souces*:*

3 No pixels x-pos y-pos L_s Omega_s Posindx L_b L_t E_vert Edir Max_Lum Sigma xdir ydir zdir Eglare_cie Lveil_cie teta glare_zone

1 11444.000000 217.984349 352.904716 1556.418219 0.1678747451 2.364898 155.048325 215.517090 983.203954 437.027954 10225.375000 41.705430 0.648264 0.149599 0.746575 437.027954 2.512604 41.705430 0

2 9347.000000 275.979872 404.776444 1641.751643 0.1453221544 1.412642 155.048325 215.517090 983.203954 437.027954 10225.375000 27.337378 0.457045 -0.044732 0.888318 0.000000 0.000000 27.337378 2

3 2013.000000 338.901363 416.186370 1577.686503 0.0324782728 1.194143 155.048325 215.517090 983.203954 437.027954 10225.375000 13.742772 0.218148 -0.094064 0.971372 0.000000 0.000000 13.742772 1



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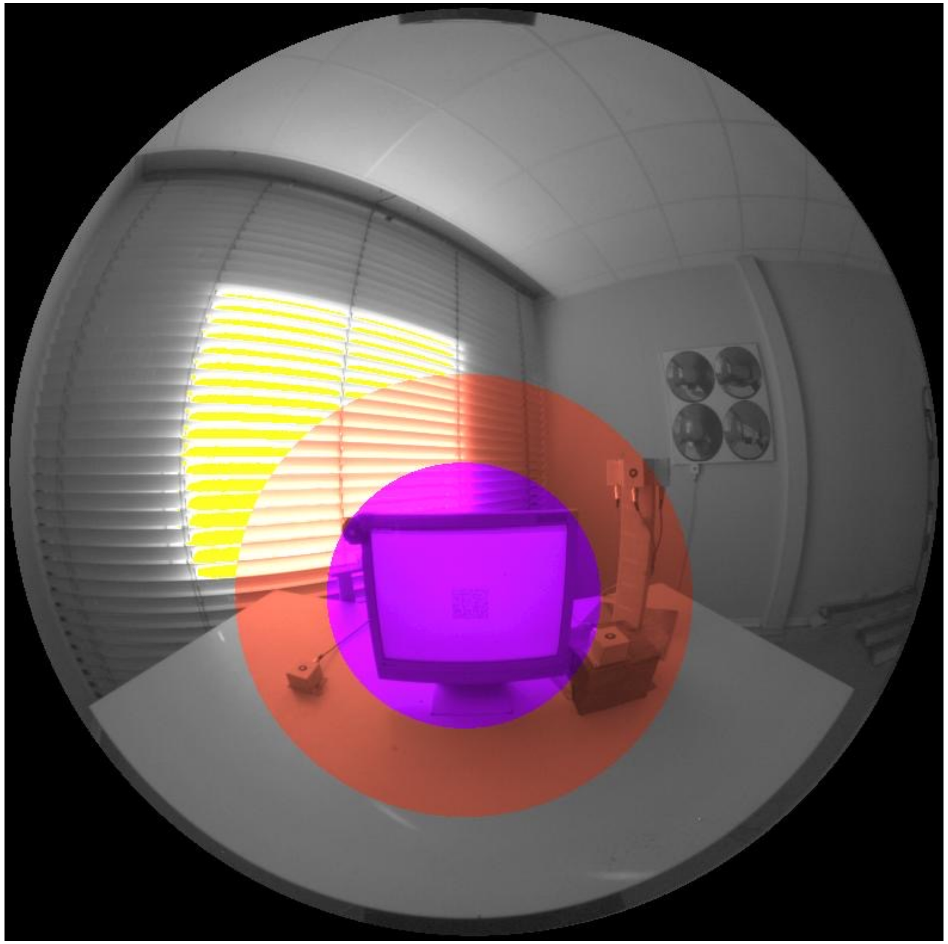
Does the zonal evaluation influence other metrics???

Yes! -> glare sources are split up!

For our example:

	DGP	DGI
0 zones	0.240684	17.445793
1 zone	0.240124	18.075613
2 zones	0.240755	18.872232

-> influence is usually small



Masking evaluation

e.g. for evaluation of an window area

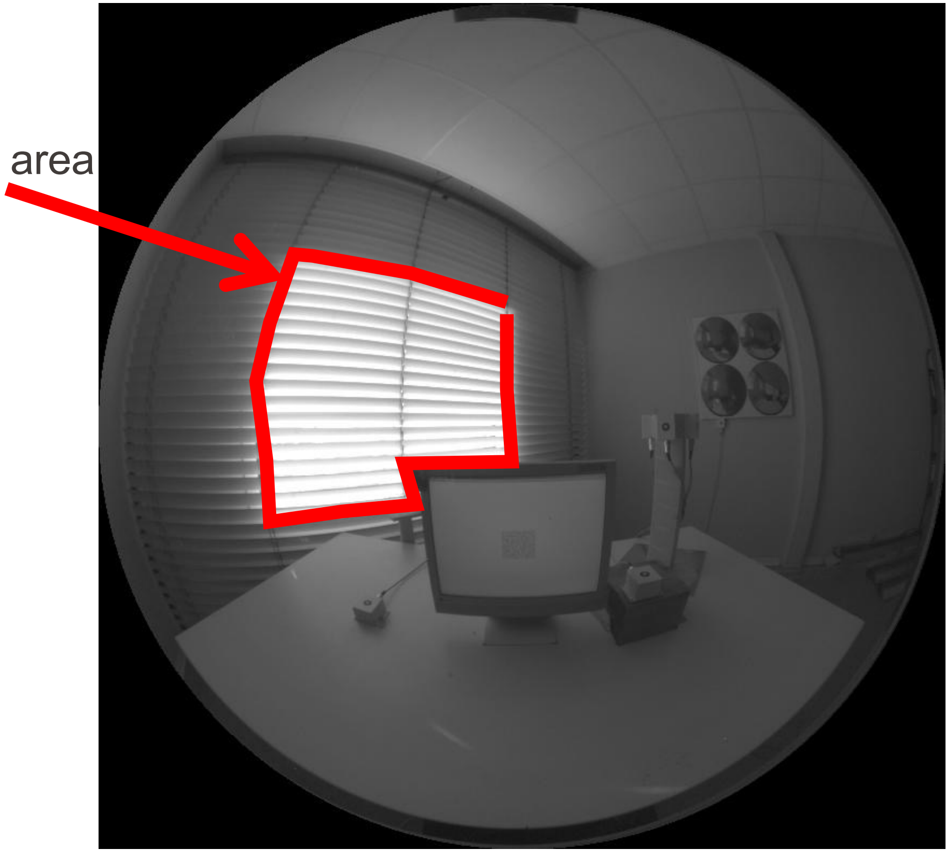
Predicted Glare Sesation Vote PGSV (Iwata)

Evalglare loads and uses a masking image to cut an area

Important: masking image must have the same size!

Not together with zoning!

activated by *-A mask.hdr*



Output in separate line (first line).
Following values within the mask area are calculated:

no_pixels: no of pixels in masking area
omega: solid angle of zone [sr]
av_lum: average luminance of zone [cd/m²]
median_lum: median luminance of zone [cd/m²]
std_lum: standard deviation of luminance of zone,
perc75: 75 percentile luminance of zone [cd/m²]
perc95: 95 percentile luminance of zone [cd/m²]
min_lum: minimum luminance of zone [cd/m²]
PGSV: Predicted Glare Sesation Vote
PGSV_SAT: Saturation Predicted Glare Sesation Vote

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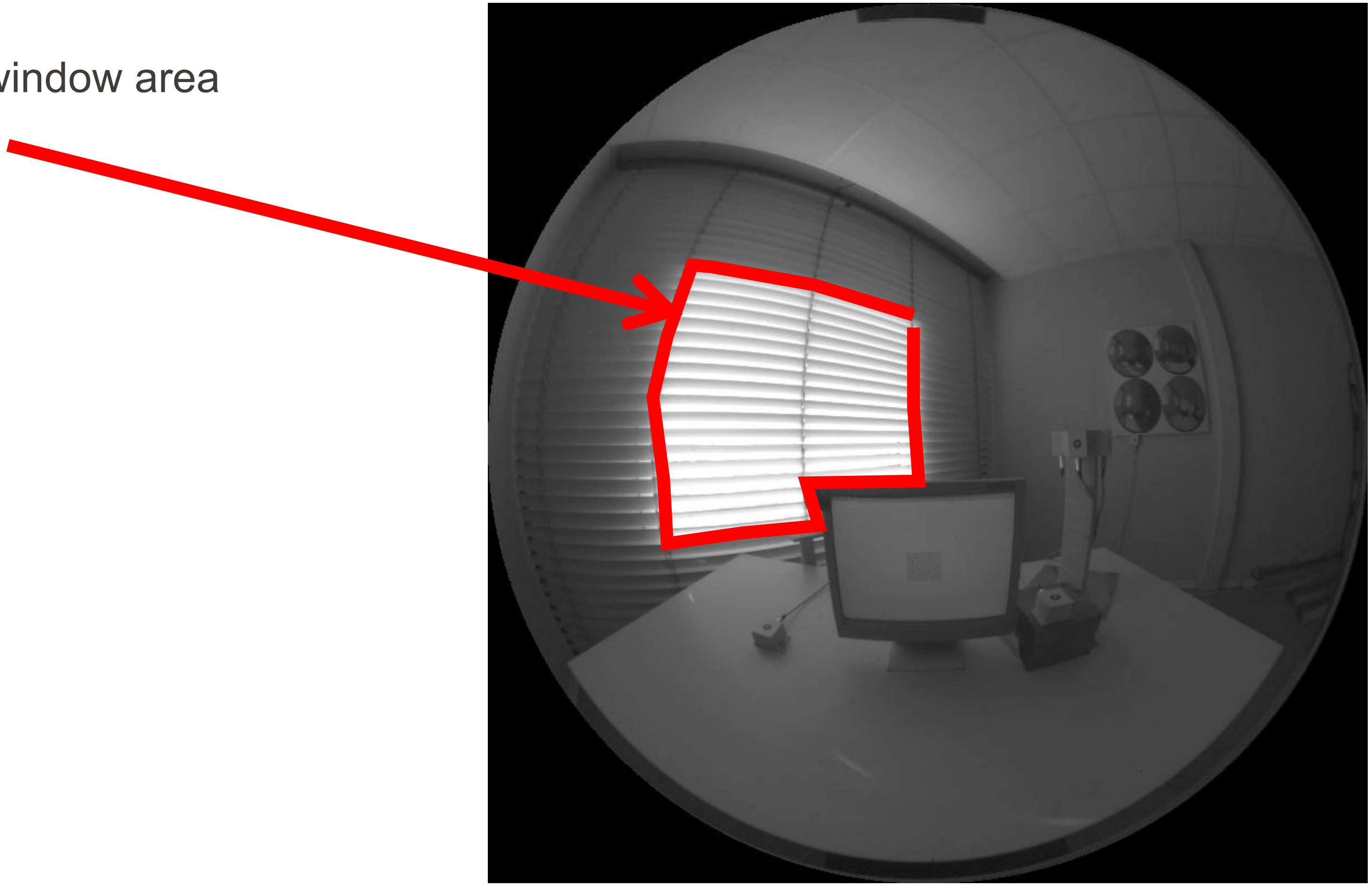
Masking evaluation - example

Steps to evaluate a window area



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Masking evaluation - example

Step 1:

Use Photoshop or similar to create mask

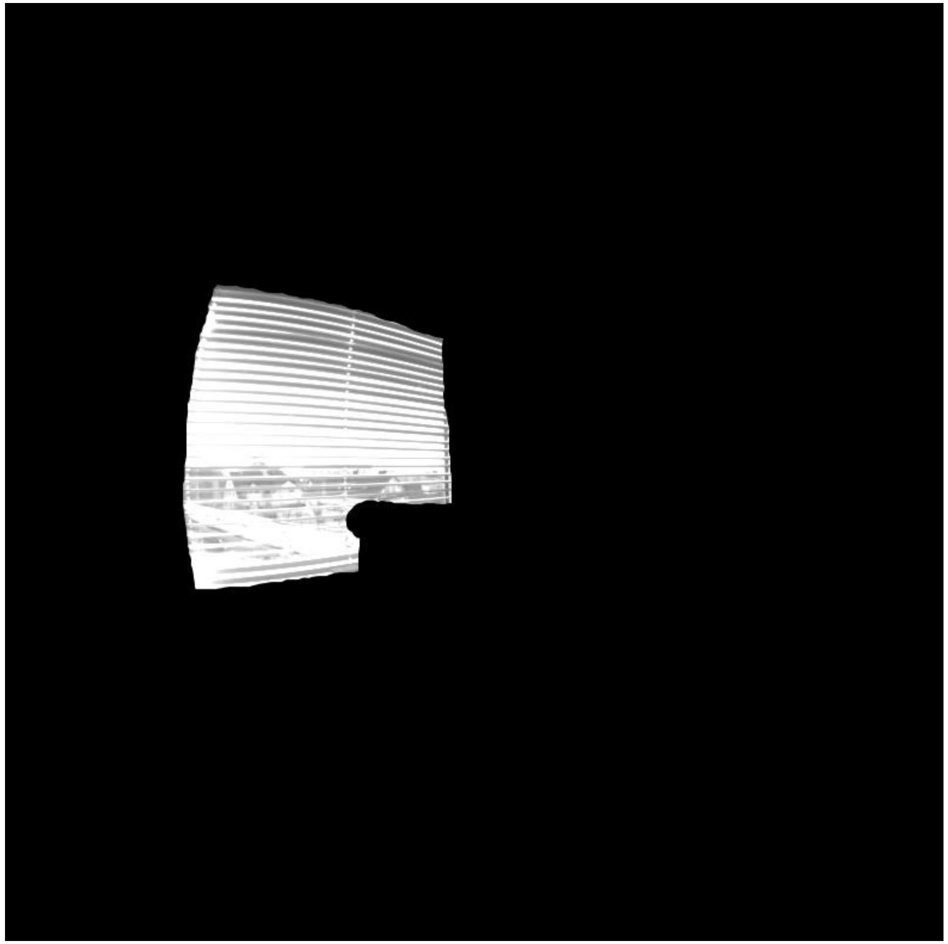
Use ra_ppm to create a ppm file

Everything not of interest should be black

It MUST be really black (RGB 0 0 0) !

Convert it back to hdr format by

ra_ppm –r mask.ppm > mask.hdr



Masking evaluation - example

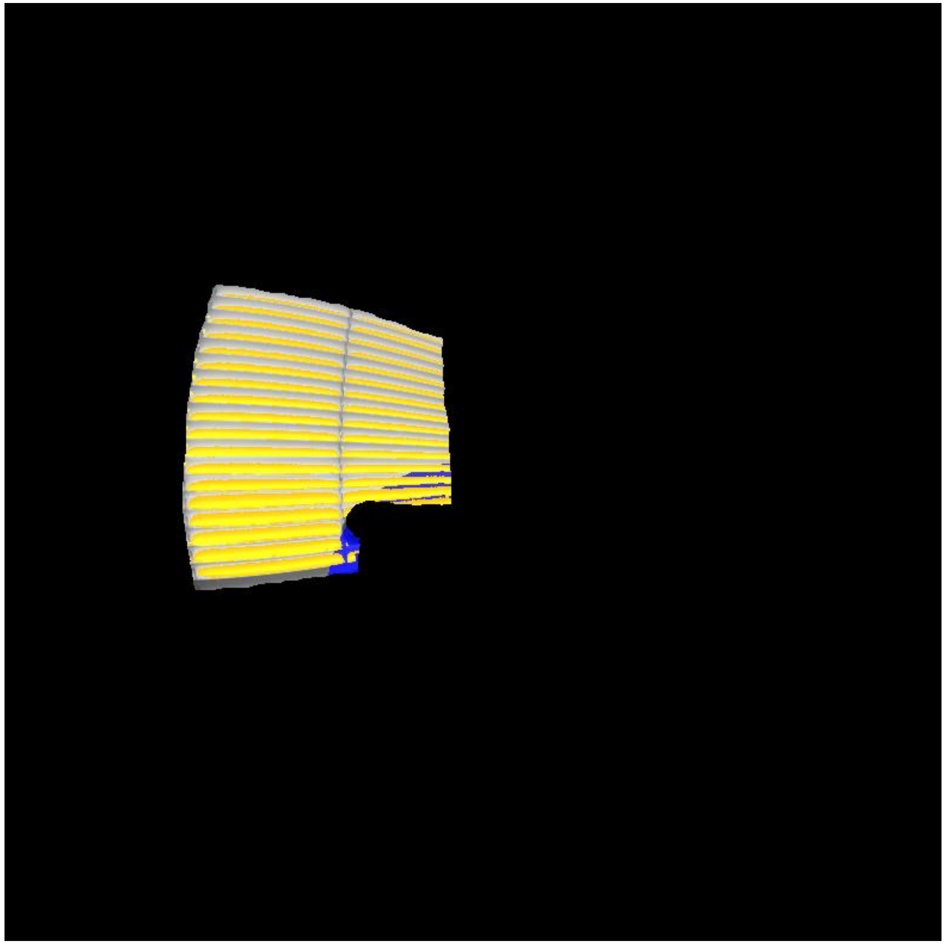
Step 2:

Run evalglare with *–A mask.hdr*

evalglare –t 384 289 0.9 –A mask.hdr -d –c output.hdr input.hdr

Output:

masking:no_pixels,omega,av_lum,median_lum,std_lum,perc_75,perc_95,lum_min,lum_max,pgsv,pgsv_sat: 44732 0.675010 1178.508190 1065.609375 543.535164 1459.968748 2164.781246 33.300294 7316.625082 0.053004 1.475234



Content

- What is glare?
- User assessments to evaluate glare metrics
- Evaluation of existing glare metrics – cross-validation study
- Current research on glare
- Introduction to evalglare
- What is a glare source, how to detect them reliably
- Important boundaries for glare evaluations
- Annual glare evaluations – short overview

Important boundary conditions for a meaningful glare evaluation

The image should correctly represent the scene….

1) HDR-imaging

- Detailed calibration of camera necessary
- Correct header describing the lens characteristics
- Correct exposure value in the header
- No pixel overflow

- Effort is higher that people usually expect!

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Important boundary conditions for a meaningful glare evaluation

2) Simulations

- Material Models of surfaces that can cause glare should be accurate, especially for the specular reflection/transmittance
  - Models should be supported by measurements, ideally by BTDF or BRDF measurements
  - BSDF models using BSDF or aBSDF material need to have a high resolution that is smaller than the glare source size (typically sun)
  - Image should be large enough to have correctly represent a glare source (minimum recommendation is around 10pixels for the glare source -> around 1000-1200 pixels for a fish-eye

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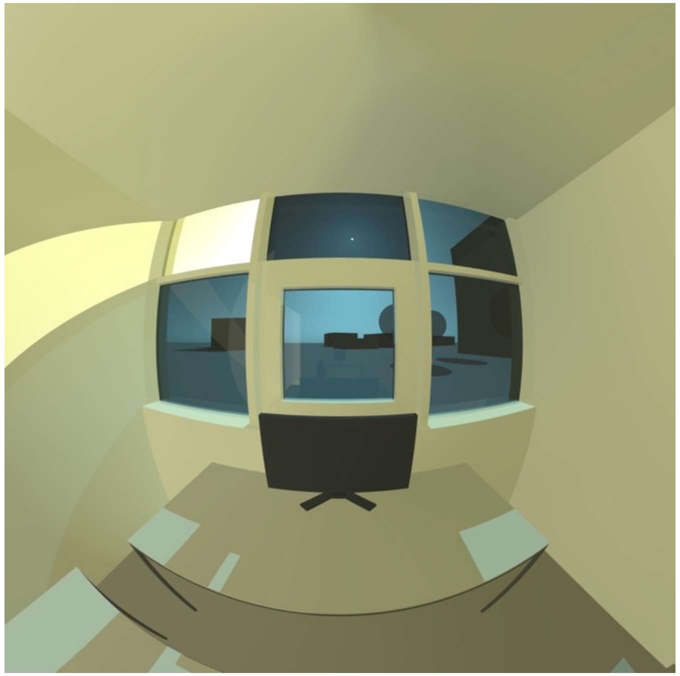
Important boundary conditions for a meaningful glare evaluation

2) Simulations

- Limit weight should be set very small not to miss the sun seen through a material (e.g. BSDFfunc, trans…), typically 1e-7 is on the safe side, but increases rendering time
- Pixel sampling (-ps) and pixel jitter (-pj) should be deactivated (=0)
- Eye blur should be considered

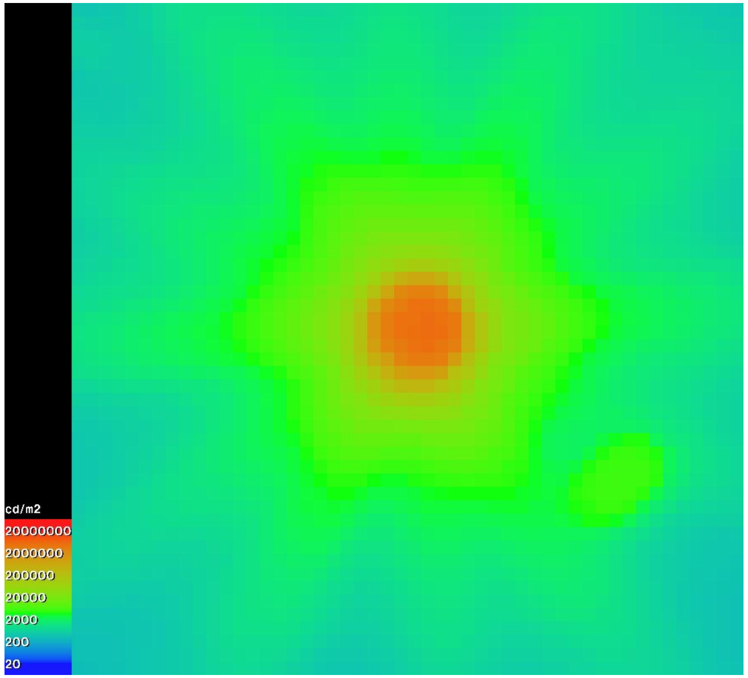
Simulation vs HDR-image : Sun disk

Measured HDR

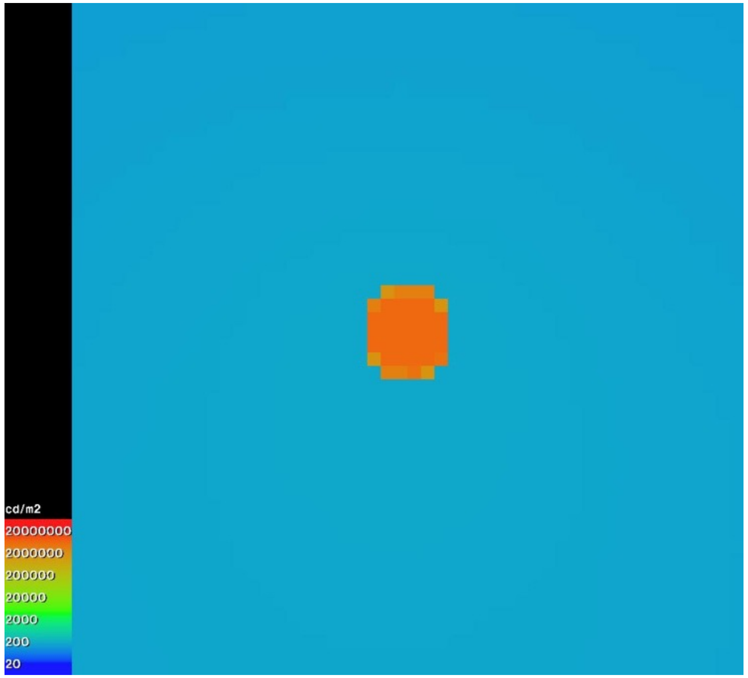


Simulated

Simulation vs HDR-image : Sun disk



Measured HDR



Simulated

Measured HDR “spreads” the energy of the sun disk to a larger area while keeping energy

Sun disk size – why does this matter?

- All glare metrics use the term $L^2 \cdot \omega$ in their equation
- Spreading (or blurring) means reducing L and increasing ω (energy conservation law: $L \cdot \omega$ = const)

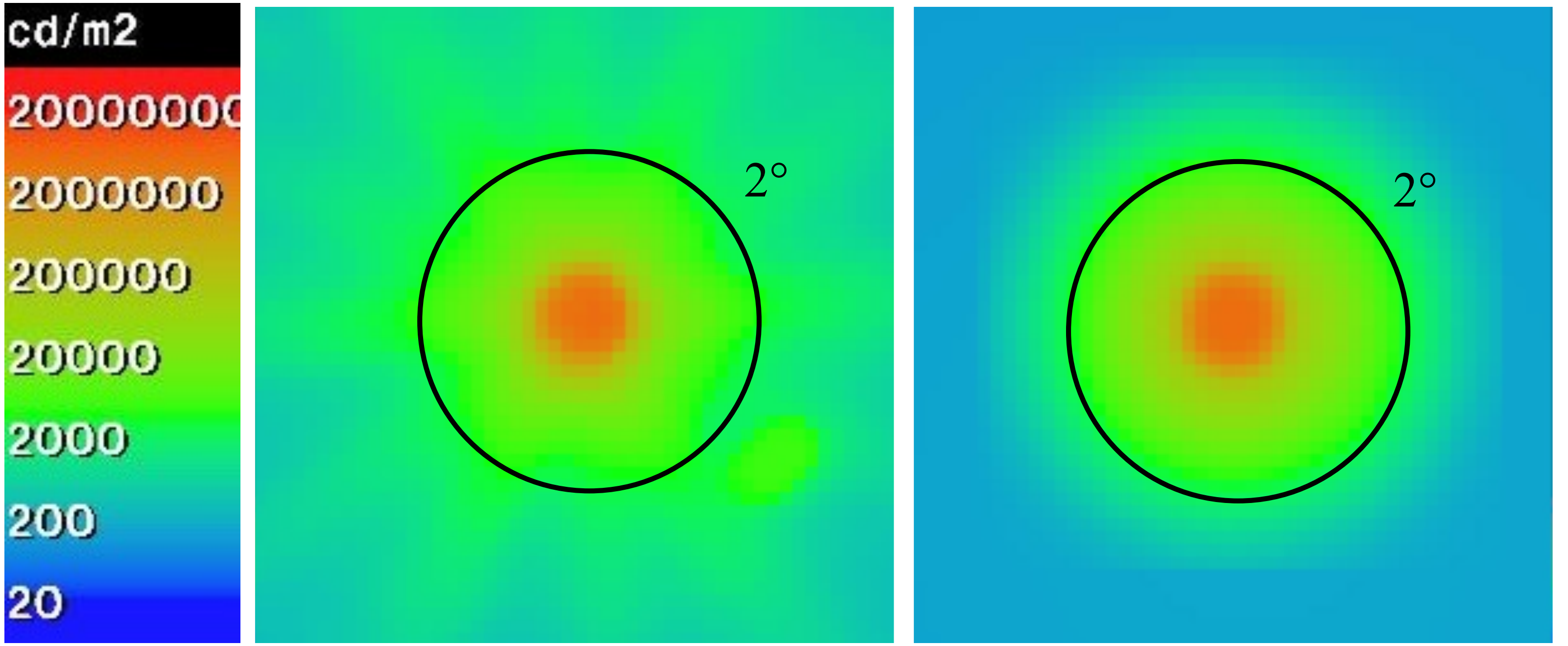
➠ Simulation results in significant higher glare values than measurements

But:

- Metrics are based on HDR images (and not on “ideal” simulation)
- Blur also happens in the eye and is quite similar to lens blur

➠ one solution is to blur the simulated HDR

Simulation vs HDR-image : Sun disk



Measured HDR

Simulated and blurred

Outcome:
Images should be blurred

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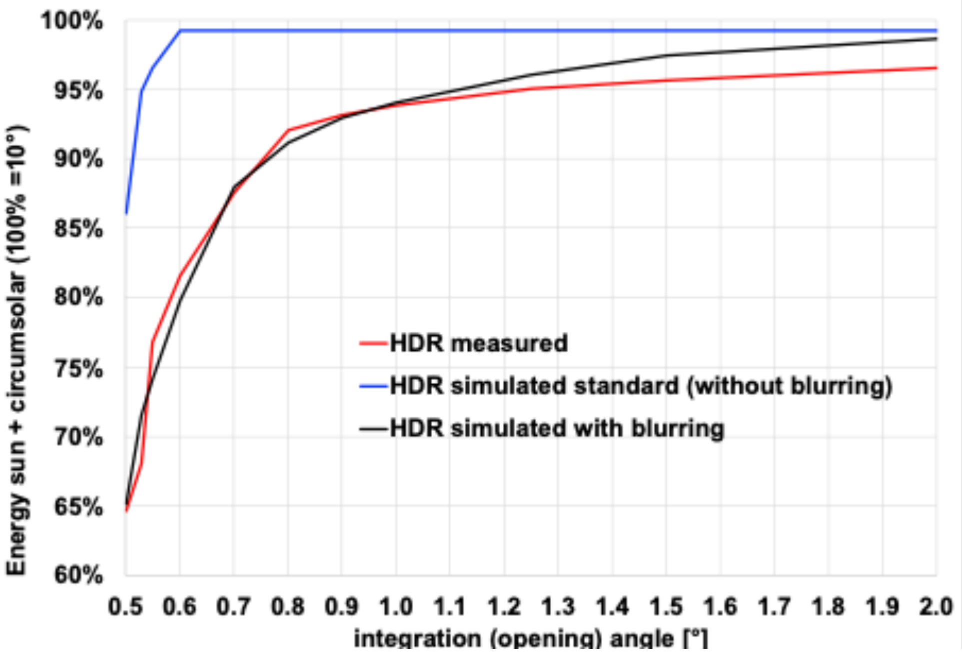
Simulation blur function

- Based on the function proposed by

  Ward, G.J., Wang, T., et al; Modeling specular transmission of complex fenestration systems with data-driven BSDFs, (2021) Building and Environment, 196, DOI: 10.1016/j.buildenv.2021.107774

- Lorentzian function is simulated by Gaussian function with FWHM=11



Energy of sun disk and circumsolar area for different integration angles

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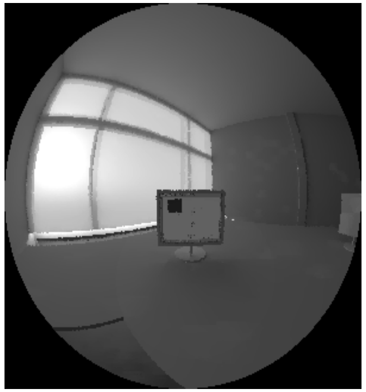
Content

What possibilities do we have to evaluate glare dynamically?

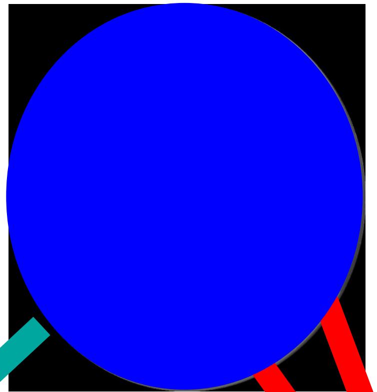
Hour by hour calculation:

Radiance reference method



Time consuming!

evalglare



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

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

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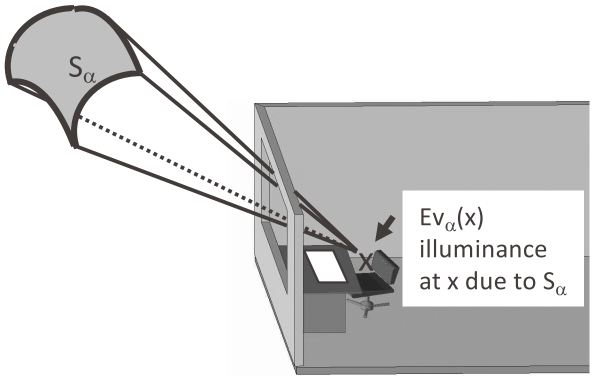
What possibilities do we have to evaluate glare dynamically?

Simplified method DGPs:

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



2-phase

Hourly E_v

But no pictures!

Ignore peak glare sources!

No option in many cases

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

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

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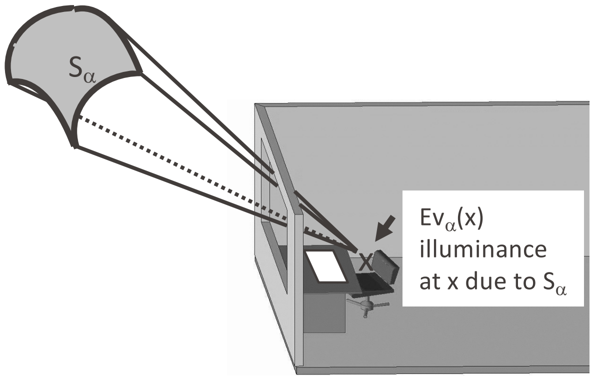
What possibilities do we have to evaluate glare dynamically?

Enhanced simplified method eDGPs: (gen_dgp_profile)

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

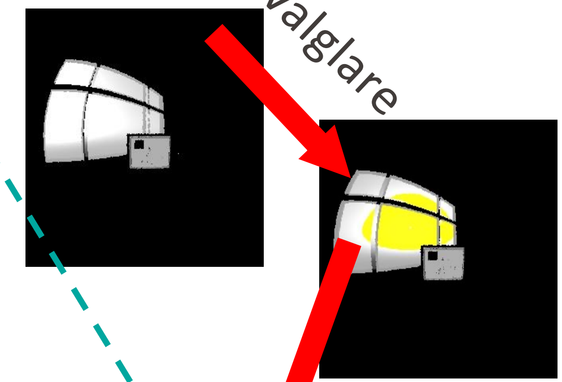


2-phase

Hourly E_v

Calculation of a simplified picture

evalglare



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

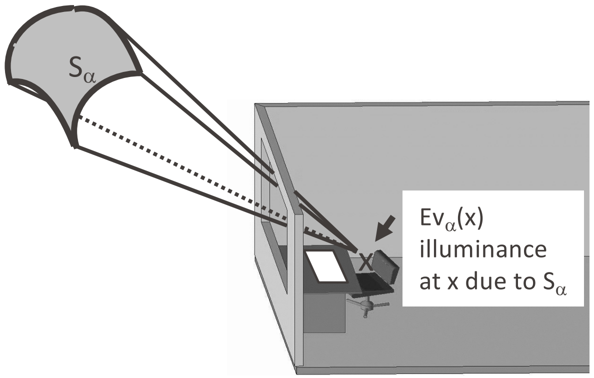
Disadvantage:

Time consuming since many images are rendered

What possibilities do we have to evaluate glare dynamically?

Adaptive glare coefccient method AGC:
(unpublished)

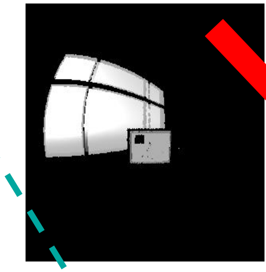
Calculating the vertical eye illuminance by the use of daylight coefficient method



2-phase

Hourly E_v

Smart rendering:
Calculation of a partly simplified picture
Only when differ from already calculated

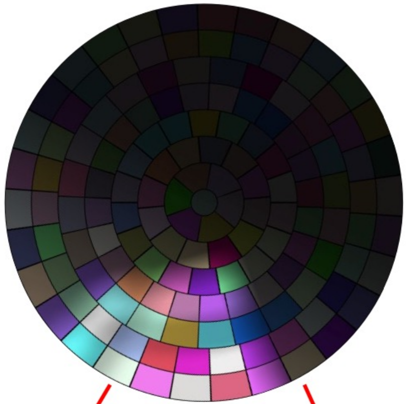


evalglare

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

What possibilities do we have to evaluate glare dynamically?

imageless DGP (dcglare)

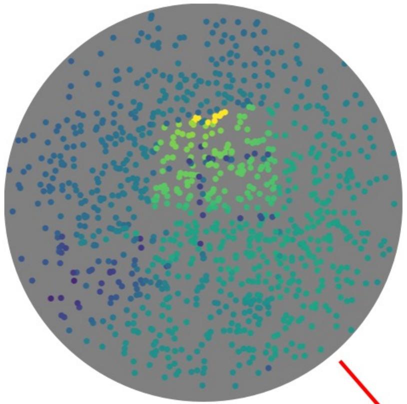


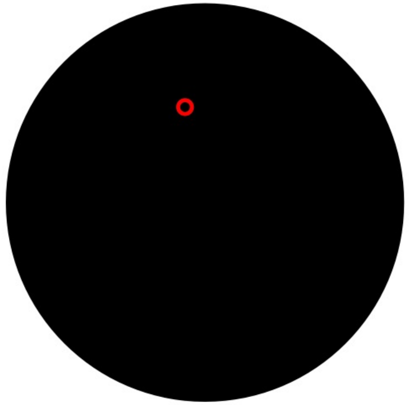
assumed

$$\text{DGP} = C_1 E_v + C_2 \log_{10}\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_{s,i}^2}\right) + C_3$$

Jones, N. L. (2019). "Fast Climate-Based Glare Analysis and Spatial Mapping". In: Proceedings of Building Simulation 2019: 16th Conference of IBPSA. Rome, Italy. doi: 10.26868/25222708.2019.210267.

ClimateStudio Annual Glare





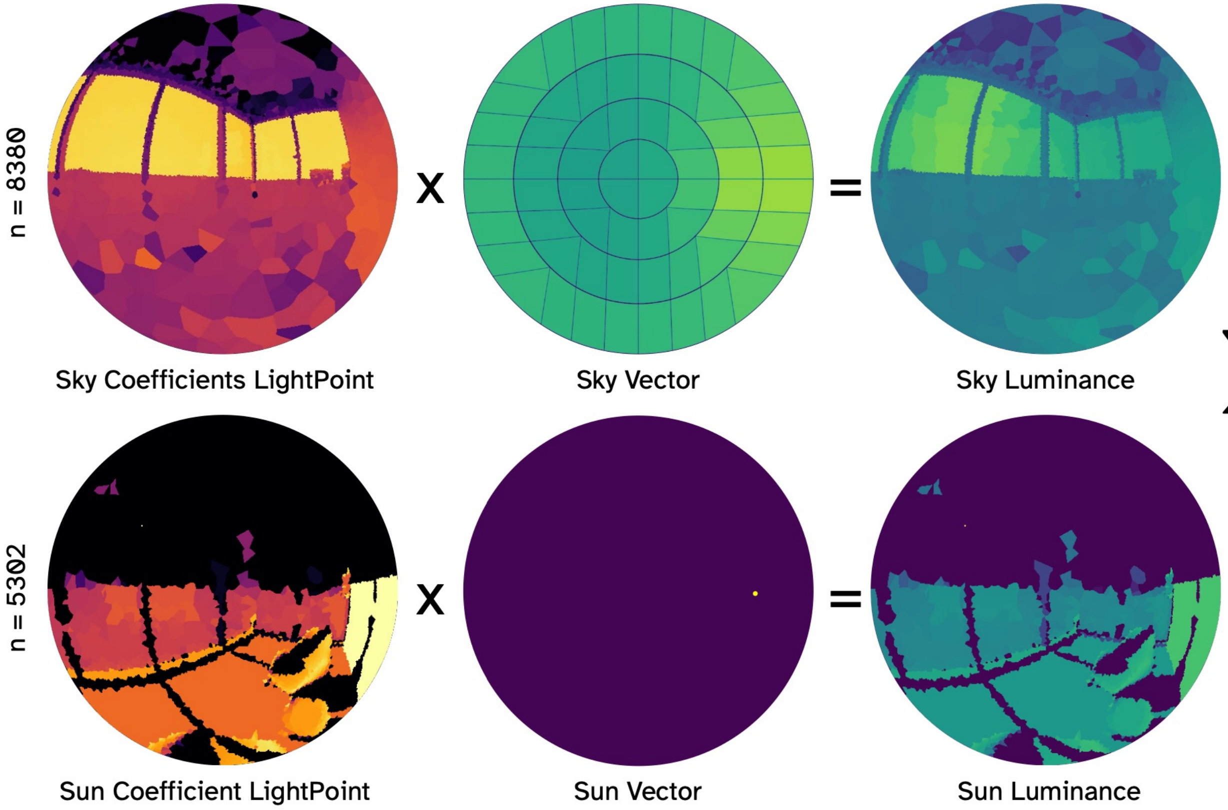
assumed

$$\text{DGP} = C_1 E_v + C_2 \log_{10}\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_{s,i}^2}\right) + C_3$$

https://climatestudiodocs.com/docs/annualGlare.html

What possibilities do we have to evaluate glare dynamically?

Raytraverse



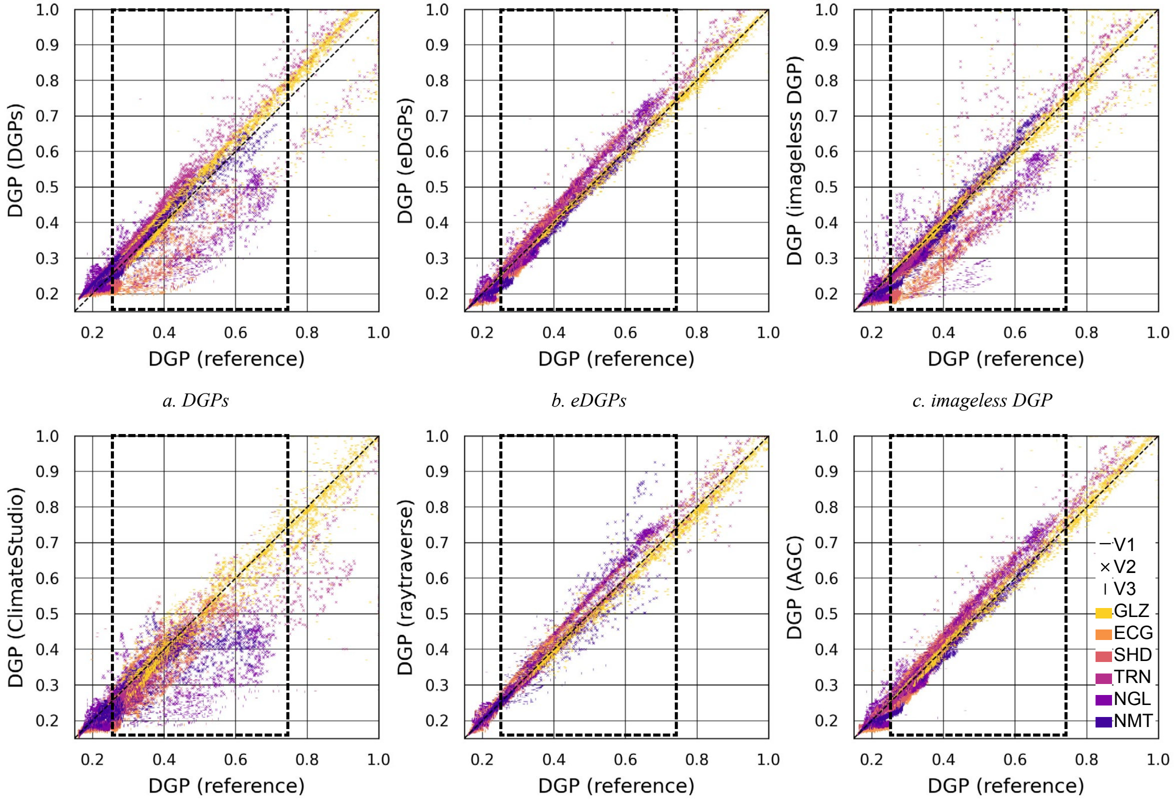
$$\sum^{n} \text{DGP, UGR, } E_v \text{, etc.}$$

What possibilities do we have to evaluate glare dynamically?

5-Phase method rendering images -> evalglare

Considering requirements regarding resolution and BSDF resolution, this method seems not to be time efficient (slower than eDGPs).
Huge memory effort for matrices multiplications.

Accuracy comparison of different methods for different façade materials



a. DGPs *b. eDGPs* *c. imageless DGP*

d. ClimateStudio *e. raytraverse* *f. AGC*

Stephen Wasilewski, Jan Wienold and Marilyne Andersen
A Critical Comparison of Annual Glare Simulation Methods
IBPSA Nordic 2022, Copenhagen; DOI: https://doi.org/10.1051/e3sconf/202236201002

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

⇒ A 5% exceedance is allowed

⇒ Daylight standard EN17037 adopted that method

Annual glare evaluation according to EN17037

A.5 Recommendation for glare protection

The Daylight Glare Probability (*DGP*) should not exceed a maximum value for more than the fraction $F_{DGP,exceed}$ =5 % of the usage time of the space.

Table A.7 — Proposed different levels of threshold $DGP_{e<5\%}$ for glare protection

Level of recommendation for glare protection	$DGP_{e<5\%}$
Minimum	0,45
Medium	0,40
High	0,35

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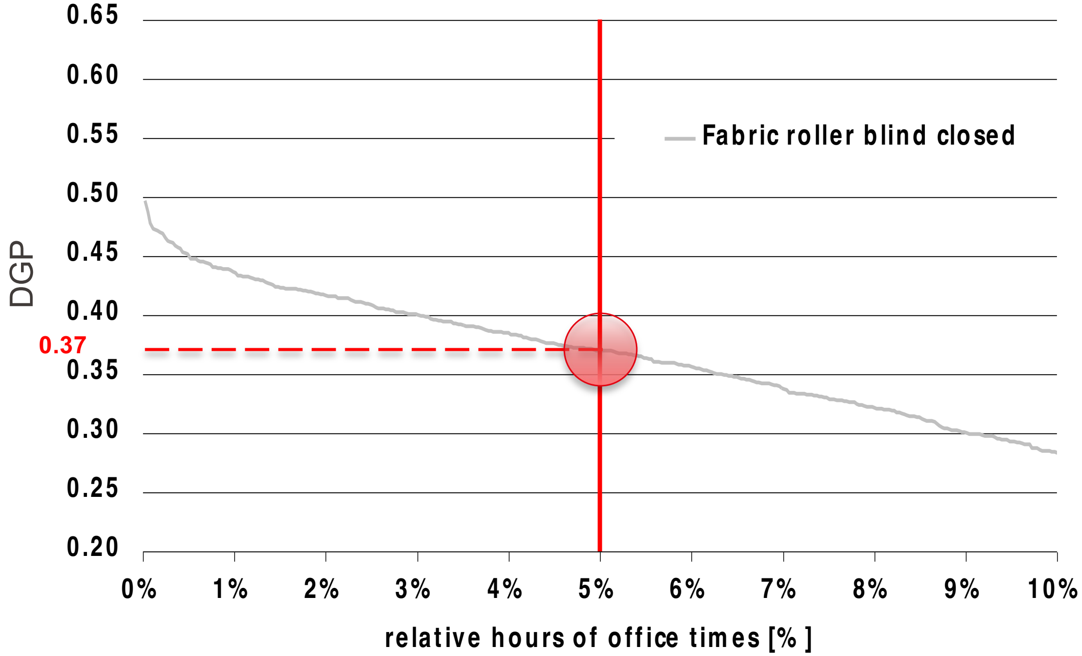
Annual glare evaluation (e.g. for EN17037)

“Histogram-evaluation” :
Not the worst hour counts, 5% temporal exceedance is allowed

95 percentile value



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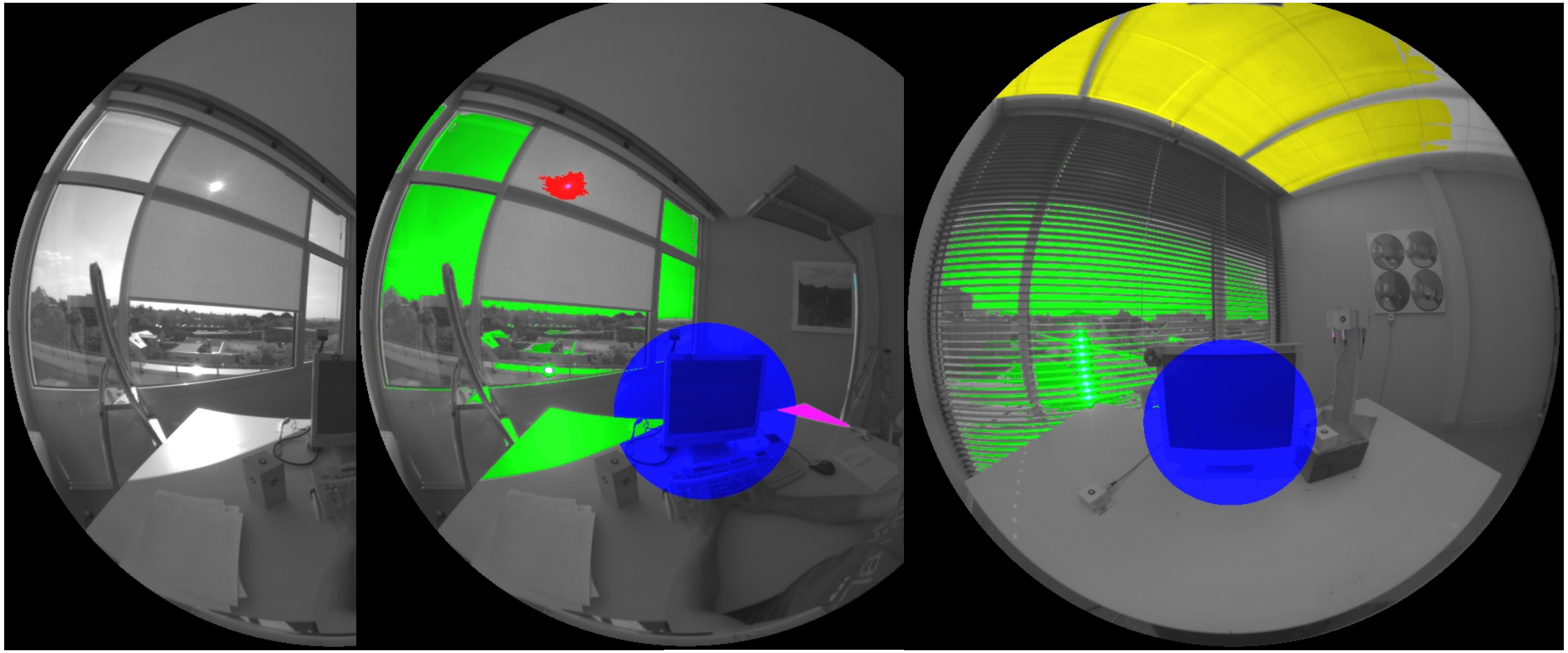
Important take-aways

Glare evaluations and calculated metrics strongly depend on reliable input and selected parameters!

-> make sure that detection parameters fit to the scene
-> appropriate material modelling necessary
-> appropriate image resolution
-> appropriate calculation method should be selected



Thank you for your attention!!