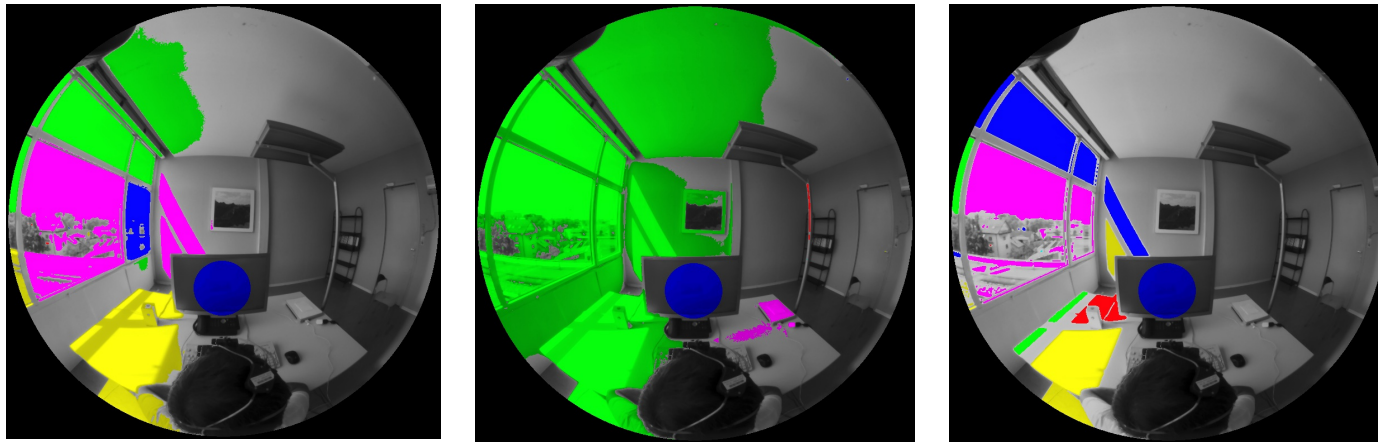


A Sensitivity Analysis On Glare Detection Parameters



Mandana Sarey Khanie¹, Yiyuan Jia^{1,2}, Jan Wienold¹, Marilyn Andersen¹

¹Interdisciplinary Laboratory of Performance-Integrated Design [LIPID]
School of Architecture, Civil and Environmental Engineering, EPFL, Switzerland

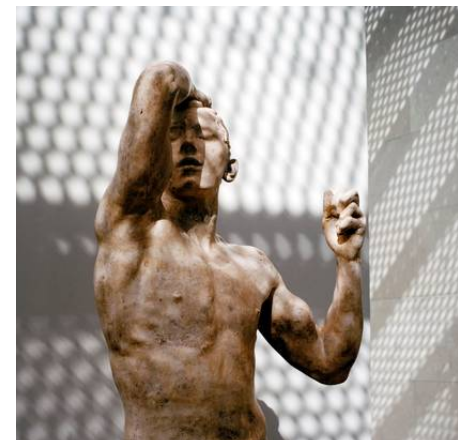
²High Performance Building Lab
College of Architecture, Georgia Institute of Technology, USA

September 5, 2014

GLARE

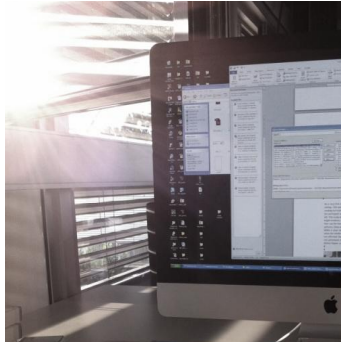
Glare is defined as: “the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility”

*"Lighting Handbook of the Illuminating
Engineering Society of North America"*
(IESNA, 2000)
(p. G -15)

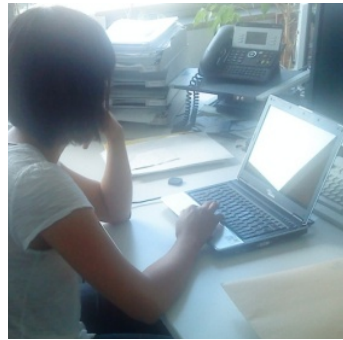


DIFFERENT TYPES OF GLARE

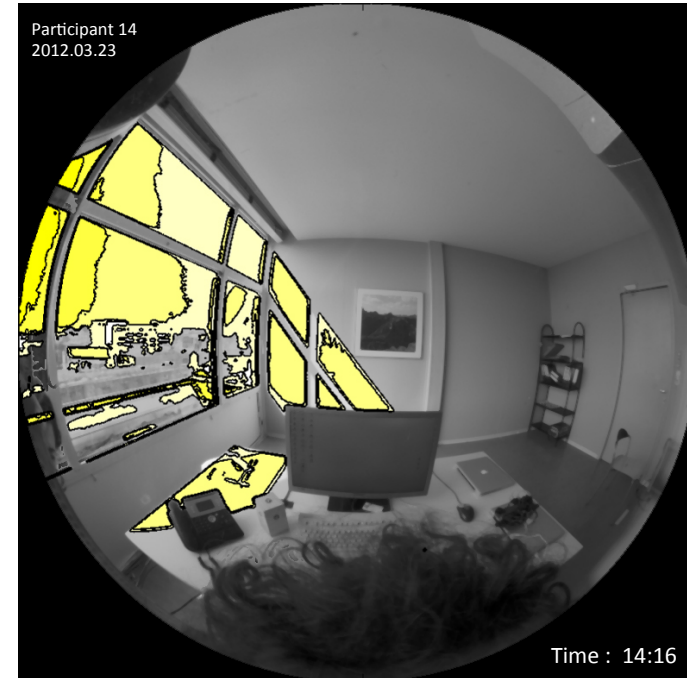
DISABILITY GLARE



VEILING GLARE



DISCOMFORT GLARE



GLARE ANALYSIS: DOES IT MATTERS?

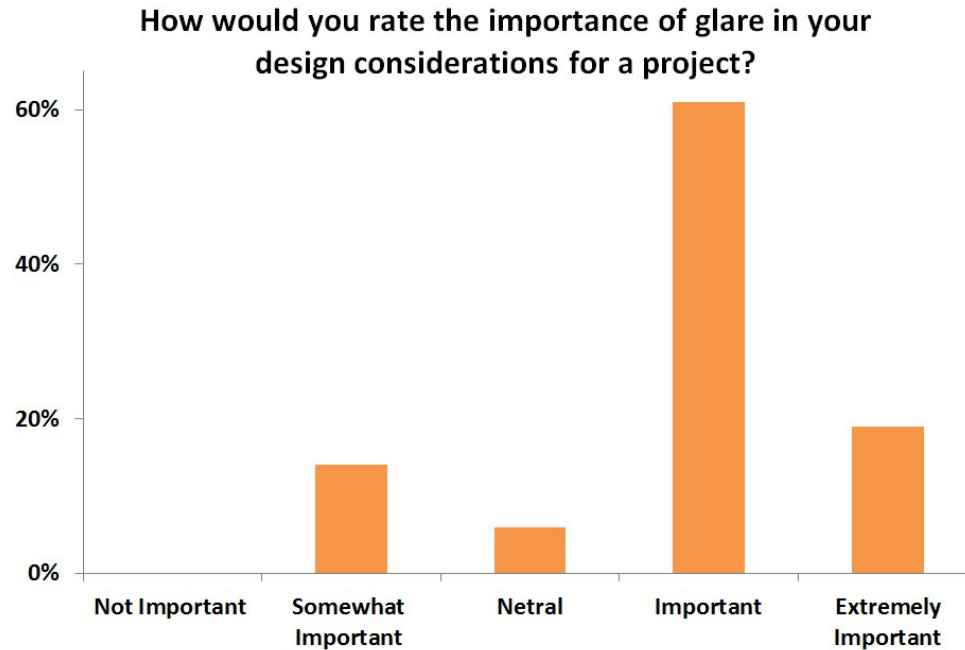


Fig 1: Survey of 135 architects, lighting designers and consultants (Mogri 2011).

In a 2011 survey of 135 architects, lighting designers and consultants over 80% of participants voted glare to be either an important or extremely important design consideration.

DISCOMFORT GLARE

$$G \approx \frac{L_s^{exp1} \times \omega_s^{exp2}}{L_a^{exp3} \times P^{exp4}}$$

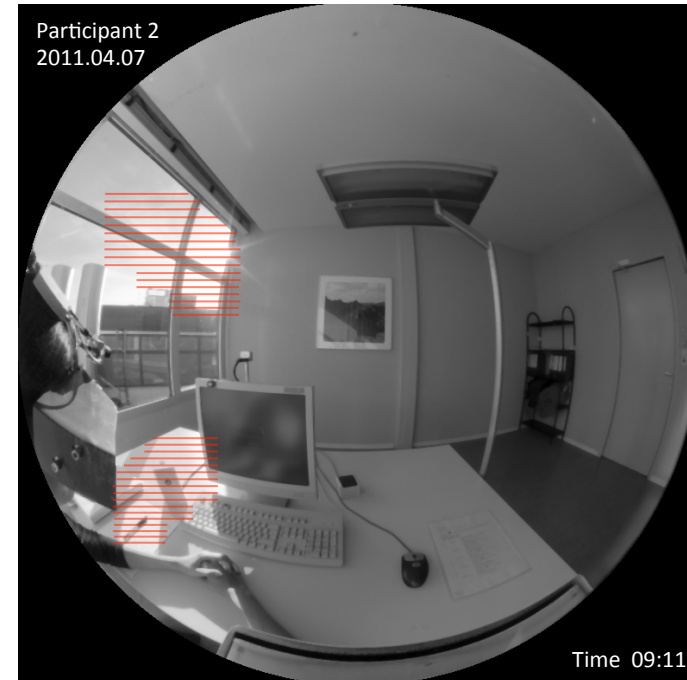


A wide angle High Dynamic Range Image

DISCOMFORT GLARE

$$G \approx \frac{L_s^{exp1} \times \omega_s^{exp2}}{L_a^{exp3} \times P^{exp4}}$$

A **brighter** and larger glare source in a highly contrasted room, depending on its angular location with respect to the view direction, induces a certain risk of glare.

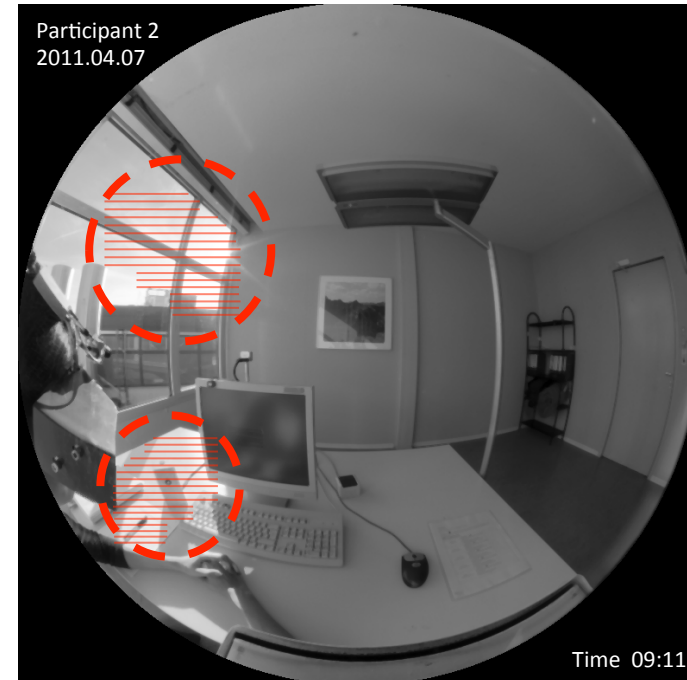


A wide angle High Dynamic Range Image

DISCOMFORT GLARE

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A brighter and **larger glare source** in a highly contrasted room, depending on its angular location with respect to the view direction, induces a certain risk of glare.

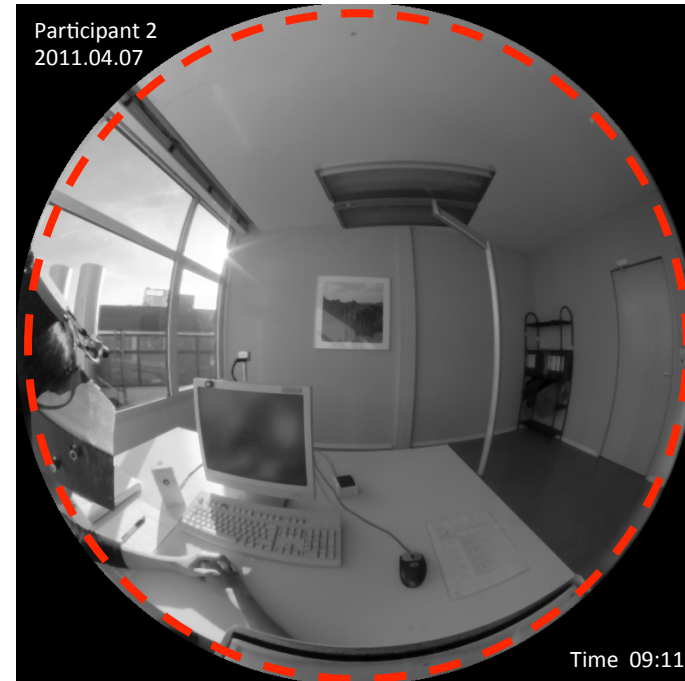


A wide angle High Dynamic Range Image

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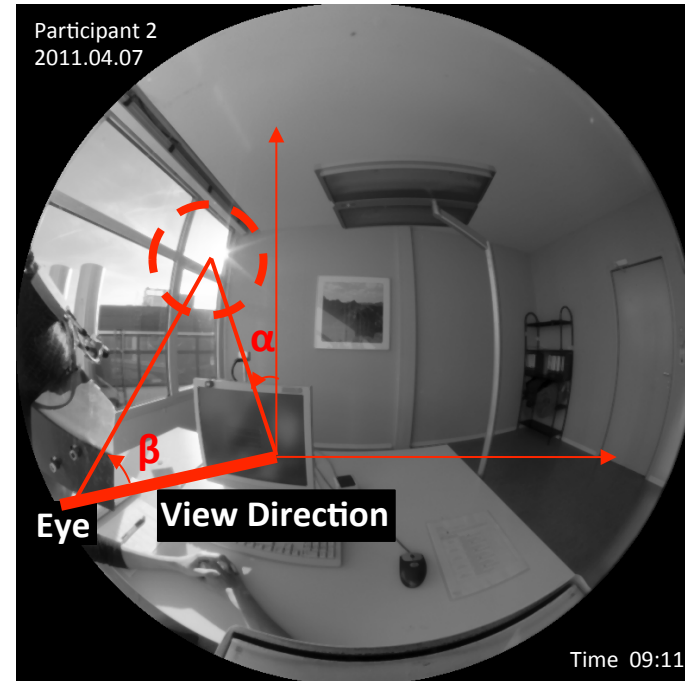


A wide angle High Dynamic Range Image

DISCOMFORT GLARE

$$G \approx \frac{L_s^{exp1} \times \omega_s^{exp2}}{L_a^{exp3} \times p^{exp4}}$$

A brighter and larger glare source in a highly contrasted room, depending on its **angular location with respect to the view direction**, induces a certain risk of glare.



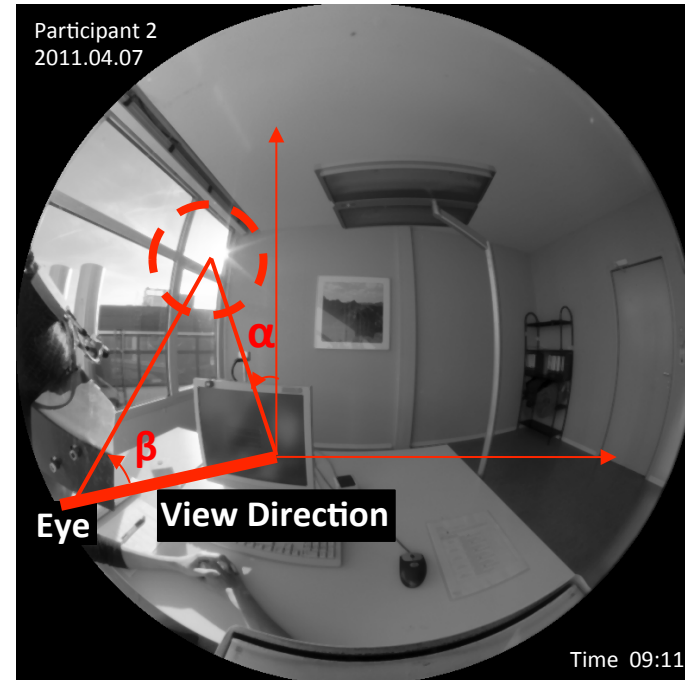
A wide angle High Dynamic Range Image

Lukiesh, Guth 1949
Iwata, et al. 1991
Kim, et al. 2009

DISCOMFORT GLARE

$$G \approx \frac{L_s^{exp1} \times \omega_s^{exp2}}{L_a^{exp3} \times P^{exp4}}$$

A brighter and larger glare source in a highly contrasted room, depending on its angular location with respect to the view direction, induces a **certain risk** of glare.



A wide angle High Dynamic Range Image

GLARE INDICES

CIE Glare Index

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

Unified Glare Rating

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

Visual Comfort Probability

$$VCP = 279 - 110 \left[\log_{10} \left[\sum_{i=1}^n \left(\frac{0.5 L_s (20.4 \omega_s + 1.52 \omega_s^{0.2} - 0.075)}{P_i E_{avg}^{0.44}} \right) \right]^{n^{-0.0914}} \right]$$

Daylight Glare Index

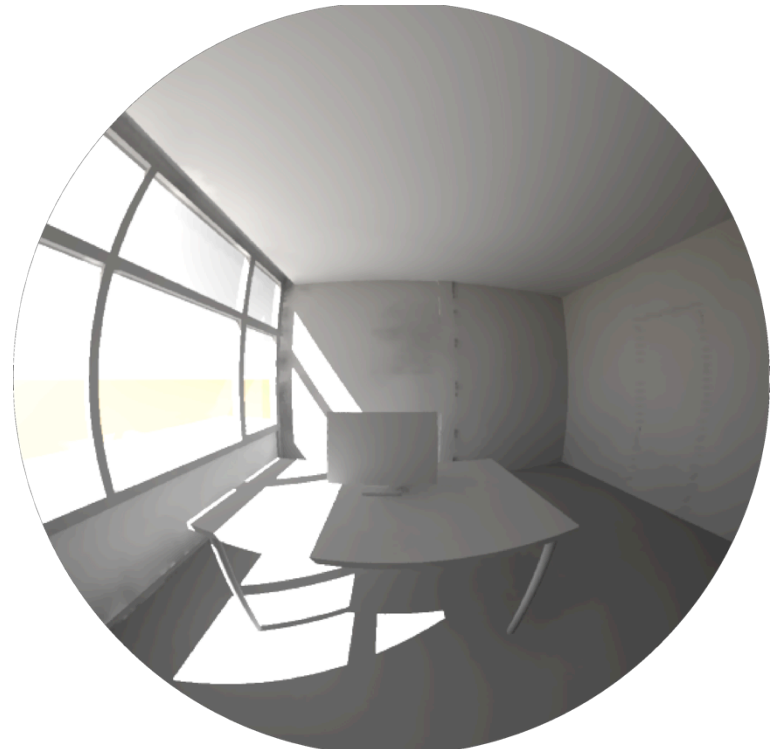
$$DGI = 10 \log_{10} 0.48 \sum_{i=1}^n \frac{L_s^{1.6} \Omega_s^{0.8}}{L_b + 0.07 \omega_s^{0.5} P_i}$$

Daylight Glare Probability

$$DGP = 5.87 \times E_v + 9.18 \times 10^{-2} \times \log \left(1 + \sum_i \frac{L_{s,i}^2 \times \omega_{s,i}}{E_v^{1.87} \times P_{i,i}^2} \right) + 0.16$$

GLARE ANALYSIS & PREDICTION PARAMETERS

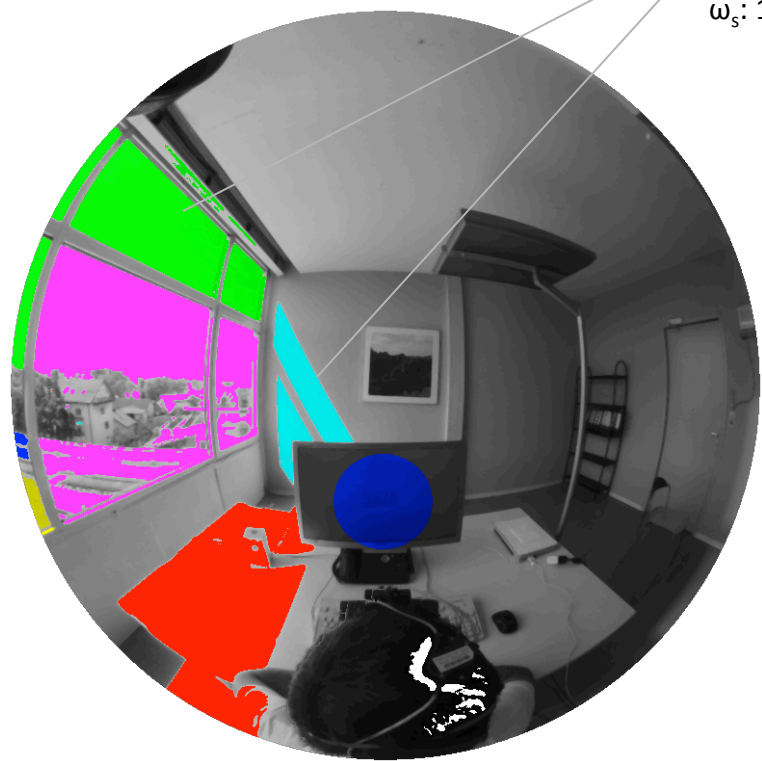
1. Input: HDR Image or Radiance picture (fish eye view)



GLARE ANALYSIS & PREDICTION PARAMETERS

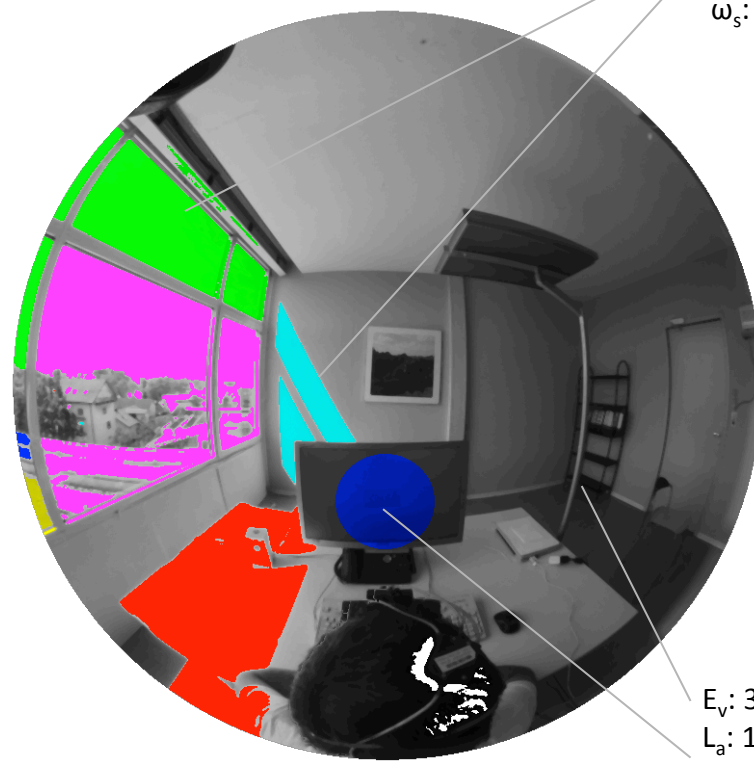
1. Input: HDR Image or Radiance picture (fish eye view)
2. Detect glare sources based on **Threshold** & **Search Radius** : Location, size and brightness

#L_s:9
L_s: 29657
 ω_s : 1.0484



GLARE ANALYSIS & PREDICTION PARAMETERS

1. Input: HDR Image or Radiance picture (fish eye view)
2. Detect glare sources based on **Threshold** & **Search Radius** : Location, size and brightness
3. Compute the rest of the components for each glare index
4. Output: Calculates glare indices (CGI, DGI, DGP, UGR, VCP)

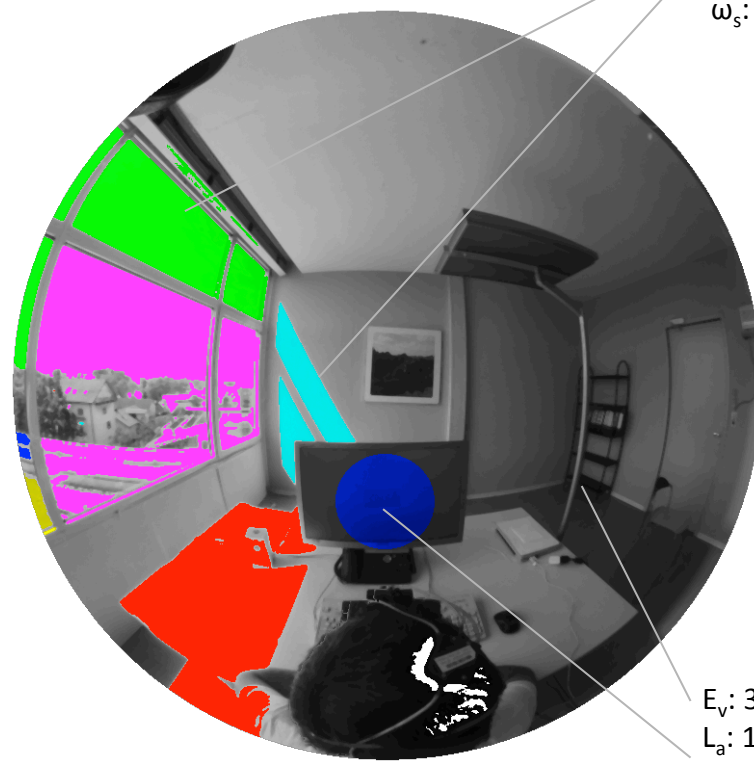


#L_s:9
L_s: 29657
ω_s: 1.0484

E_v: 3269.79 [lux]
L_a: 1146.57 [cd/m²]
L_t 212 [cd/m²]

GLARE ANALYSIS & PREDICTION PARAMETERS

1. Input: HDR Image or Radiance picture (fish eye view)
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#L_s:9
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GLARE ANALYSIS & PREDICTION PARAMETERS

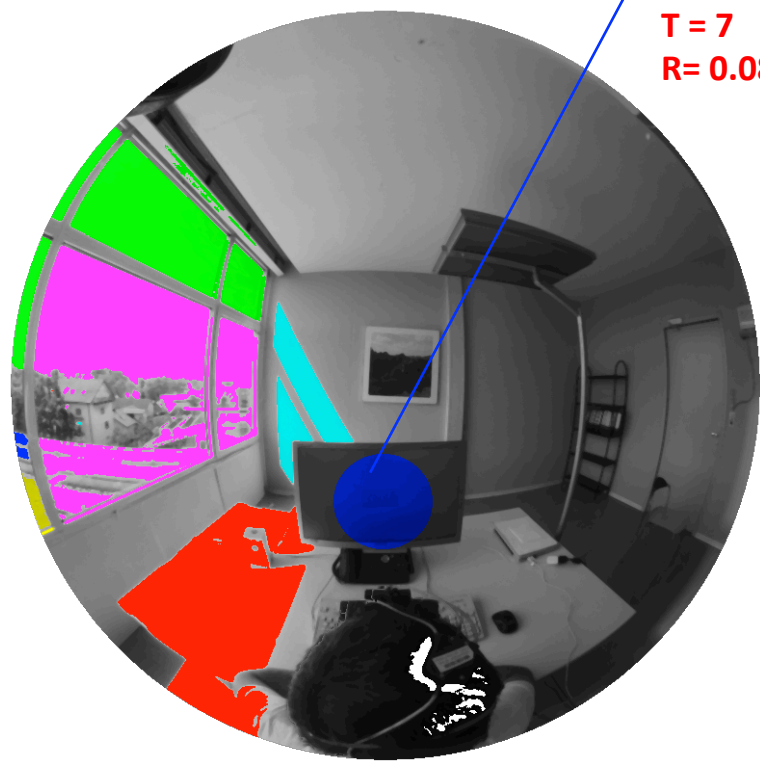
Threshold: In the detection algorithm, the glare pixels are determined such that the luminance value of this pixel is x-times greater compare to the average luminance of a reference area. With different threshold x, the glare pixels are treated differently.

Radius: After the glare pixel detection, the glare sources are merged into larger area, the search distance between each glare pixel (search radius) defines the sizes of glare sources

Reference area

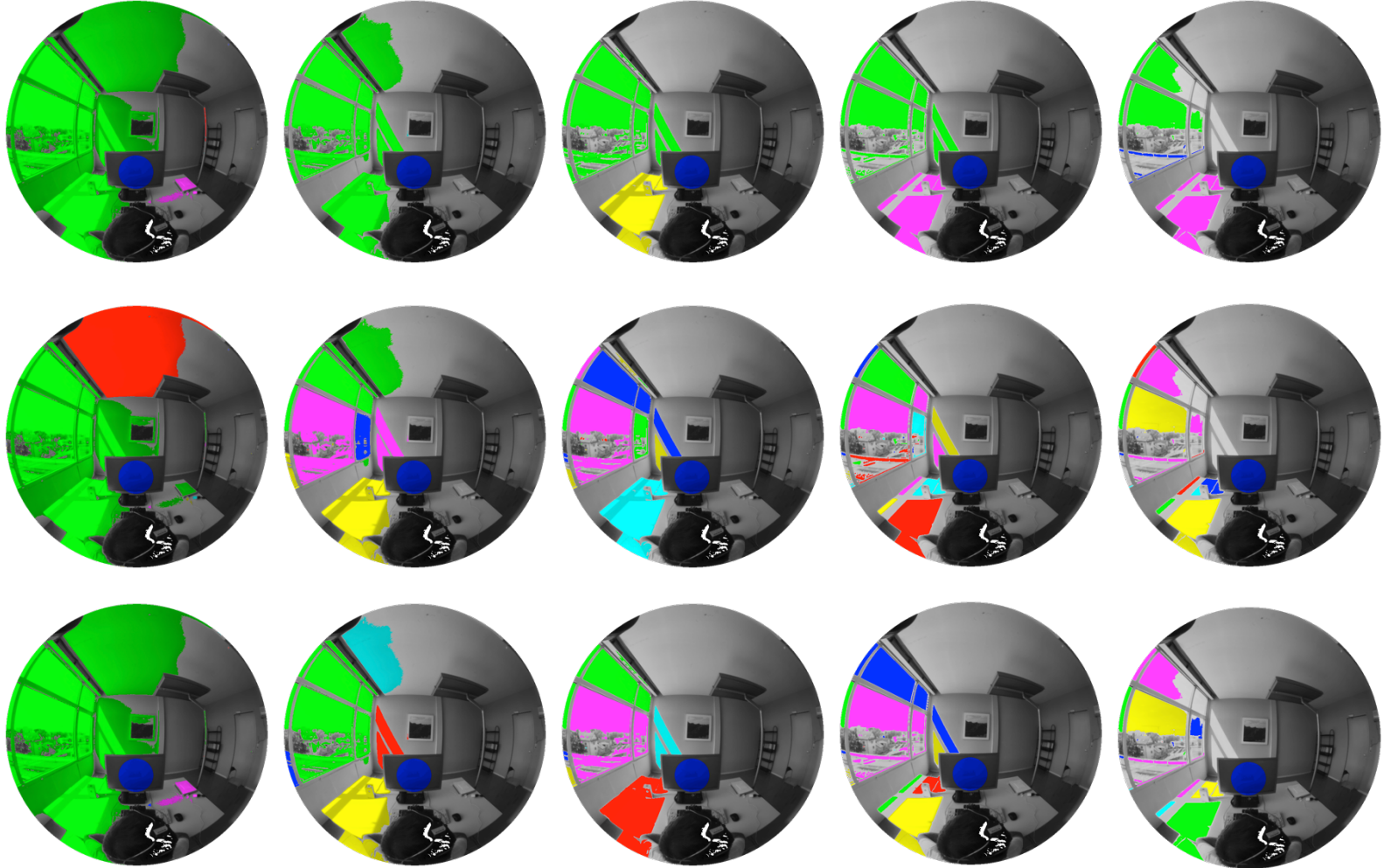
$T = 7$

$R = 0.08$



DIFFERENT THRESHOLD AND RADIUS PARAMETERS

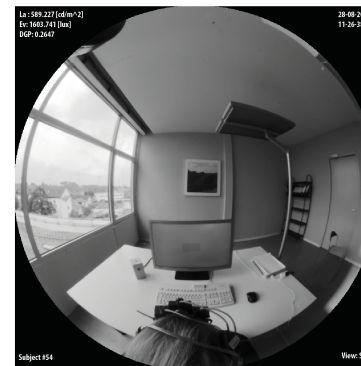
Threshold/
Radius



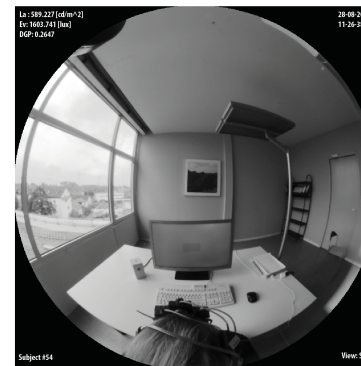
GLARE ANALYSIS & PREDICTION PARAMETERS

- Is there an effect of threshold and radius on glare analysis?
- How big is this effect?
- Are there combinations of threshold and radius that work better for a specific lighting scenario?

METHODOLOGY & EXPERIMENTAL SET UP



METHODOLOGY & EXPERIMENTAL SET UP



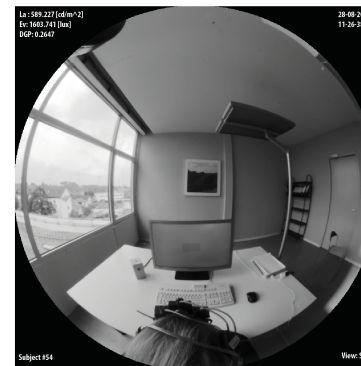
1. Recording Photometric Parameters
 2. User ratings
- 128 subjects were tested

METHODOLOGY & EXPERIMENTAL SET UP



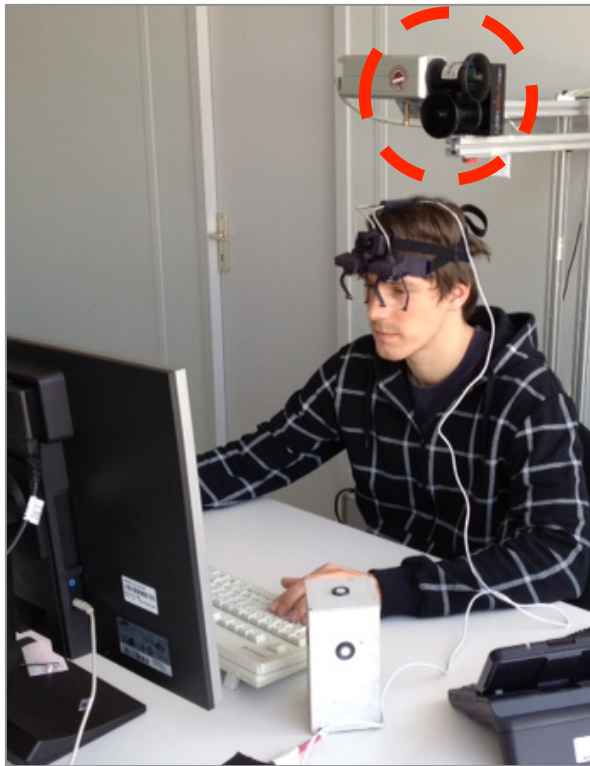
1. Recording Photometric Parameters
 2. **User ratings**
- 128 subjects were tested

METHODOLOGY & EXPERIMENTAL SET UP

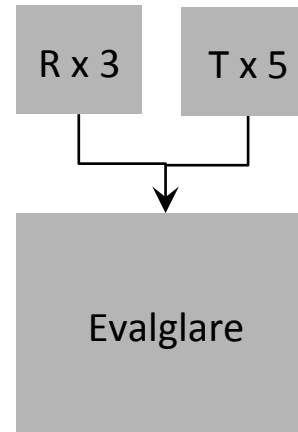


1. Recording Photometric Parameters
 2. User ratings
- 128 subjects were tested

METHODOLOGY & EXPERIMENTAL SET UP



HDR
Image



15
measures

User
Ratings

Experiments Based on a Real
Office Set-ups

DIFFERENT THRESHOLD AND RADIUS PARAMETERS

Threshold/
Radius

3

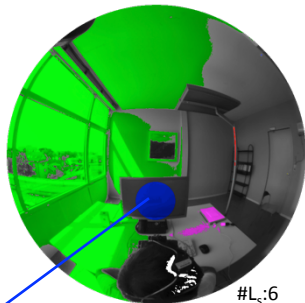
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7

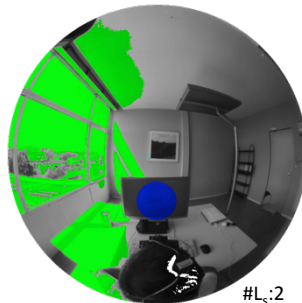
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15

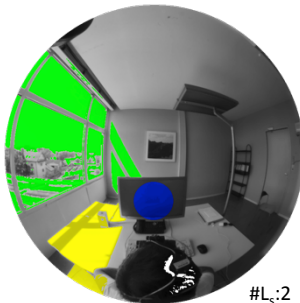
0.2



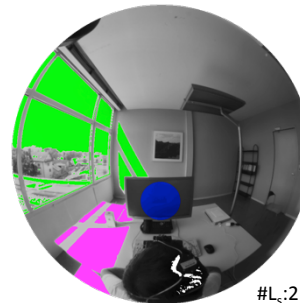
#L_s:6
L_s: 5627
ω_s: 3.0146



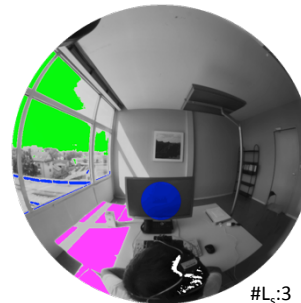
#L_s:2
L_s: 4274
ω_s: 1.5252



#L_s:2
L_s: 8856
ω_s: 1.0484



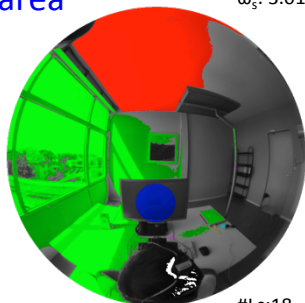
#L_s:2
L_s: 10290
ω_s: 0.8603



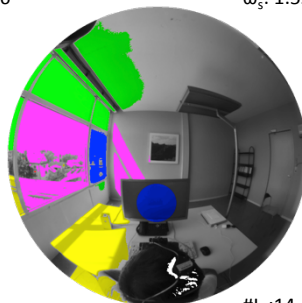
#L_s:3
L_s: 16588
ω_s: 0.6372

Reference area

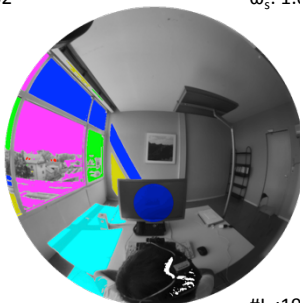
0.04



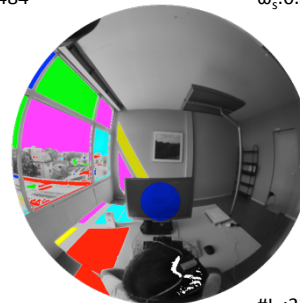
#L_s:18
L_s: 14673
ω_s: 3.0146



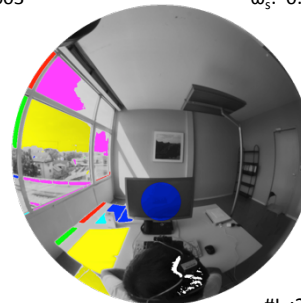
#L_s:14
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ω_s: 1.5252



#L_s:19
L_s: 54289
ω_s: 1.0484

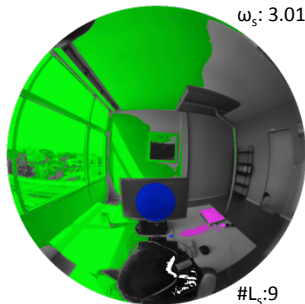


#L_s:32
L_s: 111654
ω_s: 0.8603

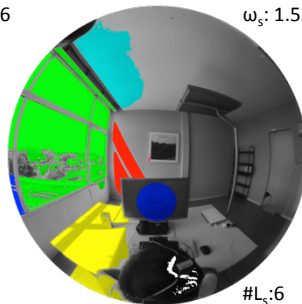


#L_s:21
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ω_s: 0.6372

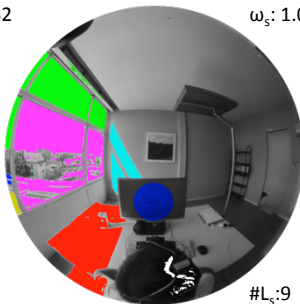
0.08



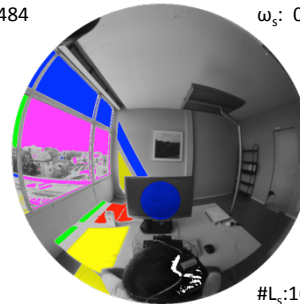
#L_s:9
L_s: 7658
ω_s: 3.0146



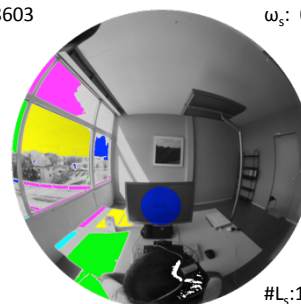
#L_s:6
L_s: 14652
ω_s: 1.5252



#L_s:9
L_s: 29657
ω_s: 1.0484

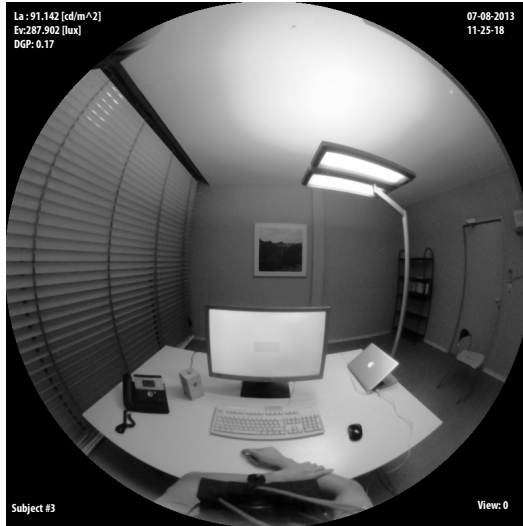


#L_s:16
L_s: 64847
ω_s: 0.8603

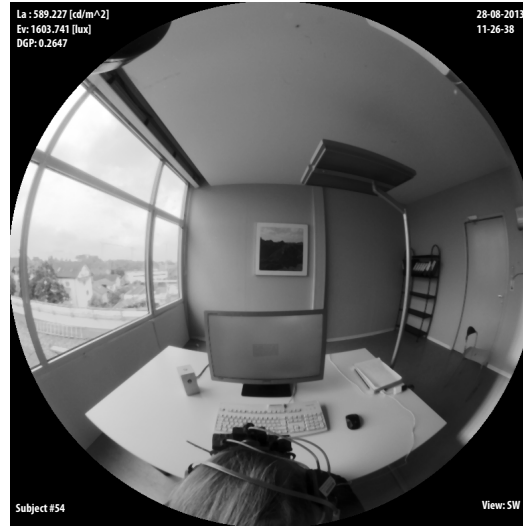


#L_s:18
L_s: 7658
ω_s: 87704

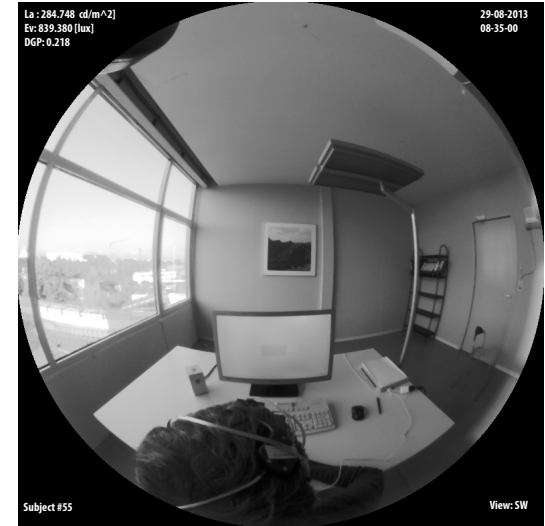
METHODOLOGY & EXPERIMENTAL SET UP



LC1, Artificial lighting



LC2, Overcast sky



LC3, Clear sky, no direct sun inside



LC4, Clear sky, direct sun inside

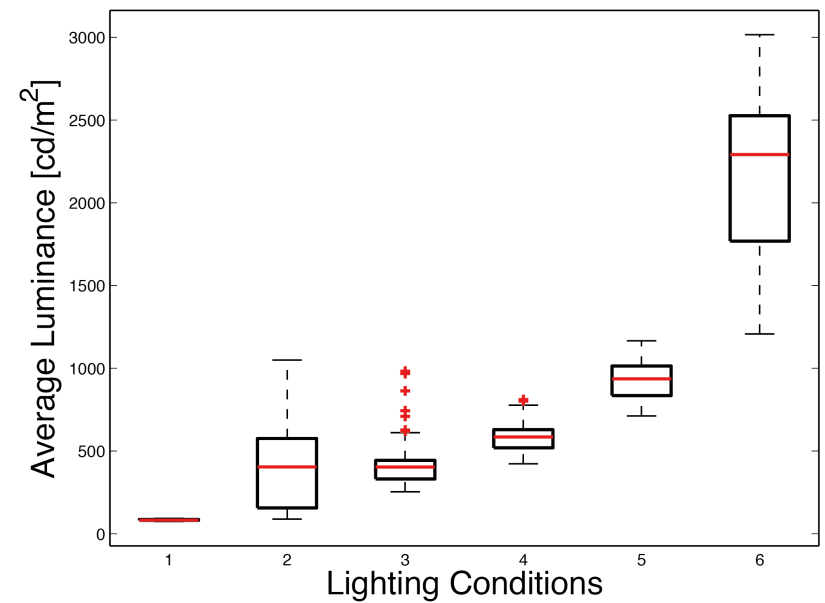
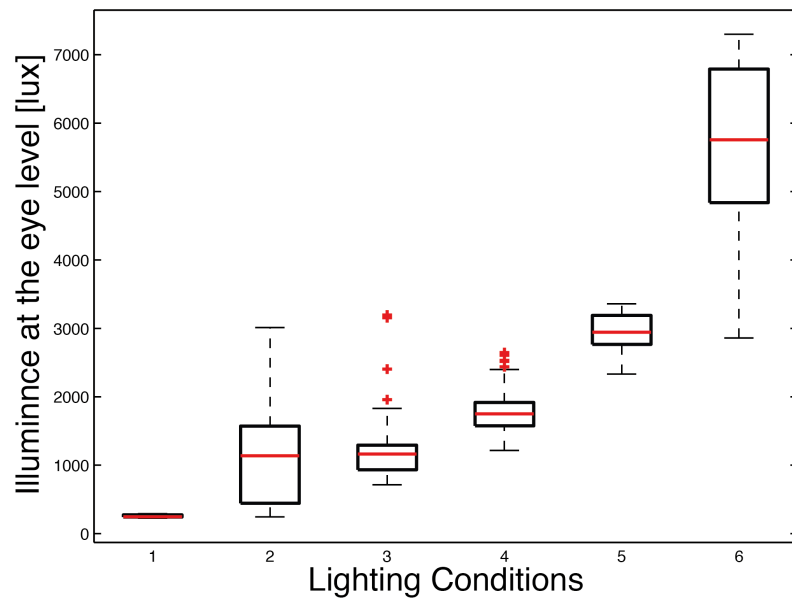


LC5, Clear sky, direct sun inside



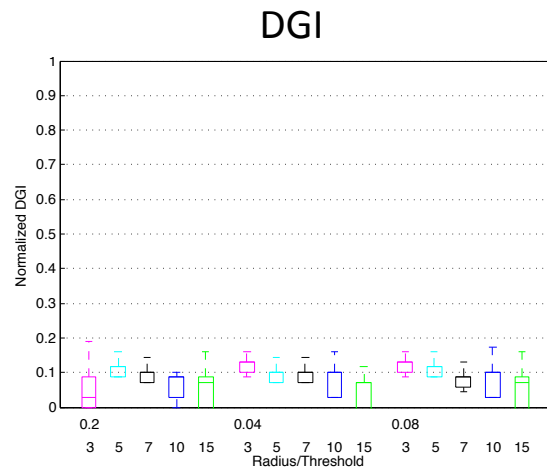
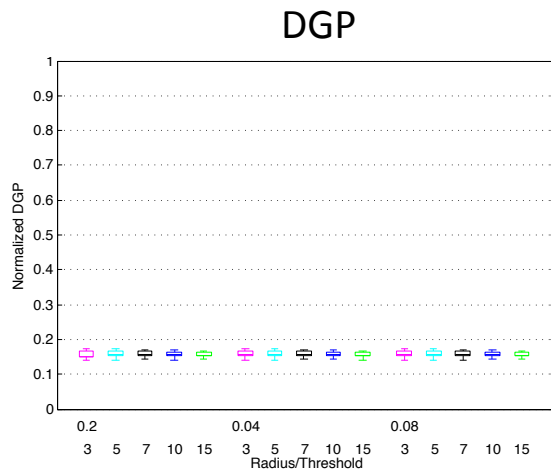
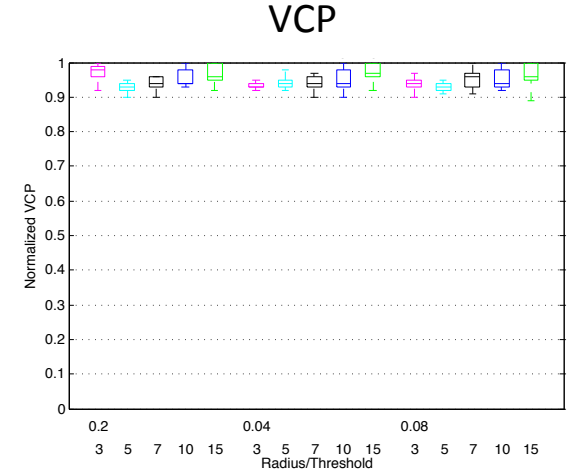
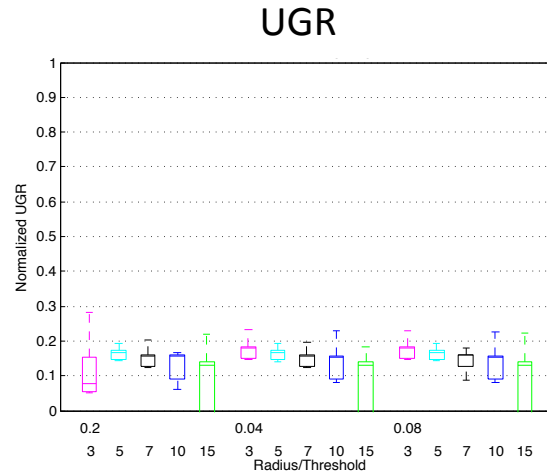
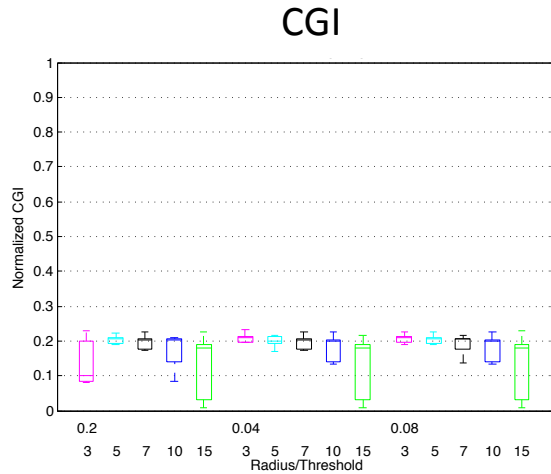
LC4, Clear sky, sun in FOV

METHODOLOGY & EXPERIMENTAL SET UP



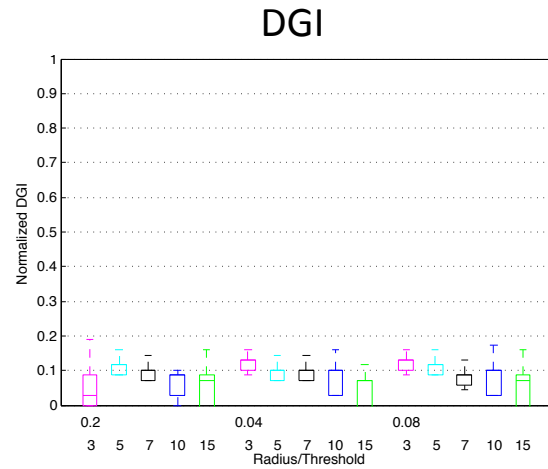
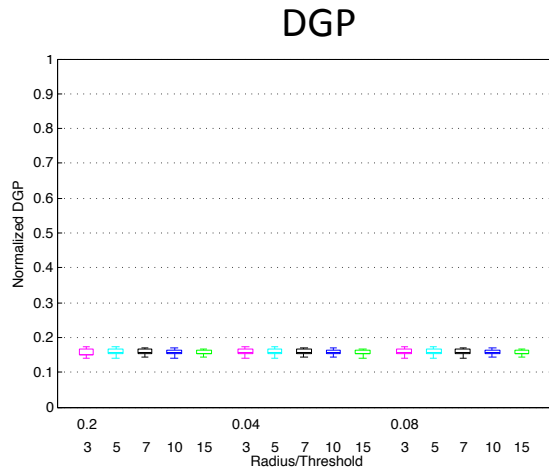
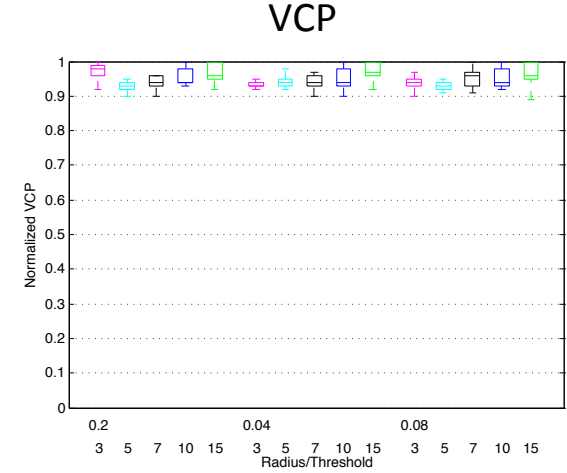
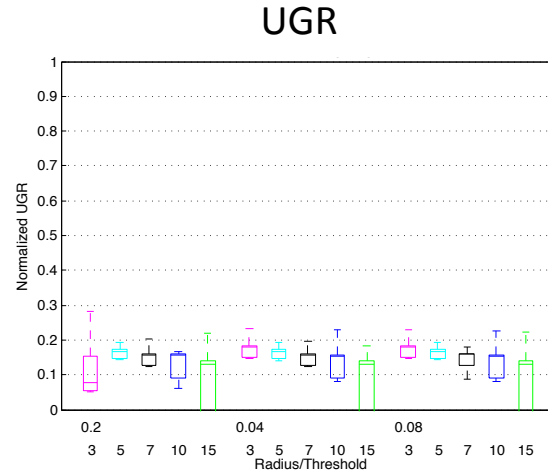
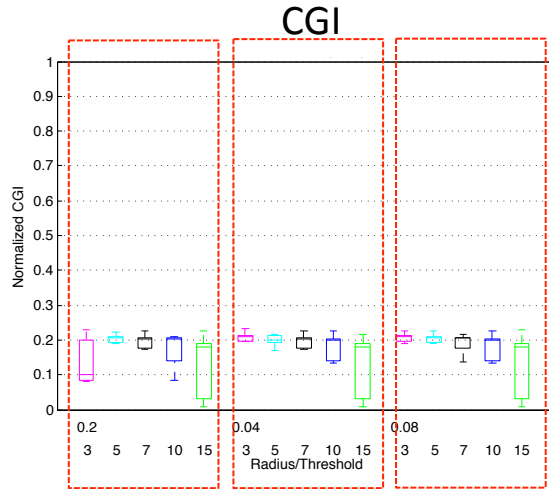
LIGHTING CONDITION 1 – NORMALIZED INDICES DISTRIBUTION

artificial lighting



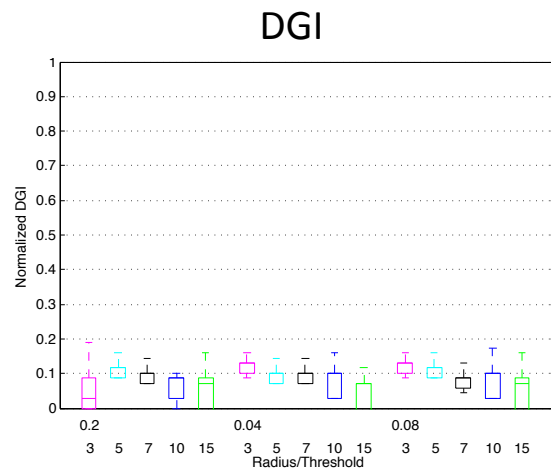
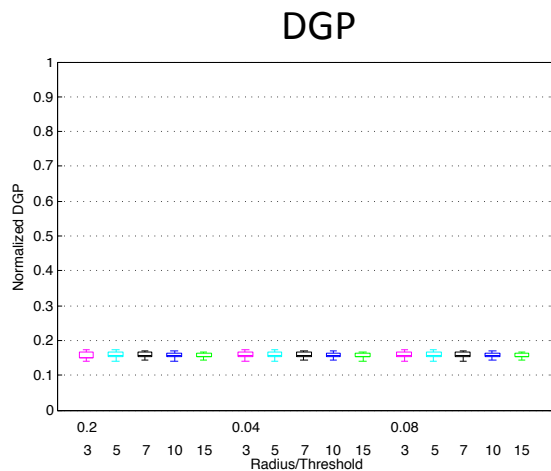
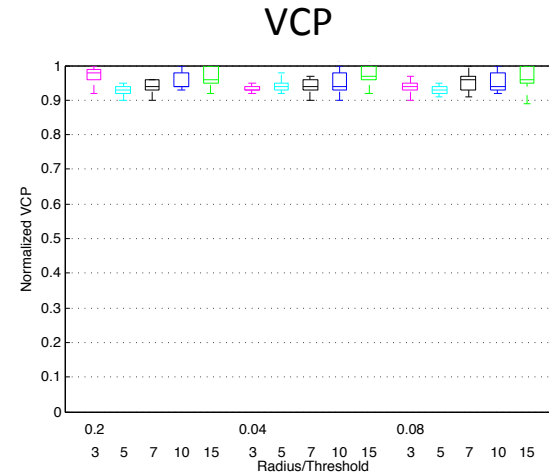
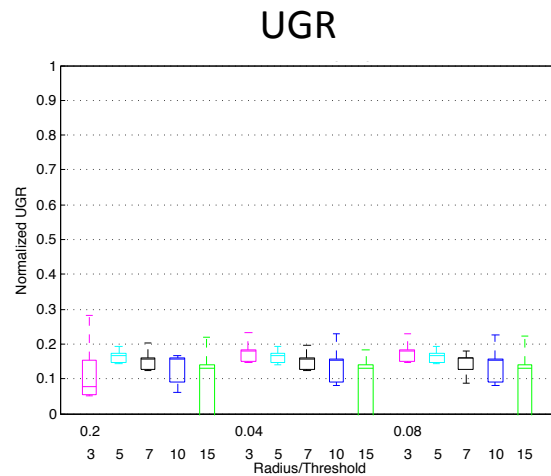
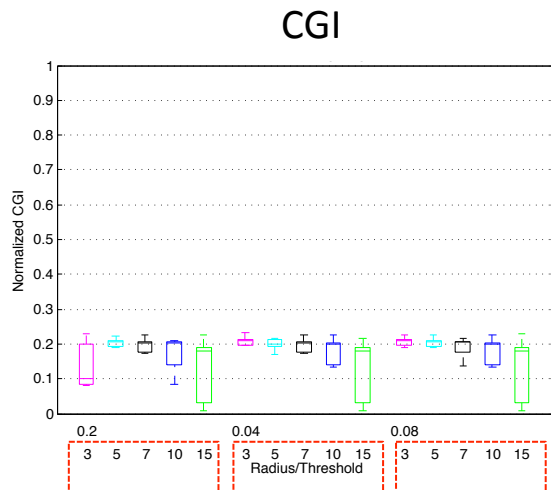
LIGHTING CONDITION 1 – NORMALIZED INDICES DISTRIBUTION

artificial lighting



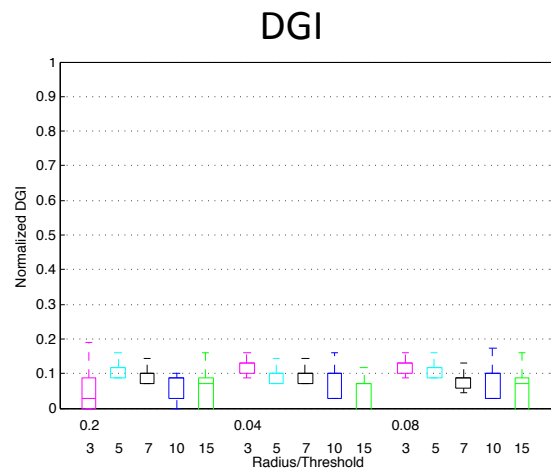
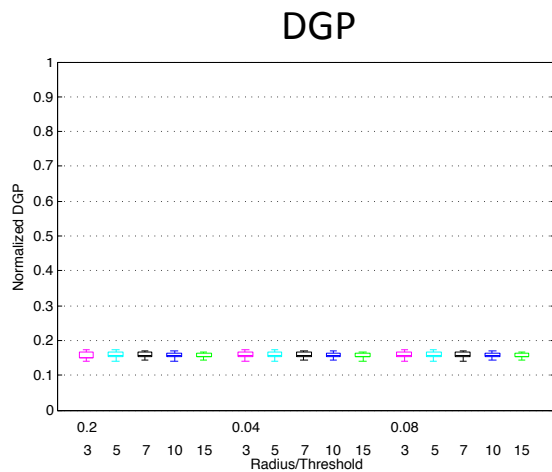
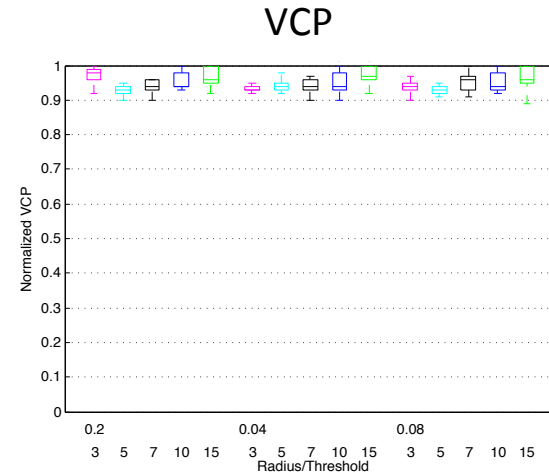
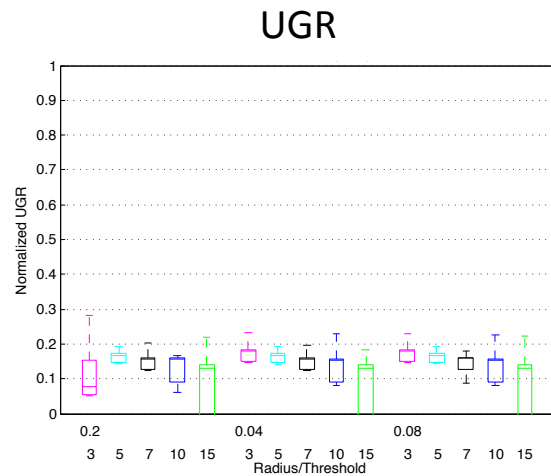
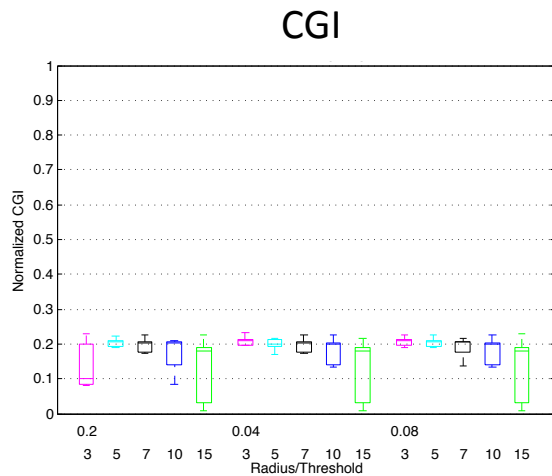
LIGHTING CONDITION 1 – NORMALIZED INDICES DISTRIBUTION

artificial lighting



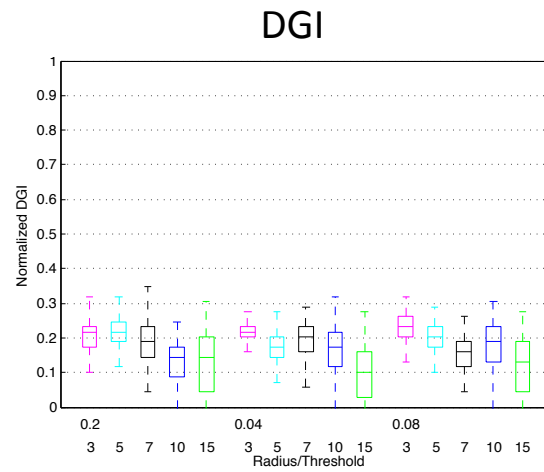
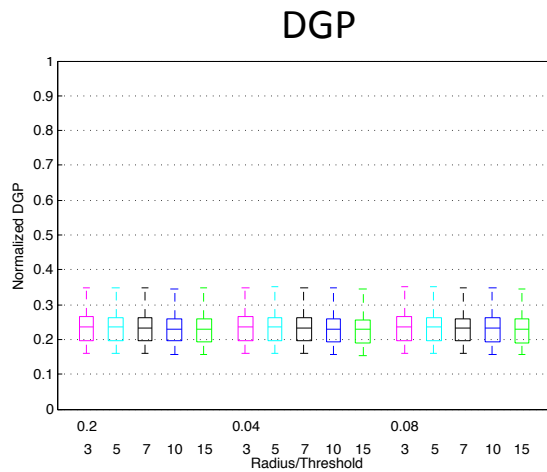
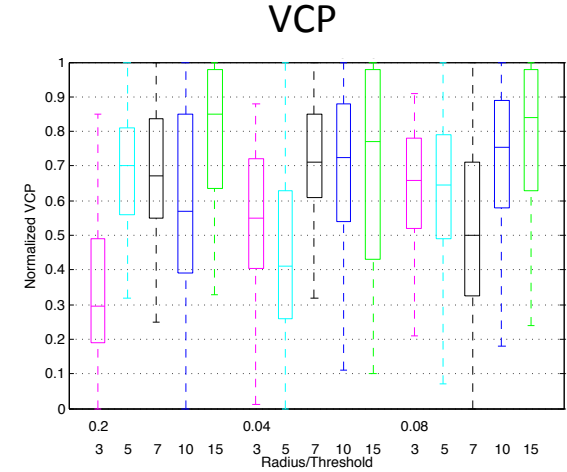
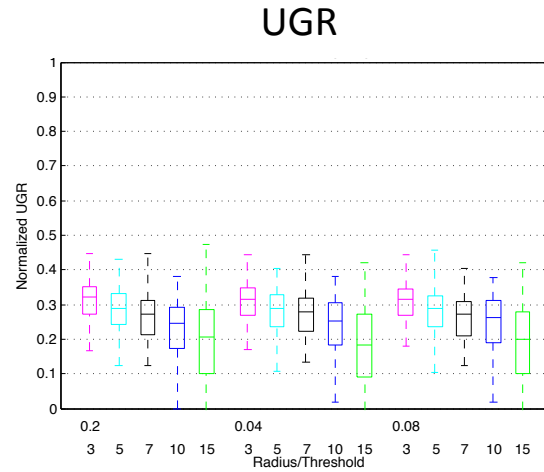
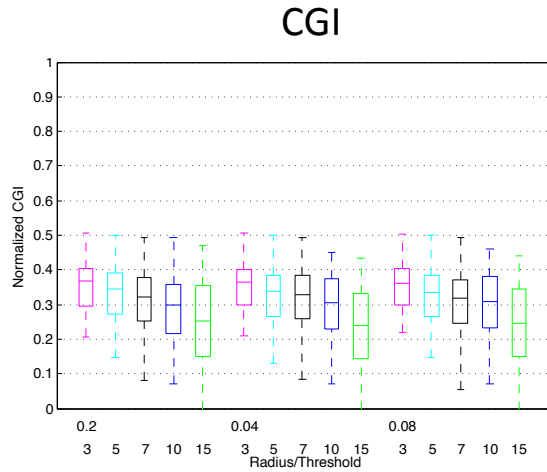
LIGHTING CONDITION 1 – NORMALIZED INDICES DISTRIBUTION

artificial lighting



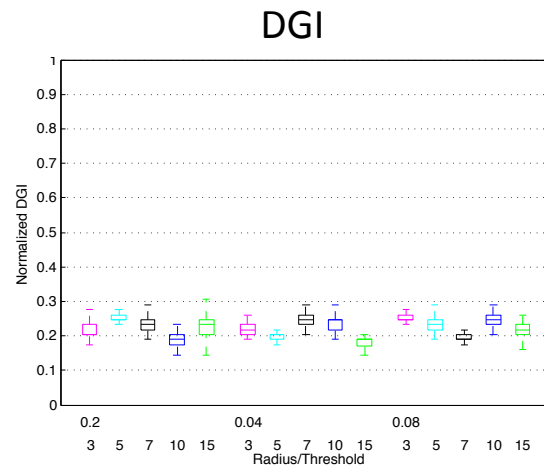
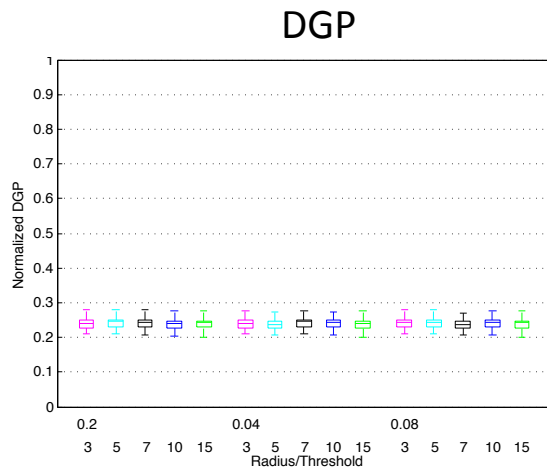
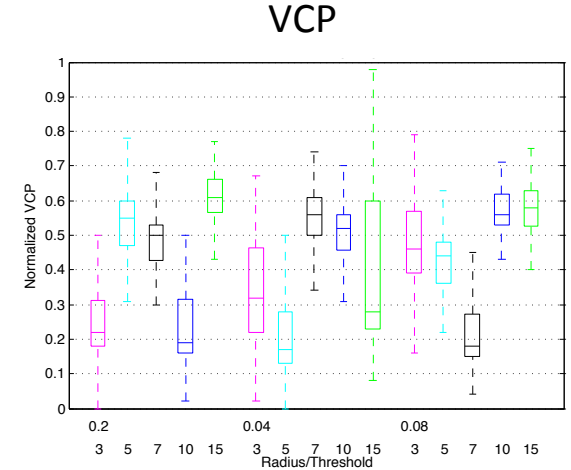
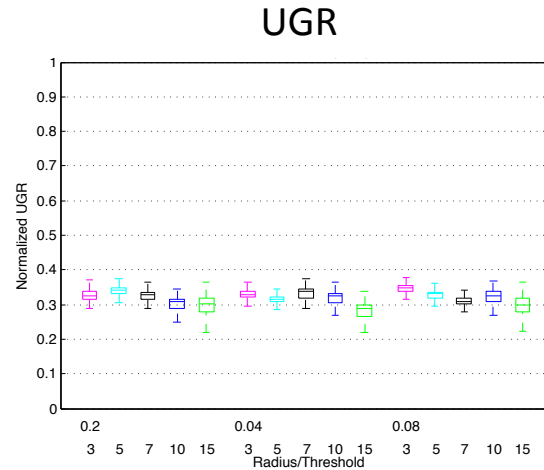
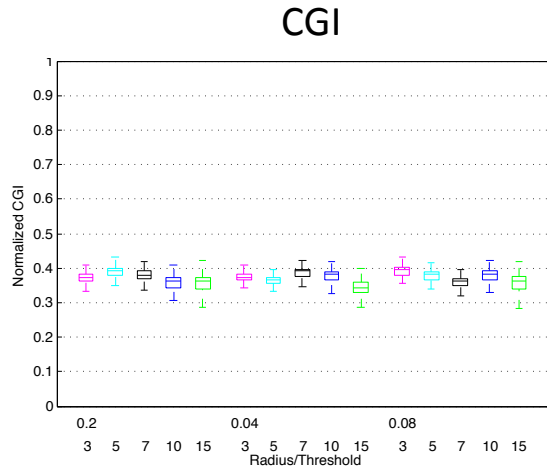
LIGHTING CONDITION 2 – NORMALIZED INDICES DISTRIBUTION

overcast sky



LIGHTING CONDITION 3 – NORMALIZED INDICES DISTRIBUTION

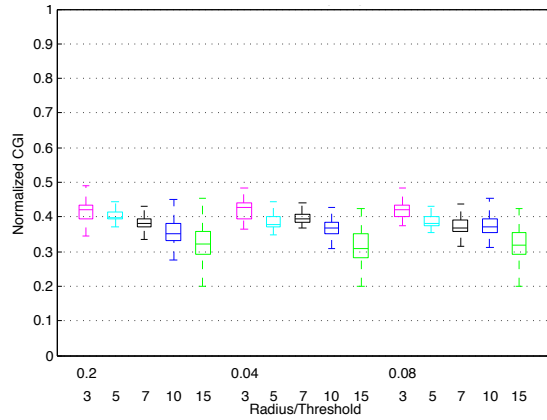
clear sky, No direct sun



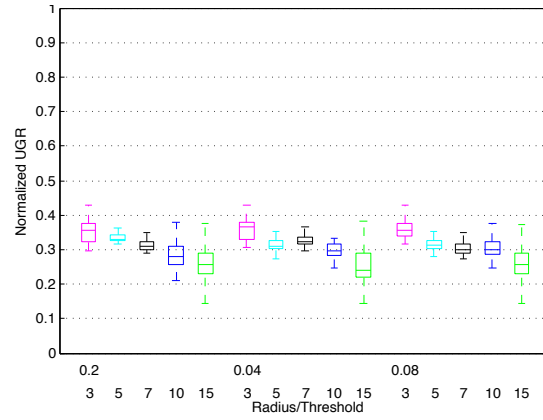
LIGHTING CONDITION 4 – NORMALIZED INDICES DISTRIBUTION

clear sky, direct sun inside

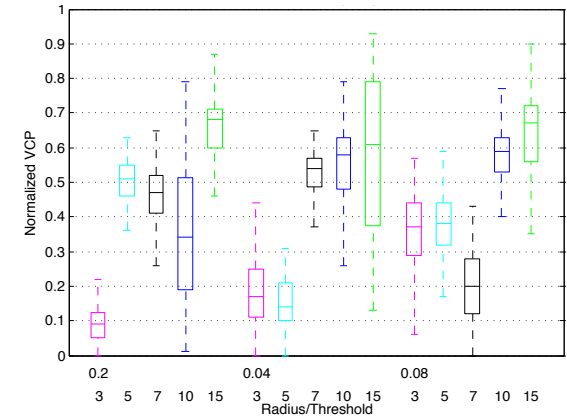
CGI



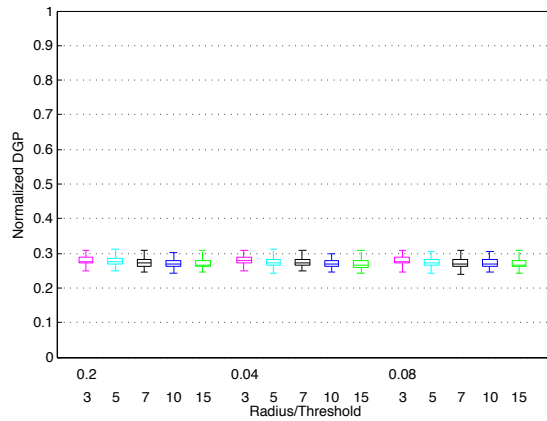
UGR



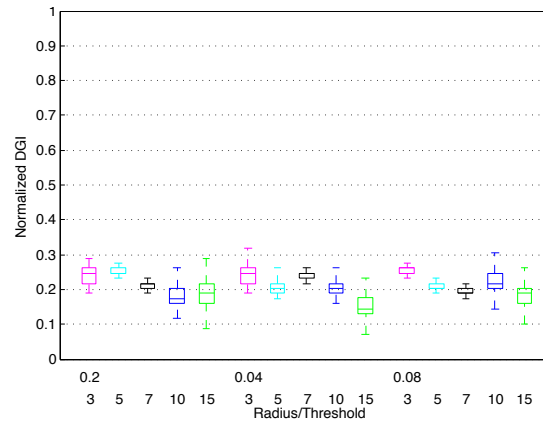
VCP



DGP



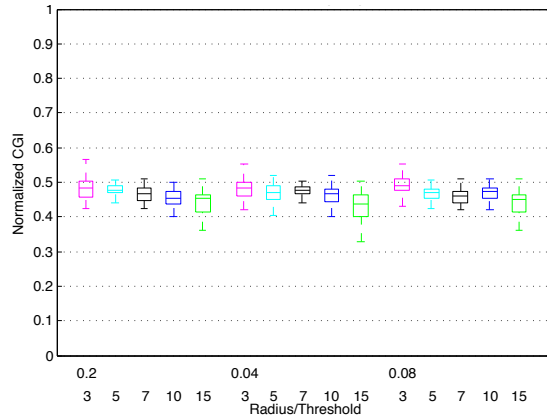
DGI



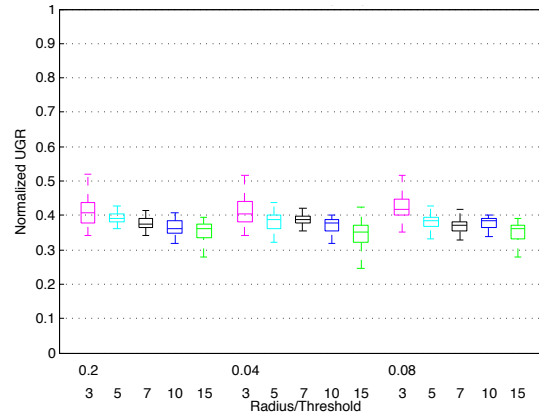
LIGHTING CONDITION 5 – NORMALIZED INDICES DISTRIBUTION

clear sky, direct sun inside

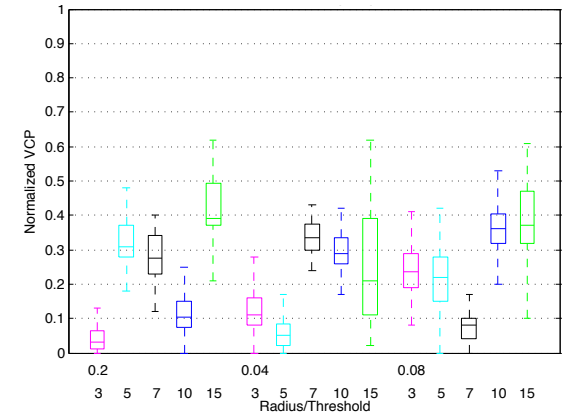
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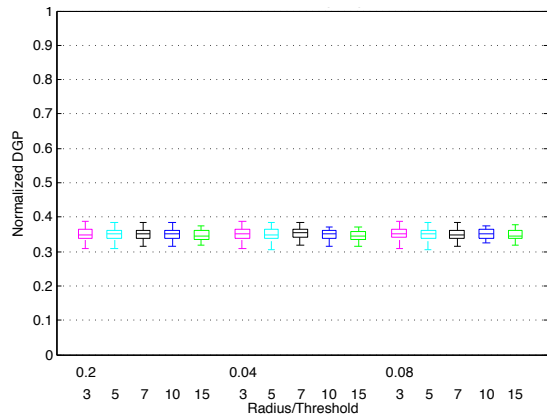
UGR



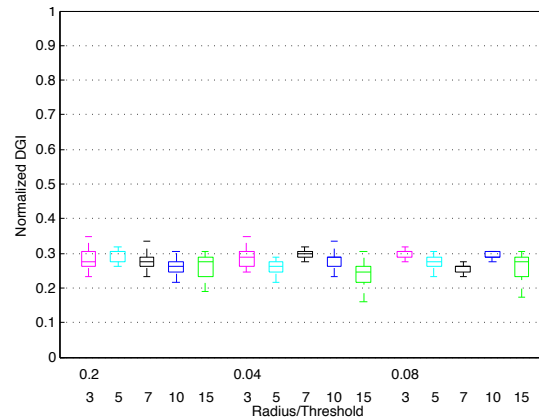
VCP



DGP

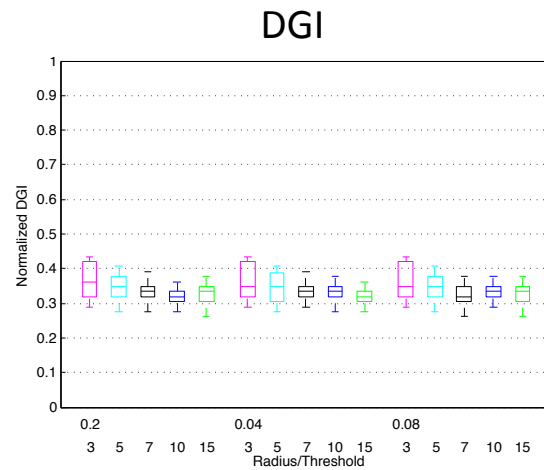
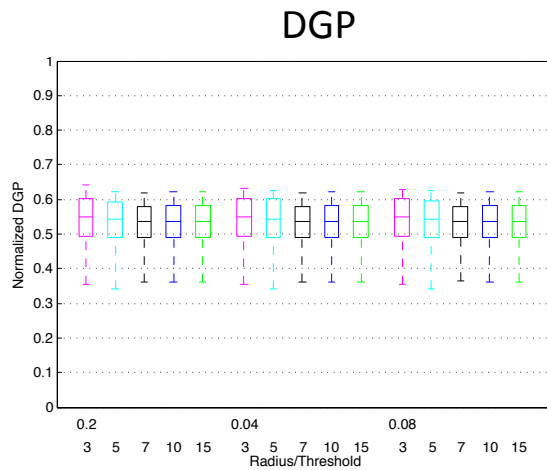
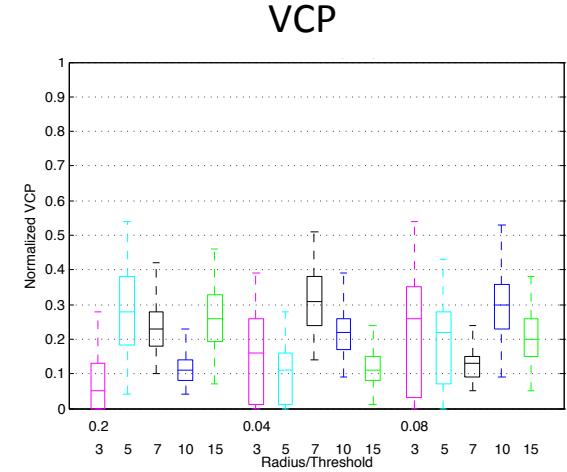
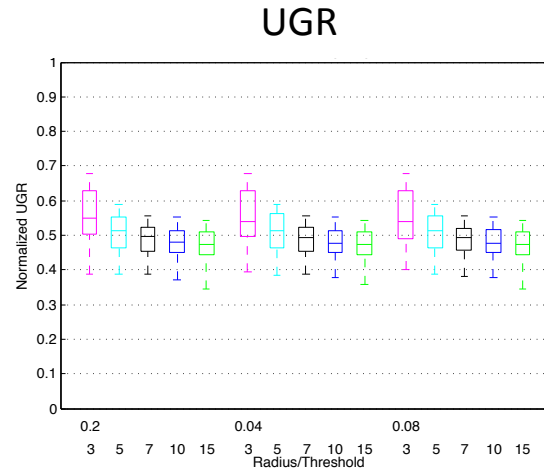
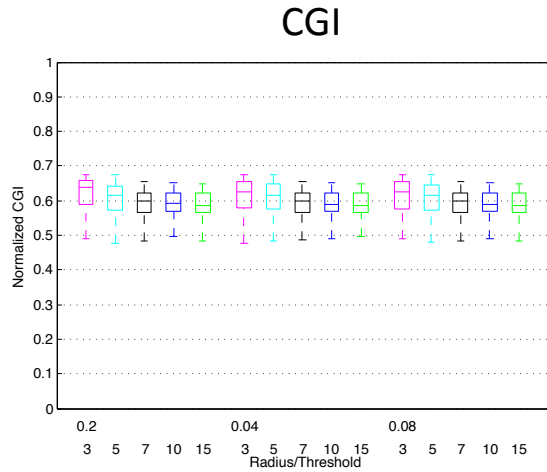


DGI



LIGHTING CONDITION 4 – NORMALIZED INDICES DISTRIBUTION

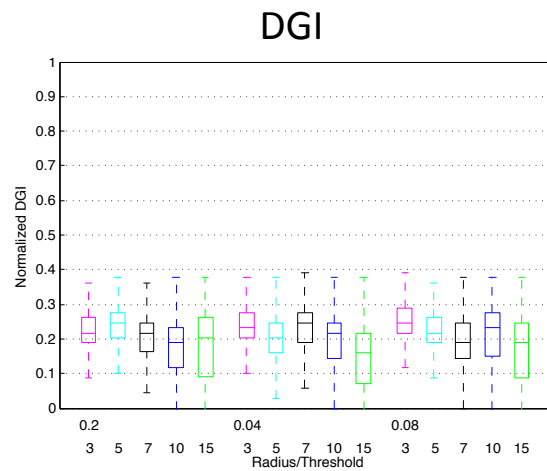
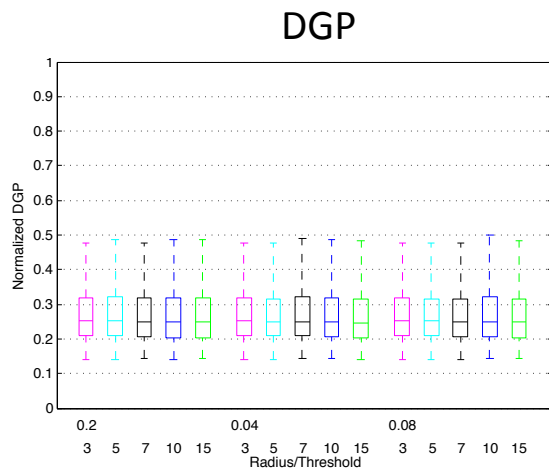
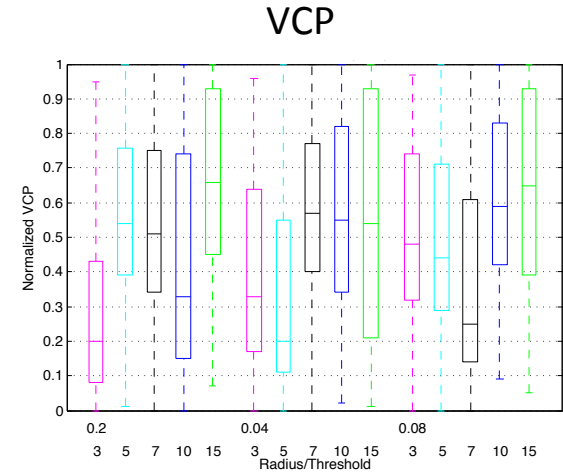
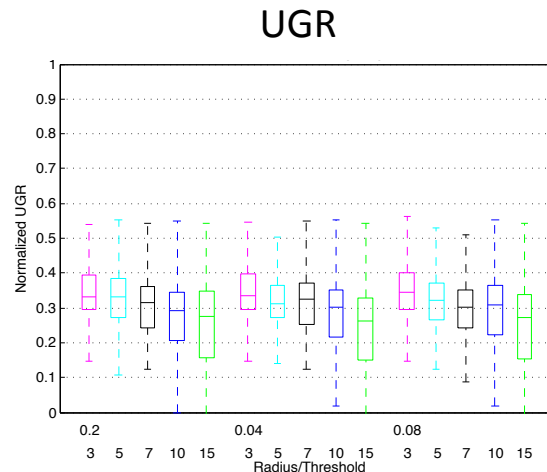
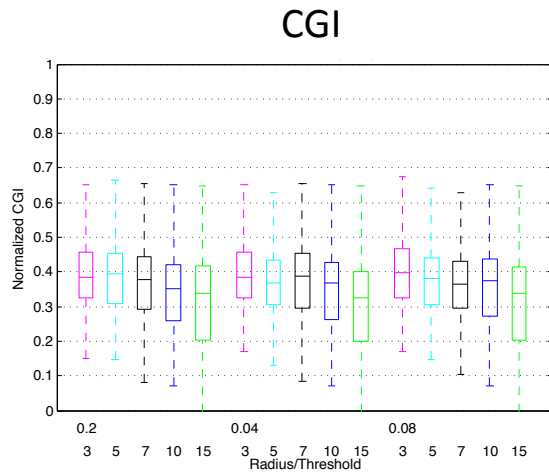
clear sky, sun in FOV



CONCLUSION

- There is an effect of threshold for most glare metrics
- This effect is minimum for DGP
- There is an effect of search radius for most glare metrics
- This effect is none for DGP and minimum for UGR
- These effects are higher for lower luminance levels

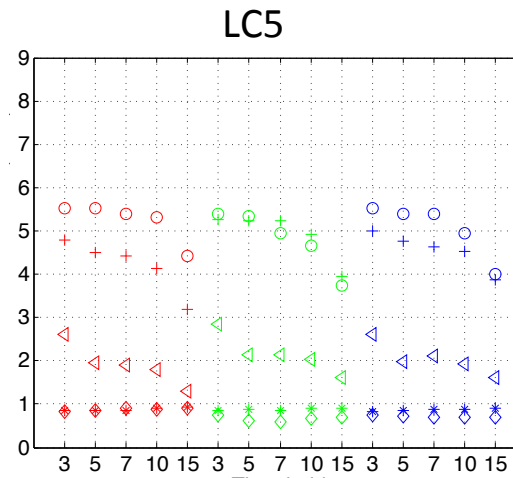
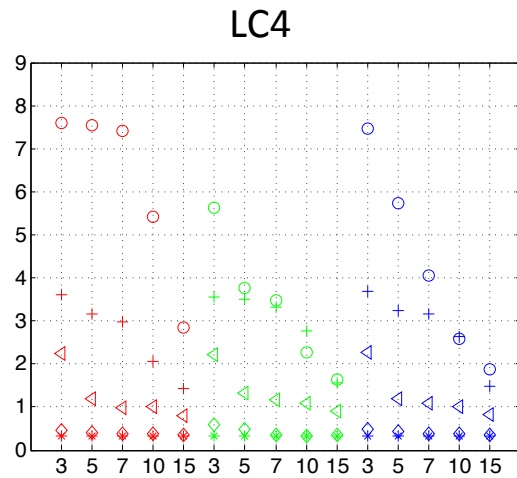
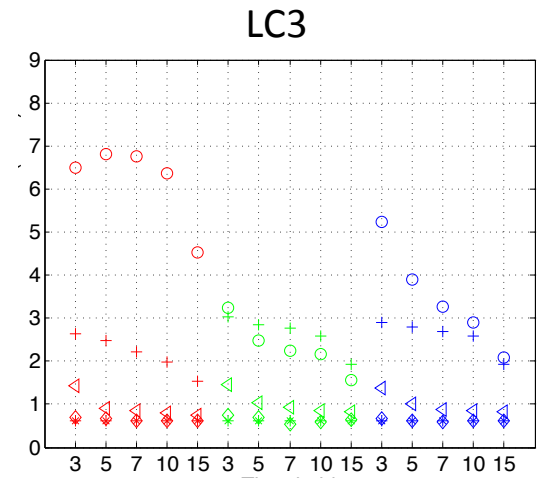
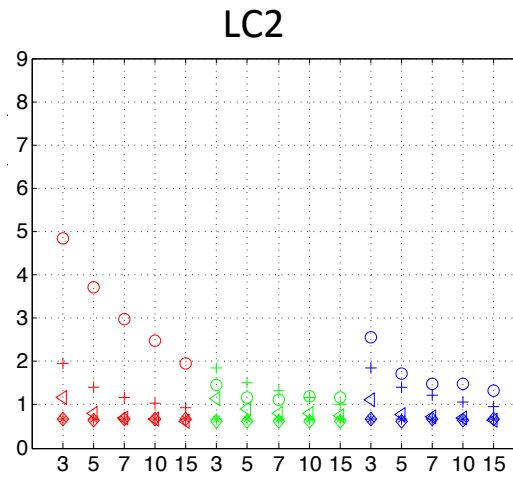
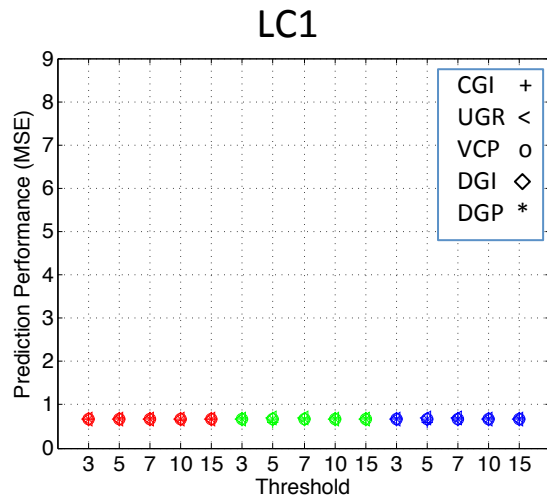
LIGHTING CONDITION – NORMALIZED INDICES DISTRIBUTION



GLARE ANALYSIS & PREDICTION PARAMETERS

- Is there an effect of threshold and radius on glare analysis?
 - How big is this effect?
- Are there certain combinations of threshold and radius that work better for a specific lighting scenario?

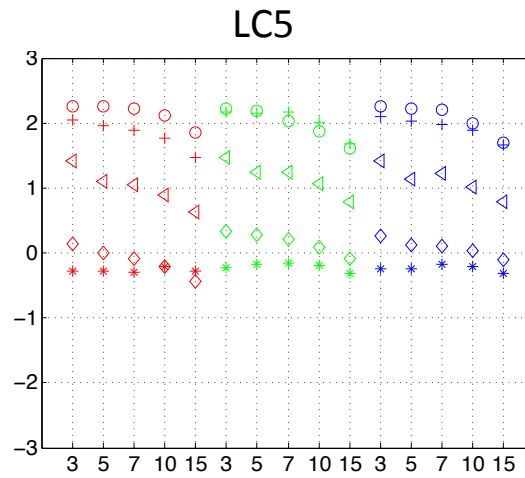
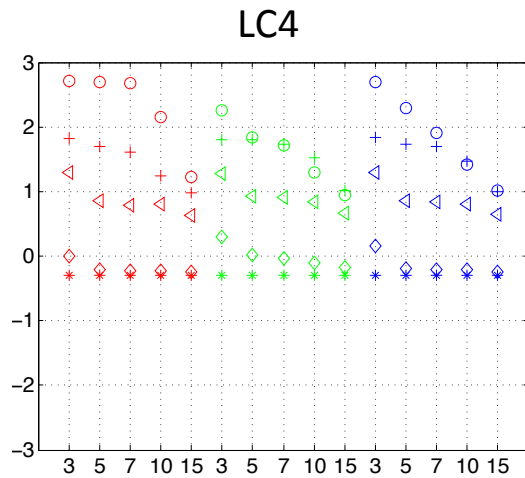
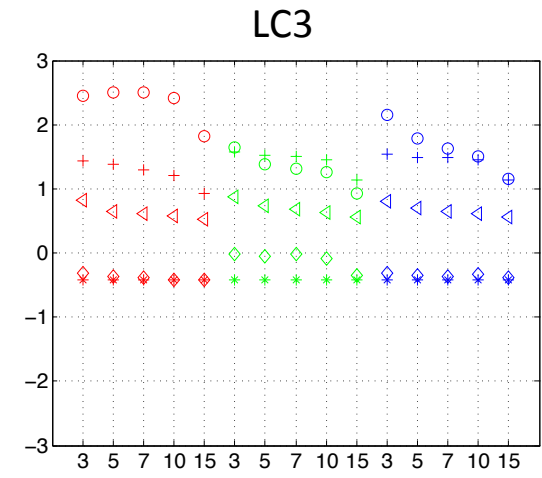
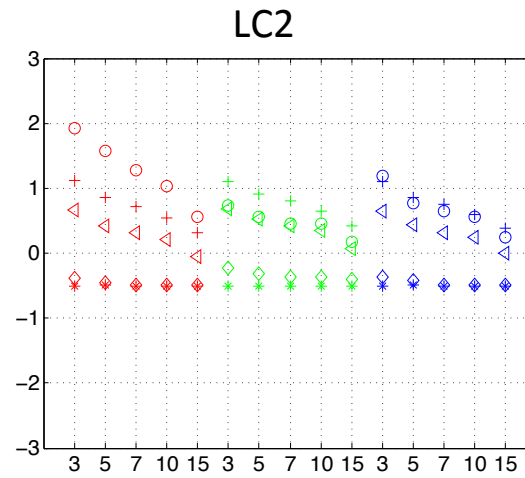
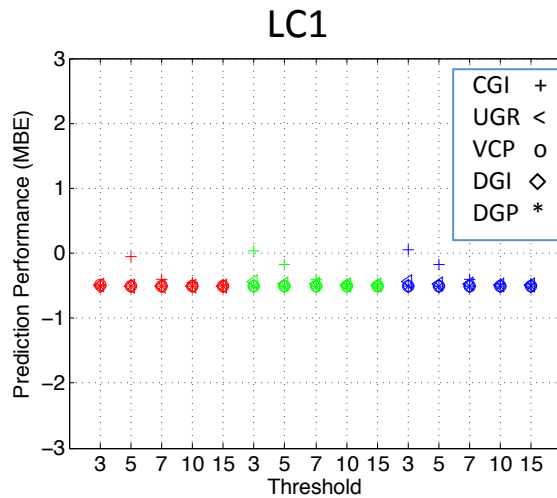
PREDICTION PERFORMANCE (MSE)



LC6

PREDICTION PERFORMANCE (MBE)

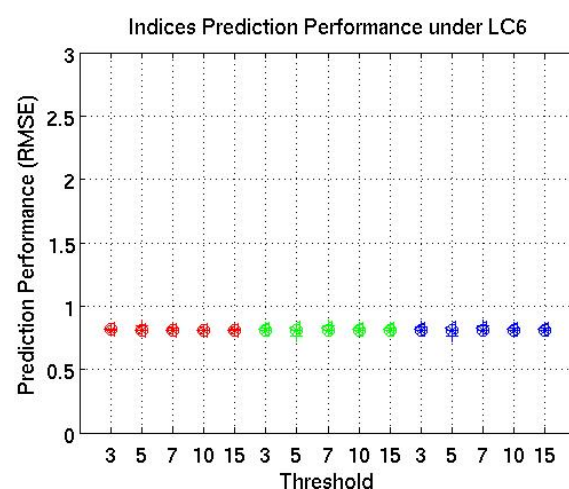
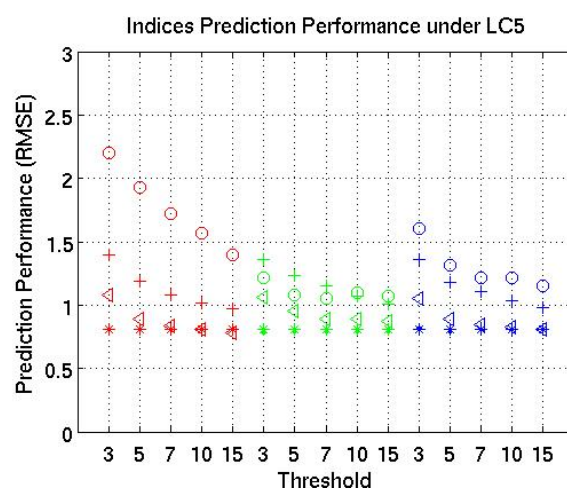
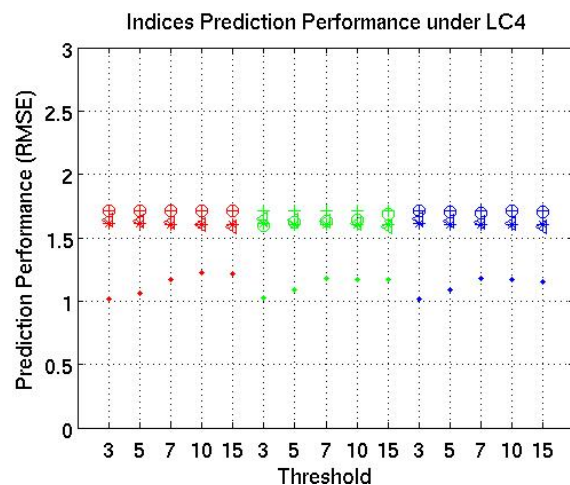
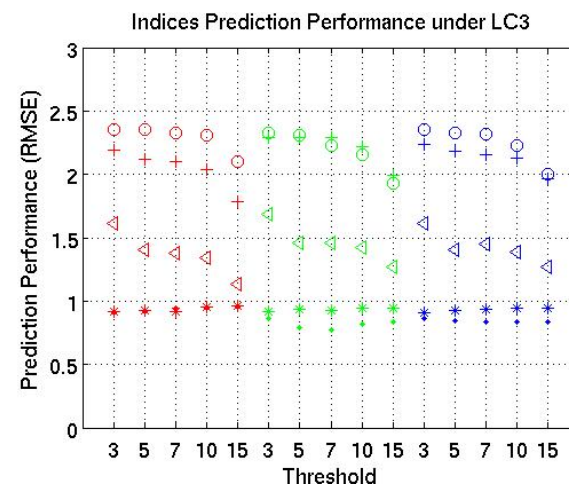
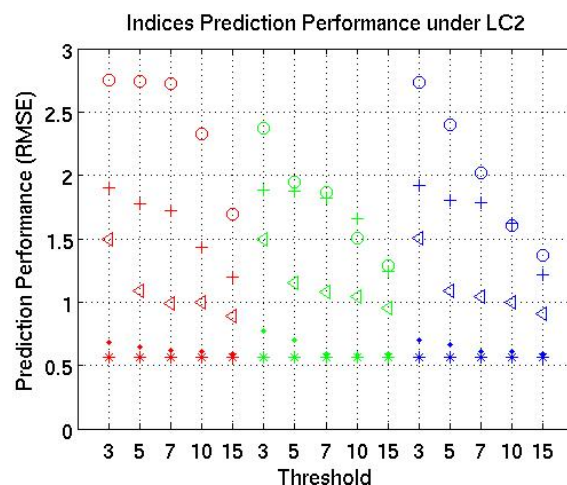
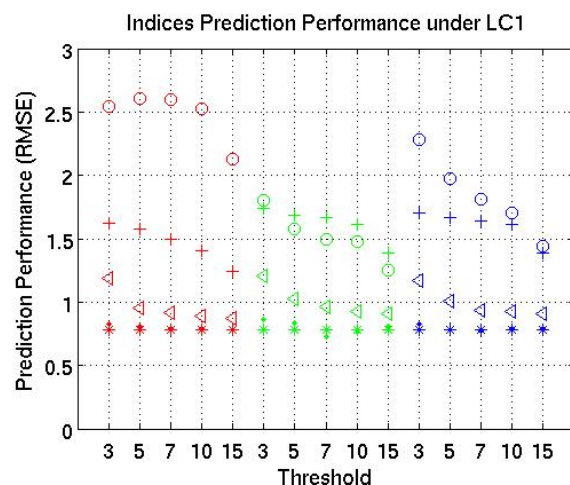
$$MBE = \frac{1}{n} \sum_{i=1}^n \frac{x_p - UR}{UR}$$



LC6

Prediction Performance (RMSE) under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



"+": CGI

"diamond" : DGI

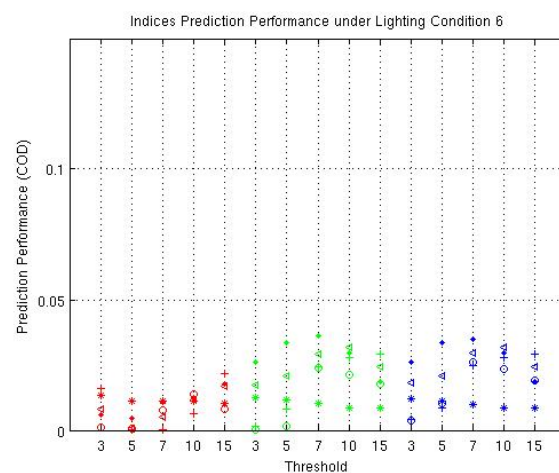
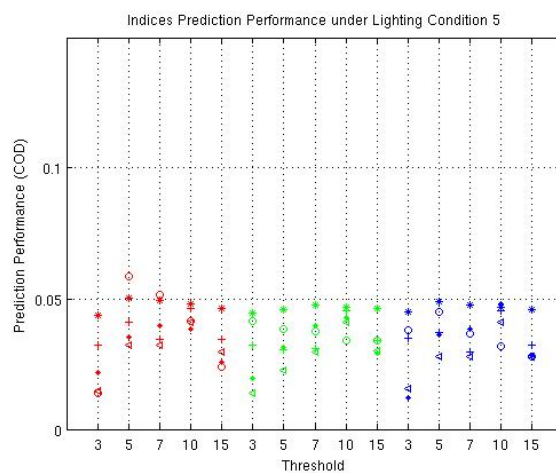
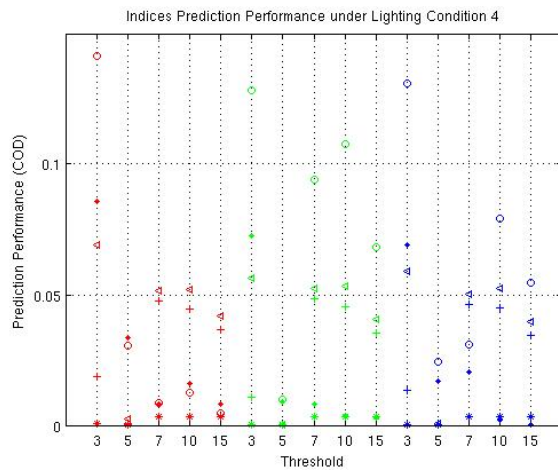
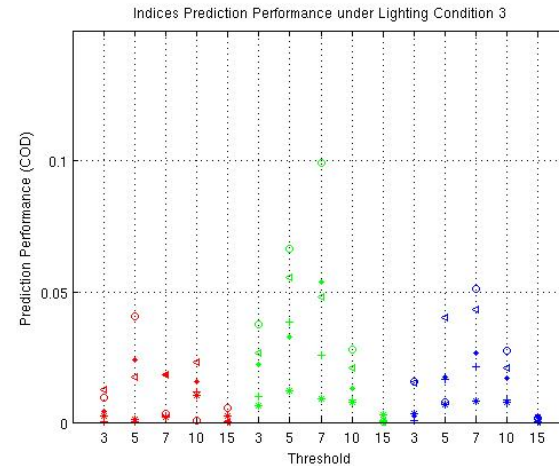
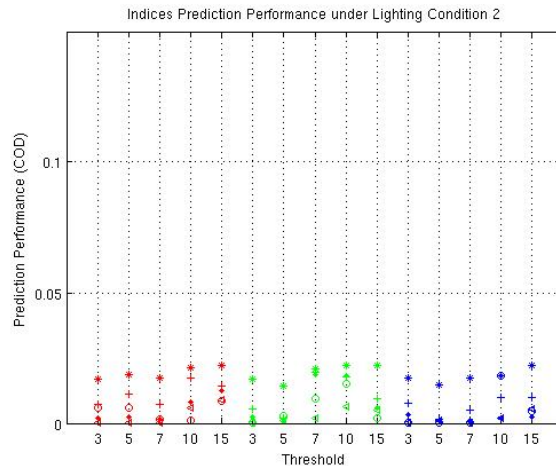
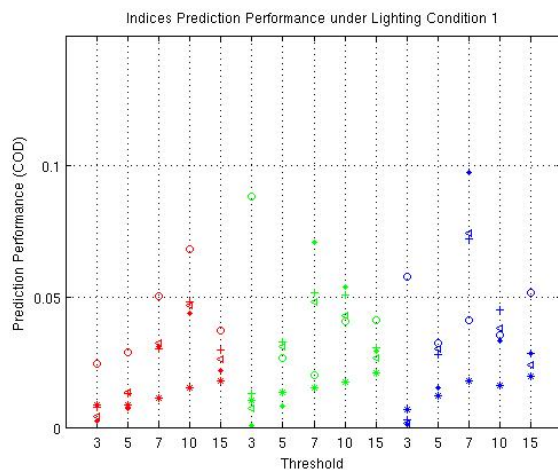
"*": DGP

"<": UGR

"o": VCP

Prediction Performance (COD) under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



“+”: CGI

“.” : DGI

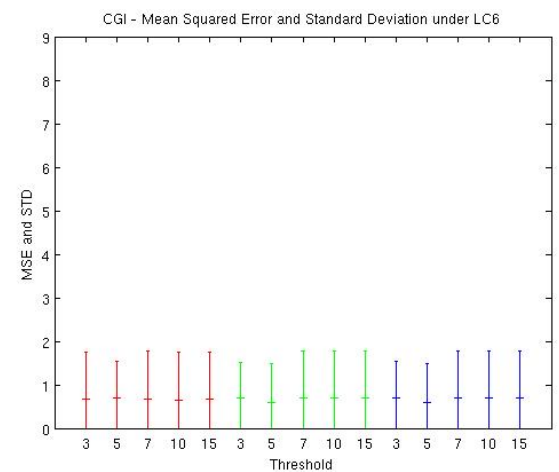
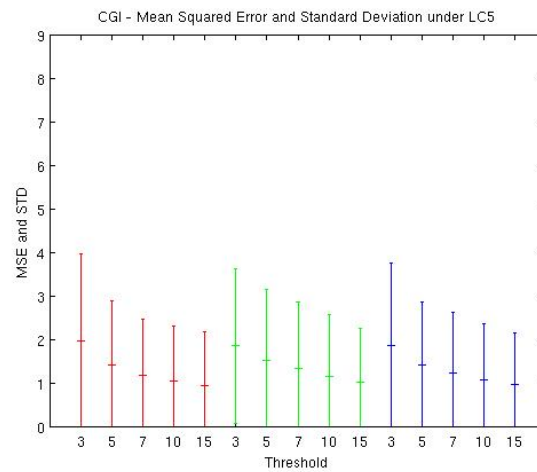
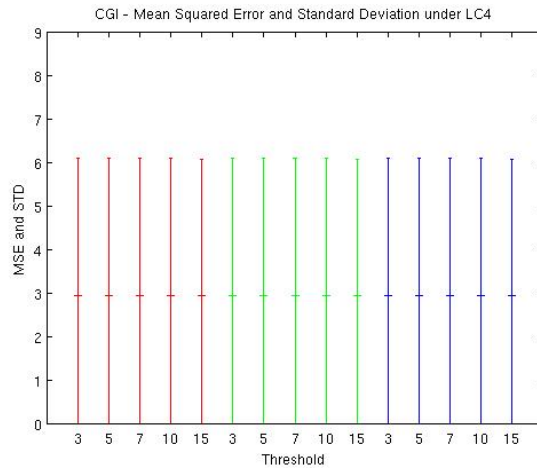
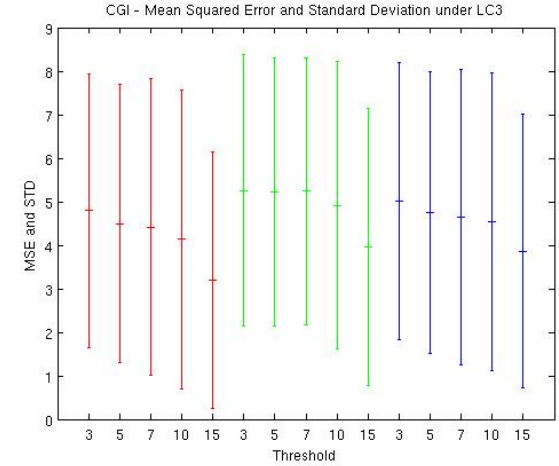
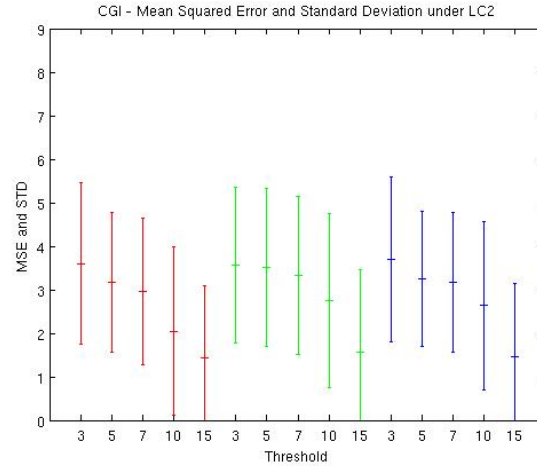
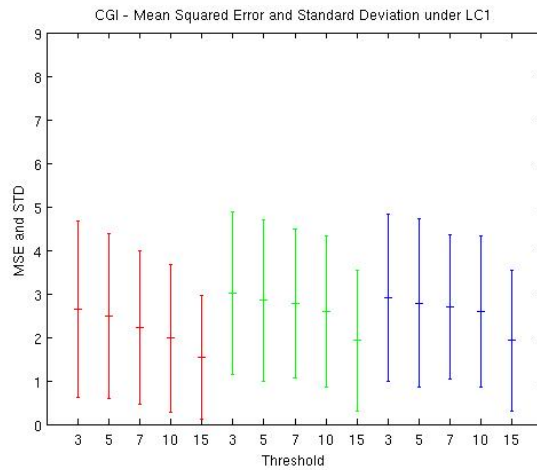
“*”: DGP

“<”: UGR

“o”: VCP

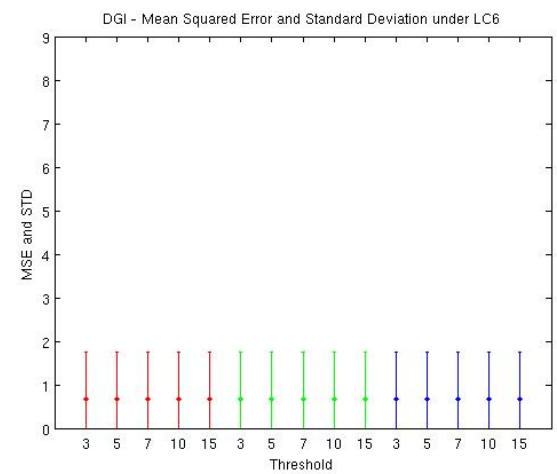
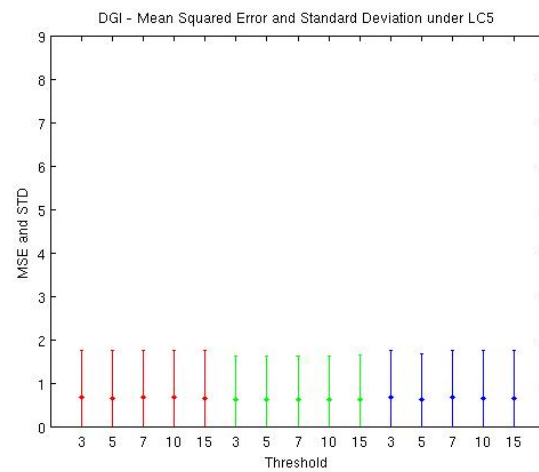
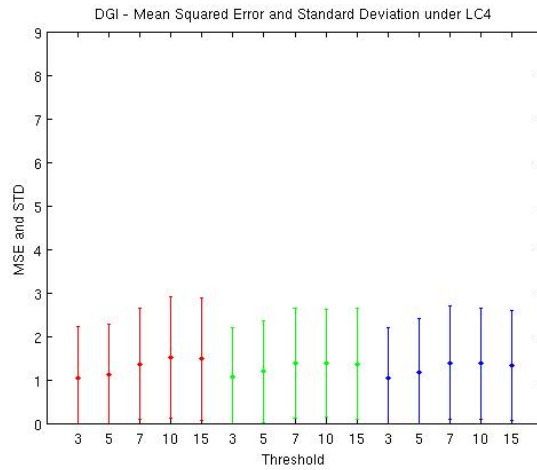
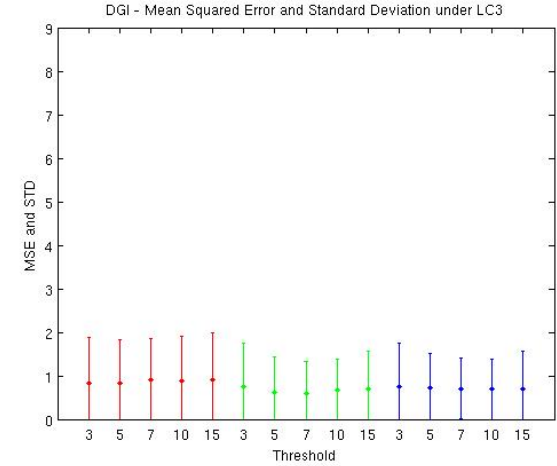
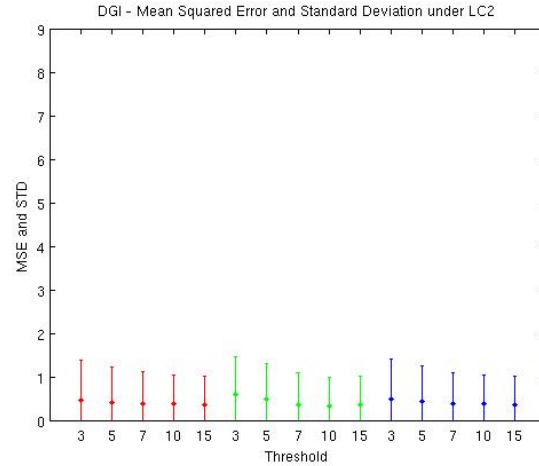
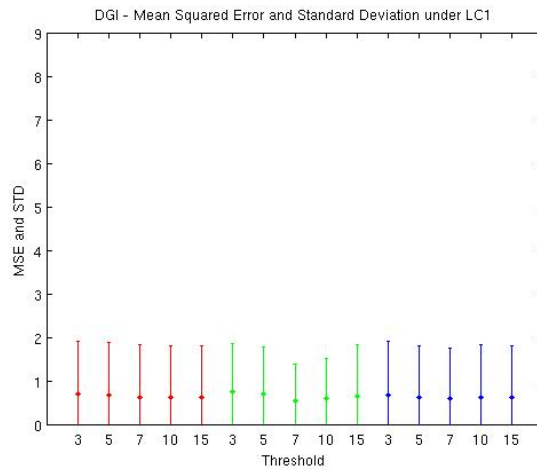
CGI Prediction Performance under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



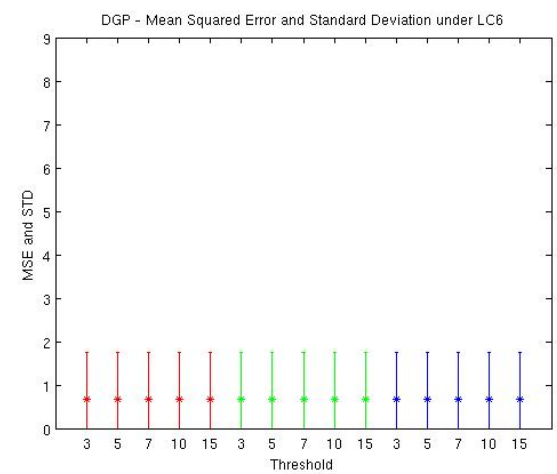
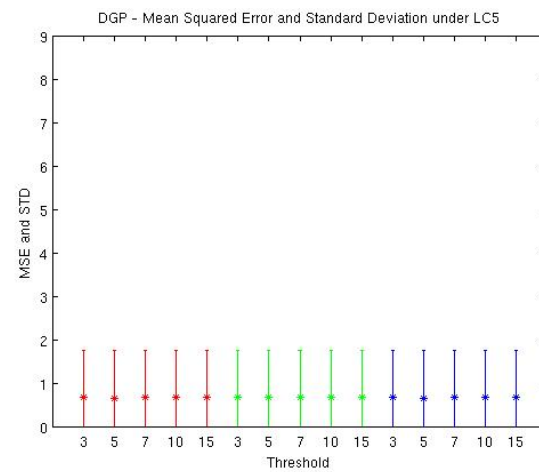
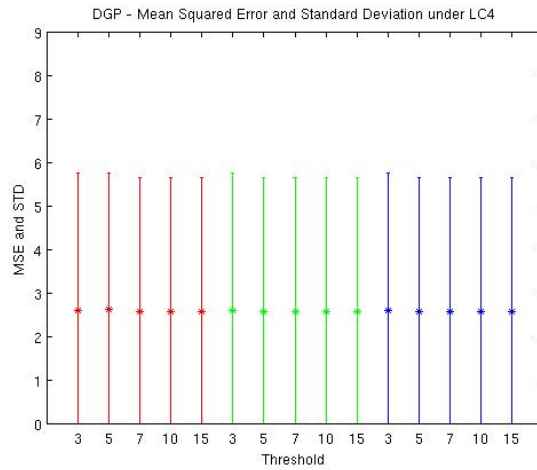
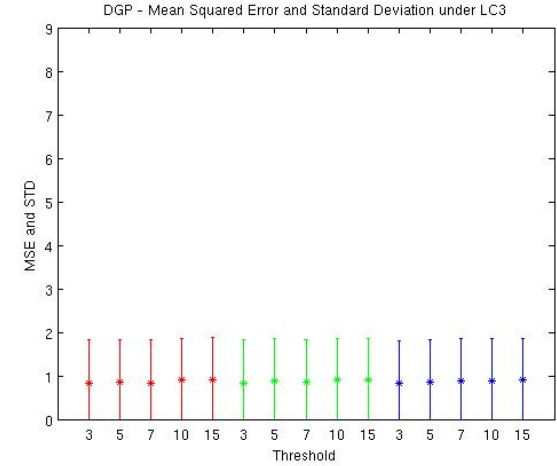
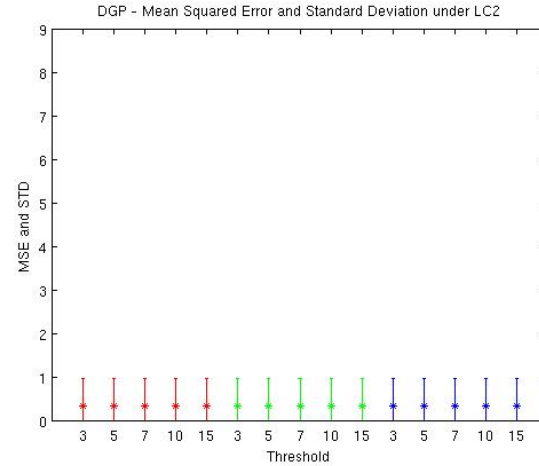
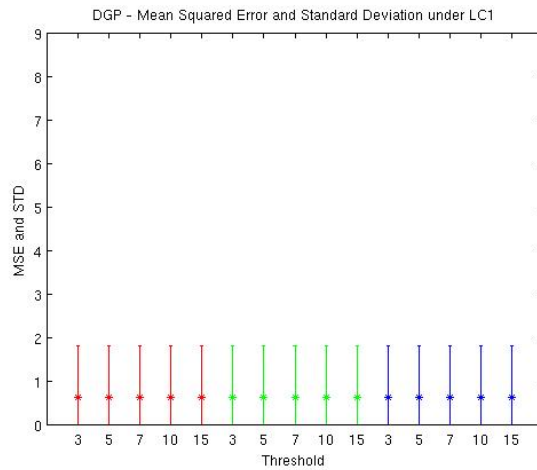
DGI Prediction Performance under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



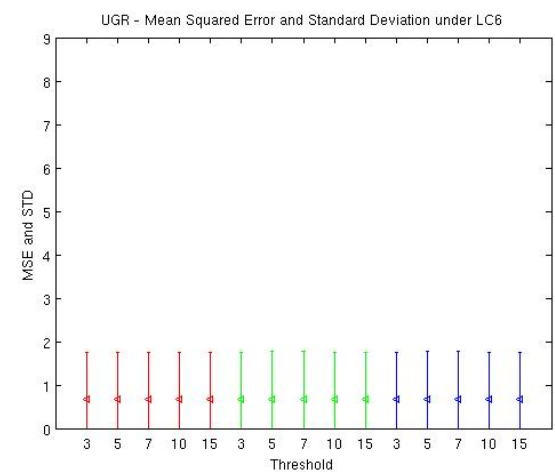
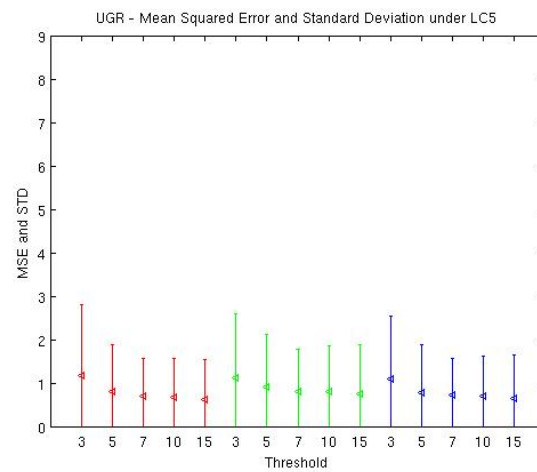
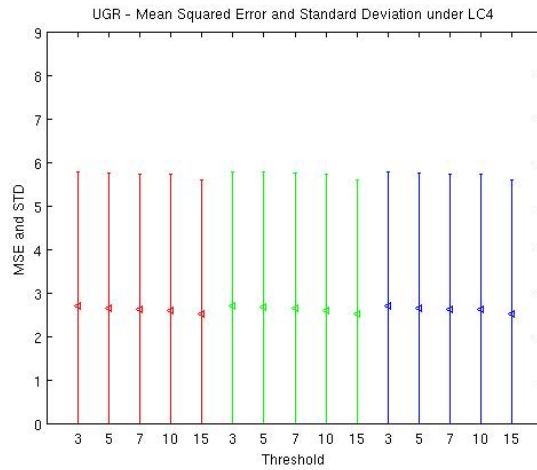
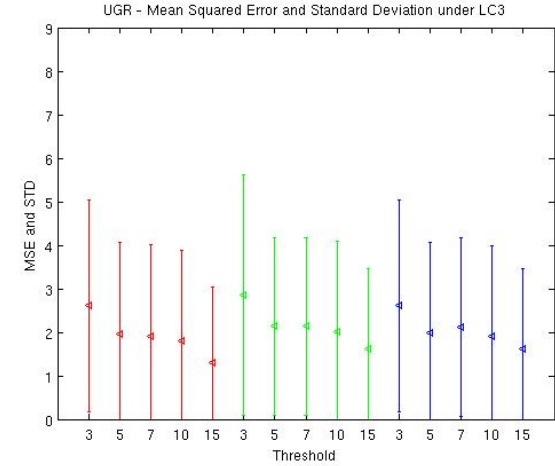
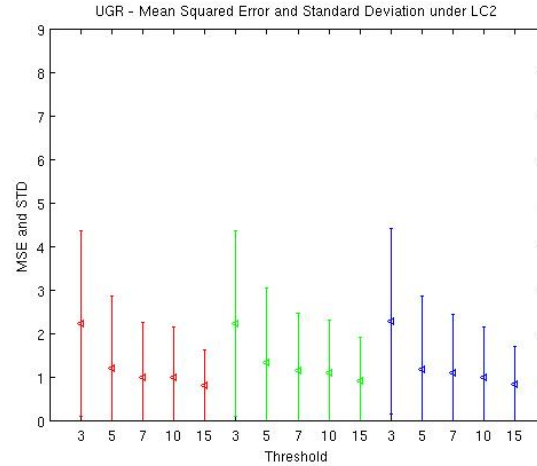
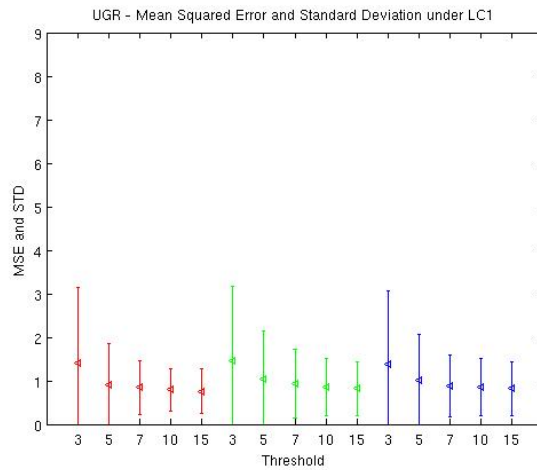
DGP Prediction Performance under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



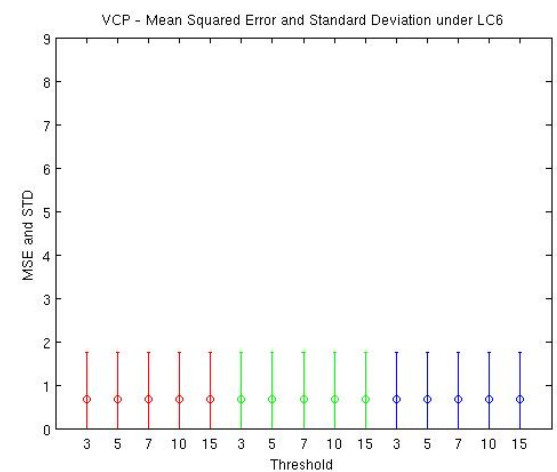
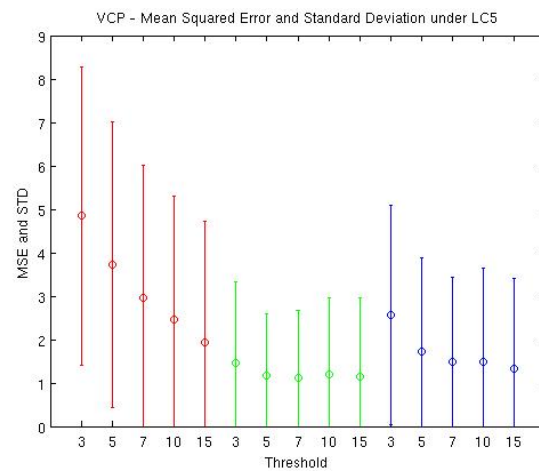
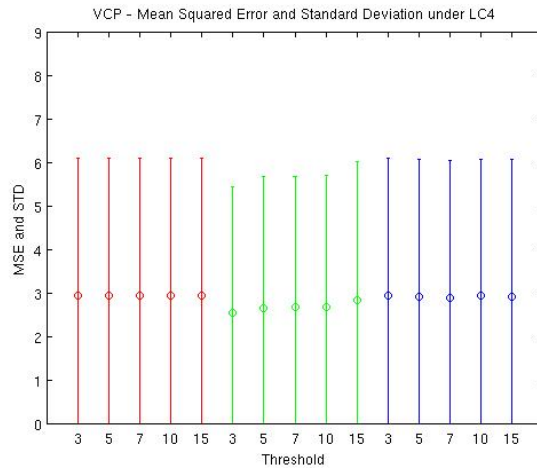
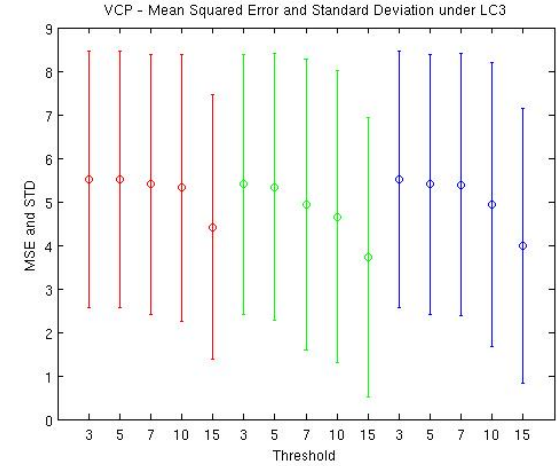
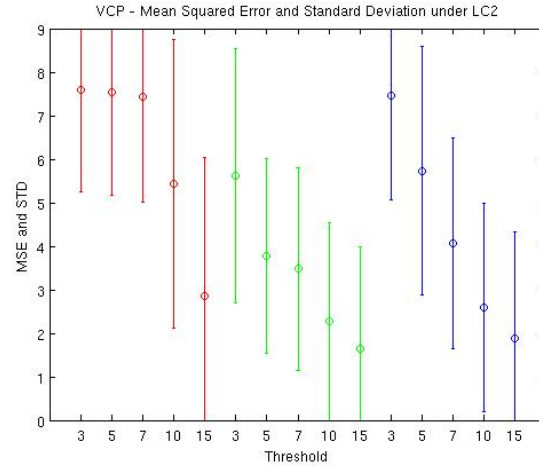
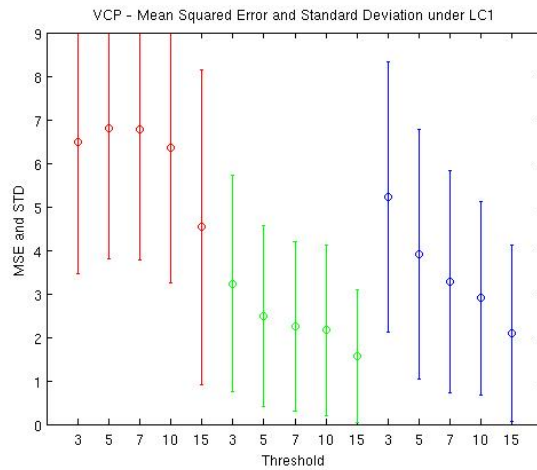
UGR Prediction Performance under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



VCP Prediction Performance under Each Lighting Conditions

Red: Radius=0.2
Green: Radius=0.04
Blue: Radius=0.08



GLARE ANALYSIS & PREDICTION PARAMETERS

- By Comparing the Prediction indices with user ratings(true values), we could have better insight in how to use the tool to make more accurate prediction of a given scenario.
- Specifically, we could have a better knowledge of how to choose the Radius and Threshold values in Evalglare for each index in order to make a better prediction.
- In this project, we have used mean squared error(MSE), root mean squared error(RMSE), mean bias error(MBE) and coefficient of determination(r^2) as indicators of the indices prediction performance.

CONCLUSION

For lighting condition 1 to 5

- The highest threshold and smaller search radius combination works best for most glare indices
- DGI is better predicted for Threshold 3 and search radius 0.2
- DGP predictions are the most robust for all daylit conditions

SENSITIVITY ANALYSIS OF THRESHOLD AND RADIUS FOR GLARE INDICES

- Threshold and Search radius are sensitive parameters for glare evaluations using Radiance based tools such as Evalglare
- By Comparing the prediction parameters with user ratings (true values), we can have better insight in how to use the tool to make more accurate prediction of a given scenario.
- To make a conclusion on how to best use this parameters more lighting scenarios and façade systems should be analyzed

Thank You!