

# Evaluation and validation of the calculation of illuminance in evalglare

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This report summarizes the evaluation of the calculation of illuminance in evalglare [1] to prove the embedded algorithm.

## Theoretical background:

Illuminance can be determined from a luminance-based image when the image covers 180° and the projection method is known. The illuminance calculates

$$E = \int_{H(x)} L(x, \omega) \cdot \cos(\theta) \cdot d\omega \quad (1)$$

with  $H(x)$  : Hemisphere above point x  
 $L(x, \omega)$  : Luminance seen from point x  
 $\cos(\theta) \cdot d\omega$  : Projected solid angle

For an image, this integral can be transferred into a sum:

$$E = \sum_i L_i \cdot \omega_i \cdot \cos(\theta_i) \quad (2)$$

with  $i$  :  $i^{\text{th}}$  Pixel within hemisphere  
 $\omega_i$  : solid angle of pixel  $i$   
 $\theta_i$  : angle between image center and pixel  $i$

Equation (2) is implemented in evalglare. Therefore, evalglare can determine the illuminance from an image as long as the image covers 180°. In general, evalglare supports three different projection methods: angular fish-eye projection, hemispherical fish-eye projection and perspective projection (according to the definitions in the RADIANCE [2] software). The perspective projection cannot cover 180°.

## Methodology

To check the illuminance calculation and to minimize the inaccuracies introduced by raytracing, the calculated values are compared to analytical derived values. To minimize aliasing effects, large images are used (10000x10000 pixels, 8000x8000 for the perspective projection). For this, a “theoretical sun” with an opening angle of 0.5° and with a fixed luminance of 2e9cd/m<sup>2</sup> is placed in the center, and in different angular distances to the center (10°, 30°, 45°, 60° 75° and 85°) in separate images (one image contains one sun only). Except the sun luminance, all other areas of the image contain 0 cd/m<sup>2</sup> values (ideal black). This method allows for the comparison of calculated values from the fish-eye projection with an analytical approximation. For the perspective projection, angles 0°-60° can also be evaluated. With this method, potential errors in the solid-angle calculation would be detected easily, due to the linear relationship of the solid angle in the equation. For the fish-eye projections, a uniform luminance distribution of the entire hemisphere is also compared to the analytical value.

An independently supplied calculation method for the illuminance from author of Radiance has been applied to the images as well. This method is based on the Radiance tool “pcomb” (see appendix).

For the analytical calculation, the following equations are used:

The solid angle of a cone is defined as

$$\omega = 2\pi \cdot (1 - \cos(\alpha/2)) \quad (3)$$

with  $\alpha$ : opening angle of the sun, for  $0.5^\circ$  the solid angle is  $w=0.00005981140$ .

The analytical approximation (valid only for small  $\alpha$ ) for the illuminance is then:

$$E \approx L_{sun} \cdot \omega_{sun} \cdot \cos(\theta) \quad (4)$$

The illuminance for a uniform hemisphere becomes

$$E = \pi \cdot L_{hemisphere} \quad (5)$$

The images were generated by the RADIANCE-tools gensky and rpict. The detailed commands are documented in the appendix. Evalglare version 2.03 was used and all values were identically repeated in the versions 1.11 and 1.12.

## Results

In the following table, the analytically derived illuminance values are compared to the image-calculated values from the two methods (evalglare and the RADIANCE-tool pcomb) for the three supported projection methods:

*Table 1: Comparison between analytical derived illuminance values and values derived from images with different projection methods by using evalglare and the independently provided calculation method based on pcomb.*

Angle [°]	Analytical Value [lux]	Illuminance by pcomb						Illuminance by evalglare					
		angular fish-eye		hemispherical fish-eye		perspective view		angular fish-eye		hemispherical fish-eye		perspective view	
		[lux]	Deviation [%]	[lux]	Deviation [%]	[lux]	Deviation [%]	[lux]	Deviation [%]	[lux]	Deviation [%]	[lux]	Deviation [%]
0	119623	119883	0.22%	120295	0.56%	119251	-0.31%	119824	0.17%	119928	0.25%	119205	-0.35%
10	117805	118422	0.52%	118208	0.34%	117497	-0.26%	118373	0.48%	117847	0.04%	117484	-0.27%
30	103596	103193	-0.39%	103675	0.08%	103238	-0.35%	103174	-0.41%	104007	0.40%	103211	-0.37%
45	84586	85071	0.57%	84535	-0.06%	84444	-0.17%	85079	0.58%	84805	0.26%	84423	-0.19%
60	59811	59998	0.31%	59892	0.14%	59913	0.17%	59992	0.30%	60084	0.46%	59902	0.15%
75	30961	30930	-0.10%	30385	-1.86%			30916	-0.14%	30482	-1.55%		
85	10426	10399	-0.26%	10667	2.31%			10399	-0.26%	10802	3.60%		
uniform sky	31416	31421	0.02%	31381	-0.11%			31421	0.02%	31398	-0.06%		

The results in table 1 show that the deviations are generally very low. Except for the two largest angles for the hemispherical projection, all deviations are less than 0.6%. The deviations for  $75^\circ$  and  $85^\circ$  for the hemispherical projection are due to aliasing effects as well as the relatively small number of pixels at the sun disk near the border of the image in the hemispherical projection method.

The independently supplied calculation method from the author of Radiance arrives at nearly identical results for illuminance as evalglare.

## Conclusion

From the results, it can be concluded that the illuminance calculation in evalglare is reliable and delivers correct values. Remaining deviations to analytical values are very small and due to rounding and aliasing errors.

## Acknowledgement

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## References

- [1] Wienold, Jan. Evalglare: A new RADIANCE-based tool to evaluate glare in office spaces, 3rd International Radiance Workshop, 2004, Fribourg, CH.
- [2] Greg Ward Larson and Rob A. Shakespeare. Rendering with Radiance, Morgan Kaufmann Publishers, 1998, Revised edition 2007, ISBN 0-9745381-0-8.

## Appendix – Documentation of the applied bash scripts to generate the illuminance values with evalglare for three projection methods

```
#!/bin/bash
for ang in 0.0000001 10 30 45 60 75 85
do
# fix the sun luminance to 2e9 cd/m2
echo " void light solar 0 0 3 11173184.36 11173184.36 11173184.36 " >sky.rad
gensky -ang $ang 0 +s |awk '{ if (NR>7 && NR<13) print $0 }'>>sky.rad
oconv -f sky.rad >sky.oct

# angular projection, 180°
e_vta=`rpict -vp 0 0 0 -vd 0 -1 0 -dj 0 -ps 0 -dc 1 -dt 0 -x 10000 -y 10000 -ab 0 -vta -vh 180 -vv 180 sky.oct |evalglare -d -x -V `
# hemispherical projection, 180°
e_vth=`rpict -vp 0 0 0 -vd 0 -1 0 -dj 0 -ps 0 -dc 1 -dt 0 -x 10000 -y 10000 -ab 0 -vth -vh 180 -vv 180 sky.oct |evalglare -d -x -V `
# perspective projection, 122°
e_vtv=`rpict -vp 0 0 0 -vd 0 -1 0 -dj 0 -ps 0 -dc 1 -dt 0 -x 8000 -y 8000 -ab 0 -vtv -vh 122 -vv 122 sky.oct |evalglare -f -d -x -V |awk '
END{print $1 }'

#print values
echo $ang $e_vta $e_vth $e_vtv
done

----- for the uniform sky -----
#sky description, uniform_sky.rad
void glow sky_glow
0
0
4 55.86592178771 55.86592178771 55.86592178771 0
sky_glow source sky
0
0
4 0 0 1 180

-----
oconv -f uniform_sky.rad >sky.oct
# angular projection, 180°
rpict -ab 0 -ps 0 -vd 0 0 1 -vu 0 1 0 -vta -vv 180 -vh 180 -x 10000 -y 10000 sky.oct> uni_vta.hdr
evalglare -V uni_vta.hdr
# hemispherical projection, 180°
rpict -ab 0 -ps 0 -vd 0 0 1 -vu 0 1 0 -vth -vv 180 -vh 180 -x 10000 -y 10000 sky.oct> uni_vth.hdr
evalglare -V uni_vth.hdr

----- independend calculation method provided by the Radiance author -----

pcomb -e `vwright -vf input.hdr V` \
-e 'dot=Dx(1)*Vdx+Dy(1)*Vdy+Dz(1)*Vdz' \
-e 'lo=if(dot,WE*S(1)*dot*li(1),0)' -o input.hdr \
| pvalue -h -H -b -df \
| total -if
```