4.430 Daylighting

Christoph Reinhart
4.430 Visual Comfort & Occupant Behavior

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Department of Architecture
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Daylighting/Lighting in LEED

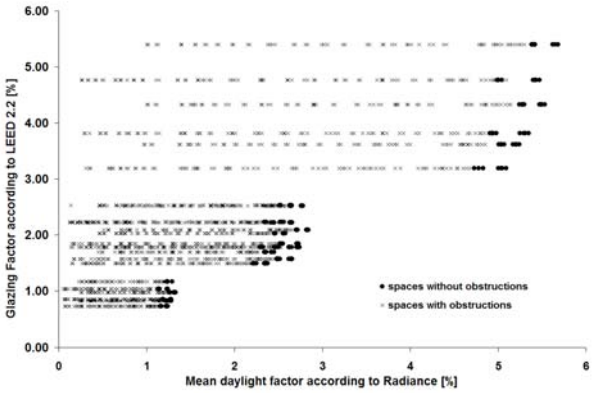
Indoor Environmental Quality section:
credits for:

- (a) glazing factor (daylight factor) of 2%
  (b) Between 250 and 5000 lux under equinox clear sky at 9AM and 3PM.
- view to the outside

Compliance via spreadsheet method.

LEED 2.2 Glazing Factor Formula

$$\text{Glazing Factor} = \frac{A_{glazing}}{A_{floor}} \bullet \text{Window Geometry Factor} \bullet \frac{\tau_{vis\,actual}}{\tau_{vis\,reference}} \bullet \text{Window Height Factor}$$



View to the Outside in LEED I 2

Credit 8.2 Views for 90% of Spaces Achieve direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples for exceptions copy rooms, storage areas, mechanical, laundry and other low occupancy support areas.

View to the Outside in LEED II

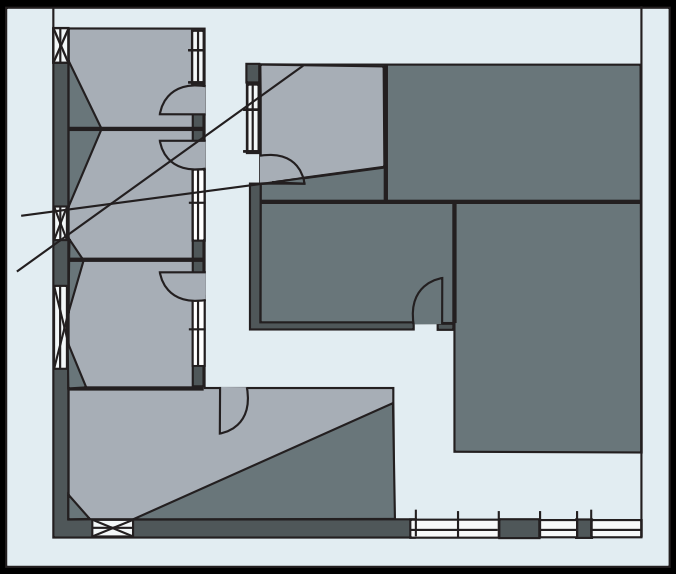


Image by MIT OpenCourseWare.

View to the Outside

- Size and content matter
- Information rich views with natural elements provide satisfaction and health benefits

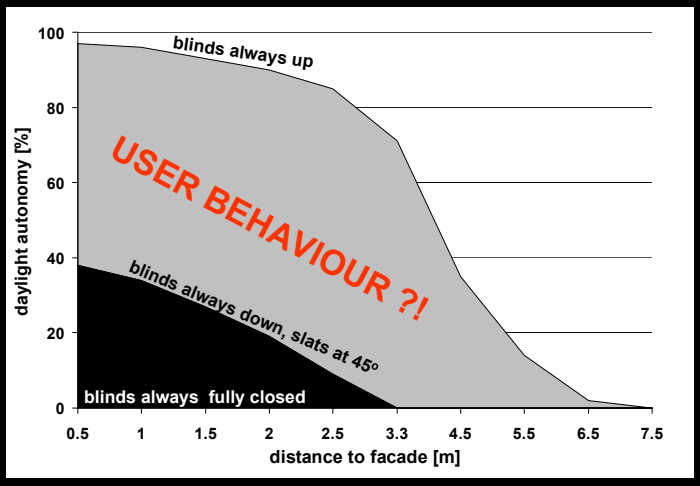
Daylighting/Lighting in LEED

Sustainable Sites:

Light Pollution Credit "eliminate light trespass from the building and site, improve night sky access and reduce development impact on nocturnal environments".

Occupant Behavior

Occupant Behavior



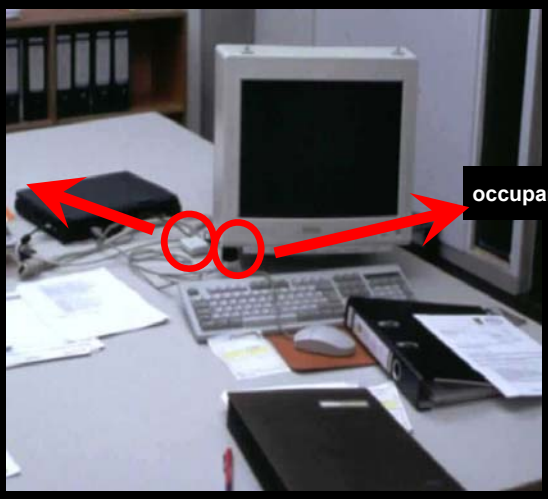
Monitoring User Behavior

architecture: Meier-Weinbrenner-Single, Nürtingen

Paper: Reinhart C F, Voss K, Monitoring manual control of electric lighting and blinds. Lighting Research & Technology, 35:3 pp. 243-260, 2003.

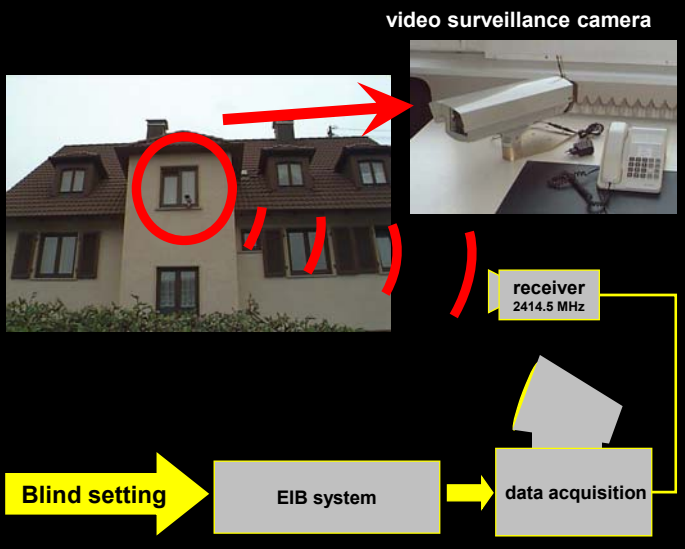
Monitoring Setup in the Offices

Illuminance
Temperature



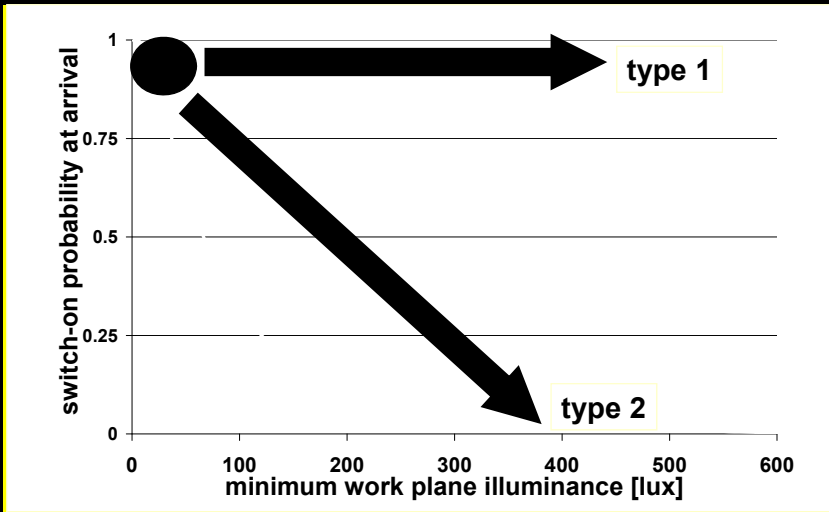
HOBO data logger

Monitoring Blind Usage



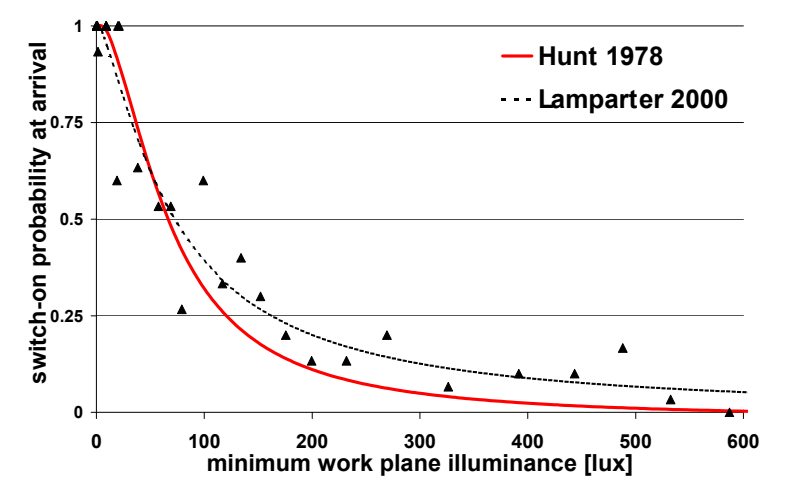
Example Picture

Switch-On Probability (I)

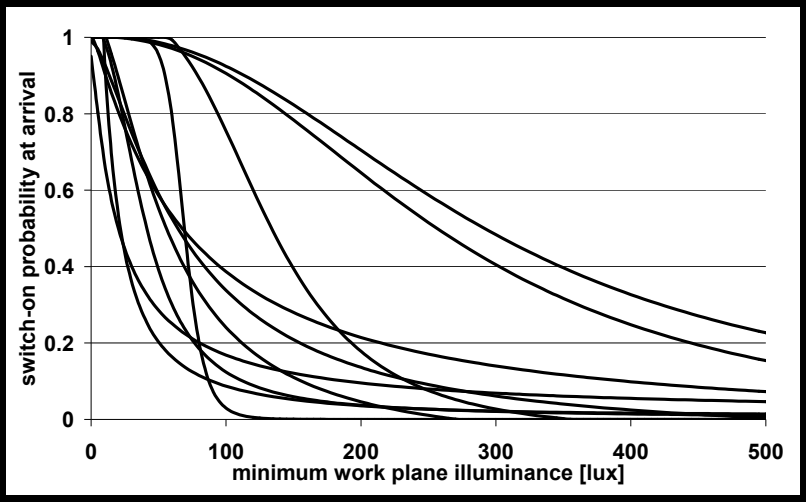


Jim Love, University of Calgary

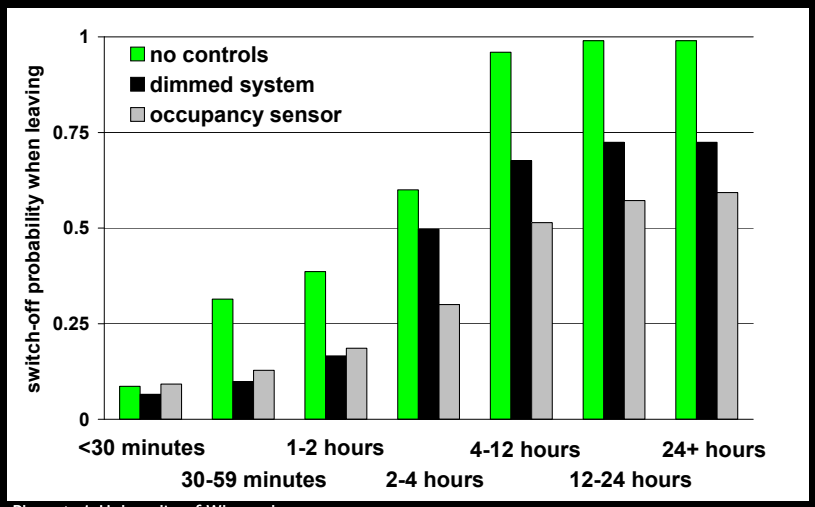
Switch-On Probability (II)



People are Consistent but Different



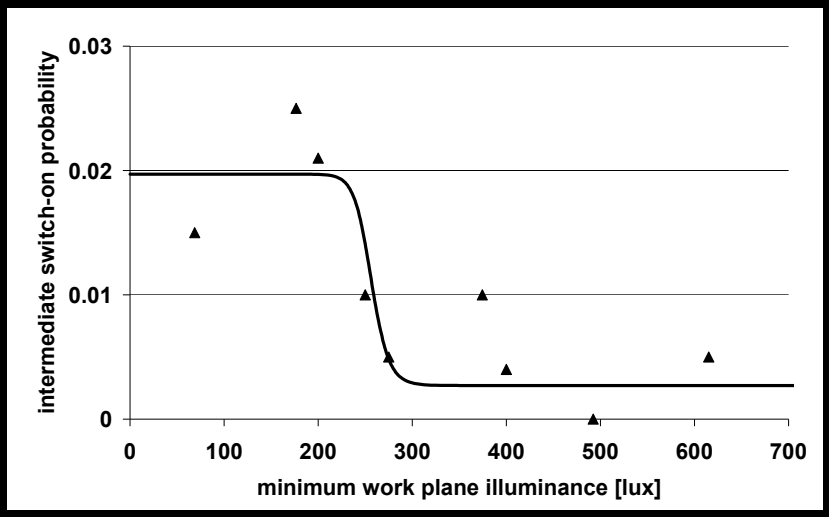
Switch-Off Probability



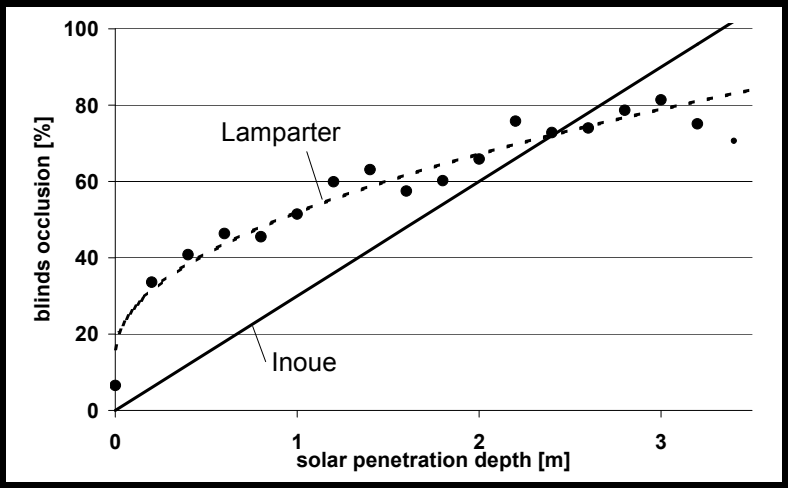
Pigg *et al.* University of Wisconsin

behavioral patterns change in the presence of automated controls

Intermediate Switch-On Probability

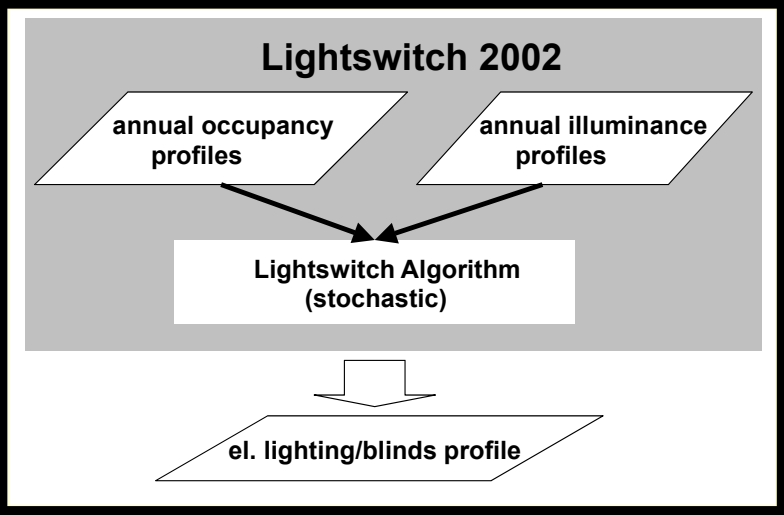


Manual Lighting Control Algorithm



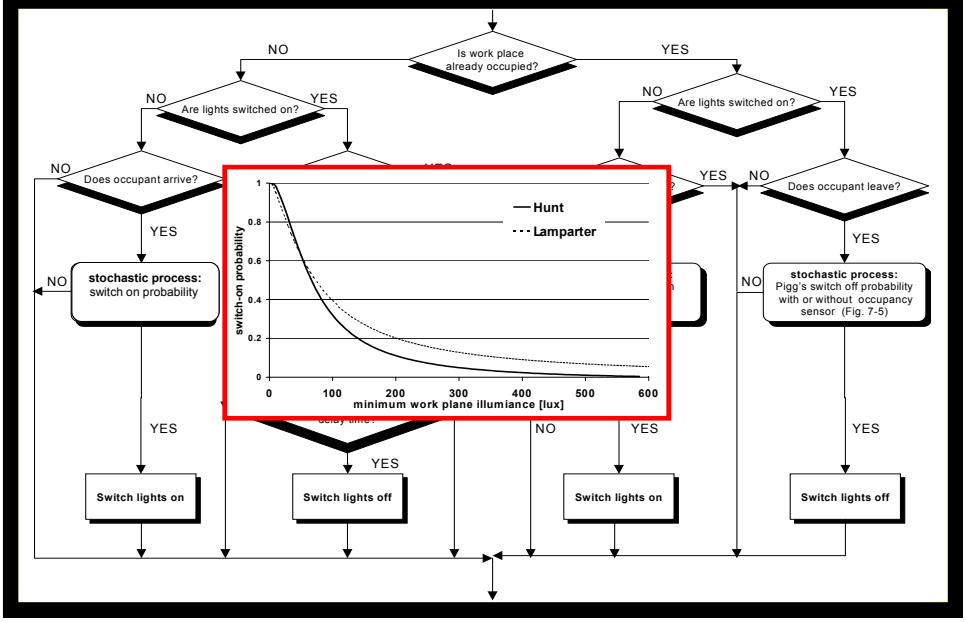
❑ Blinds get lowered to avoid direct sunlight falling on the work plane.

Model Overview

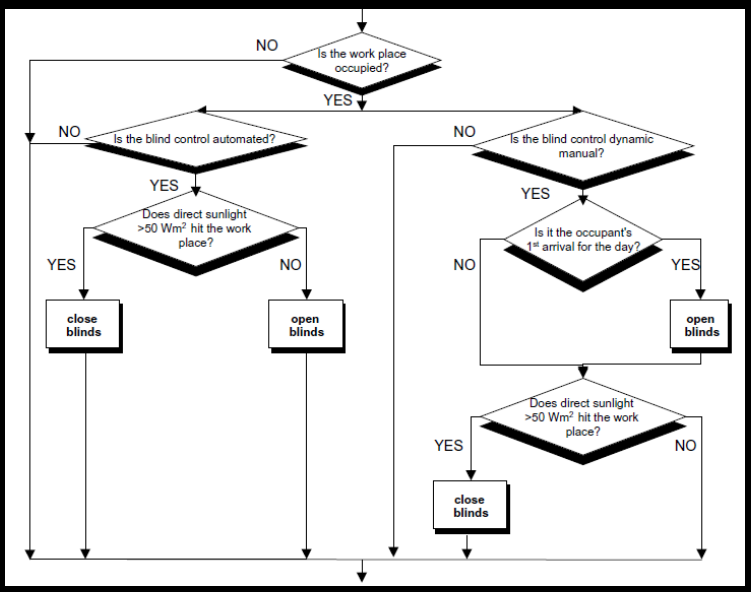


Paper: Reinhart C F, Lightswitch 2002: A model for manual control of electric lighting and blinds", Solar Energy, 77:1 pp. 15-28, 2004

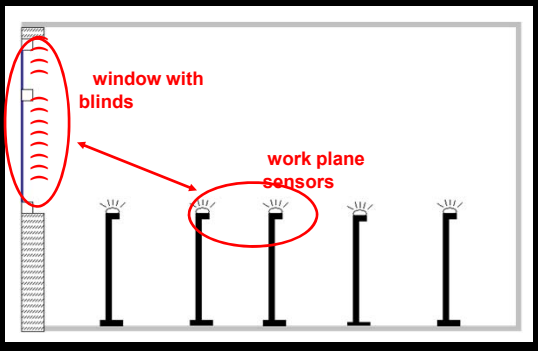
Lightswitch - Manual Lighting Control



Lightswitch - Manual Blind Control



Lightswitch - Manual Blind Control



- ❑ Define work plane sensors that define where the occupants are usually located.
- ❑ Associate sensors with shading groups. A shading group consists of a (set of) blinds that are opened and lowered at the same time.
- ❑ Check when direct sunlight (>50Wm^{-2}) is incident on a work plan sensor.
- ❑ Close shading device if yes until occupant is away for more than an hour.

Blind Use in New York City Classrooms

Question 14: How often do you adjust the shading device(s)?

MDesS thesis, Jennifer Sze 2009

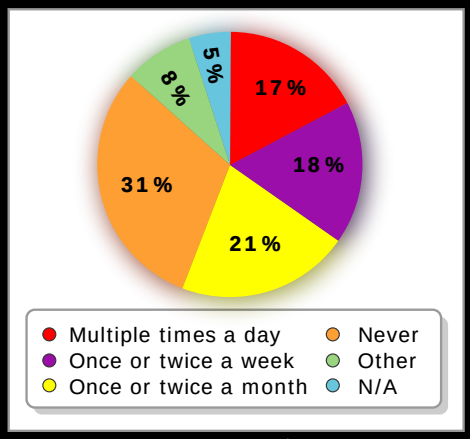
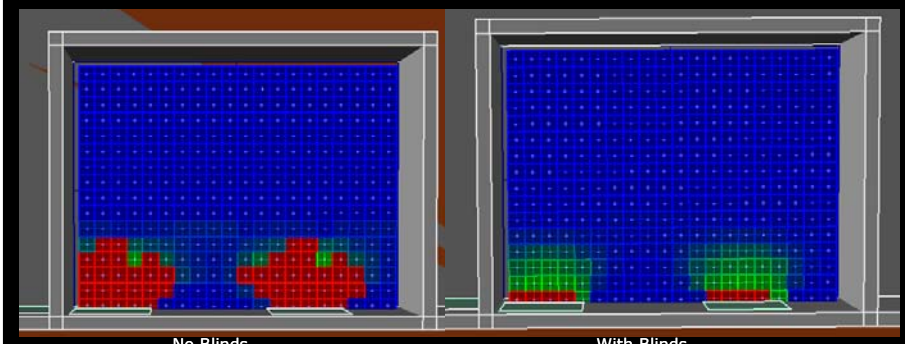


Image by MIT OpenCourseWare.

- 183 teacher surveys, 9 participating schools

DIVA Demo: Occupant Behavior

Modeling Occupant Behavior



No Blinds

With Blinds

Detecting Glare

What is glare?

❑ Glare is a subjective human sensation that describes 'light within the field of vision that is brighter than the brightness to which the eyes are adapted' (HarperCollins 2002).

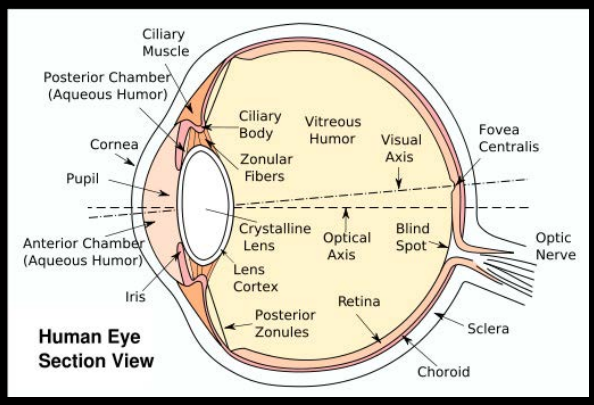


Illustration by ZStardust on Wikimedia Commons.

Glare Indices

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

CIE Unified Glare Rating

❑ *glare index* is a numerical evaluation of high dynamic range images using a mathematical formula that has been derived from human subject studies.

❑ Example indices include the unified glare rating (UGR) and the daylight glare index (DGI). All of these equations were derived from experiments with artificial glare sources none of them under real daylight conditions.

❑The reason for this is that until recently it has been next to impossible to collect high dynamic range images of daylit scenes under continuously changing lighting levels.

Daylight Glare Probability (DGP)

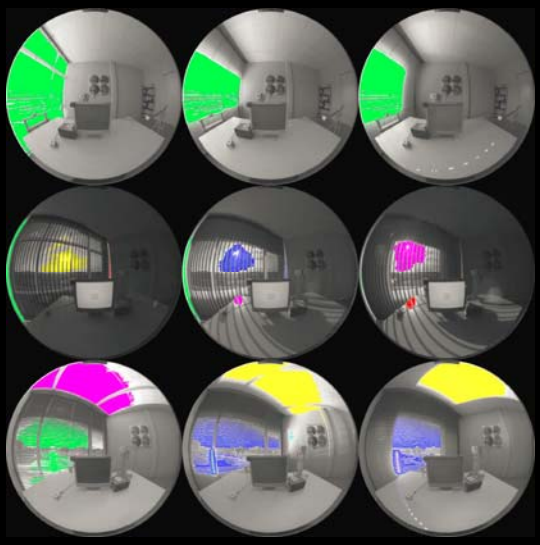
Room 1: CCD Camera

Room 2: Human Subject

- DGP is a recently proposed discomfort glare index that was derived by Wienold and Christoffersen from laboratory studies in daylit spaces using 72 test subjects in Denmark and Germany.
- Two identical, side-by-side test rooms were used. In Room 1 a CCD camera based luminance mapping technology was installed at the exact position and orientation as the head of the human subject in Room 2.

Paper: Wienold & Christoffersen, " Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras ", Energy & Buildings 2006.

Image-based Glare Source Detection using the Radiance evalglare Program



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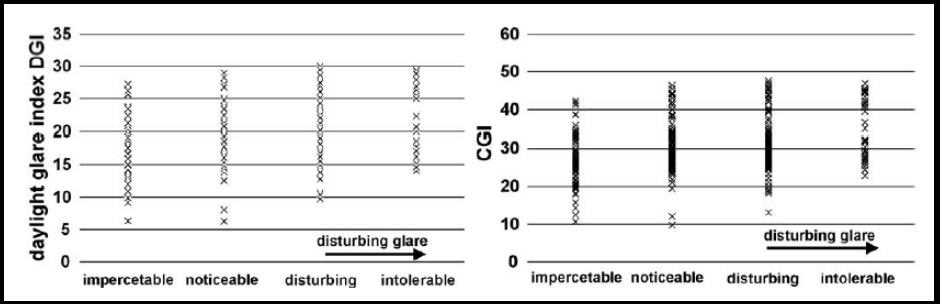
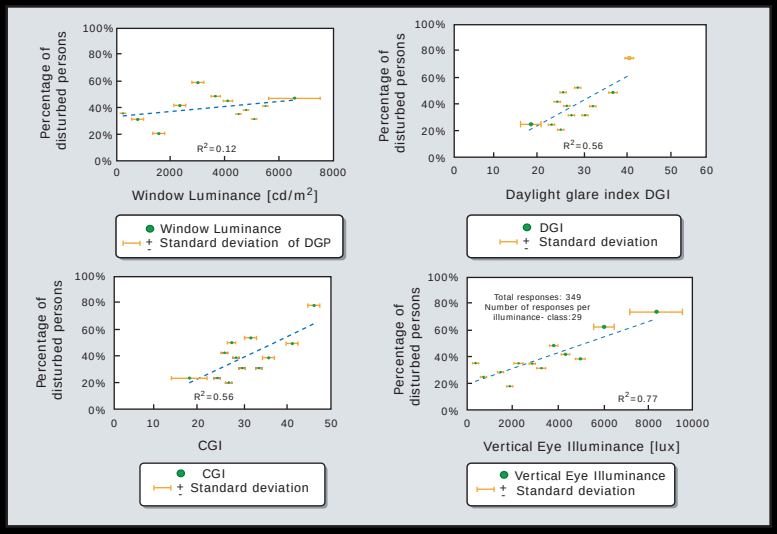
In Search of a Glare Metric…



- Weak correlation between DGI and CGI (conventional glare metrics) and occupant evaluations.

Paper: Wienold & Christoffersen, Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras ", Energy & Buildings 2006.

In Search of a Glare Metric…



- Vertical eye illuminance promising for the first term.

Final Daylight Glare Probability Metric

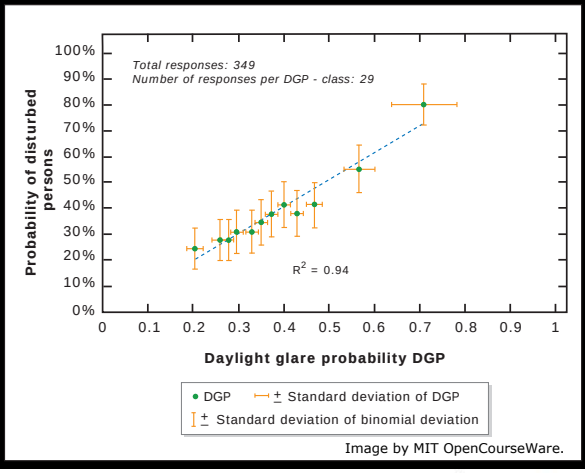
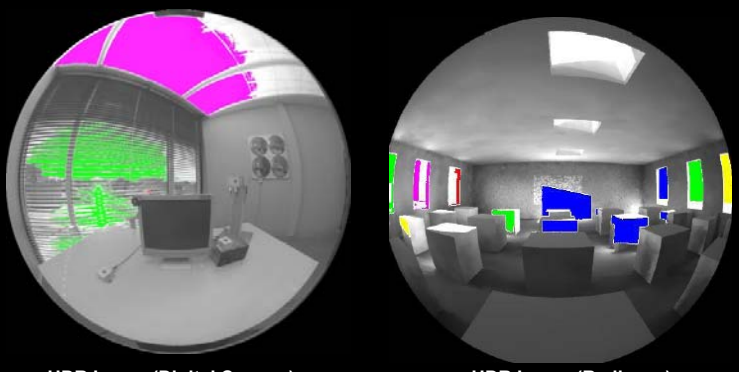


Image by MIT OpenCourseWare.

$$DGP = 5.87\times10^{-5}E_v + 9.18\times10^{-5}\log\left(1+\sum_i \frac{L_{s,i}^2\omega_{s,i}}{E_v^{1.87}P_i^2}\right)$$

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

DGP allows users to go back and forth between simulation and reality through HDR photography



HDR Image (Digital Camera)

HDR Image (Radiance)

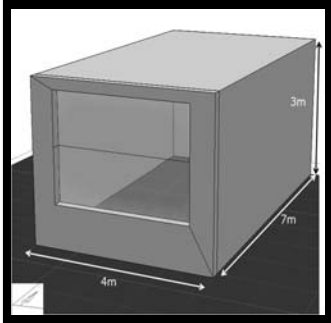
evalglare program

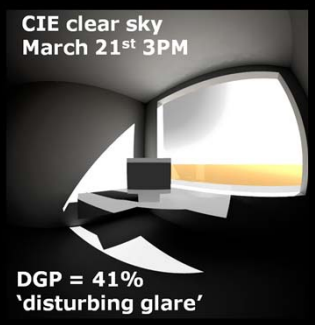
instantaneous daylight glare probability

DGP Comfort Ranges

DGP < 35%	imperceptible
35% < DPP < 40%	perceptible
40% <DGP < 45%	disturbing
DGP > 45%	intolerable

Example DGP Calculation





DIVA Demo: DGP Point in Time Calculation

Towards Annual Glare Calculations

Generated visualizations for illuminance calculation removed due to copyright restrictions.

- Wienold developed a process through which the annual glare calculation is split into a regular Daysim illuminance calculation and an ab=0 contrast image.

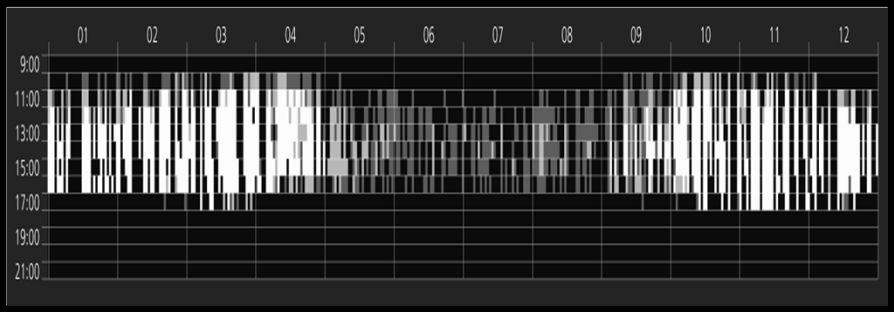
Paper: J Wienold, Dynamic Daylight Glare Evaluation , Building Simulation 2009, Glasgow Scotland.

Comparison of Simplified DGP and hour -by-hour method

Graph of vertical illuminance removed due to copyright restrictions.

Paper: J Wienold, Dynamic Daylight Glare Evaluation , Building Simulation 2009, Glasgow Scotland, 2009.

Annual Glare Map



DGP Comfort Ranges

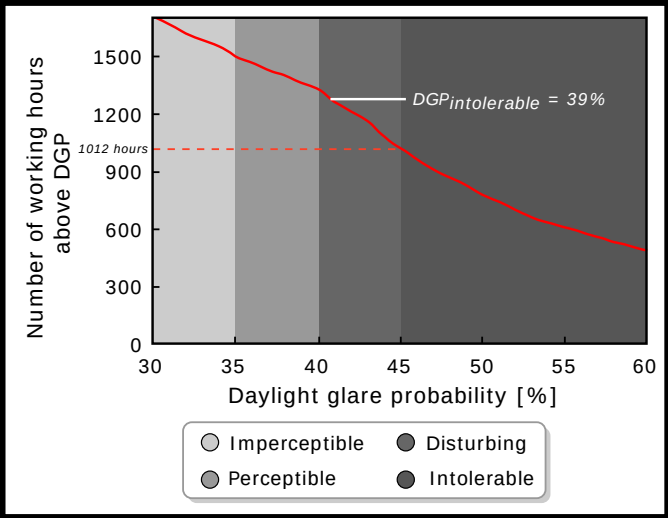


Image by MIT OpenCourseWare.

Paper: C F Reinhart, Simulation-based Daylight Performance Predictions", Book chapter in Building Performance Simulation for Design and Operation, Editors J Hensen and R Lamberts, Taylor & Francis, 2011.

Expanded Blind Control Model: Close Blinds when DGP > 40%

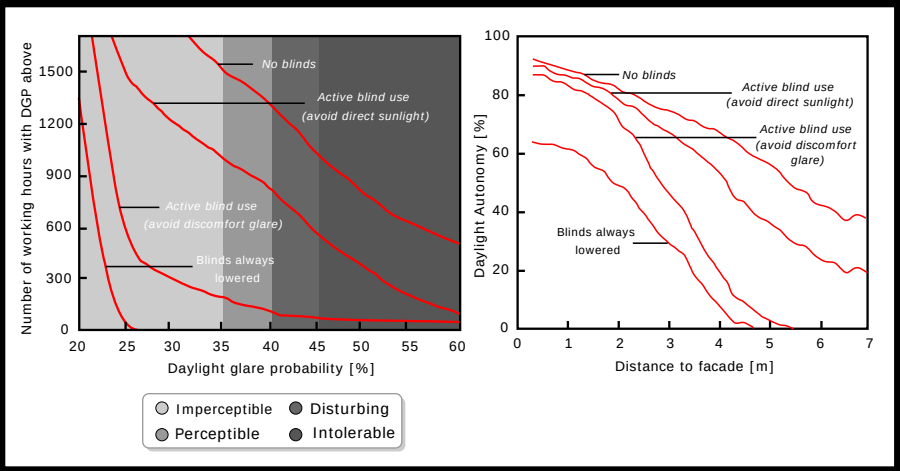
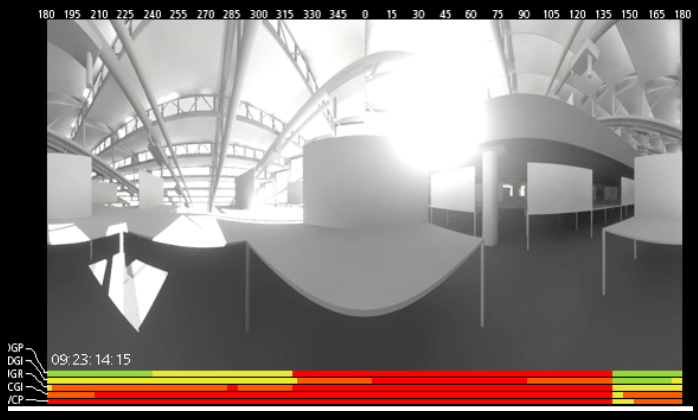


Image by MIT OpenCourseWare.

The formula makes sense. How plausible are DGP results compared to other glare indices?

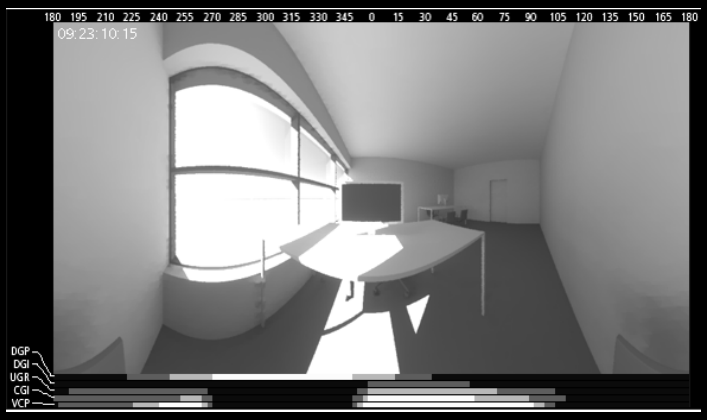
Multidirectional Time-Lapse Simulation



The image shows a cylindrical 360° view of a work space in Gund Hall. The color coded lines at the bottom show the predictions of different glare indices (DGP, DGI, UGI, CGI and VCP) whether discomfort glare will be experienced in a particular direction at different times of the day (Green=Imperceptible Glare; Yellow=Perceptible Glare; Orange=Disturbing Glare; Red=Intolerable Glare).

Paper
J A Jakubiec, C F Reinhart, The Use of Glare Metrics in the Design of Daylit Spaces: Recommendations for Practice , submitted to Lighting Research and Technology 2011.

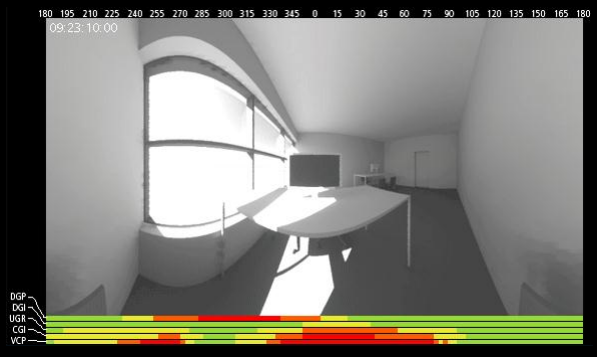
Multidirectional Time-Lapse Simulation



- DGP yields most plausible results in these spaces.

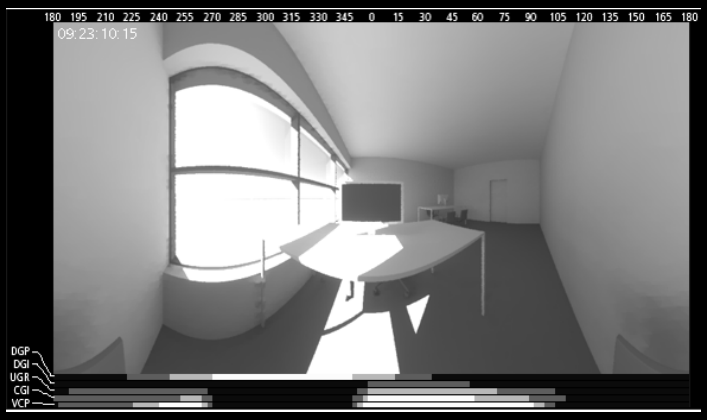
Paper
J A Jakubiec, C F Reinhart, The Use of Glare Metrics in the Design of Daylit Spaces: Recommendations for Practice , submitted to Lighting Research and Technology 2011.

How to analyze for visual discomfort?



Paper: J A Jakubiec, C F Reinhart, 2010, "The Use of Glare Metrics in the Design of Daylit Spaces: Recommendations for Practice", Lighting Research and Technology, 2011.

Multidirectional Time-Lapse Simulation



- DGP yields most plausible results in these spaces.

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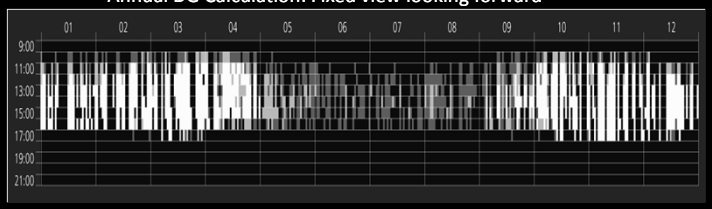
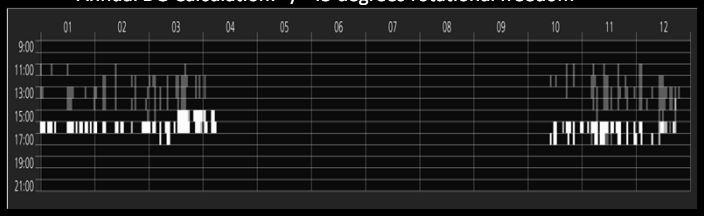
Concept of the Adaptive Zone

Annual DG Calculation: Fixed view looking forward



Annual DG Calculation: +/ 45 degrees rotational freedom



- The concept helps to quantify the benefits of flexible furniture settings etc.

Paper
J A Jakubiec, C F Reinhart, The Use of Glare Metrics in the Design of Daylit Spaces: Recommendations for Practice , submitted to Lighting Research and Technology 2011.

The Ultimate Adaptive Space

4.430 Daylighting

Spring 2012