A Historical Comparison of Glare Metrics

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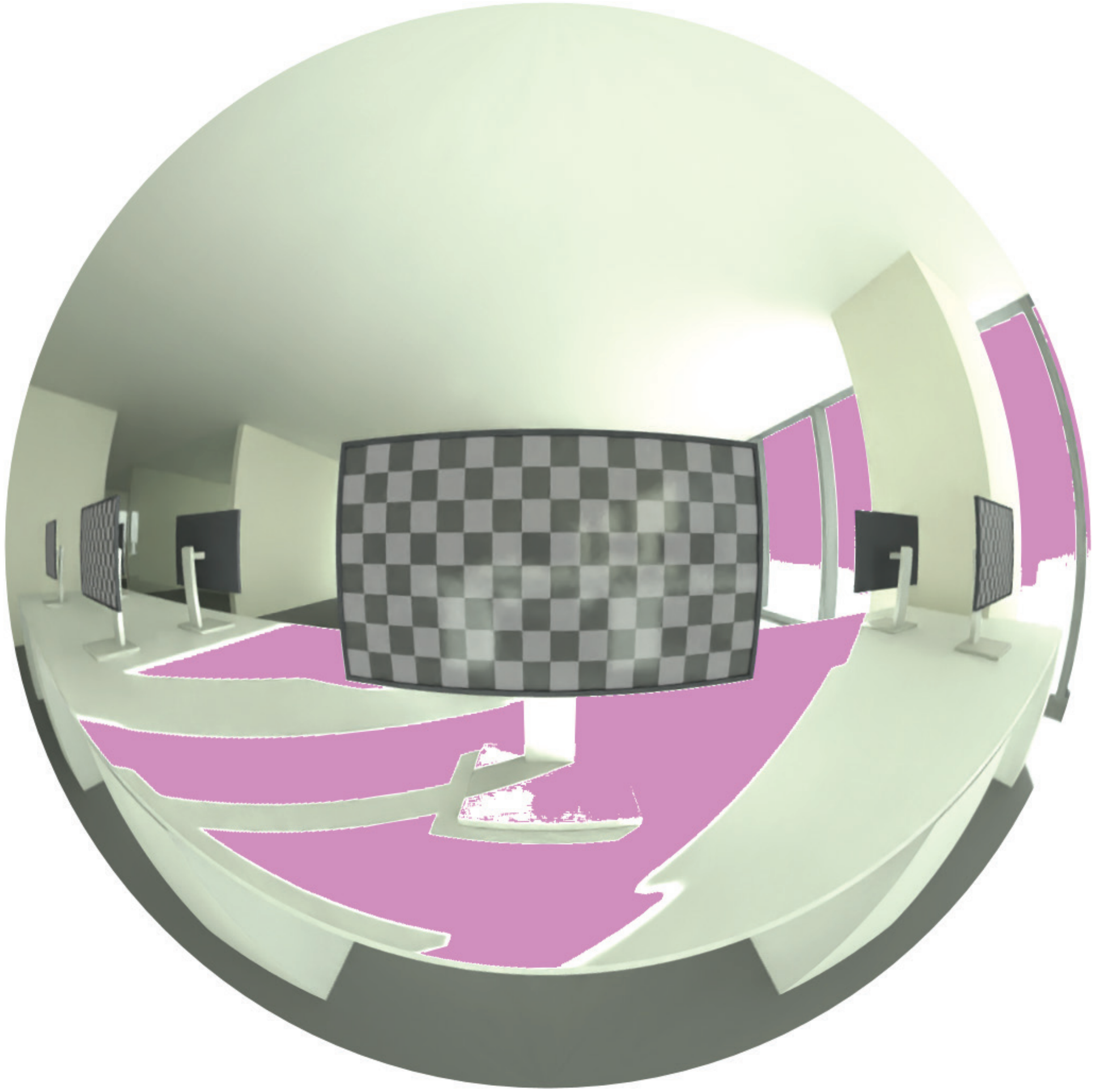


Glare metrics. A history, but why?

• It is pleasant and sometimes useful to understand the basis of how we arrived at today's evaluation methods, including sources of disagreement.

• There are broad impressions of glare prediction equations in research and practice, but we rarely have a good comparative understanding of how they lead us to interpret the luminous environment.

• I thought it was interesting!

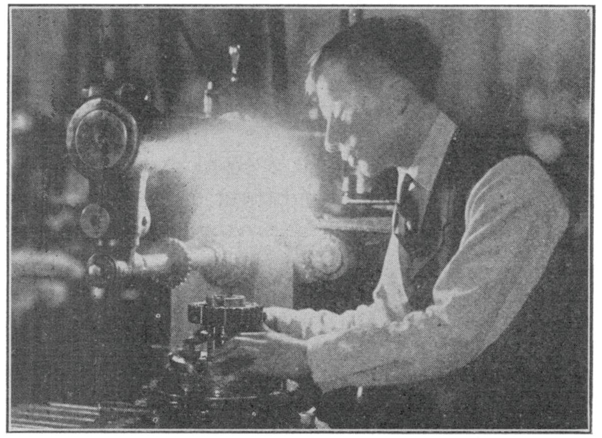


Fig. 1—Glaring Light from Unshaded Local Lamp which is a Menace to Safety and to Vision

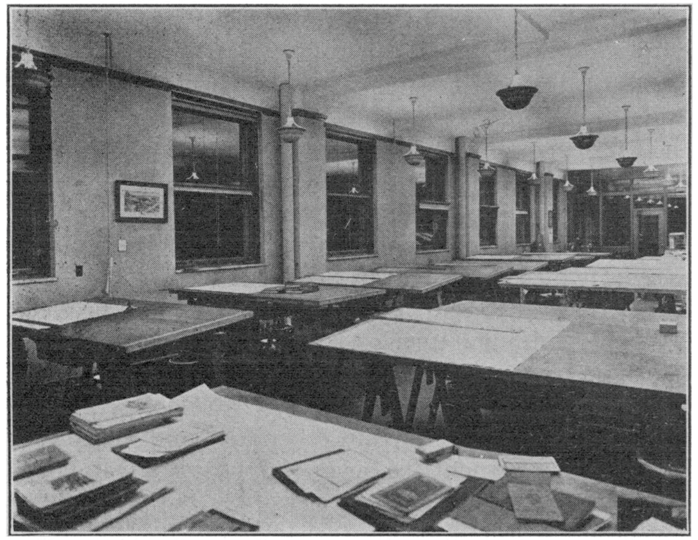
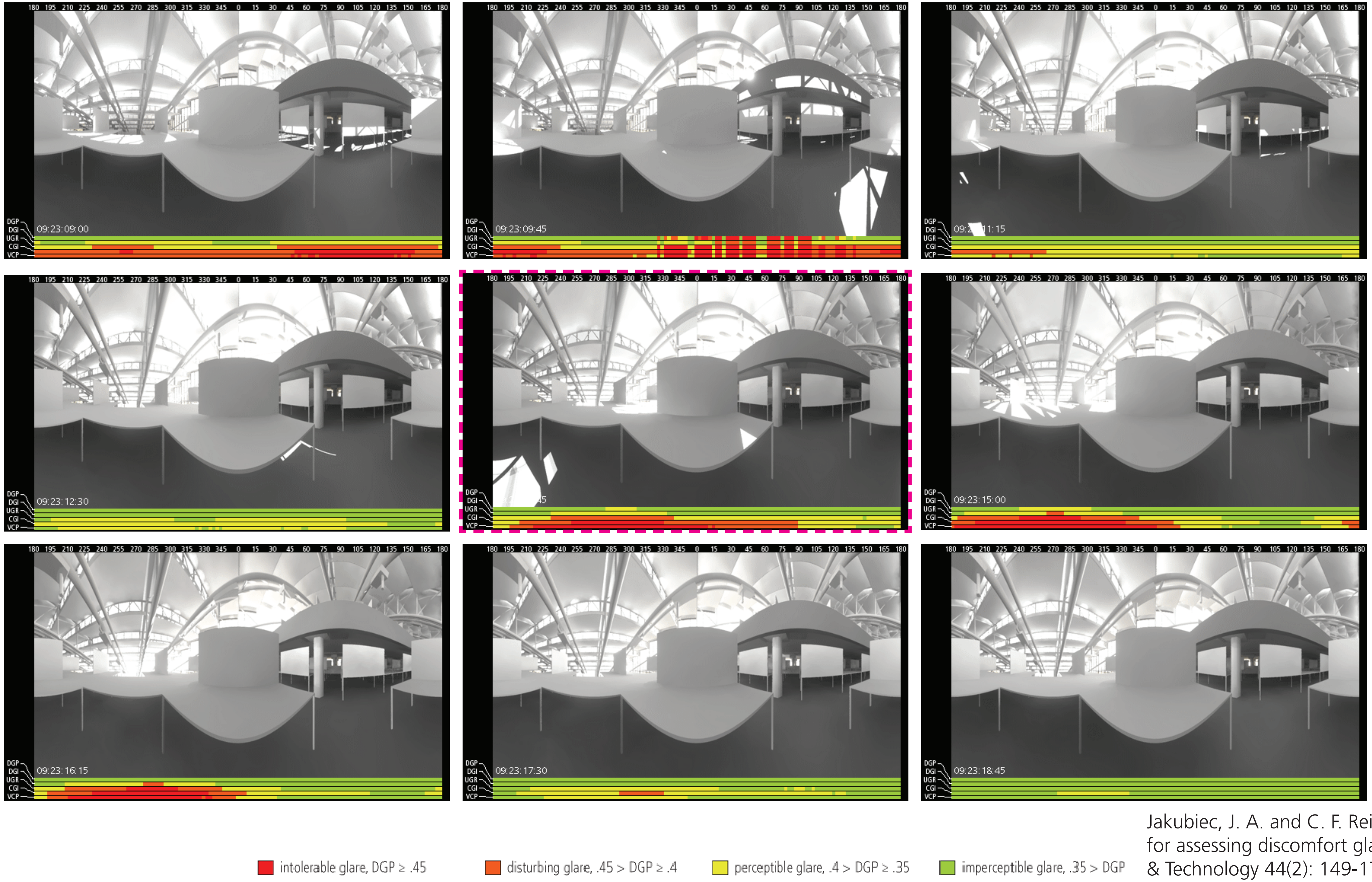


Fig. 7—An Ample Supply of Soft Well Diffused Light and Particularly Freedom from Shadows is Required for Drafting Rooms

Fig. 8—Ample Illumination without Glare

Harrison, W. (1922). "Light without glare." Transactions of the American Institute of Electrical Engineers 41: 439-445.

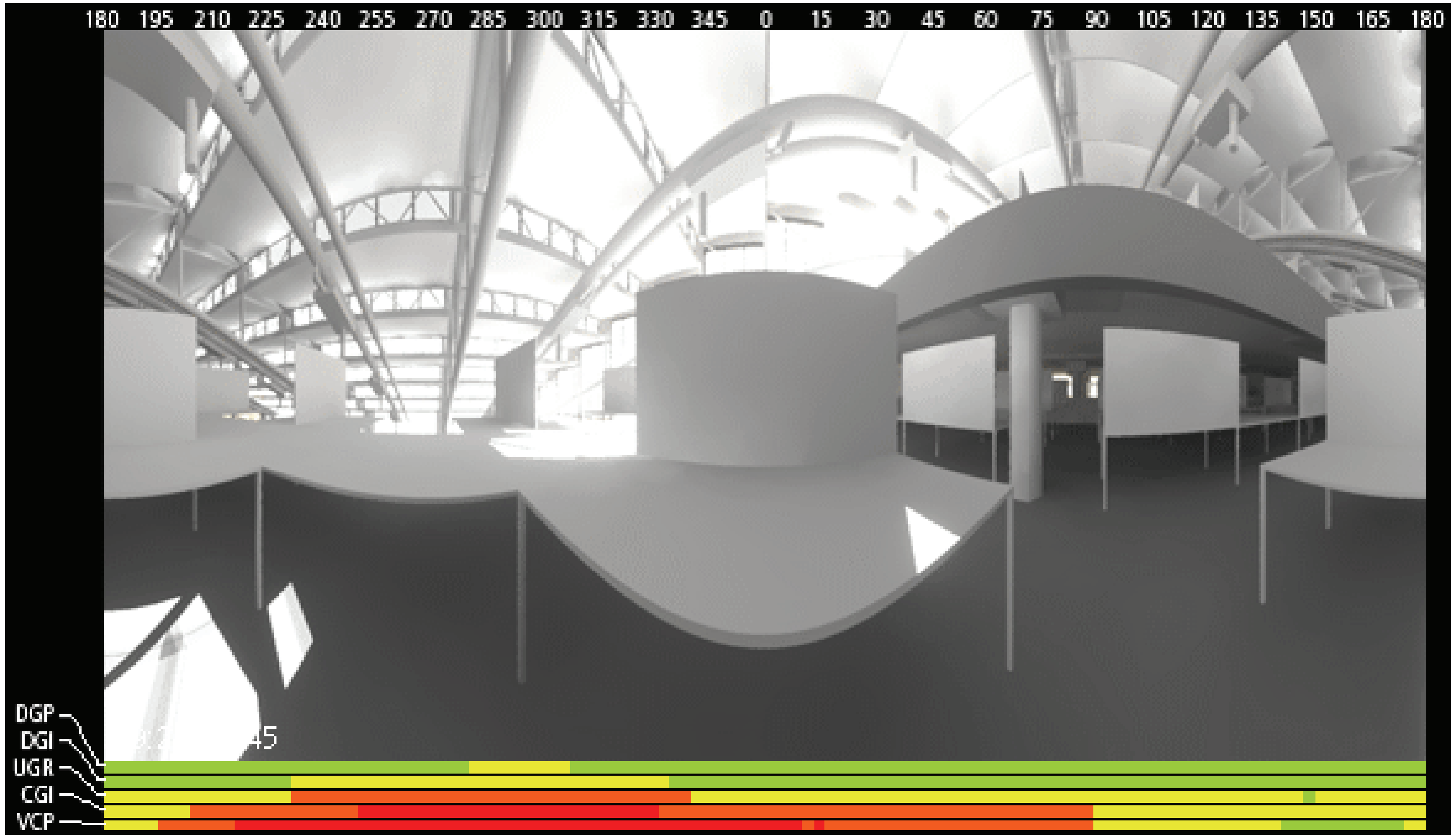
My own (early) history with glare



- Compared five glare metrics spatially in three strongly daylit spaces.
- DGP worked the best as per expectations in such spaces.
- Now: what about deeper floor plans, etc?
- Received a stern talking to from Harvard research computing for bring their computing cluster to a crawl...

Jakubiec, J. A. and C. F. Reinhart (2012). “The ‘adaptive zone’–A concept for assessing discomfort glare throughout daylit spaces.” Lighting Research & Technology 44(2): 149-170.

My own (early) history with glare



intolerable glare, DGP ≥ .45 | disturbing glare, .45 > DGP ≥ .4 | perceptible glare, .4 > DGP ≥ .35 | imperceptible glare, .35 > DGP

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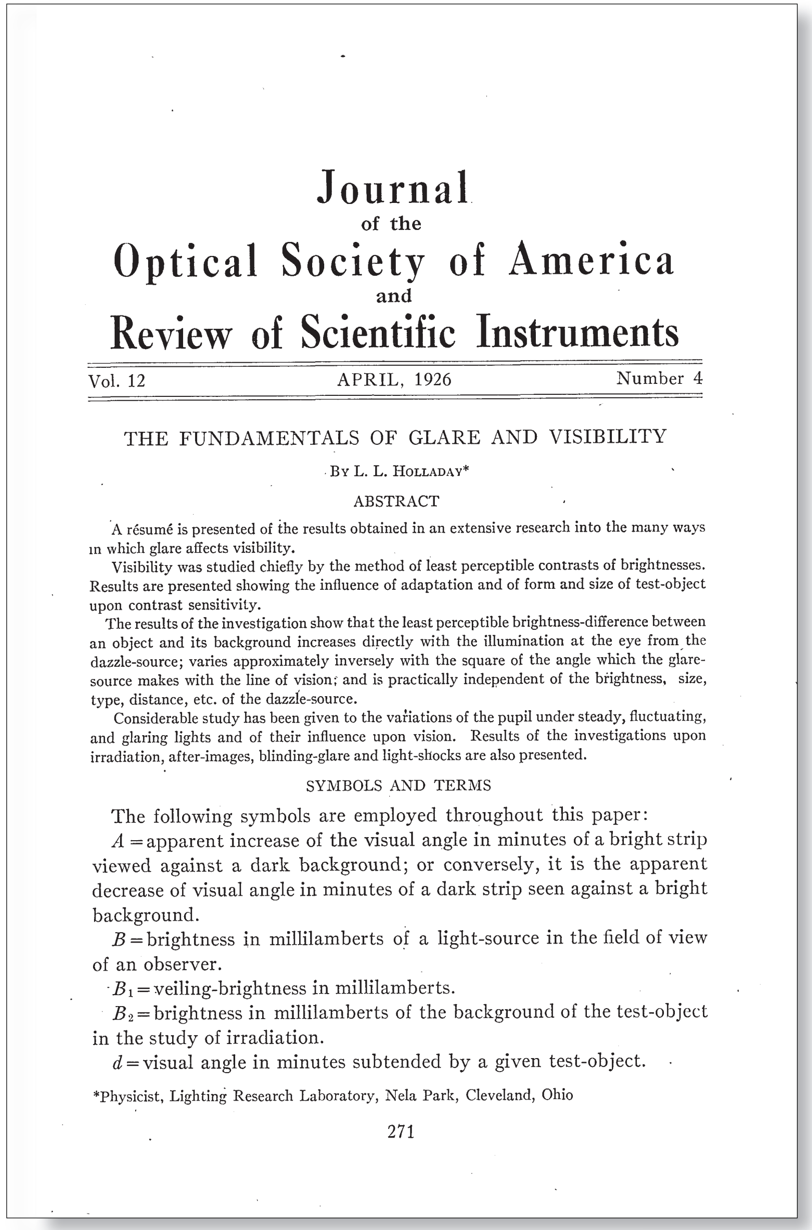
Methods, history

- (Selected) historical commentary
  - Measurement methods
  - Data collection methods / scales



Journal of the Optical Society of America and Review of Scientific Instruments

Vol. 12 APRIL, 1926 Number 4

THE FUNDAMENTALS OF GLARE AND VISIBILITY

By L. L. Holladay*

ABSTRACT

A résumé is presented of the results obtained in an extensive research into the many ways in which glare affects visibility.

Visibility was studied chiefly by the method of least perceptible contrasts of brightnesses. Results are presented showing the influence of adaptation and of form and size of test-object upon contrast sensitivity.

The results of the investigation show that the least perceptible brightness-difference between an object and its background increases directly with the illumination at the eye from the dazzle-source; varies approximately inversely with the square of the angle which the glare-source makes with the line of vision; and is practically independent of the brightness, size, type, distance, etc. of the dazzle-source.

Considerable study has been given to the variations of the pupil under steady, fluctuating, and glaring lights and of their influence upon vision. Results of the investigations upon irradiation, after-images, blinding-glare and light-shocks are also presented.

SYMBOLS AND TERMS

The following symbols are employed throughout this paper:

A = apparent increase of the visual angle in minutes of a bright strip viewed against a dark background; or conversely, it is the apparent decrease of visual angle in minutes of a dark strip seen against a bright background.

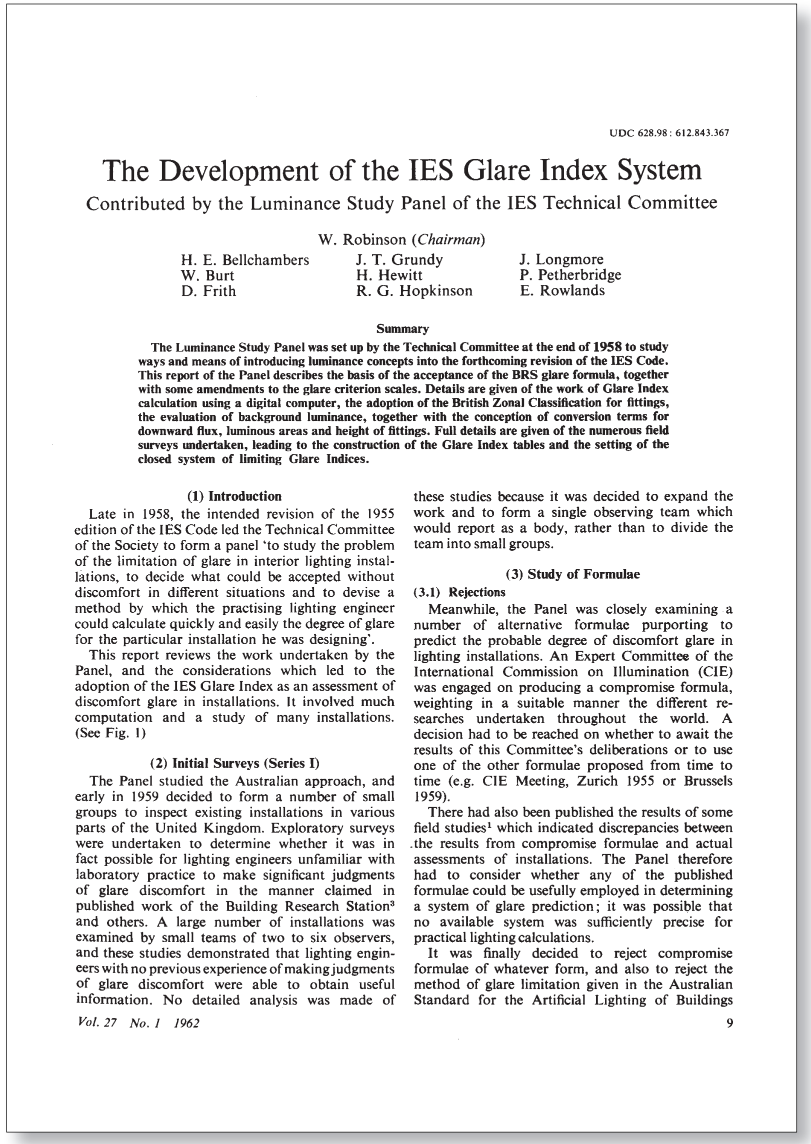
B = brightness in millilamberts of a light-source in the field of view of an observer.

B_1 = veiling-brightness in millilamberts.

B_2 = brightness in millilamberts of the background of the test-object in the study of irradiation.

d = visual angle in minutes subtended by a given test-object.

*Physicist, Lighting Research Laboratory, Nela Park, Cleveland, Ohio



UDC 628.98 : 612.843.367

The Development of the IES Glare Index System

Contributed by the Luminance Study Panel of the IES Technical Committee

W. Robinson (*Chairman*)

H. E. Bellchambers, W. Burt, D. Frith, J. T. Grundy, H. Hewitt, R. G. Hopkinson, J. Longmore, P. Petherbridge, E. Rowlands

Summary

The Luminance Study Panel was set up by the Technical Committee at the end of 1958 to study ways and means of introducing luminance concepts into the forthcoming revision of the IES Code. This report of the Panel describes the basis of the acceptance of the BRS glare formula, together with some amendments to the glare criterion scales. Details are given of the work of Glare Index calculation using a digital computer, the adoption of the British Zonal Classification for fittings, the evaluation of background luminance, together with the conception of conversion terms for downward flux, luminous areas and height of fittings. Full details are given of the numerous field surveys undertaken, leading to the construction of the Glare Index tables and the setting of the closed system of limiting Glare Indices.

(1) Introduction

Late in 1958, the intended revision of the 1955 edition of the IES Code led the Technical Committee of the Society to form a panel 'to study the problem of the limitation of glare in interior lighting installations, to decide what could be accepted without discomfort in different situations and to devise a method by which the practising lighting engineer could calculate quickly and easily the degree of glare for the particular installation he was designing'.

This report reviews the work undertaken by the Panel, and the considerations which led to the adoption of the IES Glare Index as an assessment of discomfort glare in installations. It involved much computation and a study of many installations. (See Fig. 1)

(2) Initial Surveys (Series I)

The Panel studied the Australian approach, and early in 1959 decided to form a number of small groups to inspect existing installations in various parts of the United Kingdom. Exploratory surveys were undertaken to determine whether it was in fact possible for lighting engineers unfamiliar with laboratory practice to make significant judgments of glare discomfort in the manner claimed in published work of the Building Research Station[3] and others. A large number of installations was examined by small teams of two to six observers, and these studies demonstrated that lighting engineers with no previous experience of making judgments of glare discomfort were able to obtain useful information. No detailed analysis was made of these studies because it was decided to expand the work and to form a single observing team which would report as a body, rather than to divide the team into small groups.

(3) Study of Formulae

(3.1) Rejections

Meanwhile, the Panel was closely examining a number of alternative formulae purporting to predict the probable degree of discomfort glare in lighting installations. An Expert Committee of the International Commission on Illumination (CIE) was engaged on producing a compromise formula, weighting in a suitable manner the different researches undertaken throughout the world. A decision had to be reached on whether to await the results of this Committee's deliberations or to use one of the other formulae proposed from time to time (e.g. CIE Meeting, Zurich 1955 or Brussels 1959).

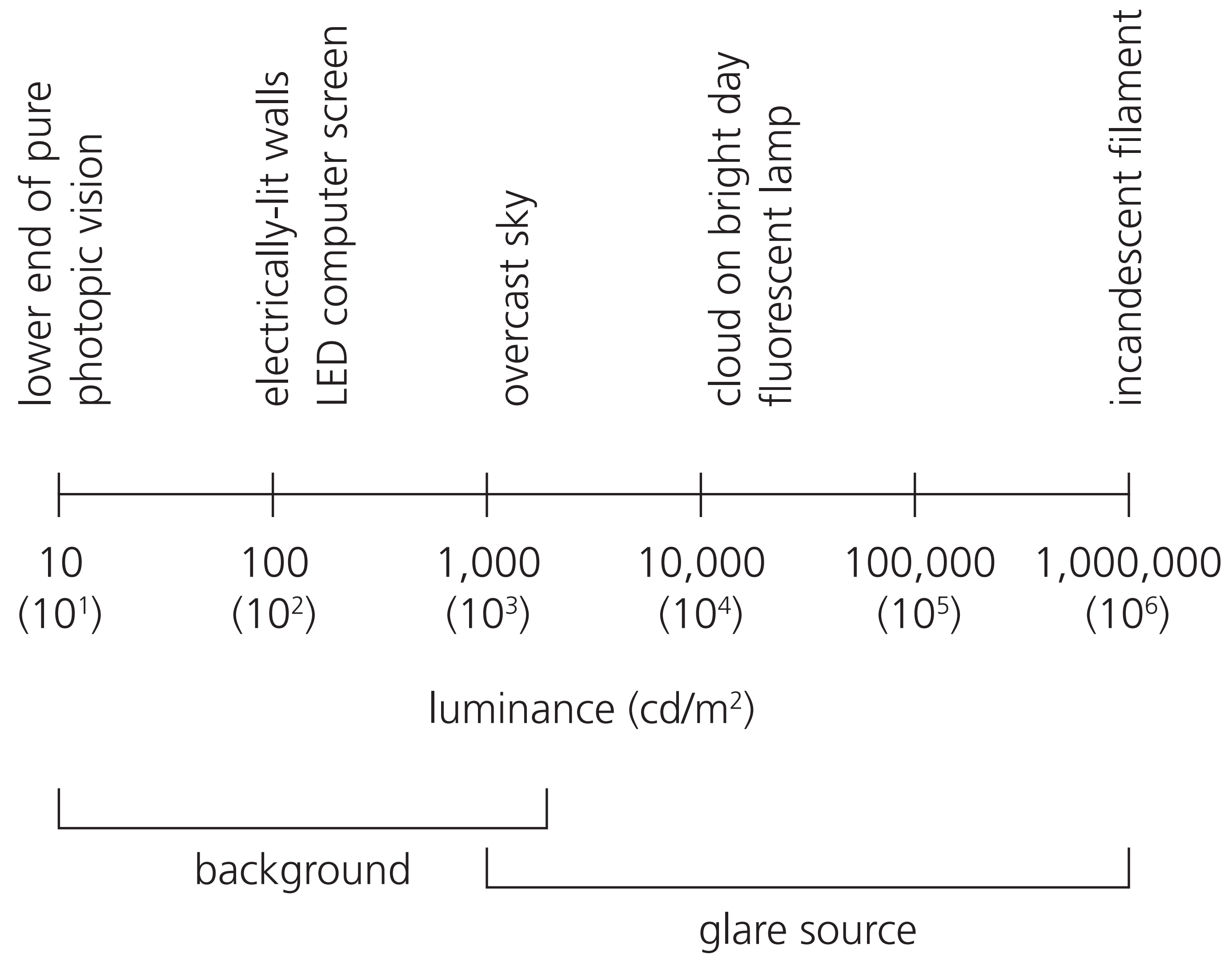
There had also been published the results of some field studies[1] which indicated discrepancies between the results from compromise formulae and actual assessments of installations. The Panel therefore had to consider whether any of the published formulae could be usefully employed in determining a system of glare prediction; it was possible that no available system was sufficiently precise for practical lighting calculations.

It was finally decided to reject compromise formulae of whatever form, and also to reject the method of glare limitation given in the Australian Standard for the Artificial Lighting of Buildings

Methods, calculations: luminance

- (Selected) historical commentary
  - Measurement methods
  - Data collection methods / scales

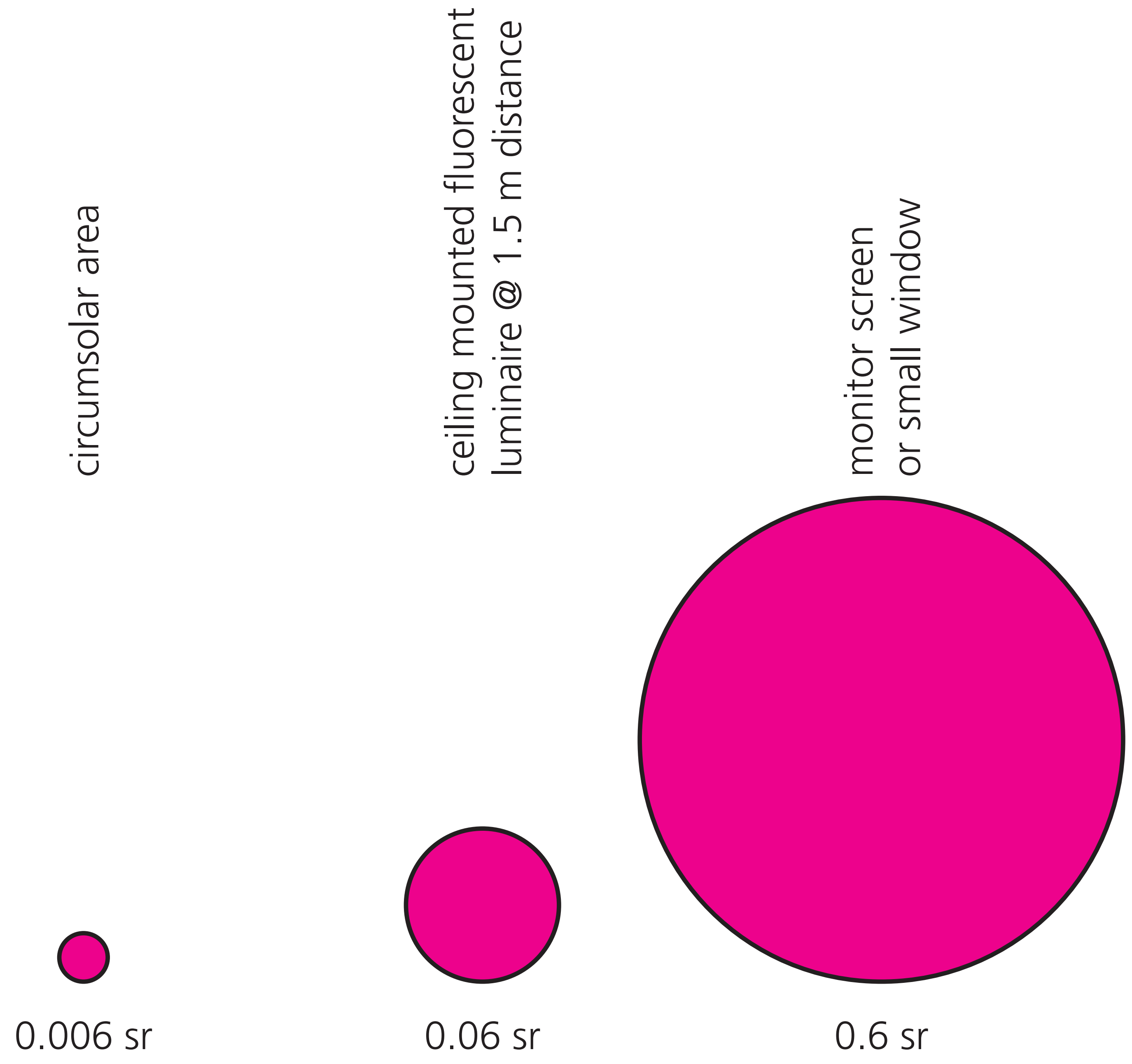
- Calculation comparisons
  - Range of luminances
    - source (Ls = 1,000 - 1,000,000 cd/m^2)
    - background (Lb = 10 - 3,000 cd/m^2)



Methods, calculations: solid angle

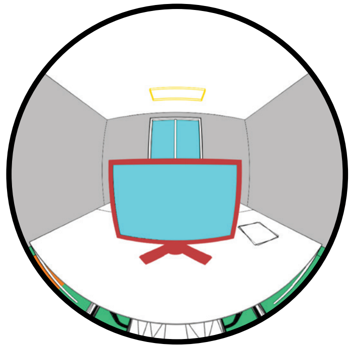
- (Selected) historical commentary
    - Measurement methods
    - Data collection methods / scales

- Calculation comparisons
    - Range of luminances
        - source (Ls = 1,000 - 1,000,000 cd/m^2)
        - background (Lb = 10 - 3,000 cd/m^2)
    - Range of source solid angles (ω = 0.006, 0.06, 0.6 sr)

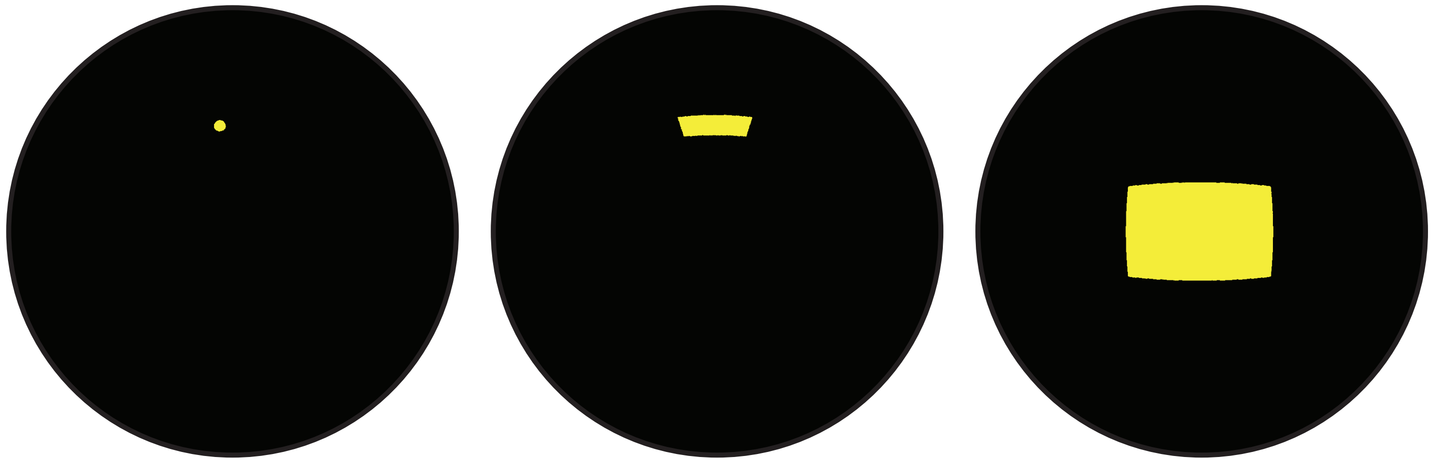


Methods, calculations: solid angle

- (Selected) historical commentary
  - Measurement methods
  - Data collection methods / scales



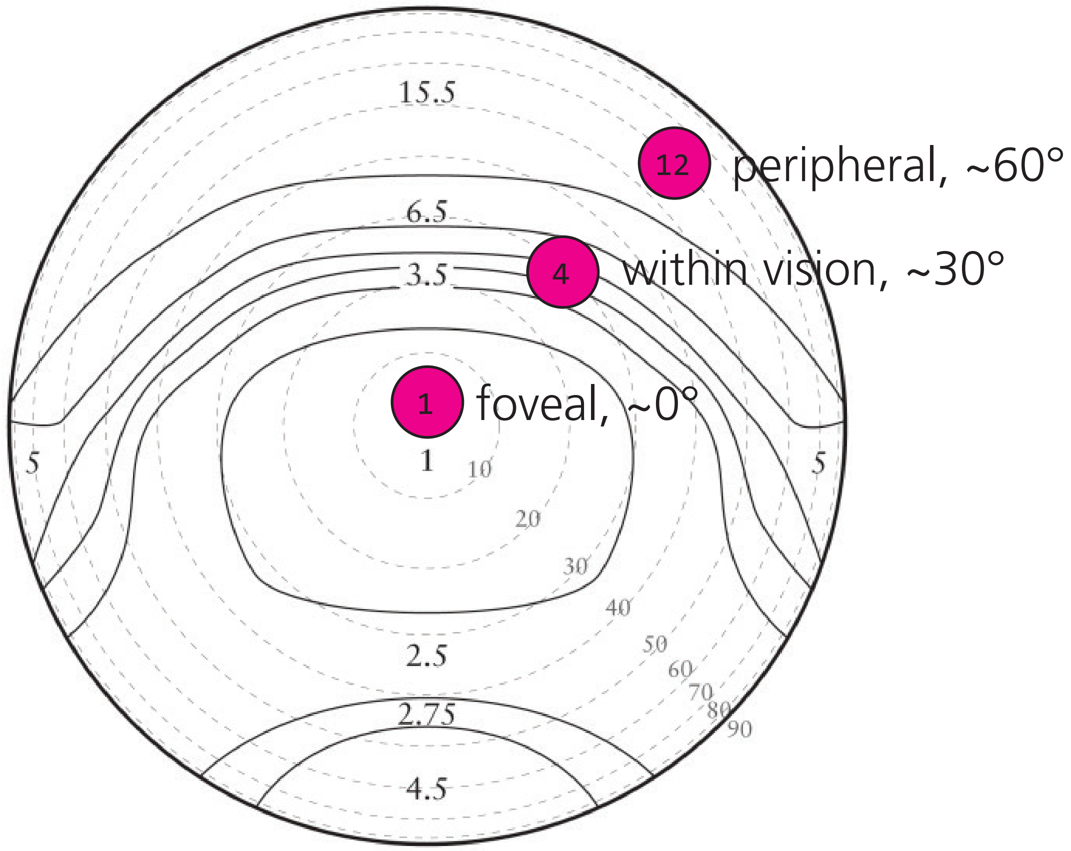
- Calculation comparisons
  - Range of luminances
    - source (Ls = 1,000 - 1,000,000 cd/m^2)
    - background (Lb = 10 - 3,000 cd/m^2)
  - Range of source solid angles (ω = 0.006, 0.06, 0.6 sr)



Methods, calculations: position index

- (Selected) historical commentary
  - Measurement methods
  - Data collection methods / scales

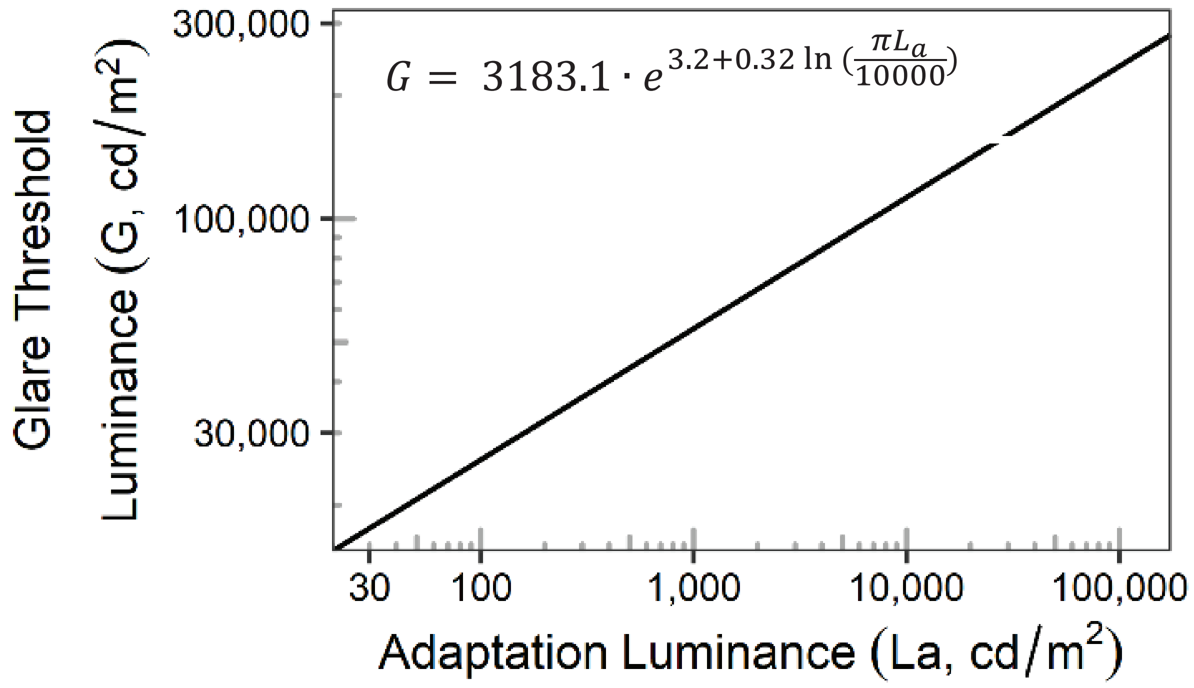
- Calculation comparisons
  - Range of luminances
    - source (L_s = 1,000 - 1,000,000 cd/m^2)
    - background (L_b = 10 - 3,000 cd/m^2)
  - Range of source solid angles (ω = 0.006, 0.06, 0.6 sr)
  - Range of position indices (P = 1, 4, 12)



Experimental procedures and a first metric

Nutting's glare threshold (1916)

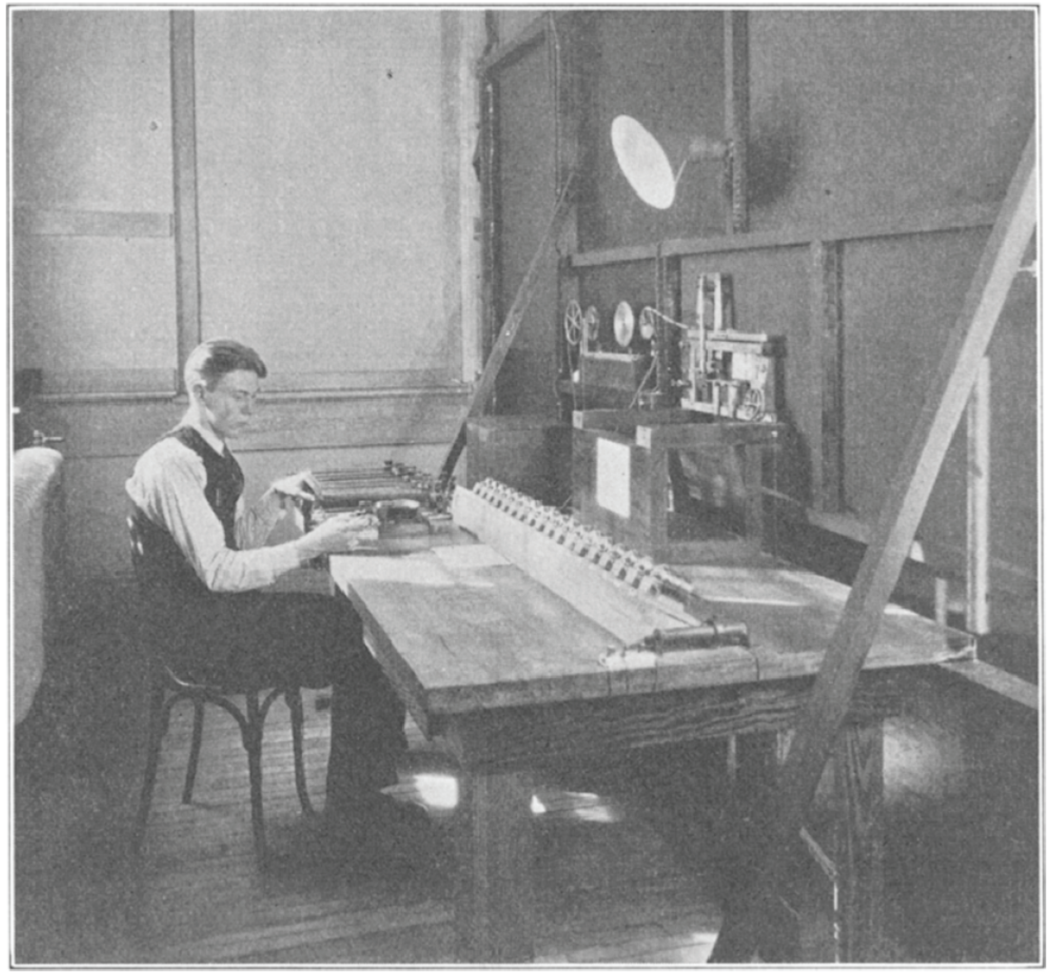
- 3 participants
- Allowed to acclimate to a background luminance
- Rapidly switched vision to a small, bright source
- Simple threshold metric
- Combined, with some creativity, to design guidelines based on inverse square law (Ward Harrison 1920's)



Nutting, P. (1916). "Effects of brightness and contrast in vision." Trans. Illum. Eng. Soc.

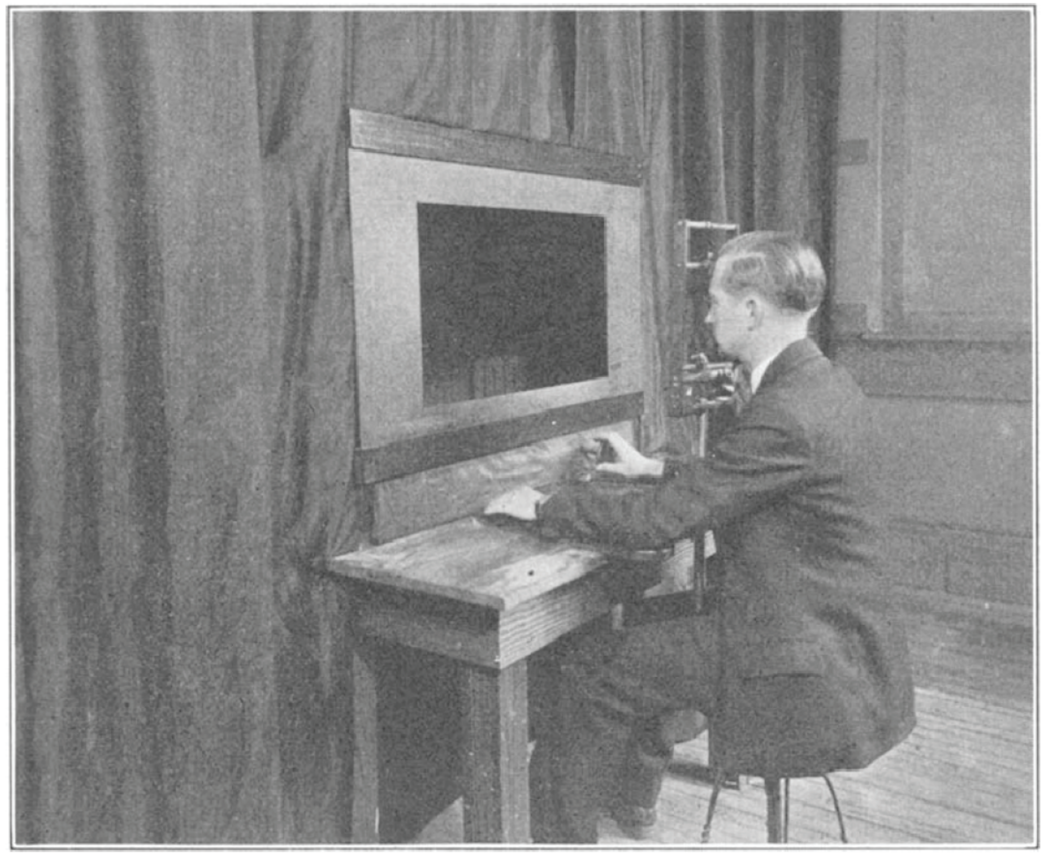
Measurements ~1928

FIG. 5.



General View of Apparatus. Compare with Figs. 1 and 3. The reverse side of the screen *S–S* shows at the right. The battery of solenoids and the counters thereby operated are shown in the foreground.

FIG. 4.



A Subject in Working Position. The head-rest, the mask *M–M* and the hand-wheel *W* are shown. Compare with Fig. 1.

Cobb, P. W. and F. K. Moss (1928). "Glare and the four fundamental factors in vision." Journal of the Franklin Institute 205(2): 251-252.

Measurements 1930’s

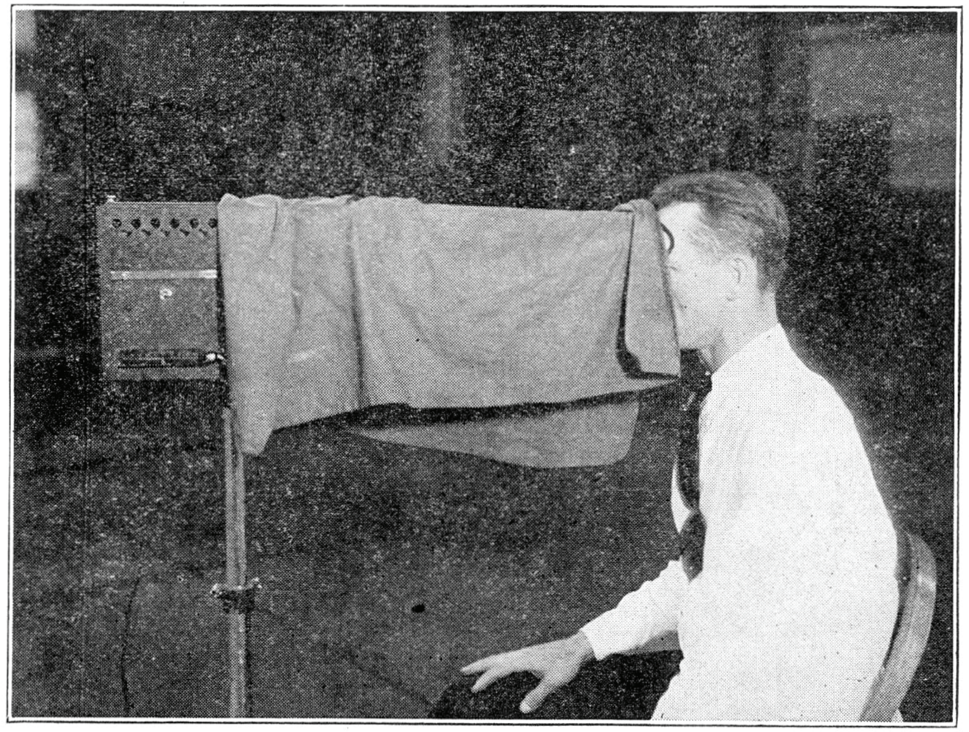


Figure 1
Showing Glarometer as used in these experiments. The cloth used to screen out extraneous light was not a part of the regular equipment of the instrument.

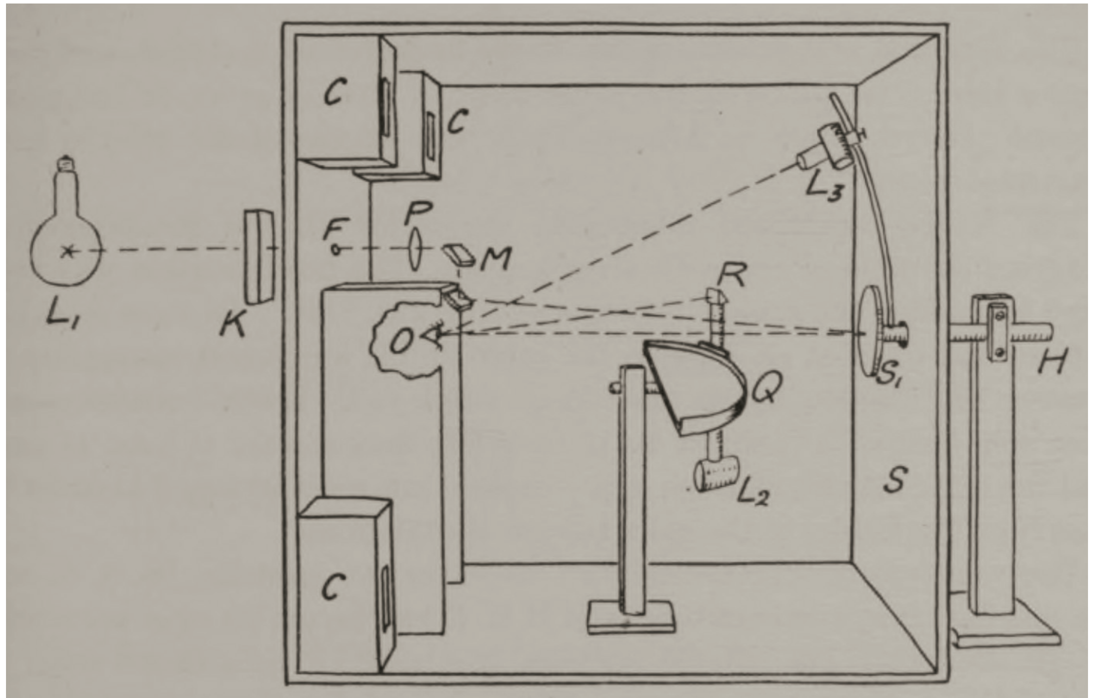


FIG. 2

Lauer, A. (1936). “An experimental study of glare susceptibility.” Optometry and Vision Science 13(6): 200-207.

Stiles, W. S. and B. Crawford (1937). “The effect of a glaring light source on extrafoveal vision.” Proceedings of the Royal Society of London. Series B-Biological Sciences 122(827): 255-280.

Holladay's equation, K

Holladay's K (1926)

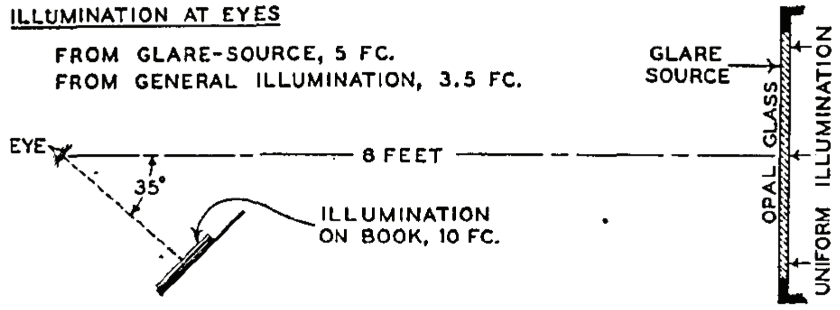
$$K = \log_{10}\left(\frac{L_s \pi}{10}\right) + 0.25 \cdot \log_{10}(\omega_s) - 0.3 \cdot \log_{10}(L_b \pi/10)$$

- 3 participants
- Adjustment task to make glare source 'just not unpleasant' under four background luminances
- A separate study investigated the effect of source size based on a single background luminance
- Adjusted mysteriously to the evaluation chart to the right
- Basis of glare analysis for quite some time!

K	Degree of glare
> 2.8	Painful
2.8	Irritating
2.6	Boundary between objectionable and intolerable
2.4	Uncomfortable
2.2	Perceptibly uncomfortable
1.9	Boundary between comfort and discomfort
1.8	Less comfortable
1.7	Still comfortable
1.5	Very comfortable
1.2	At the limit of pleasure
0.9	Still pleasant
0.6	Most pleasant
0.3	Scarcely noticeable
< 0.3	Not perceptible

Holladay, L. (1926). "The fundamentals of glare and visibility." JOSA 12(4): 271-319.

1940's measurements, metrics



GLARE-SOURCE DIAMETER	VISUAL ANGLE	BRIGHTNESS	EFFECTS RATE OF BLINKING
NO PREVENTABLE GLARE			100 PERCENT
32 INCHES	19 DEGREES	150 FOOTLAMBERTS	118 "
10 "	6 "	1770 "	133 "
3 "	2 "	18000 "	160 "

FIG. 1. A diagrammatic representation of the lighting environments involved in the present study; and a summary of the rates of blinking while reading under these environments. The data for the smallest glare source are extrapolated.

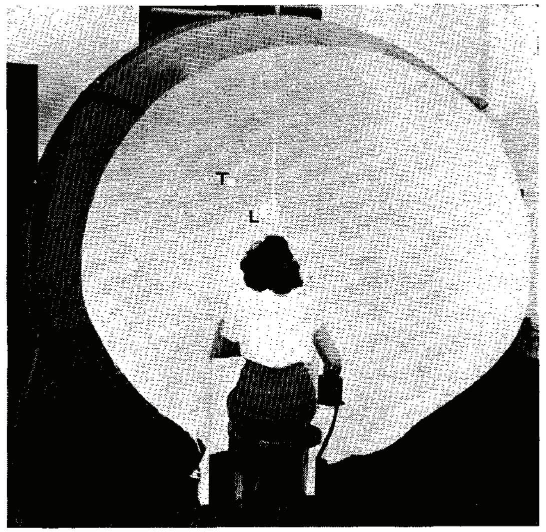


Figure 1. The experimental environment used throughout most of the present investigation was the illuminated white inner surface of an 80-inch sphere at the center of which the subject's eyes were located. This unrestricted surrounding visual field was illuminated by the lamp *L* located near the center of the sphere and concealed from the subject. The brightness of the test-sources *T*, which consist of circular apertures in the spherical surface, is adjusted by the control under the subject's right hand. The photograph illustrates the brief period during which a test-source *T* located 20 degrees above the line of vision was exposed.

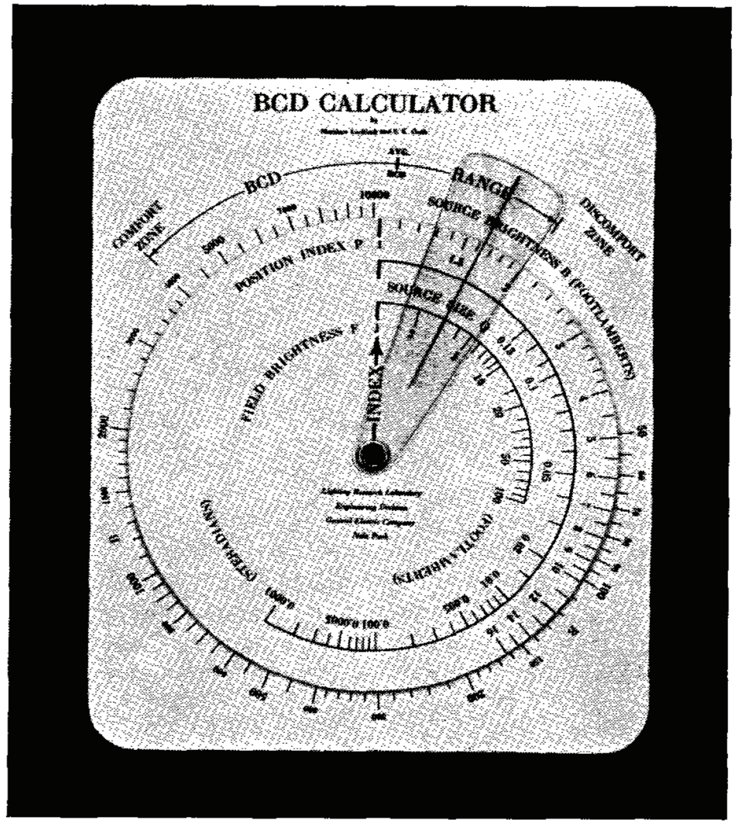


Figure 13. A disk calculator which contains in circular form the scales of the nomogram of Fig. 12.

- Long(er) exposure to glare sources became common.
- Luckiesh and Guth: 1 sec, 10 sec exposure times.

Luckiesh, M. and S. K. Guth (1949). "Brightness in visual field at borderline between comfort and discomfort (BCD)." Illuminating engineering 44(11): 650-670.

Luckiesh, M. and F. K. Moss (1942). "Intrinsic brightness as a factor in discomfort from glare." JOSA 32(1): 6-7.

1949, Position index

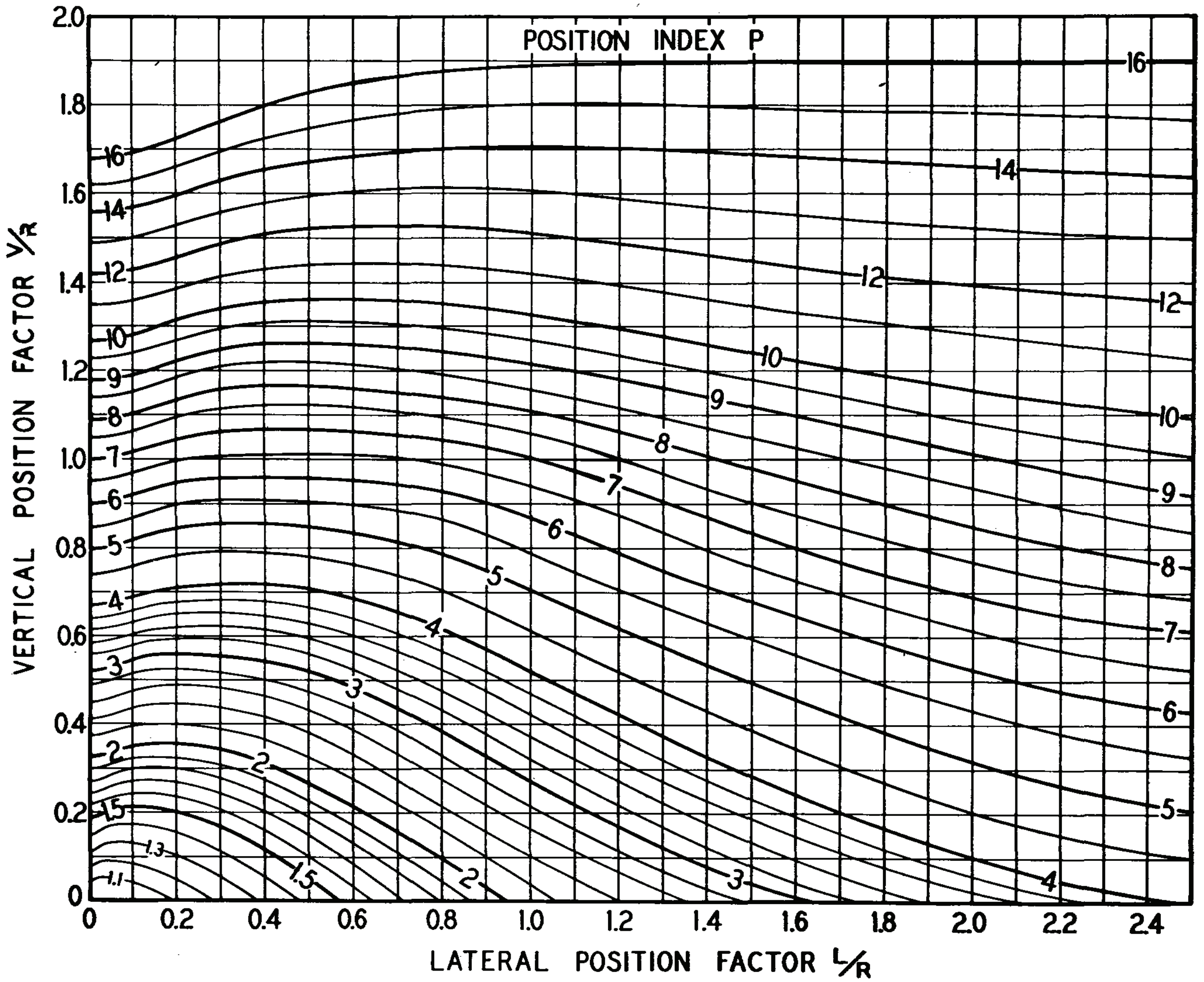


Figure 11. Chart for determining the Position Index *P* of sources located at various positions in the visual field. *V* and *L* are the vertical and lateral distances, respectively, from the line of vision and *R* is the distance from the eye to the vertical plane normal to the line of vision in which the source is located.

Luckiesh, M. and S. K. Guth (1949). "Brightness in visual field at borderline between comfort and discomfort (BCD)." Illuminating engineering 44(11): 650-670.

- Derived by tracking relative differences in the threshold 'between comfort and discomfort' for different glare source positions with fixed participant focal points.
- Later extended by Iwata & Tokura (1997) for glare sources in the lower hemisphere of vision.
- BCD derived based on adjustment task where occupants adjusted the glare source until it became glaring.
- 50 subjects!!!
- Hopkinson and Petherbridge (1954): 'experienced' observers tasked with more glare evaluations were more sensitive to discomfort than new participants.

Hopkinson and Petherbridge's glare index, 10log10(K)

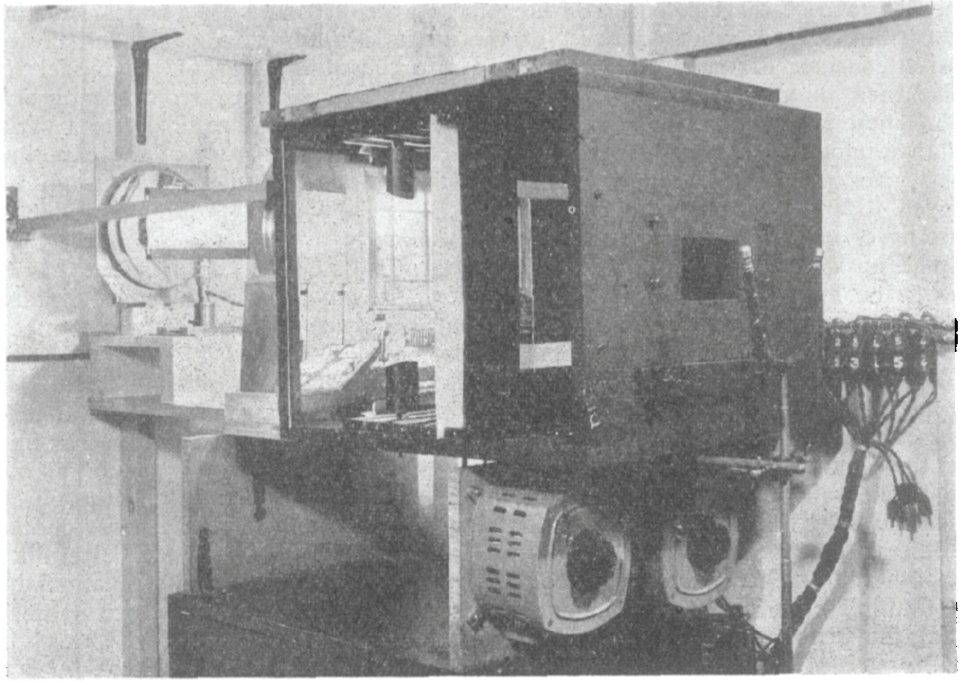
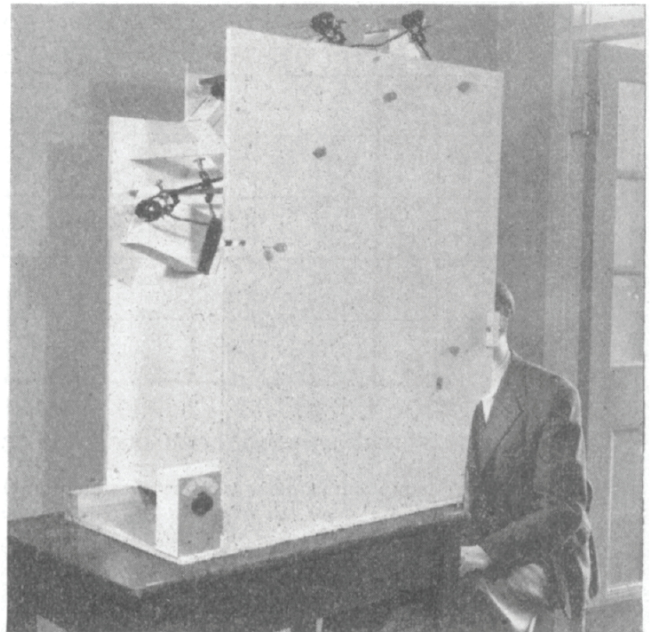


Fig. 1. General view of apparatus for the appraisal of glare, one side of the model removed to show interior.

Fig. 10. Apparatus for the study of glare sources displaced from the direction of viewing.



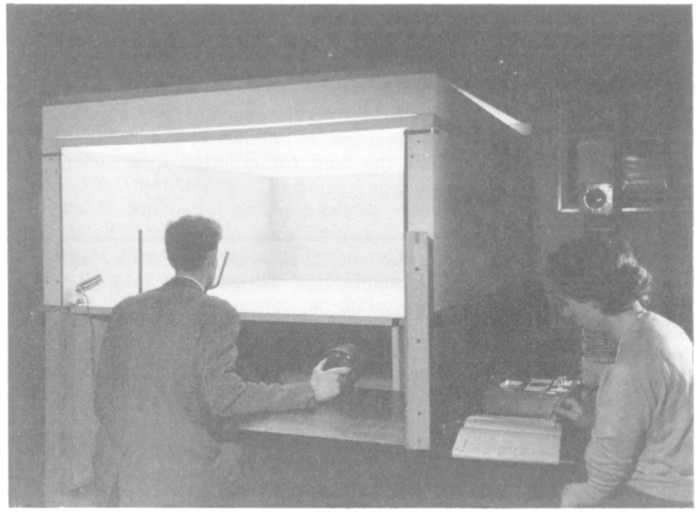


Fig. 1. Observer making subjective judgment of glare in experiment using model room with diffusing luminous ceiling,

Hopkinson, R. (1960). "A note on the use of indices of glare discomfort for a code of lighting." Transactions of the Illuminating Engineering Society 25(3_IEStrans): 135-138.

Petherbridge, P. and R. Hopkinson (1950). "Discomfort glare and the lighting of buildings." Transactions of the Illuminating Engineering Society 15(2_IEStrans): 39-79.

Hopkinson and Petherbridge's glare index, 10log10(K)

Hopkinson and Petherbridge's K (1960)

$$K = 0.4777 \frac{\sum\left[L_{s,i}^{1.6} \cdot \omega_{s,i}^{0.8}\right]}{L_b}$$

$$Glare\ Index = 10 \log_{10} K$$

Index	Degree of glare
28	Just intolerable
22	Just uncomfortable
16	Just acceptable
10	Just perceptible

↓ Became the 1961 IES Glare Index

$$Glare\ Index = 10 \log_{10} 0.4777 \sum \frac{L_{s,i}^{1.6} \omega_{s,i}^{0.8}}{L_b P_{s,i}^{1.6}}$$

- 1950 - Petherbridge and Hopkinson; 1960 - Hopkinson
- First kind of 'modern' glare scale. Similar evaluation units to UGR / DGI.
- Adjustment task to reach the degrees of glare indicated in the table to the left.
- No position index in 1950, by the 1960 version it modified Ls
- Recommendations per space type:
  - classrooms should limit the glare index to 16
  - operating rooms in hospitals to 10
  - train platforms to 26

Hopkinson, R. (1960). "A note on the use of indices of glare discomfort for a code of lighting." Transactions of the Illuminating Engineering Society 25(3_IEStrans): 135-138.

Petherbridge, P. and R. Hopkinson (1950). "Discomfort glare and the lighting of buildings." Transactions of the Illuminating Engineering Society 15(2_IEStrans): 39-79.

IES glare index

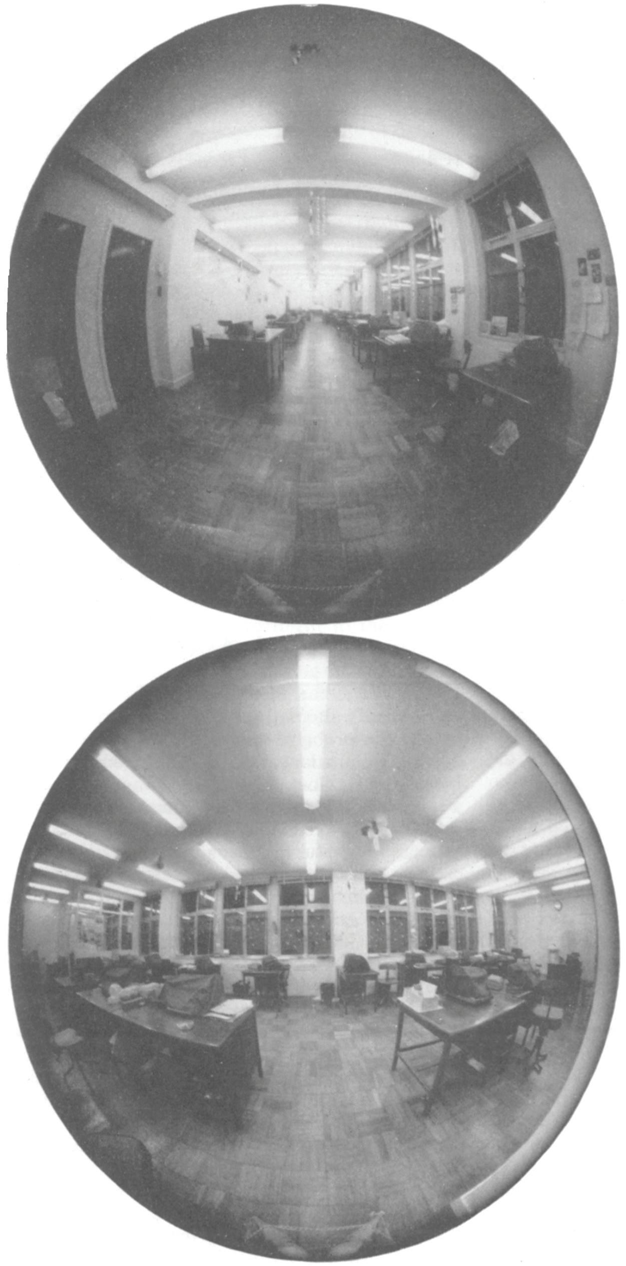


Fig. 1. Two views of an installation appraised by the Panel. The photographs were taken using a full-field camera.

- Assessed discomfort glare in real situations (left) before agreeing to accept Hopkinson and Petherbridge's glare index.

Robinson, W., et al. (1962). "The development of the IES glare index system: Contributed by the Luminance Study Panel of the IES Technical Committee." Transactions of the Illuminating Engineering Society 27(1_IEStrans): 9-26.

Hopkinson's daylight glare index, DGI

DGI (1971)

$$DGI = 10 \cdot \log_{10} 0.4777 \sum \frac{L_{s,i}^{1.6} \left(\omega_{s,i}/P_{s,i}^{2}\right)^{0.8}}{L_b + 0.07\omega_{s,i}^{0.5} L_{s,i}}$$

• Adapted to 'large' glare sources! Daylight!

• Derived using subjective lab experiments with fluorescent lamps behind diffusing screens.

• Semi-validated in hospitals and classrooms where 20 (lower end of 'unacceptable') was found to be the best limiting threshold for glare avoidance.

Robinson, W., et al. (1962). "The development of the IES glare index system: Contributed by the Luminance Study Panel of the IES Technical Committee." Transactions of the Illuminating Engineering Society 27(1_IEStrans): 9-26.

Measurements 1980's

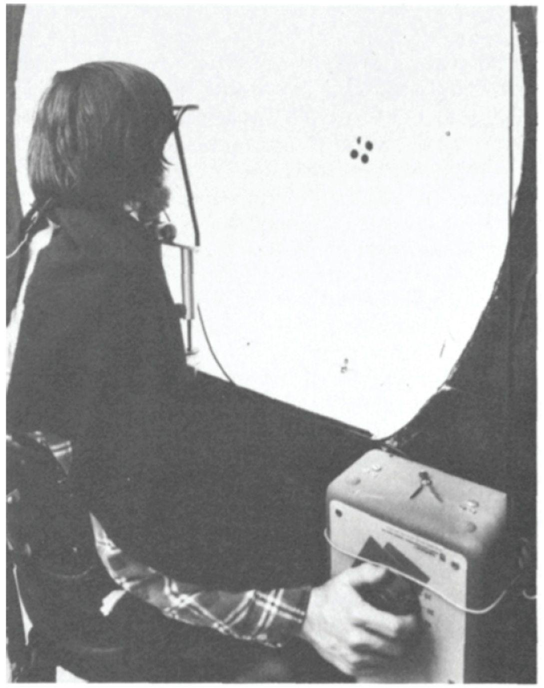
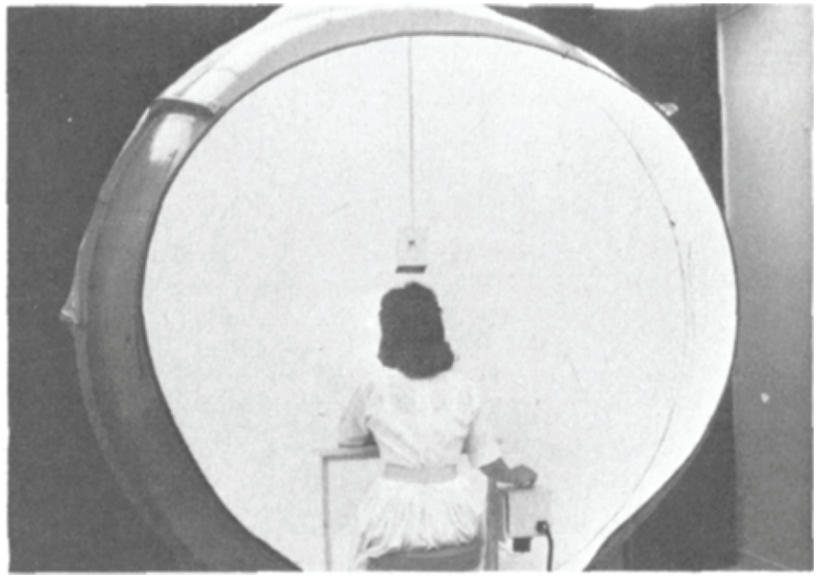


Figure 2. The glare apparatus.

Figure 1. This large sphere enclosure was the environment used in the basic BCD investigations. Comparable evaluations have been obtained with a 100 × 80 × 60 cm model room in this experiment.



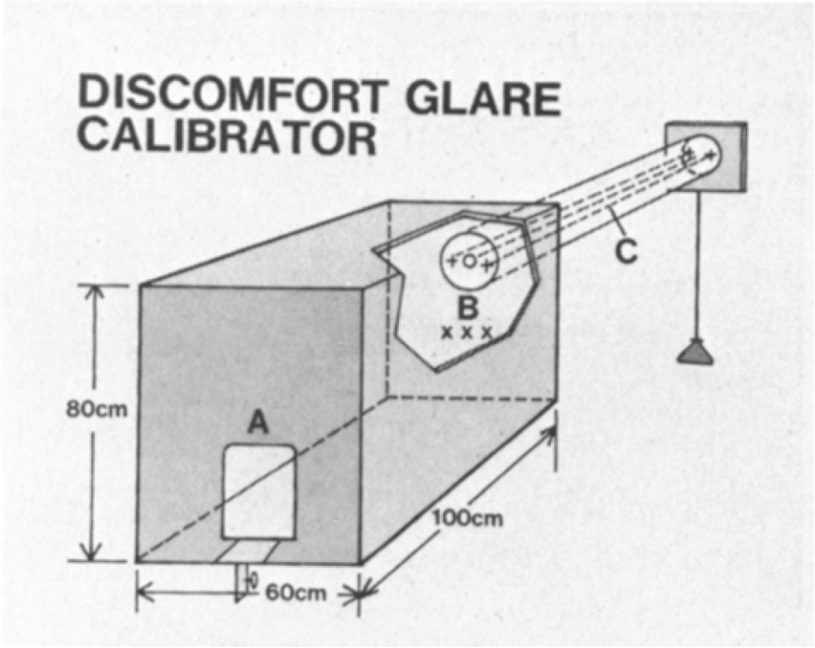


Figure A. Schematic of the discomfort glare calibrator. The observer's head is positioned at A by a chin rest. He views fixation marks on surface B. Located 20° above is the small (0.001 steradian) glare source which is seen as a bright circular area on a diffusing glass recessed six inches into chamber C. C also houses an optical track and a lamp whose position is adjusted by the observer to produce the BCD sensation.

Lulla, A. B. and C. A. Bennett (1981). "Discomfort glare: range effects." Journal of the Illuminating Engineering Society 10(2): 74-80.

McNelis, J. F. (1981). "A discomfort glare calibrating device: Subjective evaluations in a standard environment." Journal of the Illuminating Engineering Society 10(2): 85-89.

Visual Comfort Probability VCP (a brief note)

VCP (1966, 1972, 1993)

- The most fun to calculate!
- Highly dependent on the number of sources.
- Ceiling mounted luminaires only.
- Evaluates between 0 - 100, a percentage probability of comfort. Similar but opposite of DGP.
- I can’t find the 1966 report, so its derivation is a mystery to me.

$$M = \sum \frac{0.5L_{s,i} \cdot (20.4\omega_{s,i} + 1.52\omega_{s,i}^{0.2} - 0.075)}{P_{s,i}E_v/\pi}$$

$$DGR = (M^{nsources})^{-0.0914}$$

$$VCP = \frac{100}{\sqrt{2\pi}} \int_{-\infty}^{6.374-1.3227 \cdot lnDGR} e^{-x^2/2}\, dx$$
$$= 50 * Erf(6.374 - 1.3227 \cdot lnDGR \,/\, 1.4142) + 50$$

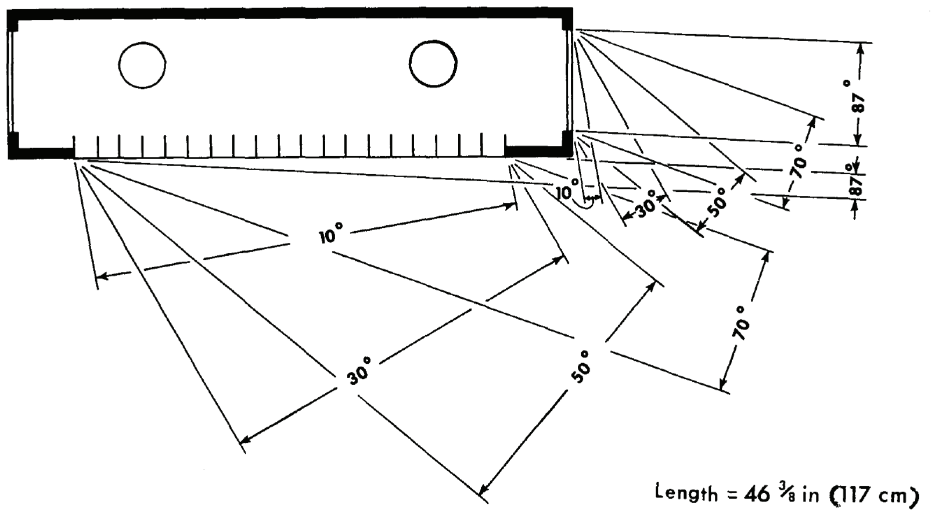


Figure 7. A scale drawing of the cross section of the luminaire. Sight lines have been drawn at five angles for determining the projected widths of the bottom and side.

[RQQ] Committee on Recommendations of Quality and Quantity of Illumination of the IES (1972). “Outline of a standard procedure for computing visual comfort ratings for interior lighting.” Journal of the Illuminating Engineering Society 2(3): 328.

CIE Glare Index CGI and Unified Glare Rating UGR

CGI (1979)

- Like DGI, can work with large sources.

- Slightly modified, but similar, evaluation scale to DGI.

- Einhorn, who developed glare metrics that did not find popularity in 1961, 1963, and 1969 created CGI as a "unified" glare metric, combining existing research without new human subject data.

- Ed is the direct illuminance contribution of glare sources.

$$CGI = 8 \cdot \log_{10}\left(2\frac{1+E_d/500}{E_d+\pi L_b}\sum\frac{L_{s,i}^2\omega_{s,i}}{P_{s,i}^2}\right)$$

UGR (1995)

- No more than 0.1 str solid angle sources.

- Derived for mathematical simplicity from CGI, omitting direct illuminance.

- Einhorn on the committee.

$$UGR = 8 \cdot \log_{10}\frac{0.25}{L_b}\sum\frac{L_{s,i}^2\omega_{s,i}}{P_{s,i}^2}$$

Committee, C. T. (1995). "CIE 117-1995 Discomfort Glare in Interior Lighting." International Commission on Illumination, Vienna.

Einhorn, H. (1979). "Discomfort glare: a formula to bridge differences." Lighting Research & Technology 11(2): 90-94.

Issues held by visual discomfort researchers

- Chauvel et al. (1981):
  - Existing metrics developed under electric lighting.
  - View could mitigate higher DGI values under daylight!
  - Solid angle of sources in derivation of DGI very narrow.

- Aubrée and Chauvel 1972; Chauvel 1977: Daylight glare sources far more difficult to assess than electric / controlled ones.

- Iwata et al. (1990):
  - DGI performed poorly in bright and indirectly lit spaces.
  - No binary classification of glare / no glare existed.

Predicted Glare Sensation Vote (PGSV)

PGSV (1996)

- Iwata et al. performed studies using actual windows (1992), but PGSV was derived using fluorescent tubes mounted outside of the window in a later study.

- Did not make use of the position index.

- Threshold-based results scale: 0, 1, 2, 3, 4.

- 240 participants.

- No control over the light source, and long exposure (15 minutes!)

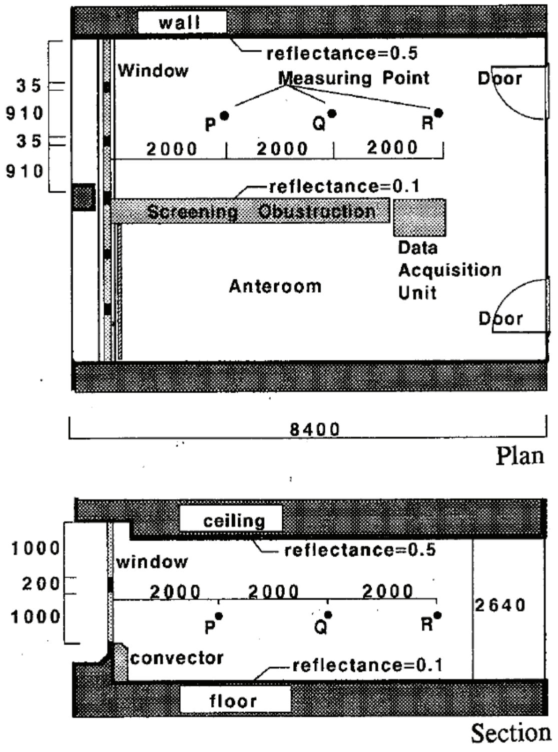


Fig. 1 Plan and sectional views of the rooms used for experiment

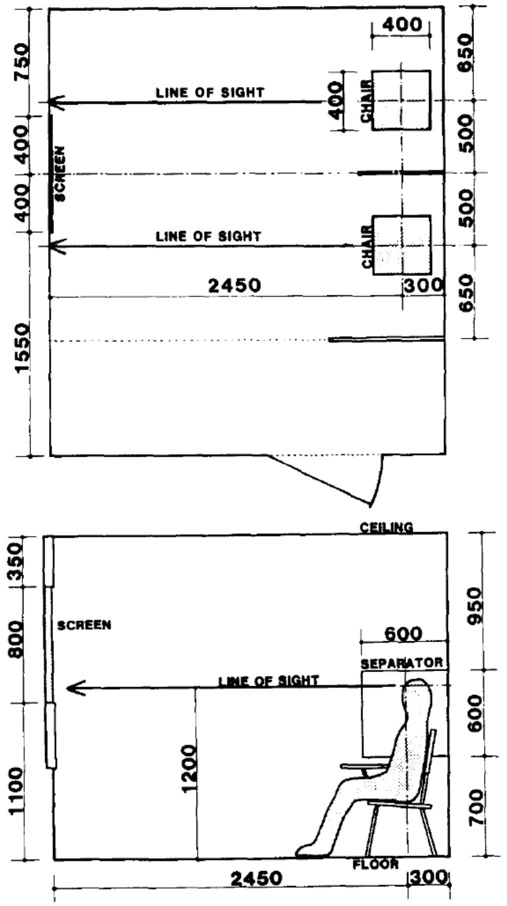


Fig. 2. Plan and section of chamber with subjects in position A (dimensions in mm).

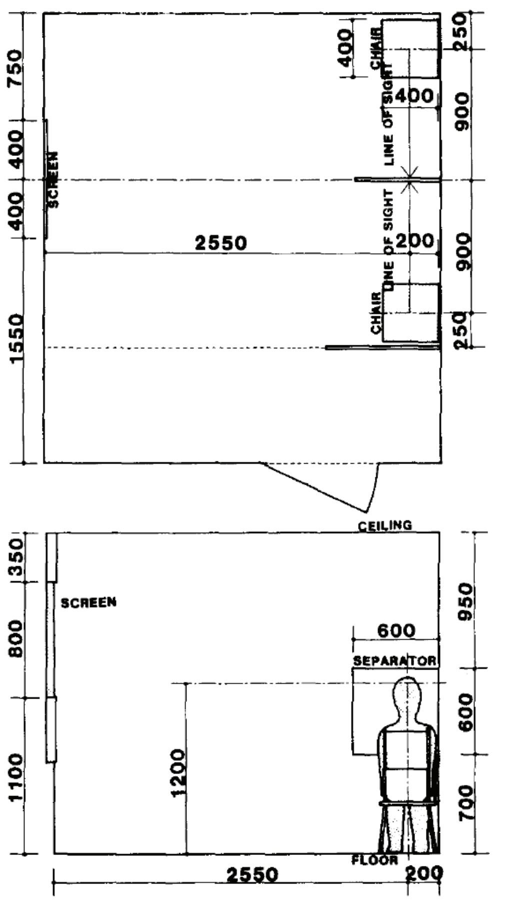


Fig. 3. Plan and section of chamber with subjects in position B (dimensions in mm).

TOKURA, M., et al. (1996). "EXPERIMENTAL STUDY ON DISCOMFORT GLARE CAUSED BY WINDOWS PART 3: Development of a method for evaluating discomfort glare from a large light source." Journal of Architecture and Planning (Transactions of AIJ) 61(489): 17-25.

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• Threshold-based results scale: 0, 1, 2, 3, 4.

• 240 participants.

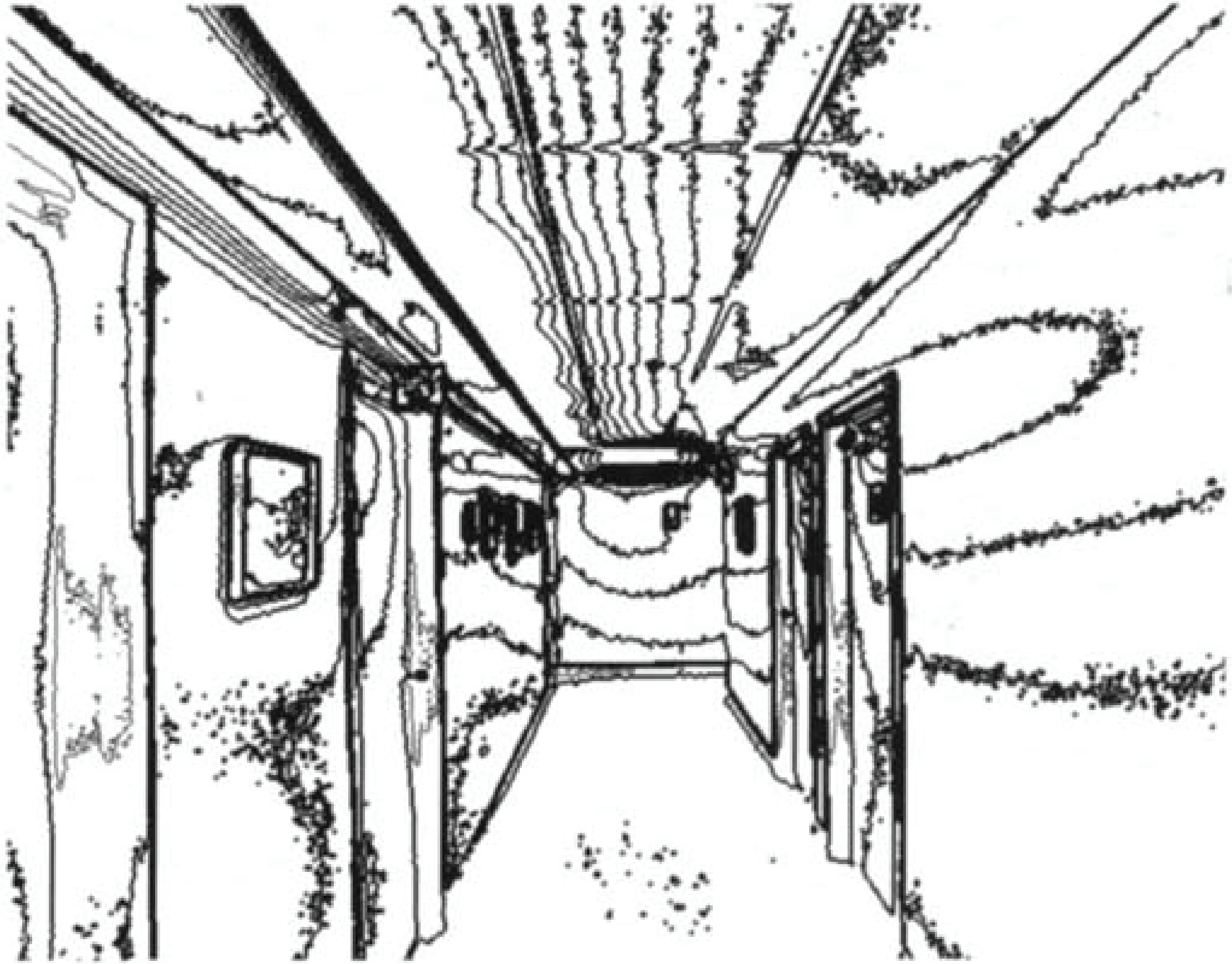
• No control over the light source, and long exposure (15 minutes!)

$$PGSV_{Tokura} = 3.2 \log_{10} L_{s,i} - 0.64 \log_{10} \omega + (0.79 \log_{10} \omega - 0.61) \log_{10} L_b - 8.2$$

$PGSV_{Tokura}$	Degree of glare
0	Not glaring
1	Slightly glaring
2	Glaring
3	Very glaring
4	Intolerably glaring

TOKURA, M., et al. (1996). "EXPERIMENTAL STUDY ON DISCOMFORT GLARE CAUSED BY WINDOWS PART 3: Development of a method for evaluating discomfort glare from a large light source." Journal of Architecture and Planning (Transactions of AIJ) 61(489): 17-25.

Technology, luminance image capture



Ashdown, I. (1996). “Luminance gradients: photometric analysis and perceptual reproduction.” Journal of the Illuminating Engineering Society 25(1): 69-82.

Technology, luminance image capture, HDR

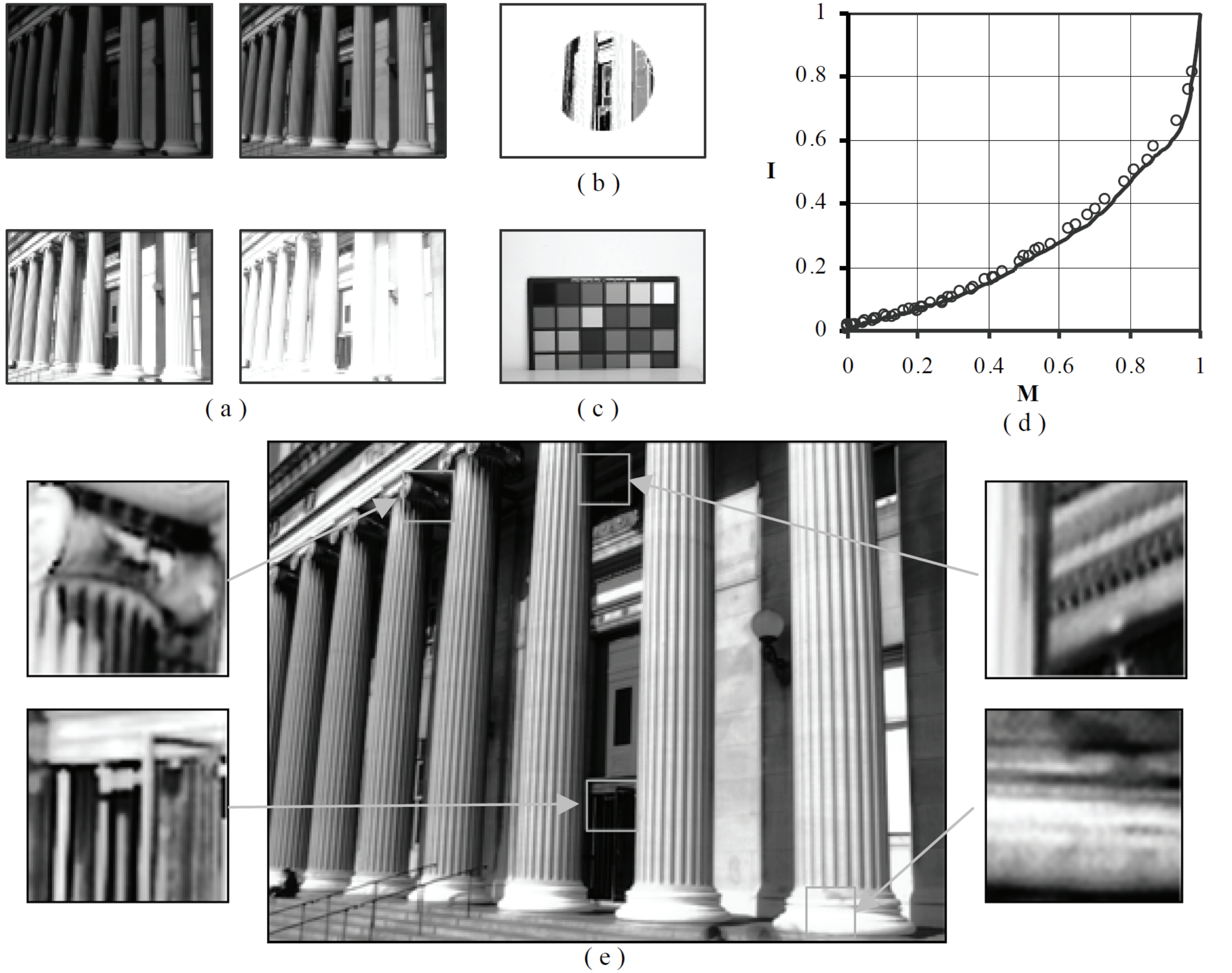


Figure 6: (a) Self-calibration results for gray scale video images taken using a Canon Optura camera. (b) Temporal averaging, spatial averaging and vignetting detection are used to locate pixels (shown in black) that produce robust measurements. (c) The self-calibration results are verified using a uniformly lit Macbeth color chart with patches of known reflectances. (d) The computed response function (solid line) is in strong agreement with the chart calibration results (dots). (e) The computed radiance image is histogram equalized to convey some of the details it includes. The image windows on the two sides of the radiance image are locally histogram equalized to bring forth further details.

Mitsunaga, T. and S. K. Nayar (1999). Radiometric self calibration. Proceedings. 1999 IEEE computer society conference on computer vision and pattern recognition (Cat. No PR00149), IEEE.

Technology, luminance image capture, HDR

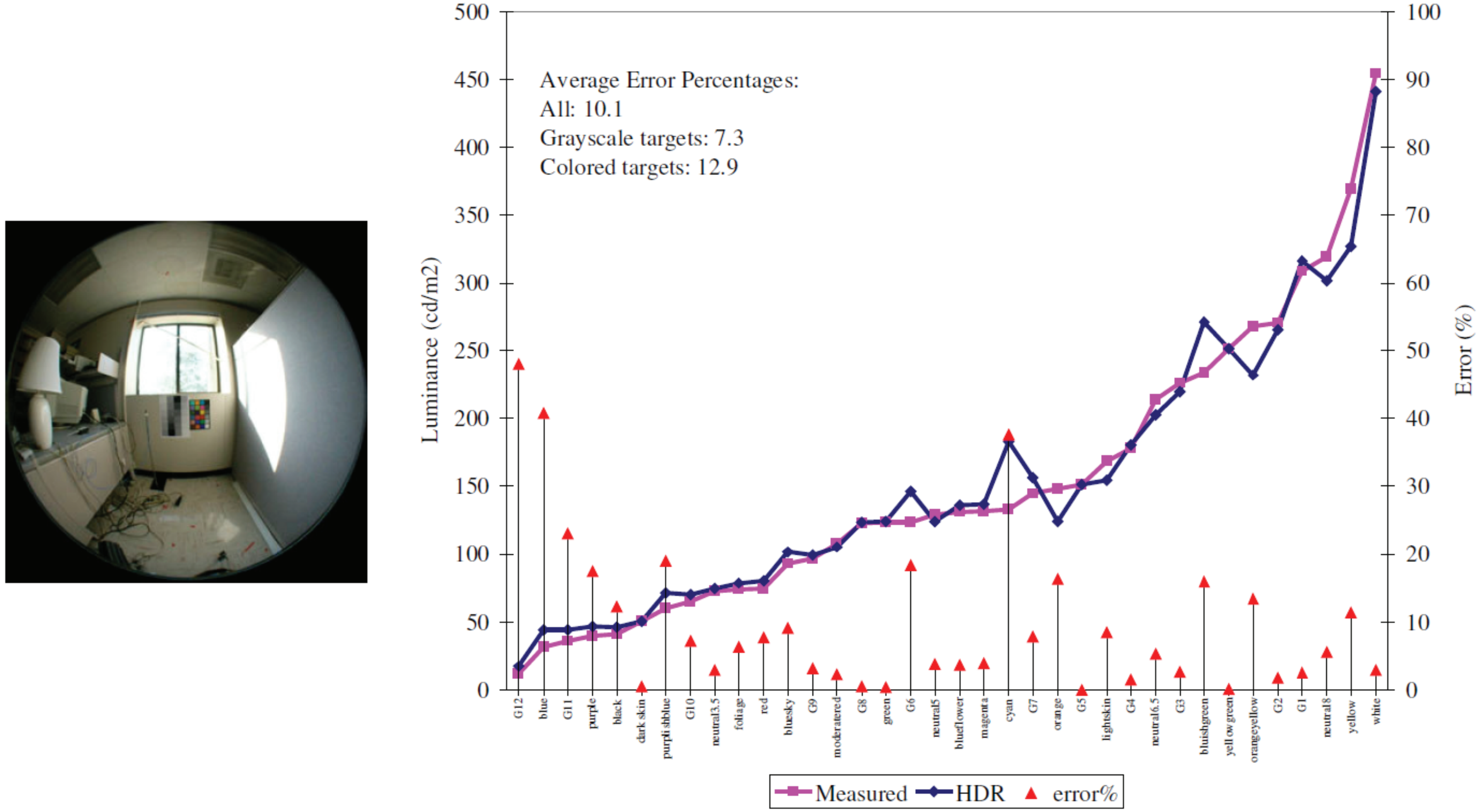
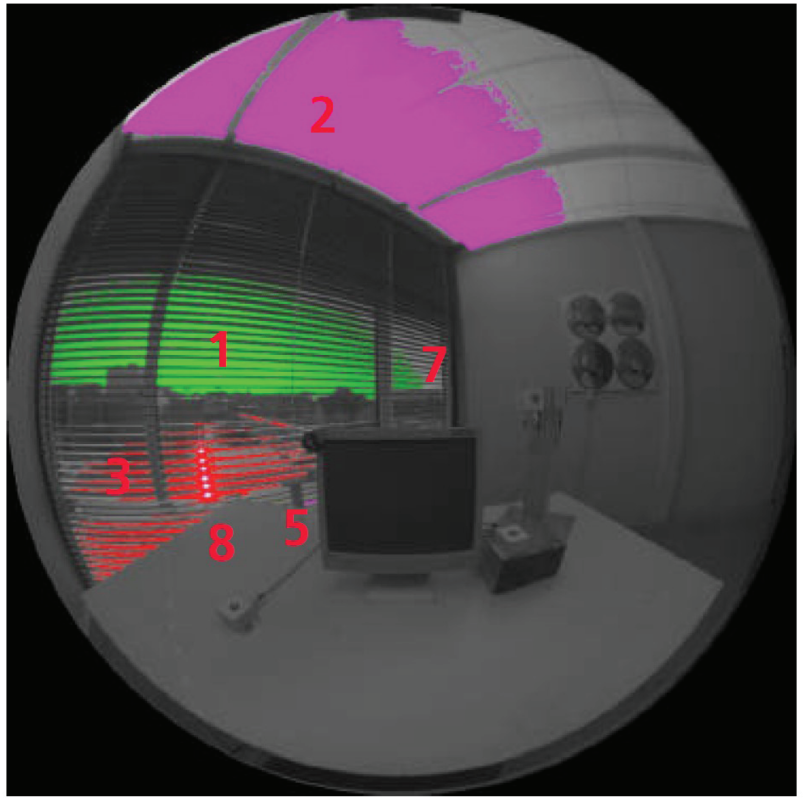


Fig. 15 Office space with daylighting

Inanici, M. and J. Galvin (2004). Evaluation of high dynamic range photography as a luminance mapping technique, Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

Measurements, evalglare tool

Example



This example shows a picture of a luminance camera converted to the pic-format and evaluated by *evalglare*. The smoothing option is not used here, but extraction of the peaks (glare source no. 8).

Below the (optional) output of *evalglare* is shown. This output is still not final, since the development of the new index is still ongoing. The headings mean:
No : Number of glare source (gs)
pixels: Number of pixels of gs
L_s: Average luminance of gs
Omega_s: solid angle of gs
Posindex: position index
Lv: weighted average luminance
L_t: task luminance
E_vert: vertical illuminance

No	pixels	x-pos	y-pos	L_s	Omega_s	Posindx	L_v	L_t	E_vert
1	14472	216.564907	442.473736	13107.75979	0.209413	2.144232	7755.061928	3142.938458	9772.462088
2	46459	368.149613	664.07898	9525.377624	0.58812	16	7755.061928	3142.938458	9772.462088
3	5485	180.177804	305.483578	11745.91399	0.075856	1.000051	7755.061928	3142.938458	9772.462088
4	5	270.206071	291.401041	6269.334165	0.000076	1.000051	7755.061928	3142.938458	9772.462088
5	17	301.300419	291.001381	7674.734499	0.000264	1.000051	7755.061928	3142.938458	9772.462088
6	1	306	365	6197.875	0.000016	1.000051	7755.061928	3142.938458	9772.462088
7	315	395.792346	416.896021	6440.339508	0.005135	1.188712	7755.061928	3142.938458	9772.462088
8	163	196.383179	317.815929	573283.0132	0.002351	1.000051	7755.061928	3142.938458	9772.462088

Wienold, J. (2004). Evalglare–A new RADIANCE-based tool to evaluate daylight glare in office spaces. 3rd International RADIANCE workshop.

Measurements, Daylight Glare Probability DGP

Test room in Denmark

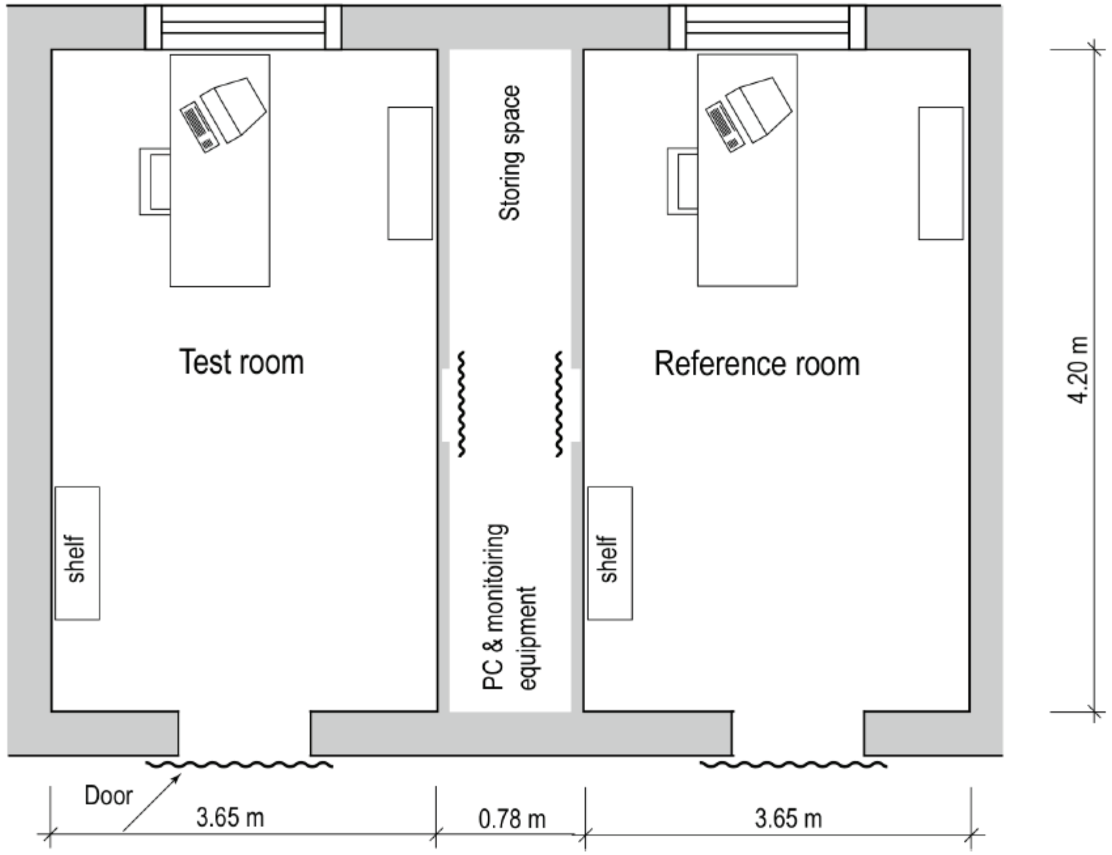
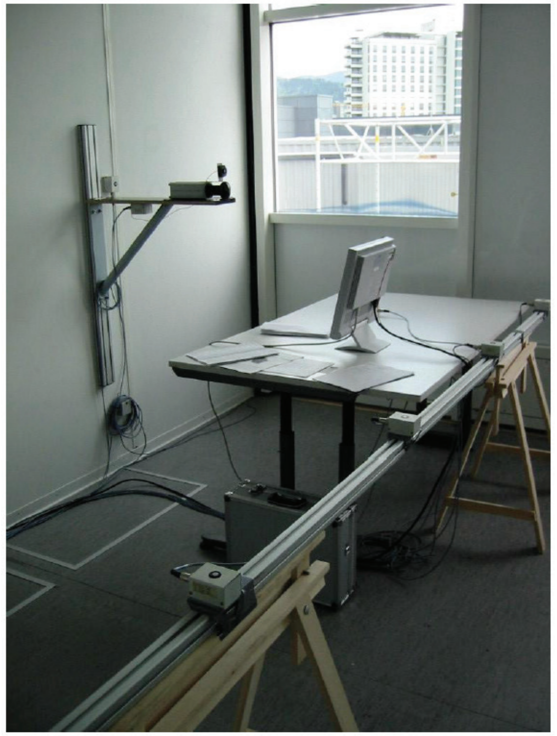


Figure 5: Plan of the experimental rooms in the Daylight Laboratory of ISE Institute showing the Test room and the Reference room, which is furnished, as a typical office room.



Reference room in Freiburg

Wienold, J. and J. Christoffersen (2006). "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras." Energy and Buildings 38(7): 743-757.

Daylight Glare Probability (DGP)

- Measurement in actual daylit spaces was taking place:
  - Velds (2002): DGI, PGSV overestimate glare sensation
  - Fisekis et al. (2003): DGI, UGR correlate with perception of occupants
  - Osterhaus (2005): Current glare metrics inadequate
  - Nazzal (2005): Adjustments to DGI

<u>DGP (2006)</u>

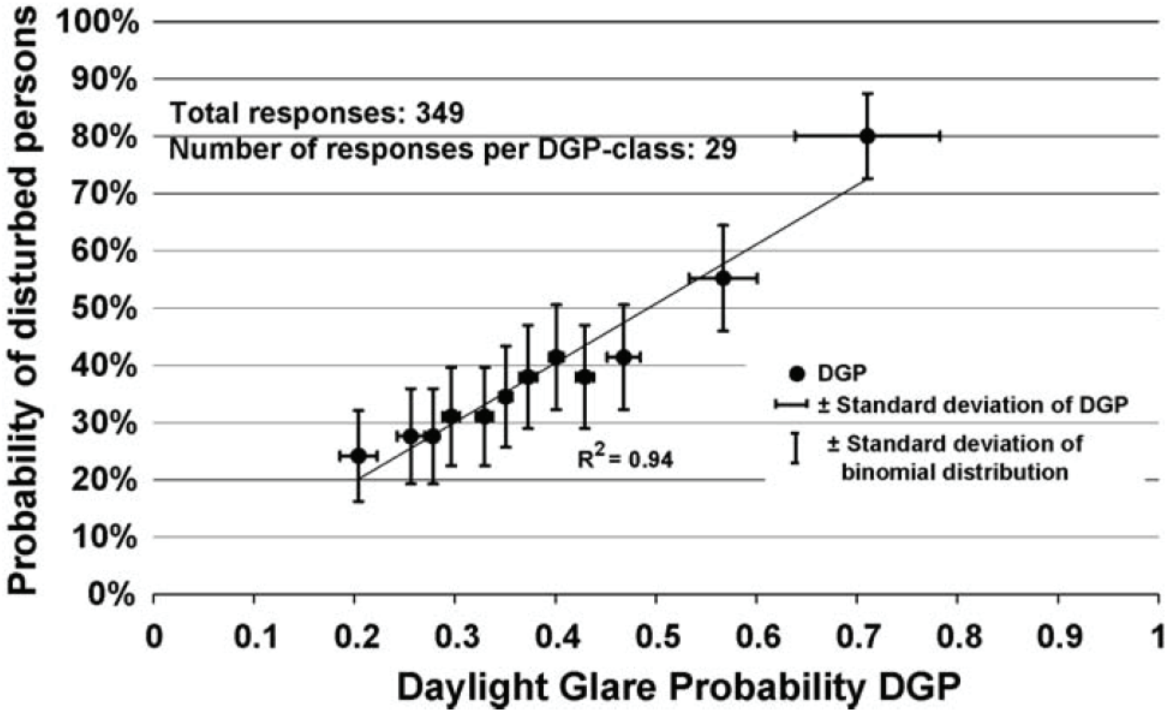
- 76 subjects / 349 HDR measurements.

- Actual daylight!

- Derived using linear regression between a calculated DGP and the glare probability of groups of participants based upon 'optimized scaling parameters'

- Fractional probability of experiencing discomfort glare.

- Practical interpretation evaluates in a narrow range (5% = a threshold change of glare perception)



$$DGP = 5.87 \cdot 10^{-5} E_v + 9.18 \cdot 10^{-2} \log_{10}\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_{s,i}^2}\right) + 0.16$$

$$DGP_{low-light} = DGP \cdot \frac{e^{0.024*E_v-4}}{1 + e^{0.024*E_v-4}}$$

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Degree of glare	**Original** (Wienold 2009)	**Current** (Wienold et al. 2019)
Imperceptible	≤ 0.35	≤ 0.34
Noticeable	0.35 – 0.40	0.34 – 0.38
Disturbing	0.40 – 0.45	0.38 – 0.45
Intolerable	≥ 0.45	≥ 0.45

$$DGP = 5.87 \cdot 10^{-5} E_v + 9.18 \cdot 10^{-2} \log_{10}\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_{s,i}^2}\right) + 0.16$$

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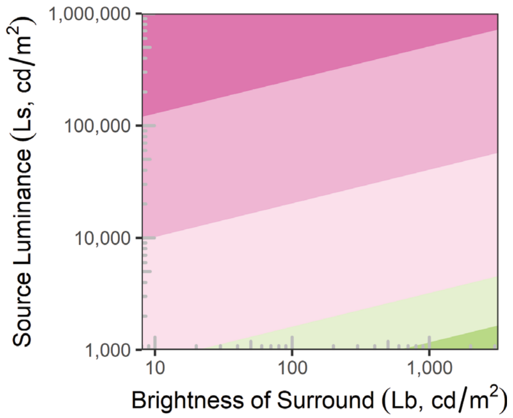
Comparison, P = 4 and ω = 0.6



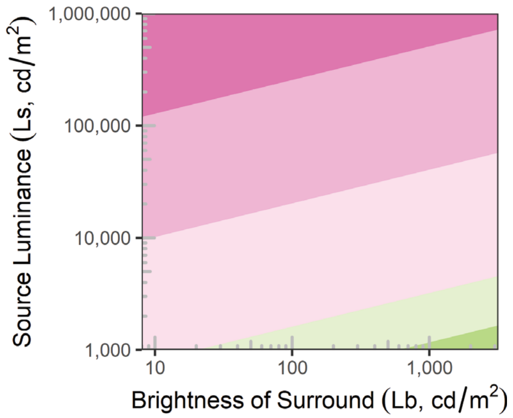
1926, K (Holladay)

- Color scales are normalized by something close to ‘disturbing’ glare.
  - Holladay: 2.2
  - Hopkinson’s glare index: 22
  - UGR, CGI: 25
  - DGI: 24
  - PGSV: 2
  - VCP = (1 - VCP / 100) / 0.4
  - DGP: 0.4

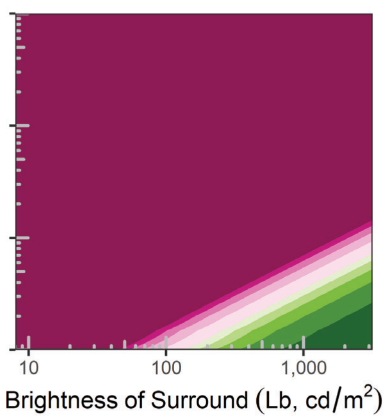
- Green colors are sub-disturbing.

- Pink colors are disturbing or worse.

Comparison, P = 4 and ω = 0.6



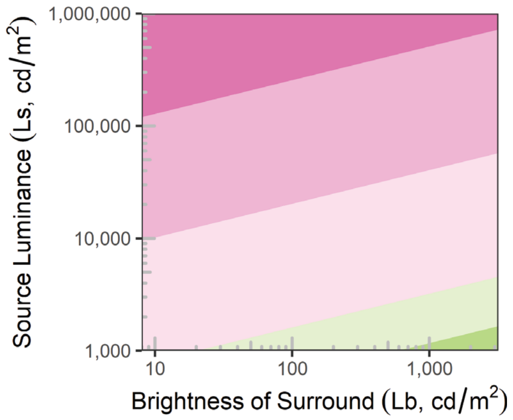
1926, K (Holladay)



1950, K (Petherbridge)

20%/disturbing 40%/disturbing 60%/disturbing 80%/disturbing 100%/disturbing disturbing +50% disturbing +100% disturbing +150% disturbing >200% disturbing

Comparison, P = 4 and ω = 0.6



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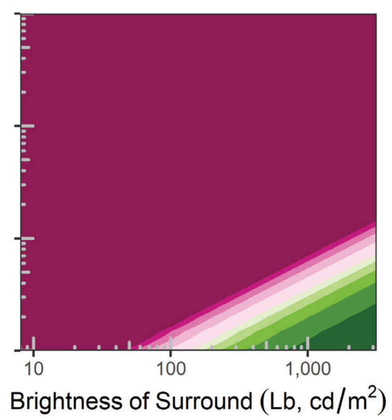
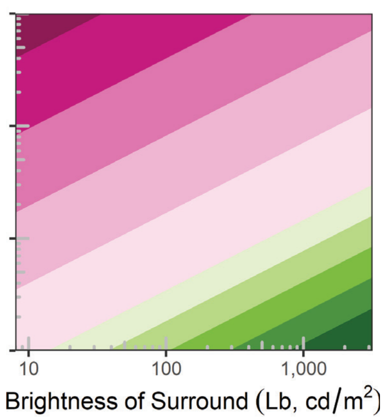
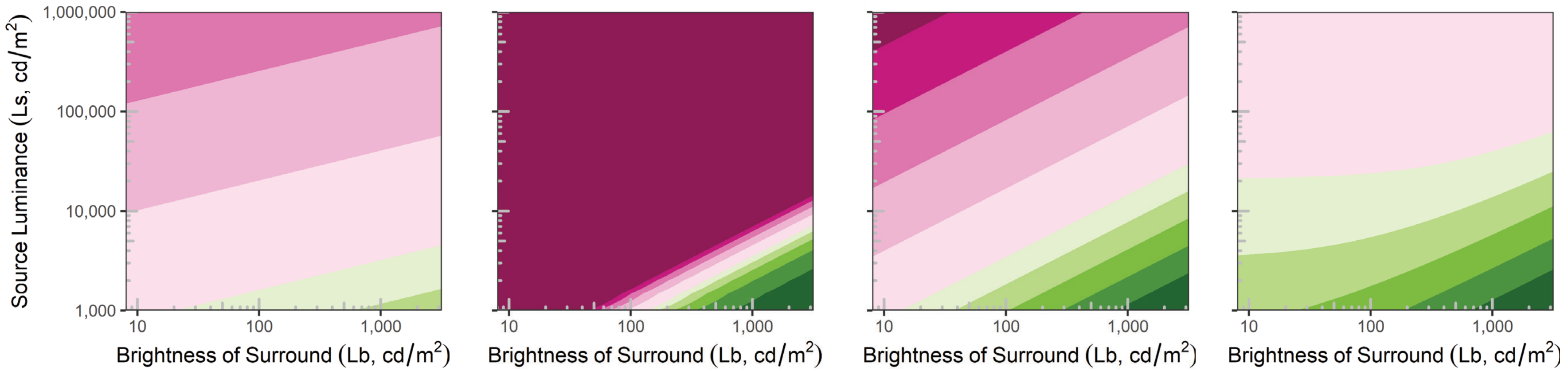


1950, K (Petherbridge)



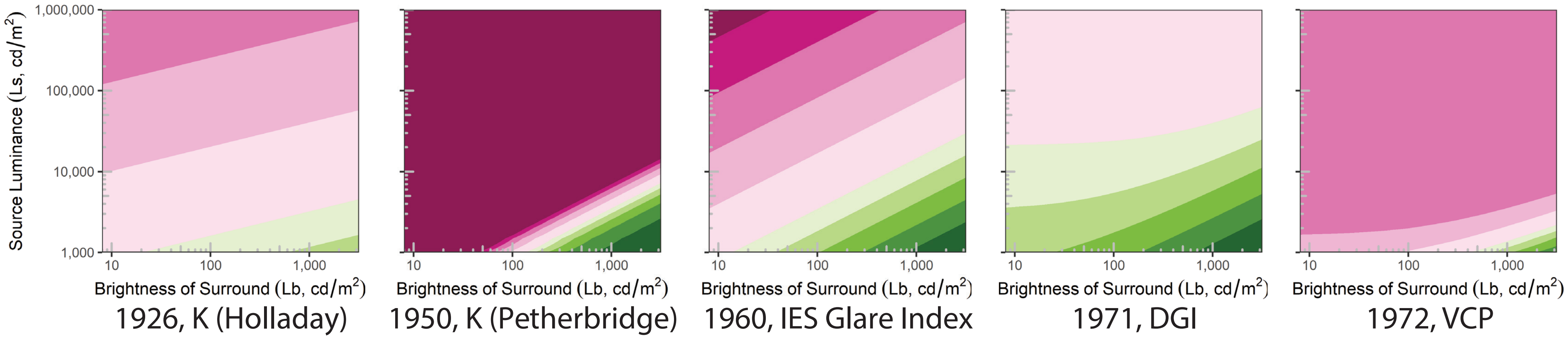
1960, IES Glare Index

Comparison, P = 4 and ω = 0.6



1926, K (Holladay) 1950, K (Petherbridge) 1960, IES Glare Index 1971, DGI

Comparison, P = 4 and ω = 0.6



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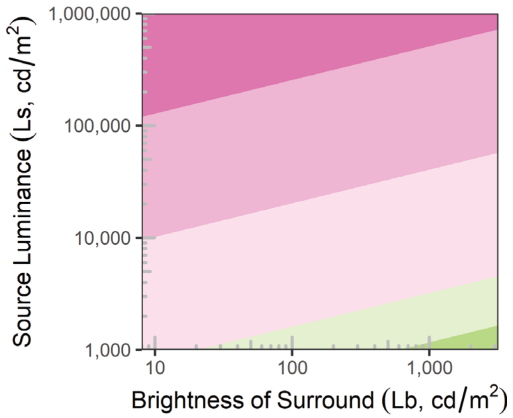
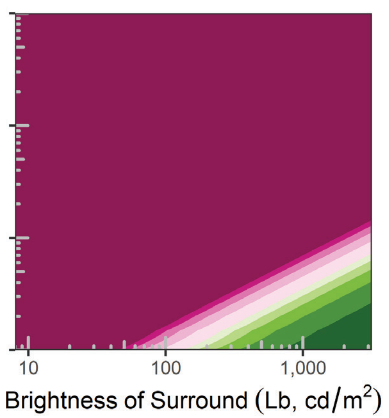
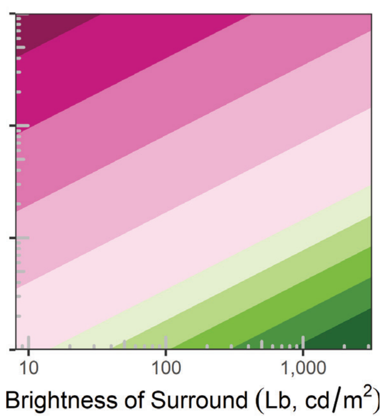


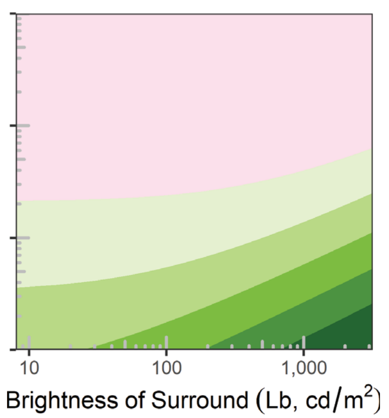
1926, K (Holladay)



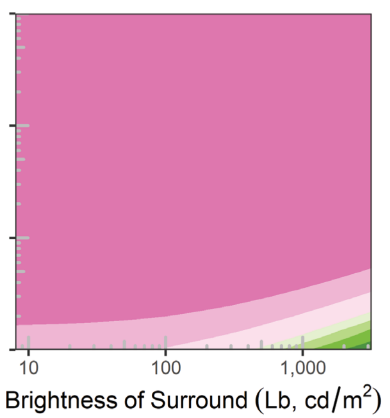
1950, K (Petherbridge)



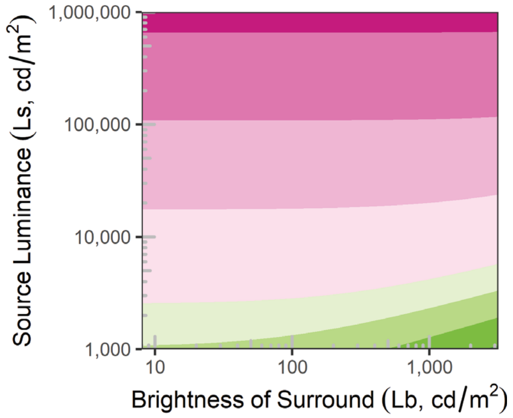
1960, IES Glare Index



1971, DGI

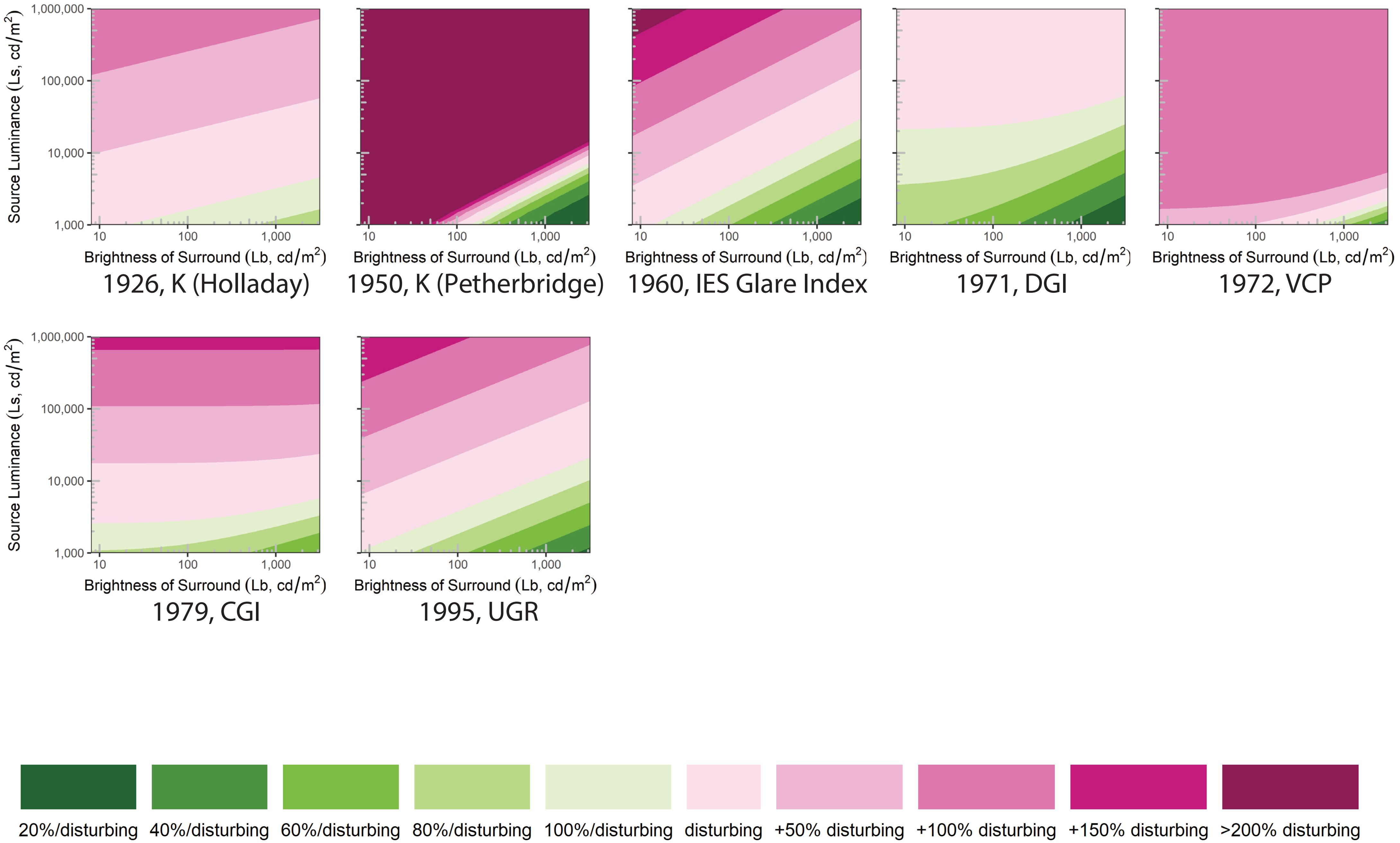


1972, VCP



1979, CGI

Comparison, P = 4 and ω = 0.6



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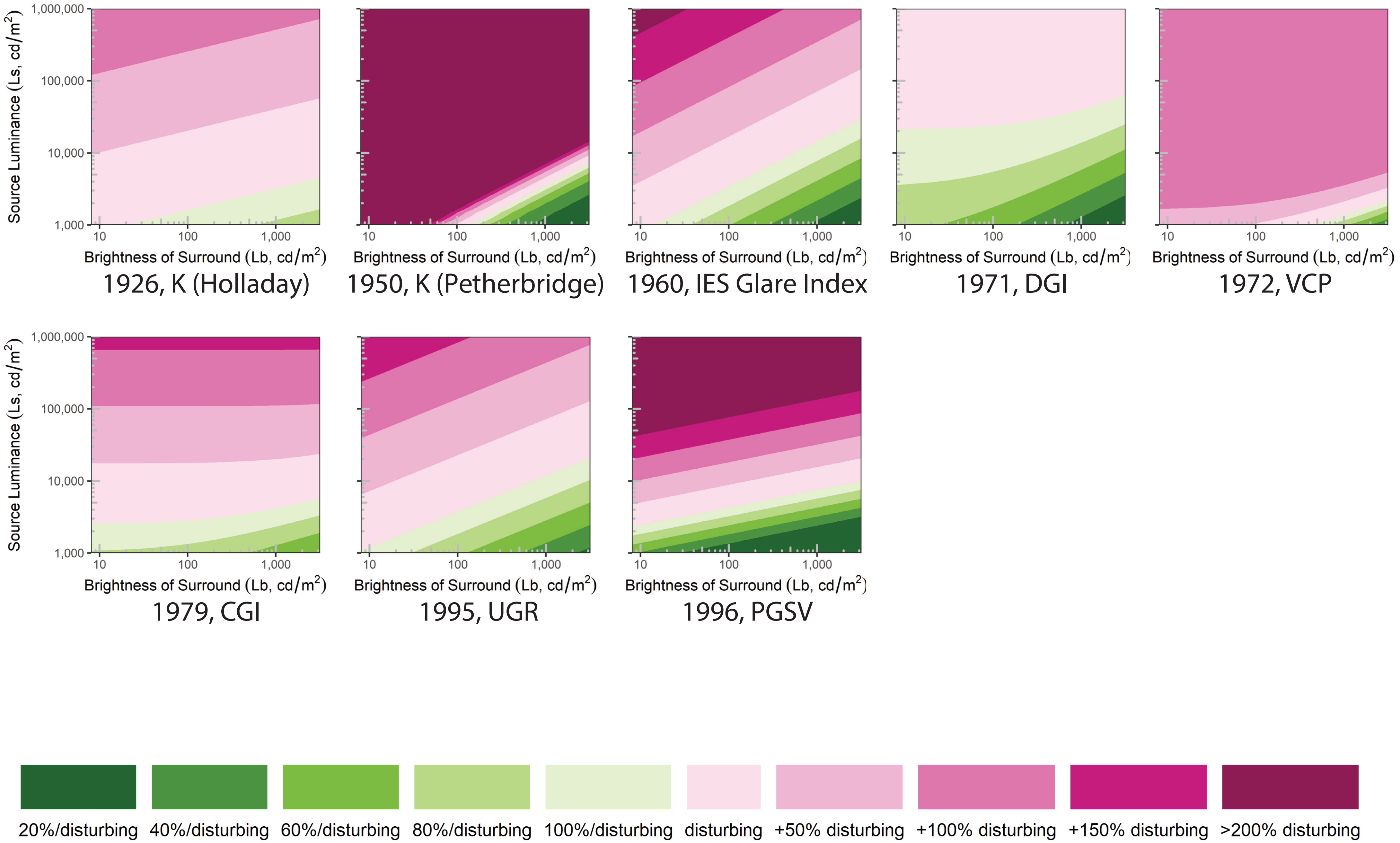

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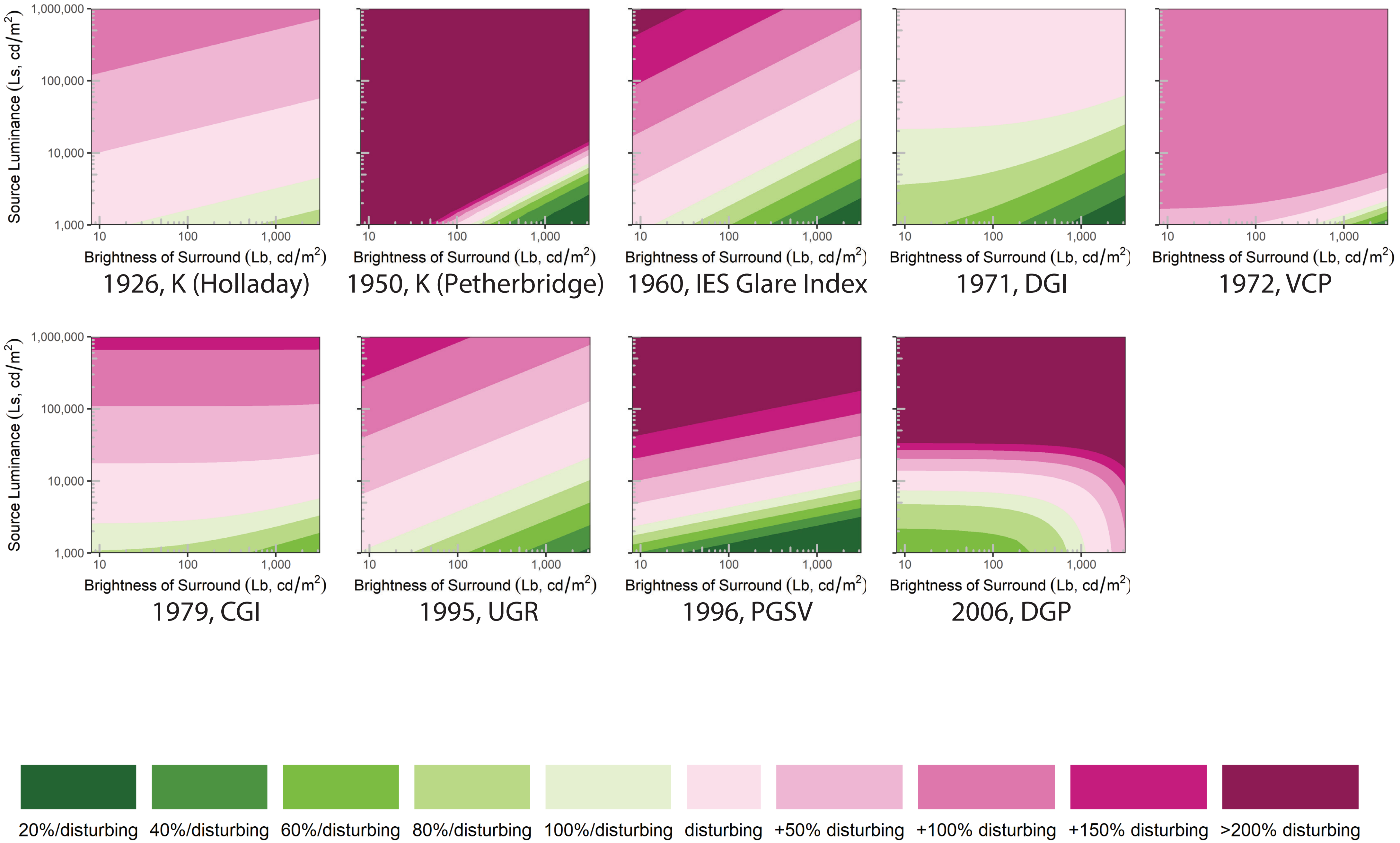

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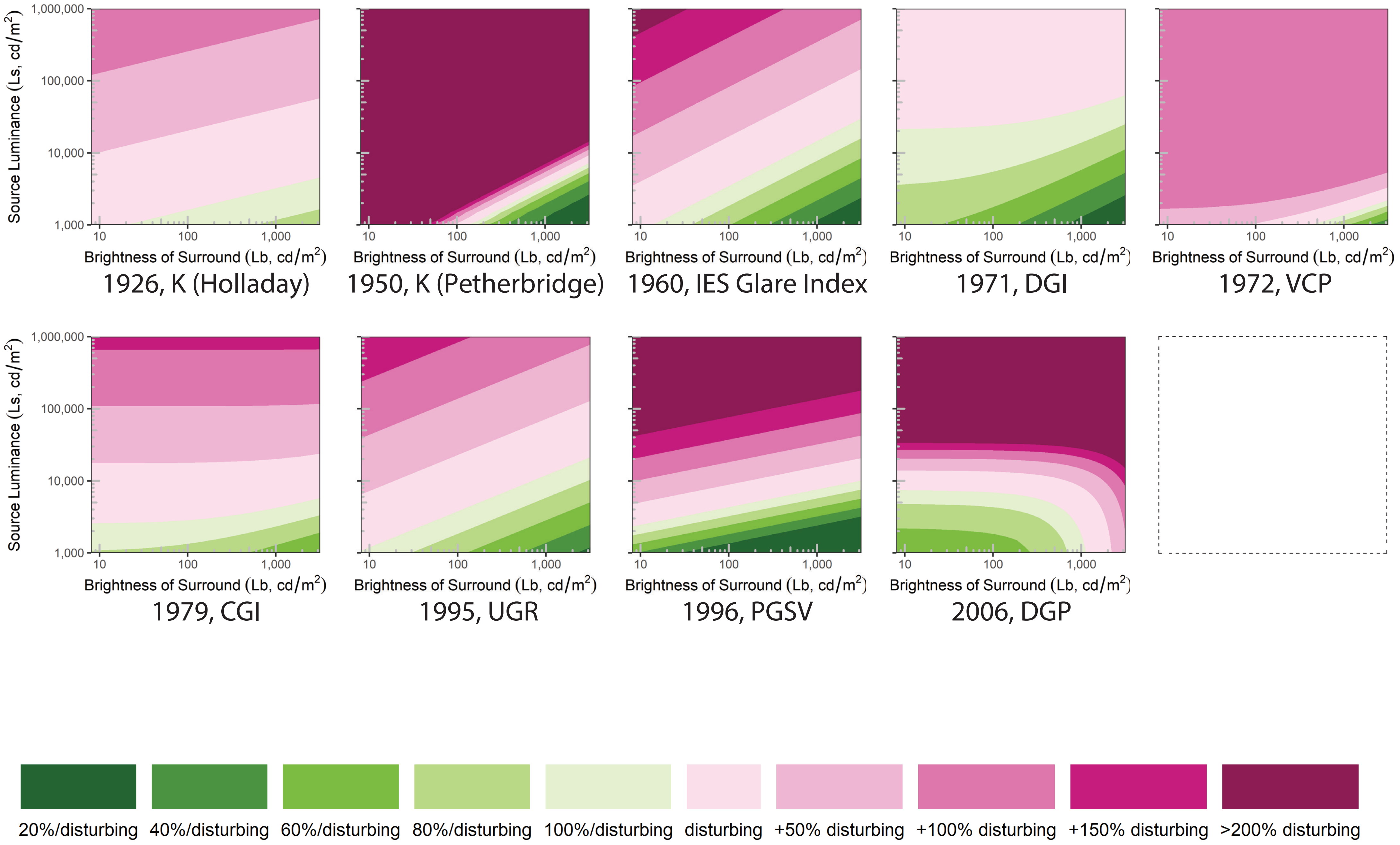
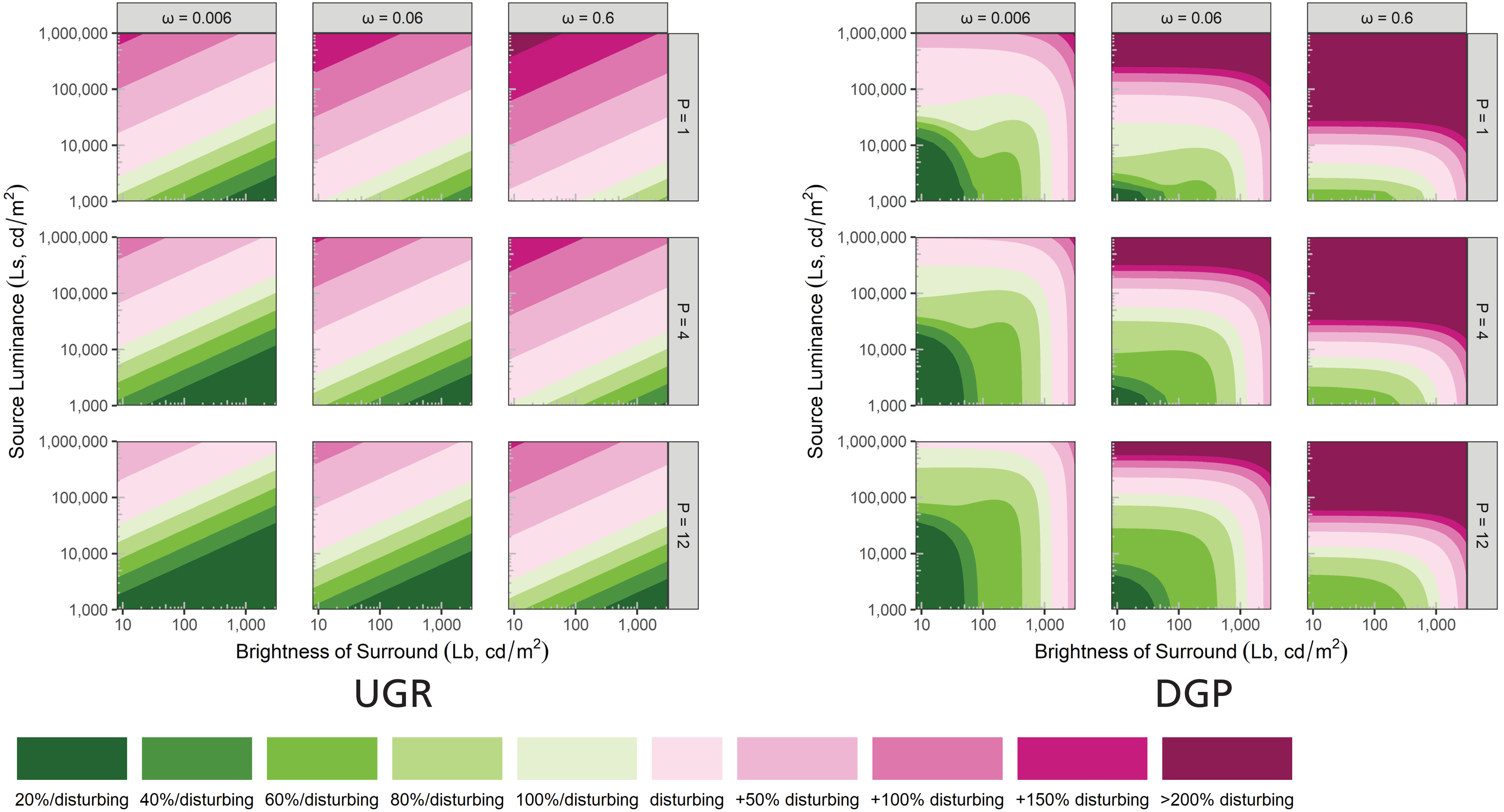
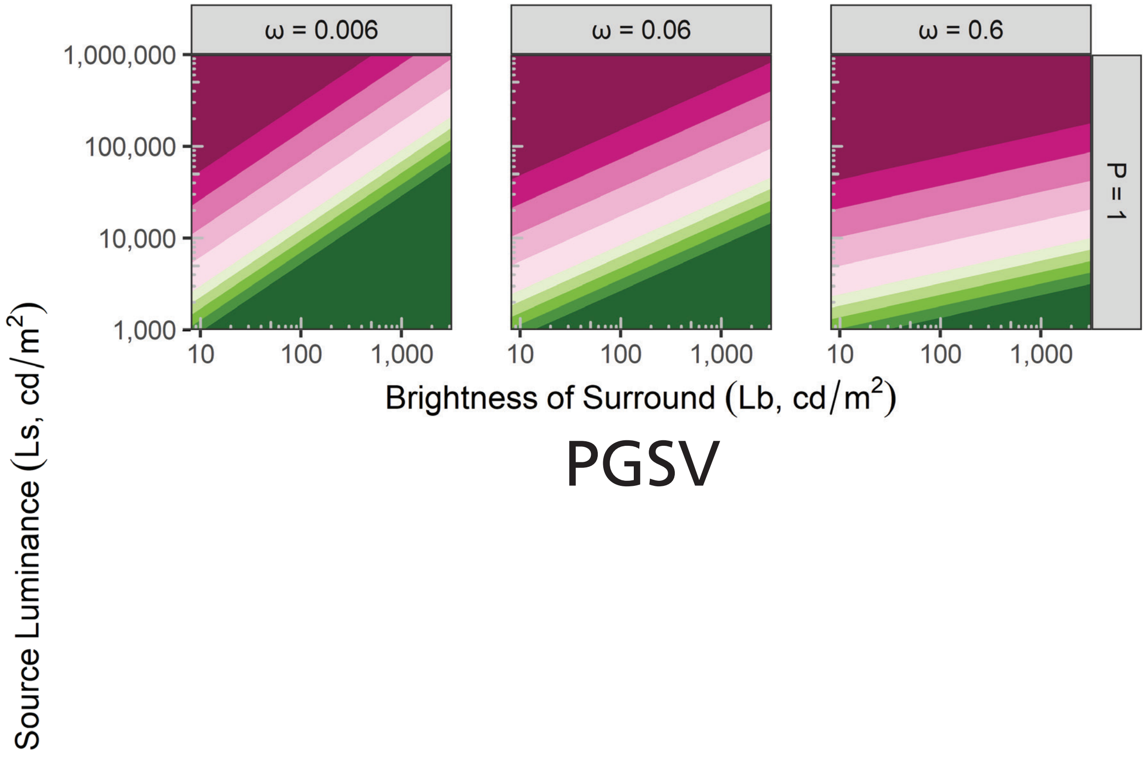


UGR vs DGP

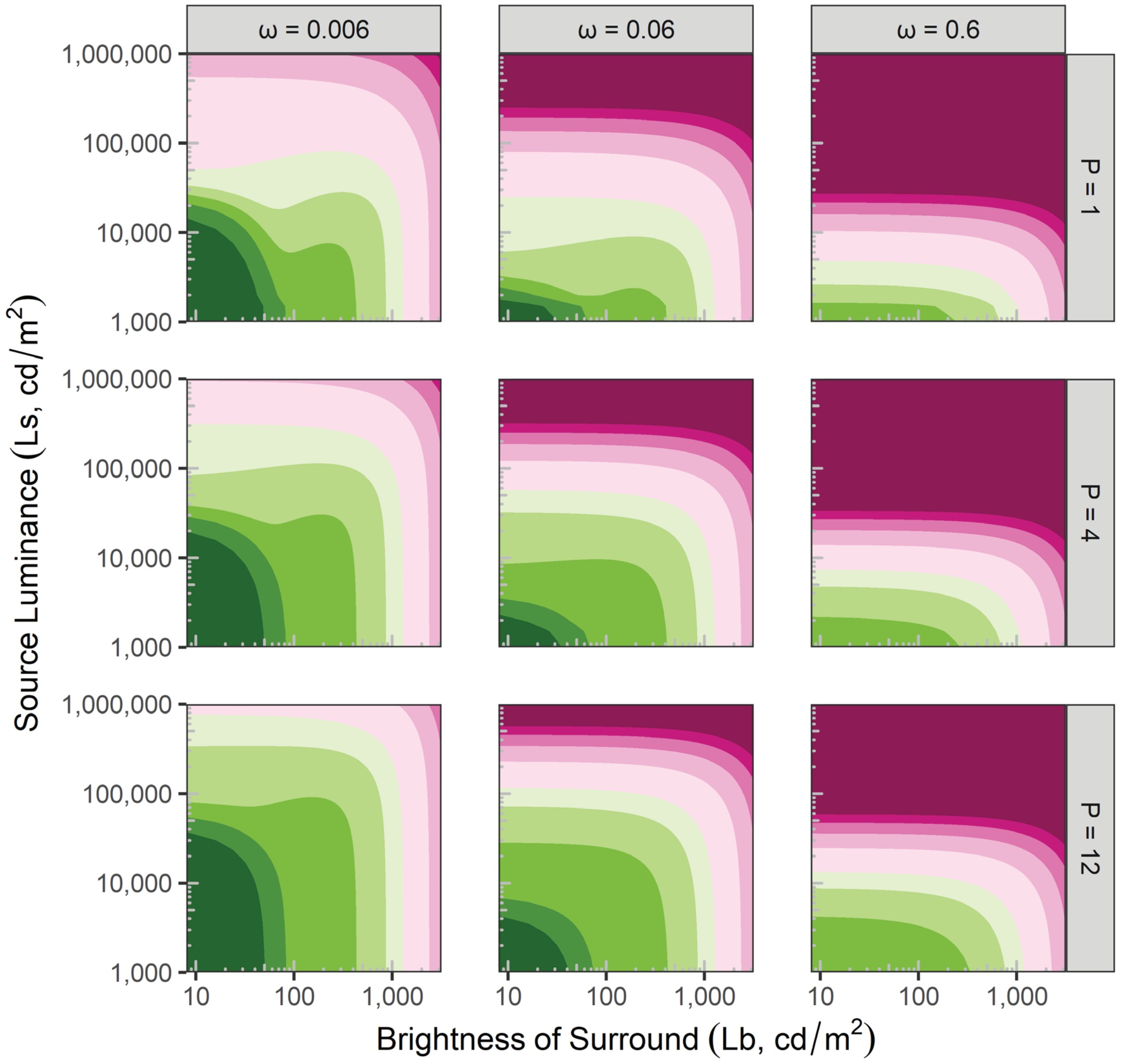


ω = 0.006
ω = 0.06
ω = 0.6
P = 1
P = 4
P = 12
Source Luminance (Ls, cd/m2)
1,000,000
100,000
10,000
1,000
Brightness of Surround (Lb, cd/m2)
10
100
1,000
UGR
DGP
20%/disturbing
40%/disturbing
60%/disturbing
80%/disturbing
100%/disturbing
disturbing
+50% disturbing
+100% disturbing
+150% disturbing
>200% disturbing

PGSV vs DGP



PGSV



DGP

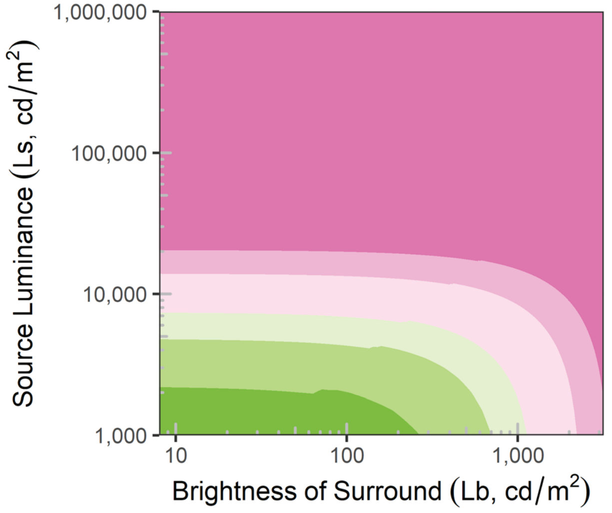
DGP, small changes over time (P = 4 and ω = 0.6)

- 2006: base metric derivation

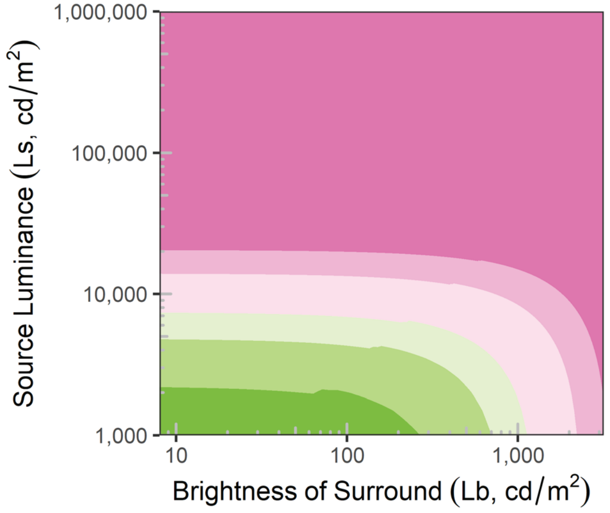
- ~2012: low light correction

- 2018: default source threshold detection
  - old: 5 times mean image luminance
  - new: 2,000 cd/m² (Pierson, Wienold, Bodart)

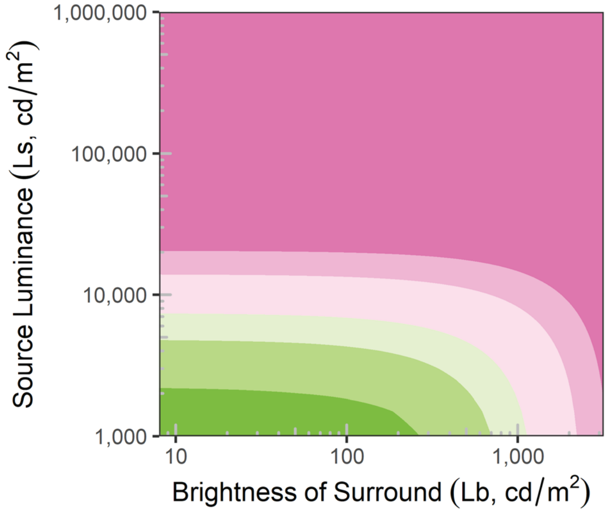
- 2019: subjective threshold fine-tuning
  - imperceptible from 0.35 to 0.34
  - noticeable from 0.34-0.40 to 0.34-0.38
  - **disturbing from 0.40-0.45 to 0.38-0.45**
  - intolerable stayed the same



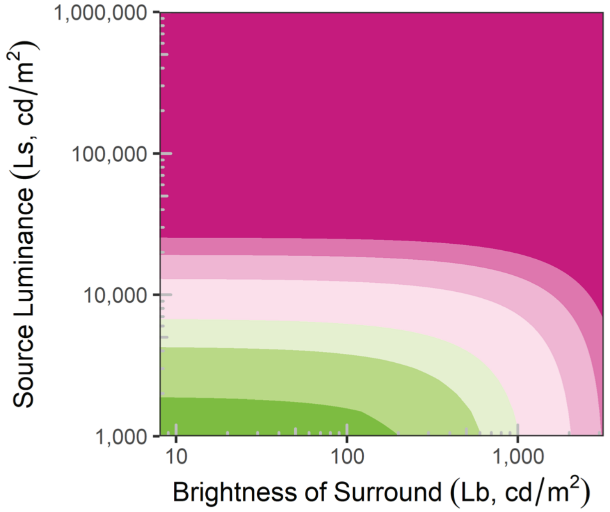
2006



2012



2018



2019

DGP, small changes over time (P = 4 and ω = 0.006)

- 2006: base metric derivation
- ~2012: low light correction
- 2018: default source threshold detection
  - old: 5 times mean image luminance
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- 2019: subjective threshold fine-tuning
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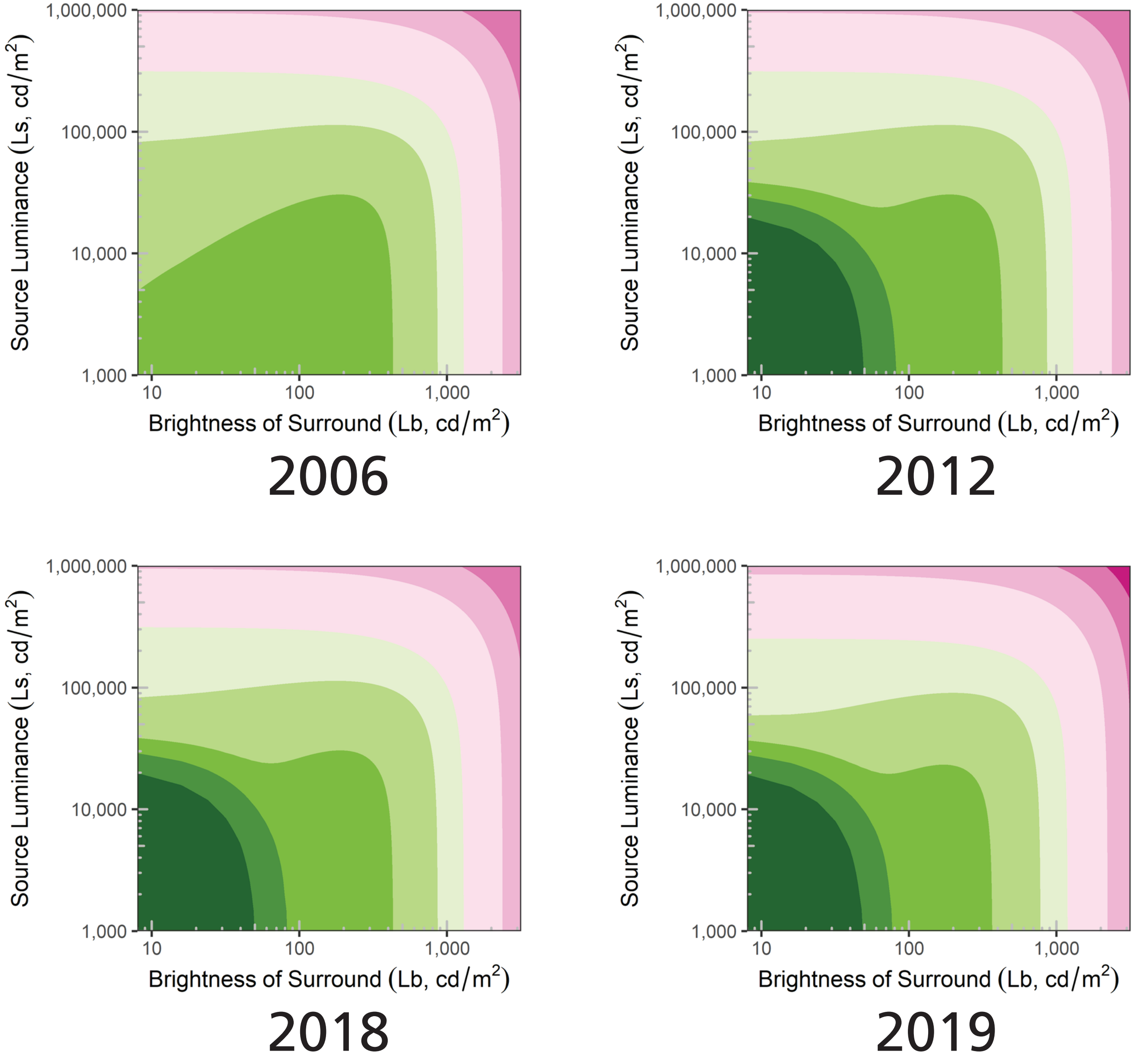

A Historical Comparison of Glare Metrics

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Thank you!