Using Climate Based Daylight Metrics
to Improve Daylighting Performance Prediction

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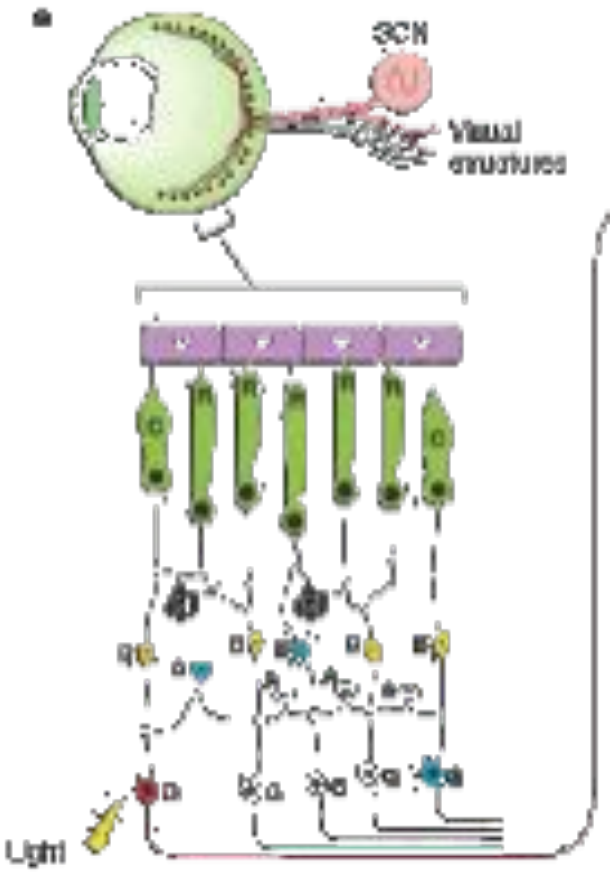
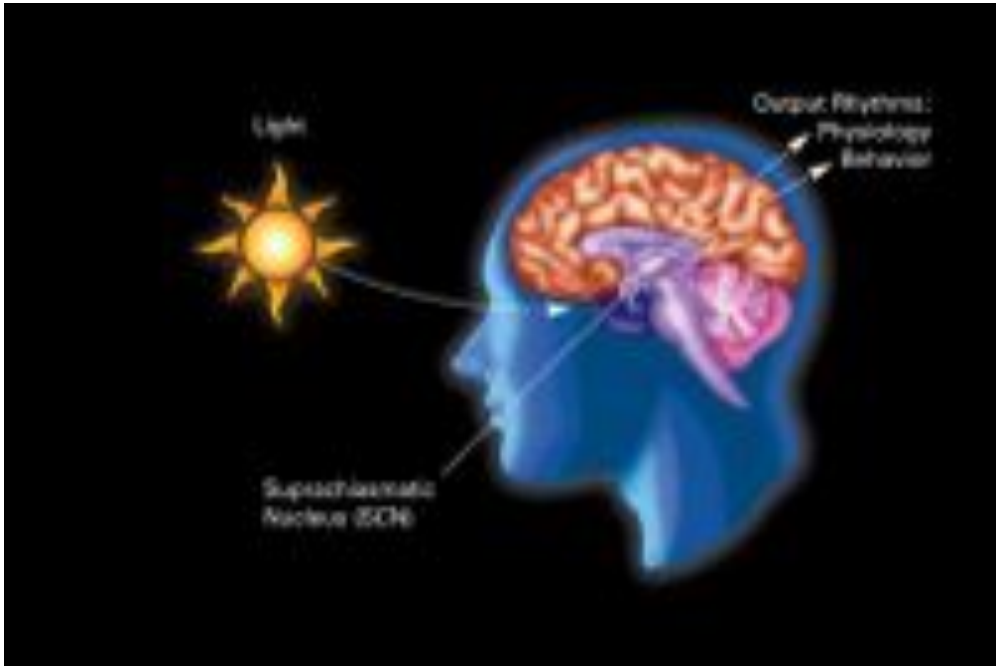
A LIGHT AFFAIR – 2014

We are daytime animals

- We expand our natural habitat
- By turning night into day

Your eye … is part of your brain

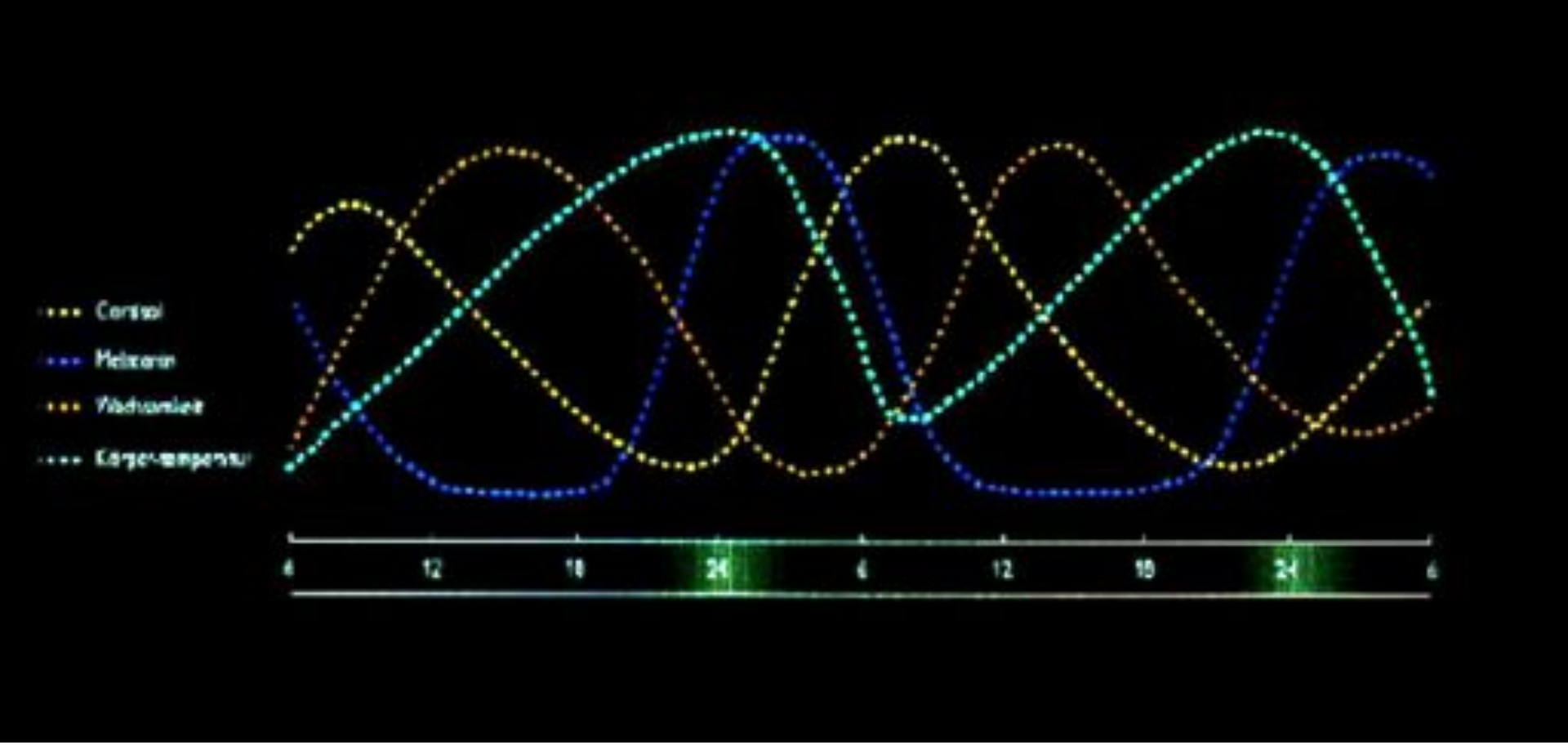




From: Reppert, S.M. & Weaver, D.R. Nature 418, 935 - 941 (2002)

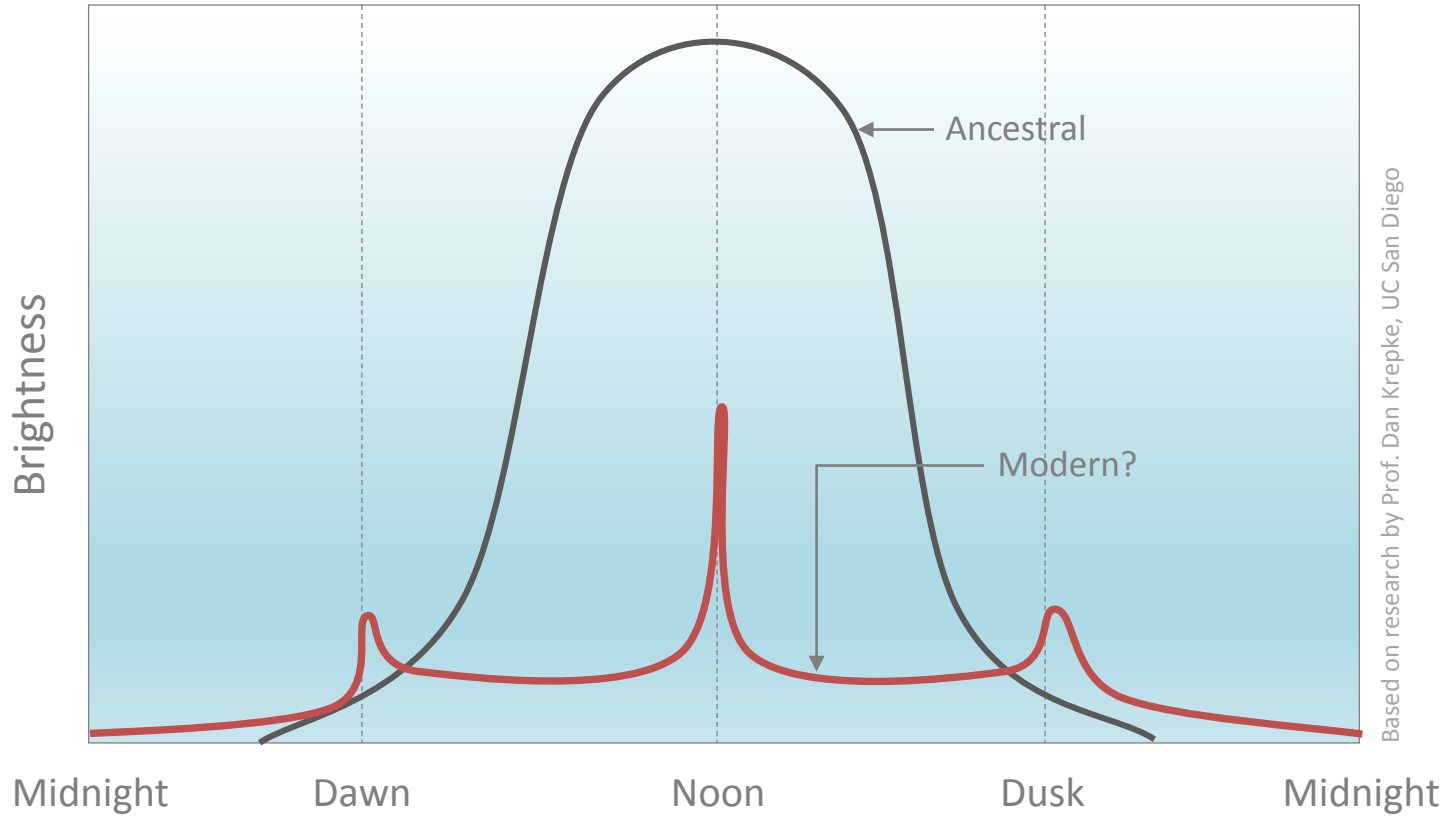
Your eye … is part of your brain

- Non-optic ganglion receptors in the retina – sensitive to blue light
- Orchestrates circadian response – melatonin, dopamine, serotonin



Circadian cycles are more comprehensive than we thought

- Patterns of LIGHT and DARKNESS are key to “entrainment”
- Affects: mood, focus, motivation, puberty, learning, memory, blood pressure, immunity, impulse control, cravings



We spend most of our lives indoors

- Exposure to full spectrum light is a fraction of what it was
- Our eyes see less brighter days and less darker nights

We seek daylight

- In our natural environment
- As well as our built environment

Designing well daylit built environments is challenging

- The sun is in never in the same place
- Weather conditions and cloud cover change seasonally
- Orientation matters
- Glare is a problem … and the sun keeps moving!
- Occupants adjust blinds/shades, hard to predict

So … we design for the worst case!

- The building has *horrible* visual quality
- Lights are always ON … everywhere!
- People close the blinds because the sun is still glaring though the tint

We all deal in Metrics …

If what you care for has **no metric** …

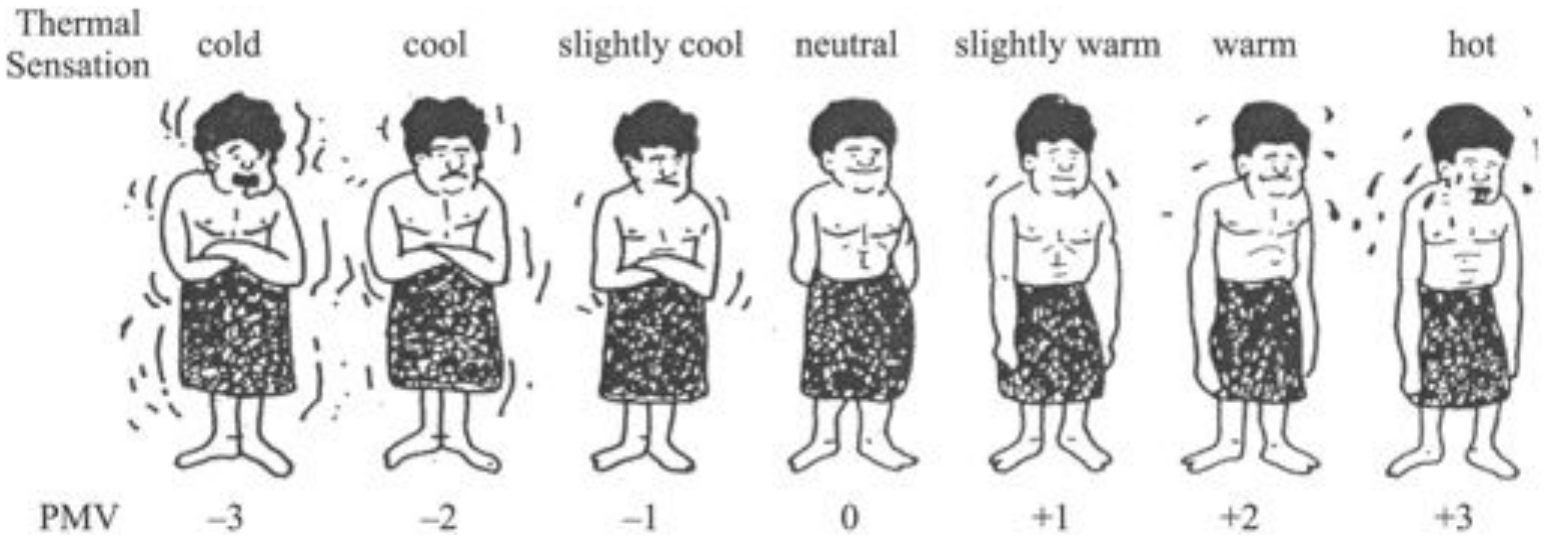
… you don't get a seat at the table!

As a result your value **cannot be measured**

… cannot be designed for

… first on the chopping block!

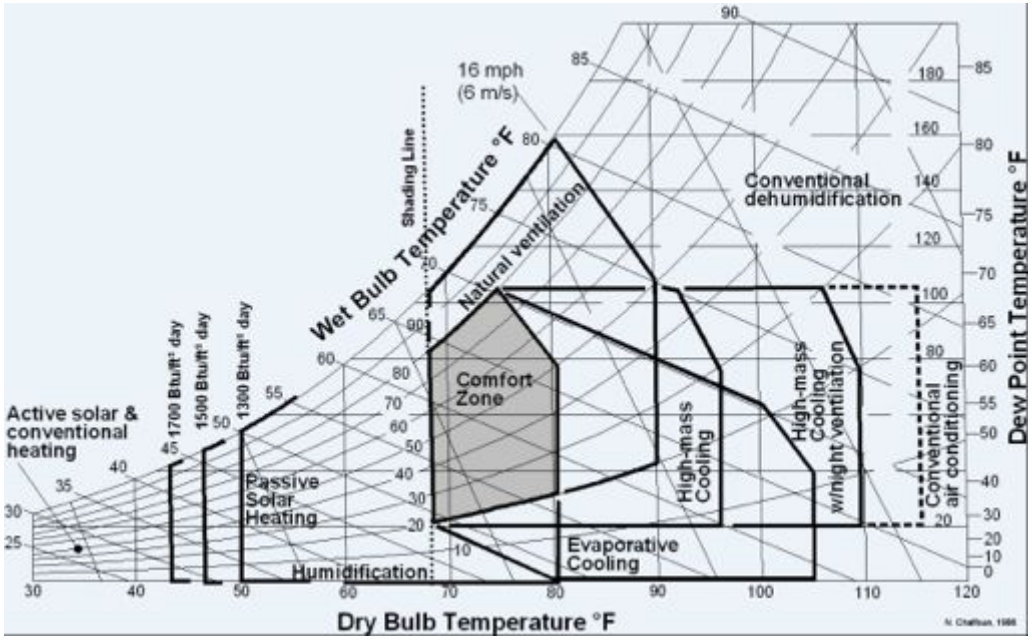
We all deal in metrics …



Metric for Thermal Comfort …

- Metric: Predicted Mean Vote or PMV (Fanger's Scale)
  - Value between -3 and +3

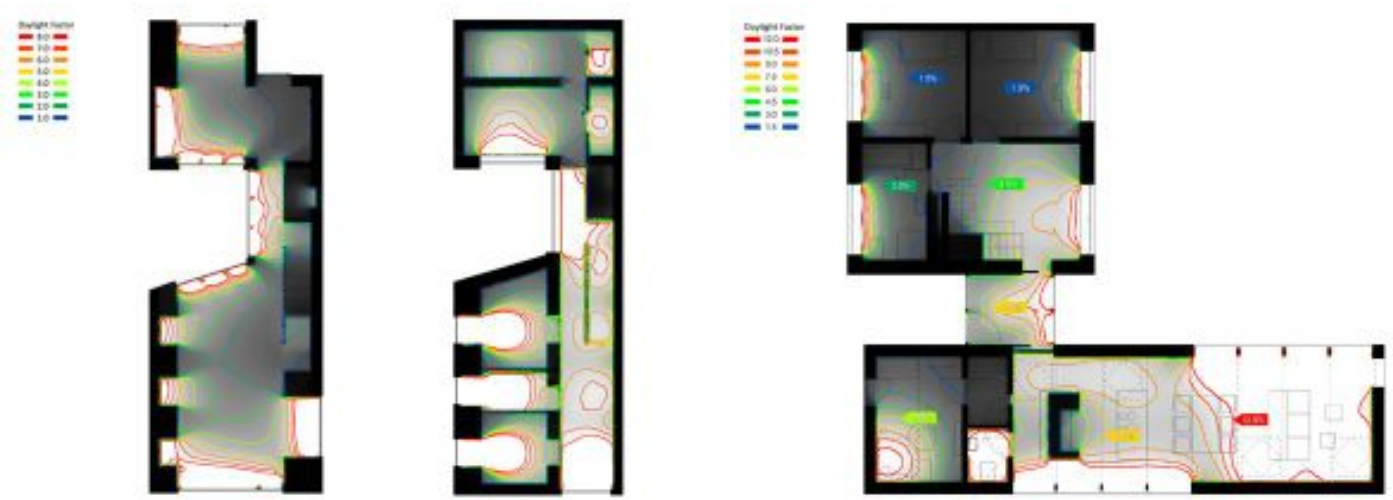
We all deal in metrics …



Metric for Air Temperature and Humidity …

- Metric: Comfort Zone on a psychrometric chart
  - Defined in terms of dry bulb, wet bulb and due point temperatures

We all deal in metrics …



Daylight and Visual Quality …

- Metric: Daylight Factor … ?
  - How much daylight is too little, too much?
  - What conditions cause glare, discomfort?
  - What do occupants think is preferred … nominal … unacceptable levels of daylight?

Metrics are essential!

- How do we optimize benefits? … while minimizing energy use?
- How do we describe “good / better / best” for daylight designs?
- How can we evaluate success and failure?

Metrics are essential!

- How much daylight is needed for comfort?
- What provides the productivity benefits?
- What is needed for circadian health?

Metrics are essential! … but!

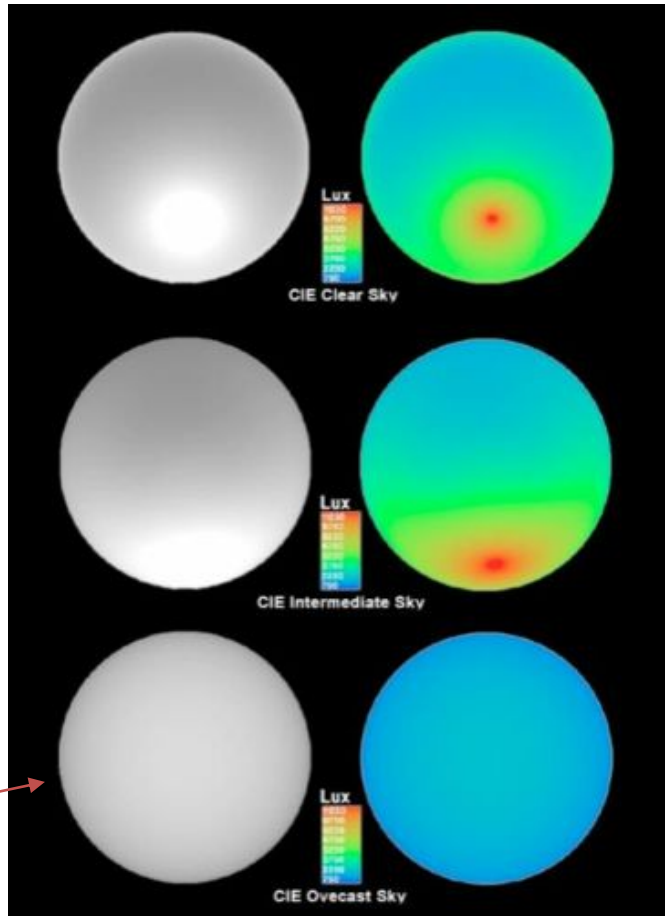
We want metrics that are sensitive indicators of
“good daylighting”

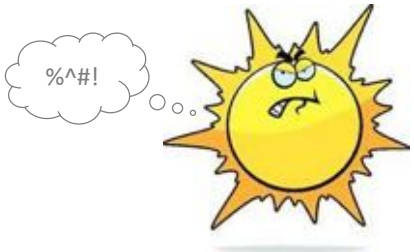
that allows designs to be optimized for the most energy efficient means to deliver
comfort

Daylight Factor … a metric from the past

- … Literally!
  - First proposed in the UK in the early 1900s
  - Formalized into building standards over fifty years ago
- Simply calculated as
  - DF = ratio of internal illuminance to unobstructed horizontal illuminance under standard CIE overcast sky

- ***But wait!! …***
  - there is no sun in a CIE overcast sky!

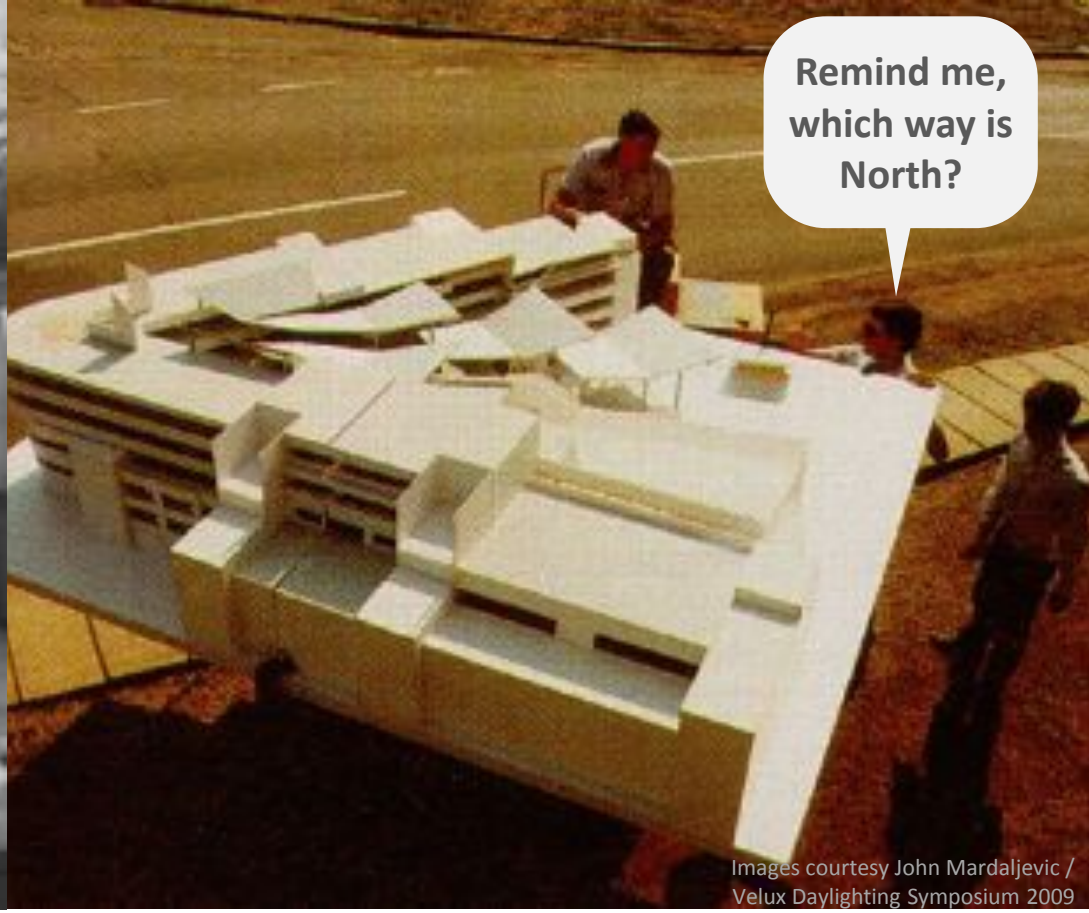




South facing in Miami & North facing in Aspen
Same Daylight Factor!

No sun means …

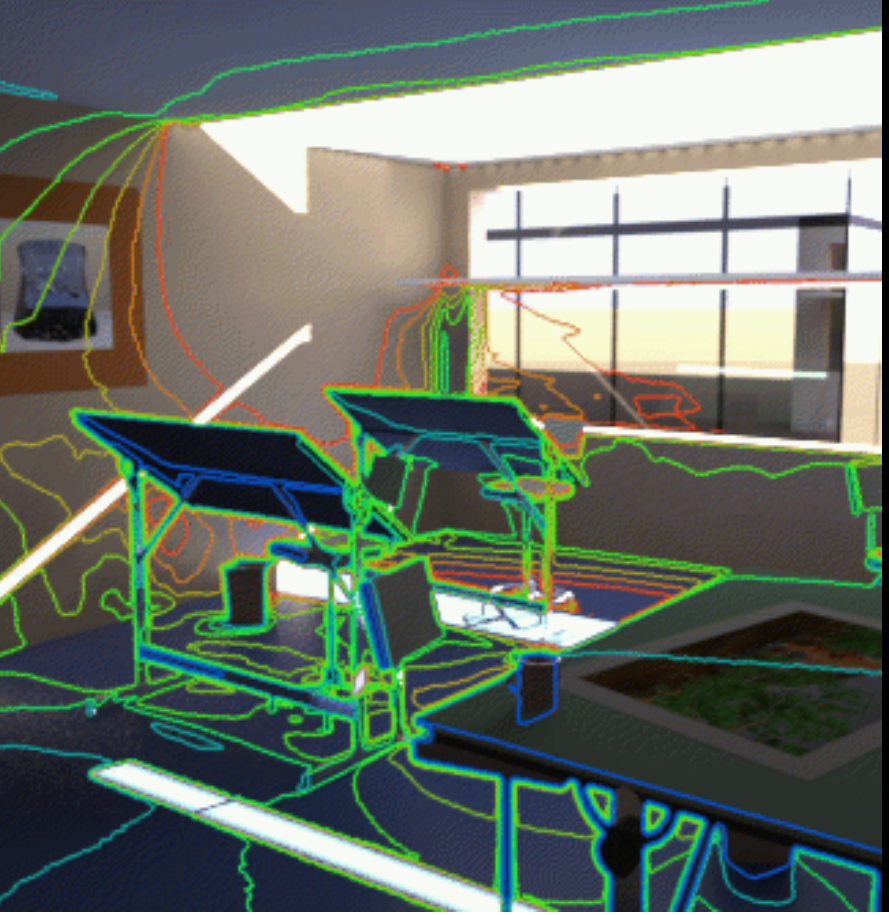
- The metric is insensitive to orientation
- The metric is insensitive to climate of the location (cloudy / sunny)
- Time of day is irrelevant
- Does not account for blinds/shades operation

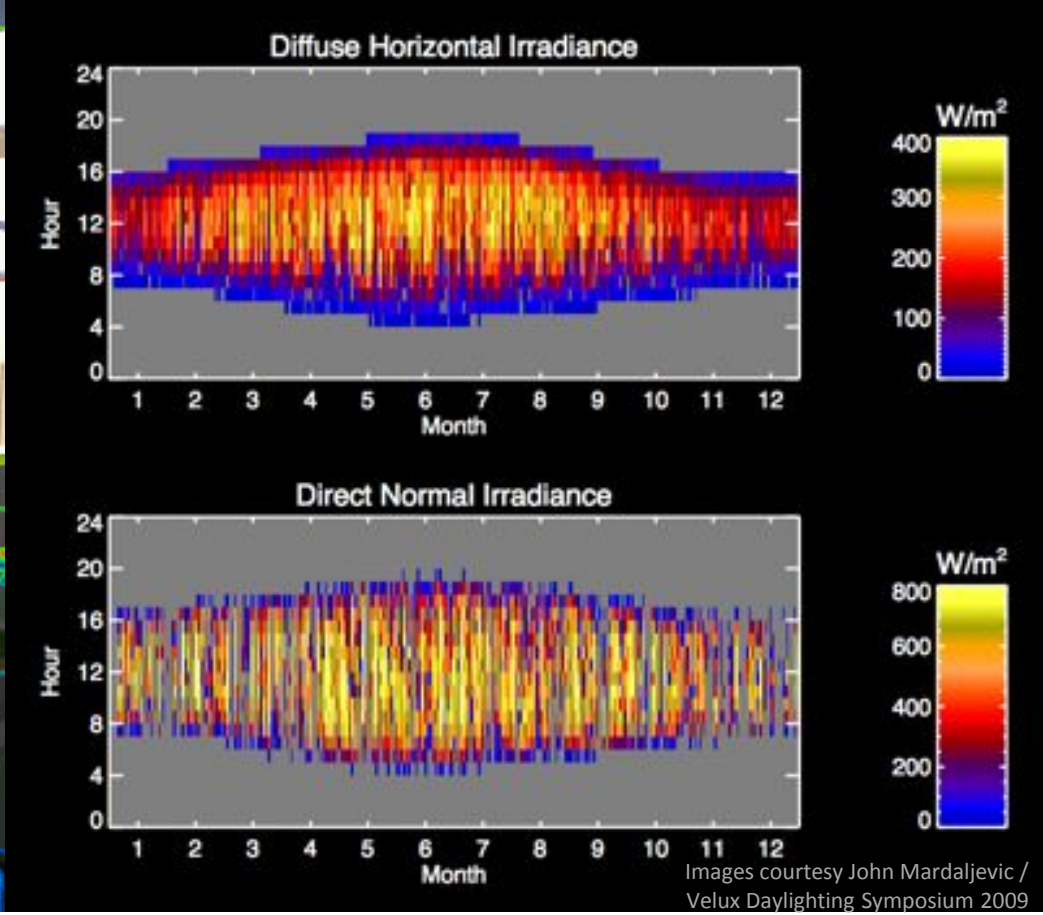


Images courtesy John Mardaljevic / Velux Daylighting Symposium 2009

DF was developed in the days of physical models

- Scale physical models positioned in daylight
- You could do one position at a time (click!) … then next (click!)





Images courtesy John Mardaljevic / Velux Daylighting Symposium 2009

Today we use computer software

- Daylighting simulation tools now have the ability to render scenes for point-in-time analysis
- As well as run annual simulations using weather files

It is time for a new metric, based on simulation and annual climate data!

- Well … quite a few exist actually

  - Daylight Autonomy
  - Continuous Daylight Autonomy
  - Zonal Daylight Autonomy
  - Spatial Daylight Autonomy
  - Temporal Daylight Autonomy
  - Useful Daylight Illuminance
  - Direct Sunlight Hours
  - Daylight Uniformity
  - Maximum Daylight Autonomy
  - Daylight Saturation Percentage
  - Annual Sun Exposure
  - Annual Light Exposure

The problem is …
we don't know which one(s)

- Correspond to true occupant preferences / dislikes
- Are nuanced enough to differentiate between good/bad architectural designs

Sneak Peek … here's the answer!!!

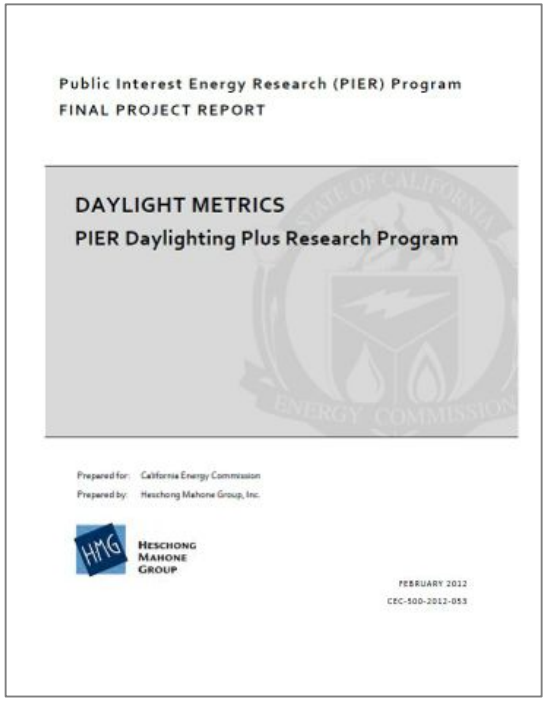
- Well … quite a few exist actually
  - Daylight Autonomy
  - Continuous Daylight Autonomy
  - Zonal Daylight Autonomy
  - Spatial Daylight Autonomy (sDA)
  - Temporal Daylight Autonomy
  - Useful Daylight Illuminance
  - Direct Sunlight Hours
  - Daylight Uniformity
  - Maximum Daylight Autonomy
  - Daylight Saturation Percentage
  - Annual Sun Exposure (ASE)
  - Annual Light Exposure

sDA and ASE were found to best correlate with occupant assessments in a recent CEC PIER Research Study involving 61 spaces.

CEC PIER Daylight Metrics Research Project

387 pages

- GOALS
  - Establish new daylight metrics
    - based on annual simulation output
    - tied to qualitative evaluations
  - Build a consensus on these metrics
    - for use in standards, codes and programs
- TEAM
    - Lead by TRC (formerly HMG)
      - Principal Investigator: Lisa Heschong
      - Project Manager: Mudit Saxena
    - Supported by team of daylighting experts
    - Guided by IES Daylight Metrics Committee



http://www.energy.ca.gov/2012publications/CEC-500-2012-053/CEC-500-2012-053.pdf

Research

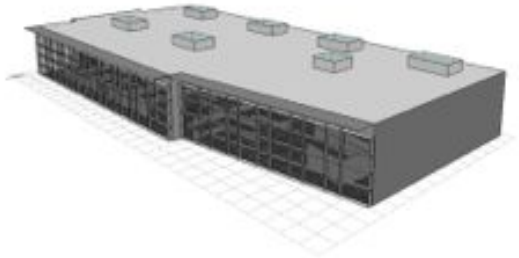
- Assessed study sites (61)
  - Across US (7 cities)
  - Collected expert (5) and occupant (10) assessments of daylight quality
- 3 types of spaces considered
  - Classrooms
  - Offices
  - Libraries

Survey form
- Filled in by Experts as well as Occupants

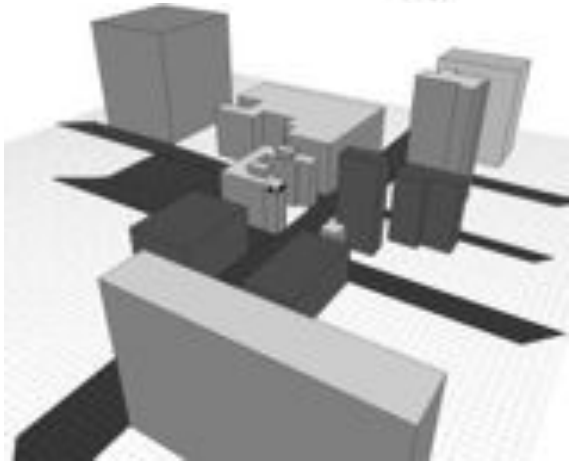
Locate yourself in two to six normal work position(s) within the study space, and consider how you would answer these questions if you were an occupant, based on your experience, and relative to projected ***annual*** *weather conditions. The 1-9 scale can be interpreted as a percent probability of the condition occurring. Ratings should integrate all representative positions.*

The blinds and electric lights in the space should be evaluated as found (or if the space is unoccupied, under expected normal operating conditions).	Worse << >> Better
1. I enjoy being in this room.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
2. I find this room visually attractive.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
3. Temperature in the room is always comfortable.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
4. Noise levels in the room always comfortable.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
5. I like the view I have from the window.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
6. I think the view out the window(s) is big enough.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a
7. I am happy with how the blinds (or curtains) can be operated.	Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 Strongly Agree ☐ n/a

Daylight modeling



- Created detailed annual simulation models
  - Standardized methodology for all study spaces
  - Simulation tool: Radiance 3-Phase Method (aka Dynamic Radiance) used to model annual hourly interior daylight illuminance



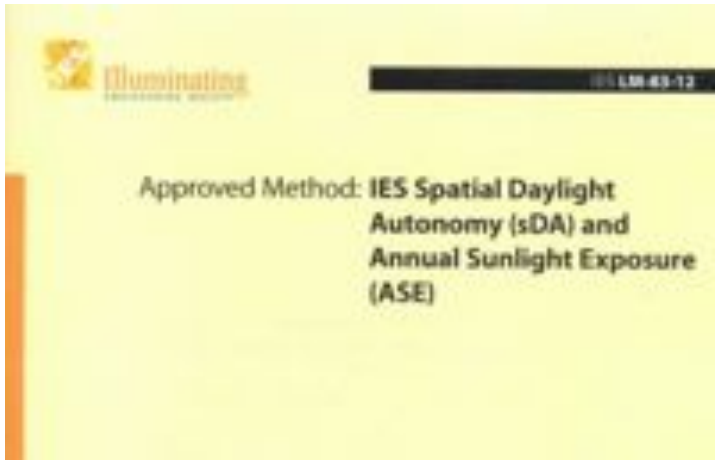
Results

- Two new climate based daylight metrics identified
  – **Spatial Daylight Autonomy (sDA)** &
  – **Annual Sunlight Exposure (ASE)**
  - Best correlation with occupant and expert assessment: When the occupants and experts told us
    - "Daylight is sufficient"
    - "I enjoy being in this room"
    - "I can work with electric lights off"
  - These metrics also predicted better values

- Adopted by the IES officially in 2012 (LM-83-12)
- Later also adopted by LEED v4 for max 3 points under IEQ

Spatial Daylight Autonomy ($sDA_{300/50\%}$)

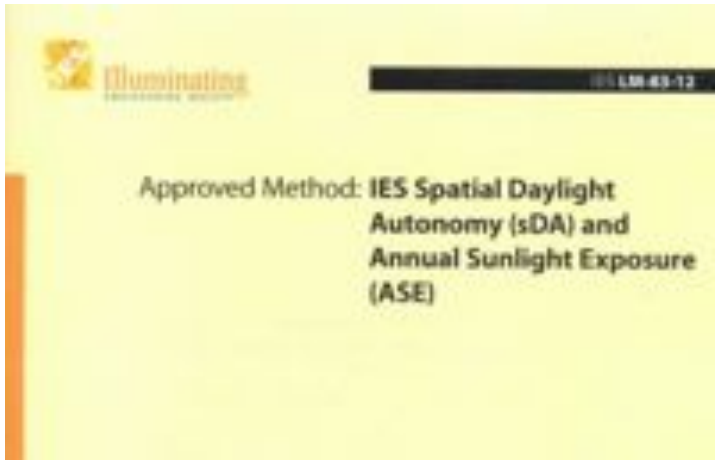
- A measure of daylight illuminance sufficiency for a given area
- Reports a percentage of floor area that exceeds a specified illuminance level, e.g., 300 lux, for a specified amount of annual hours, e.g., 50 percent of the hours from 8:00 am to 6:00 pm
  - "Preferred" threshold: $sDA_{300/50\%} \geq 75\%$ of analysis area.
  - "Nominally acceptable" threshold: $sDA_{300/50\%} \geq 55\%$ of analysis area.



http://www.ies.org/store/product/approved-method-ies-spatial-daylight-autonomy-sda-and-annual-sunlight-exposure-ase-1287.cfm

Annual Sunlight Exposure ($ASE_{1000,250h}$)

- Evaluates the potential source of visual discomfort from direct sunlight.
- It is defined as the percent of an analysis area that exceeds a specified direct sunlight illuminance level, e.g., 1000 lux, more than a specified number of hours, e.g., 250 hours per year.
  - "Preferred" threshold:
    $ASE_{1000,250h}$ < 3% of analysis area
  - "Nominally acceptable" threshold:
    $ASE_{1000,250h}$ < 7% of analysis area



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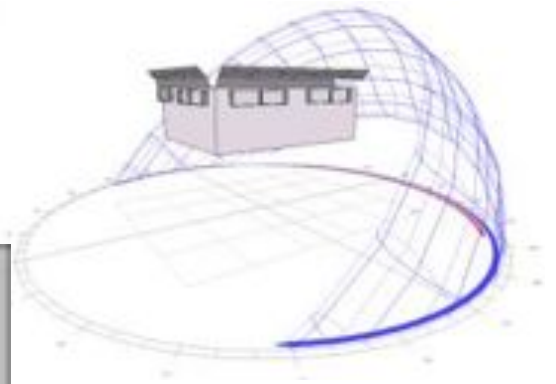
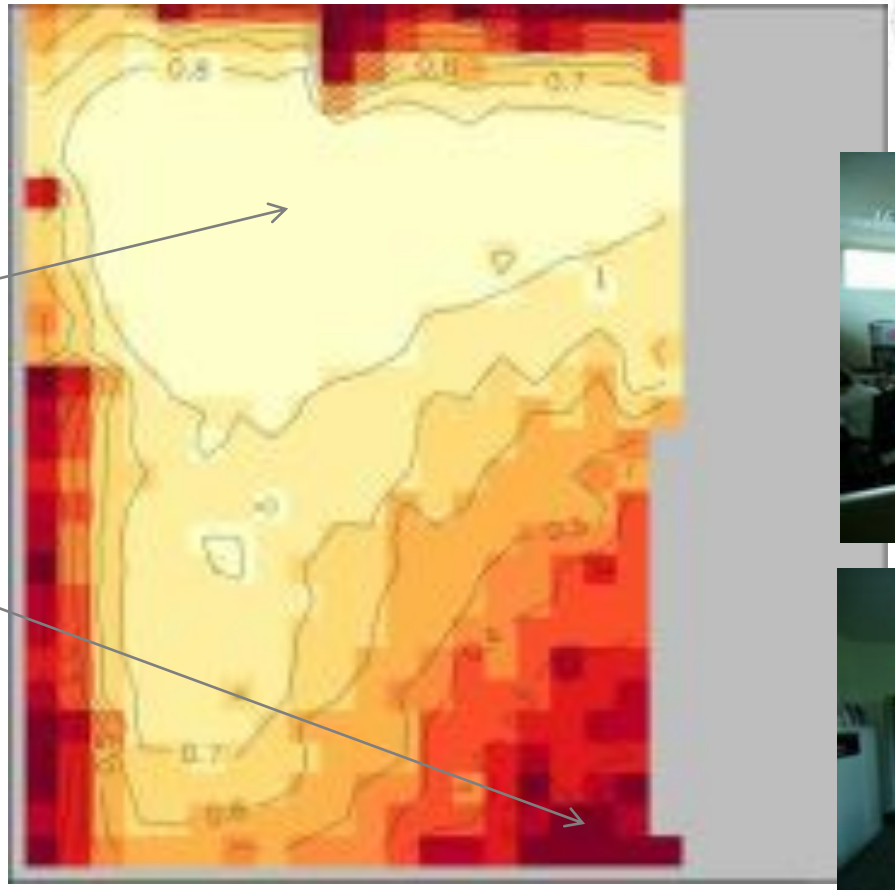
Example 1: Daylight Autonomy Plot



Total space
area =
500 sf

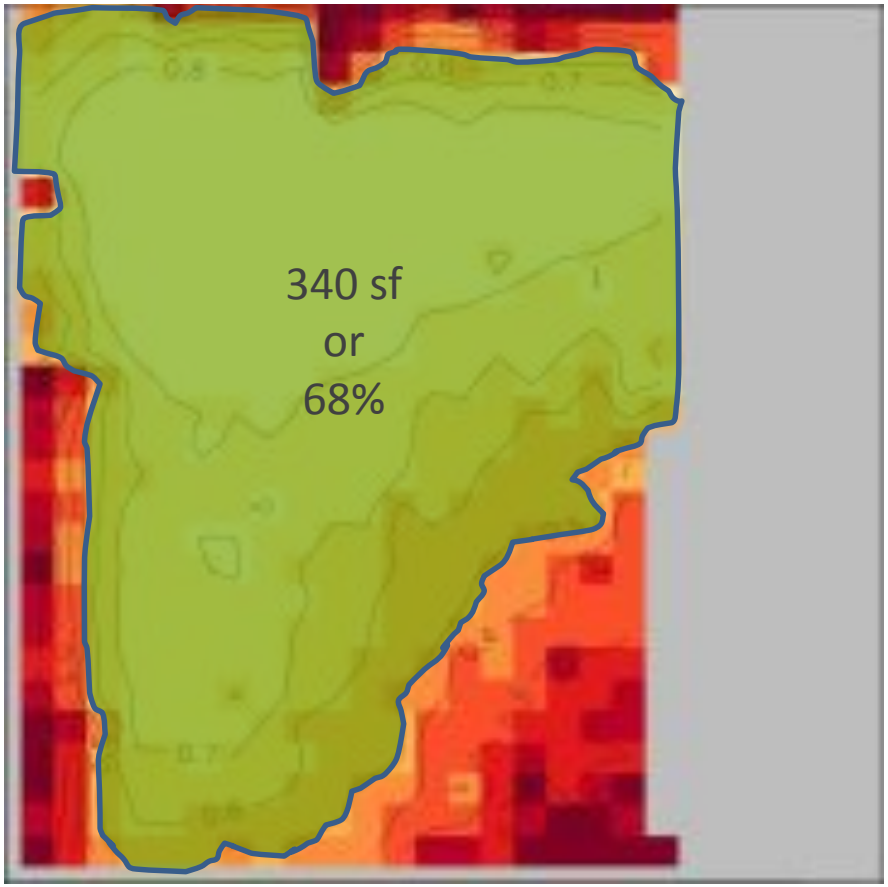
More hours with
daylight

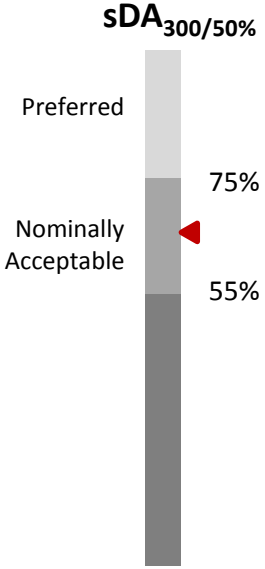


Less hours with
daylight

Example 1: $sDA_{300/50\%}$ Calculation

Total space area = 500 sf





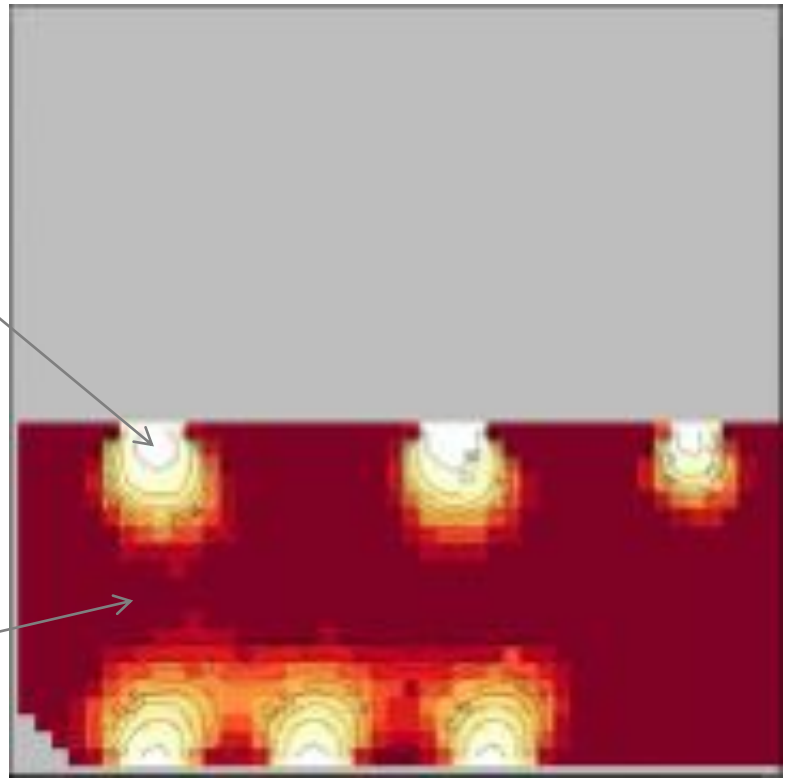
$sDA_{300/50\%}$ = 68% for this space

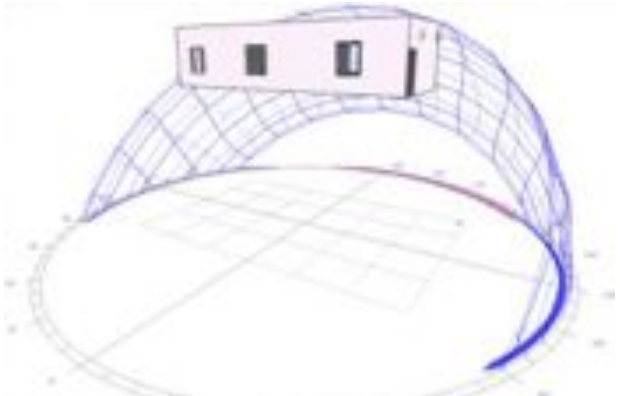
Example 2: $sDA_{300/50\%}$ Calculation

Total space area = 1200 sf

More hours with daylight

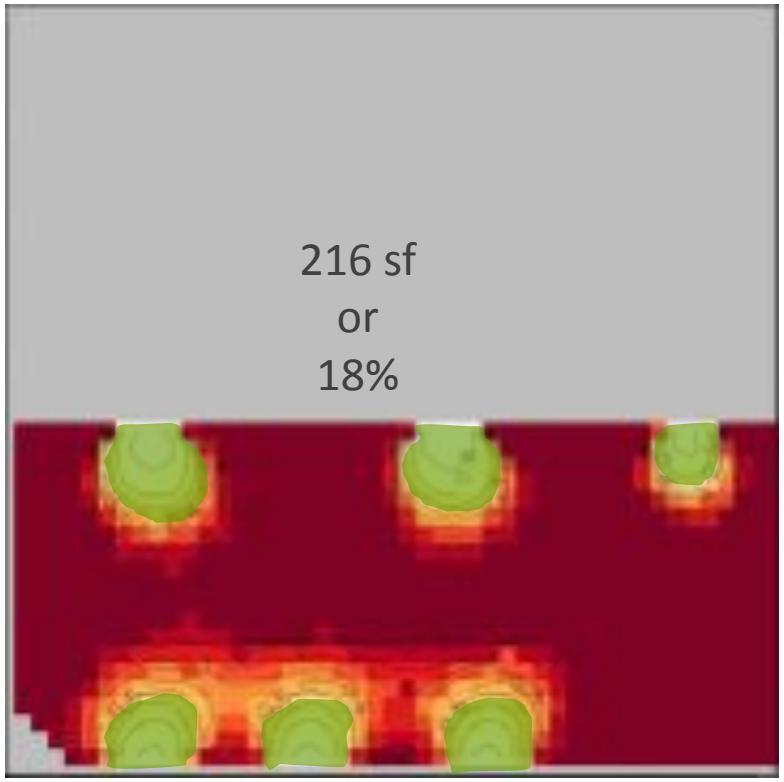
Less hours with daylight

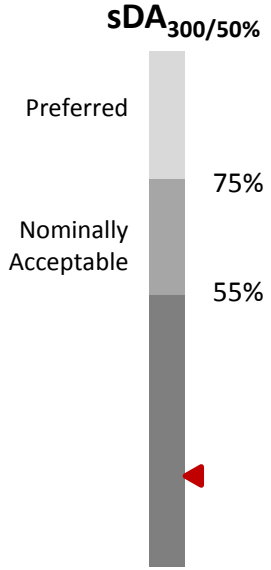




Example 2: $sDA_{300/50\%}$ Calculation

Total space area = 1200 sf

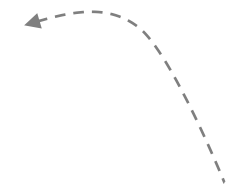




$sDA_{300/50\%}$ = 18% for this space

What are the new metrics sensitive to?

- Climate
  - Sunny / Cloudy
  - Sun angle
- Façade design
  - Window layout
  - Orientation
  - Glazing area
  - VLT
- Space Geometry
  - Small private office
  - Large open office
  - Ceiling Height
  - Window on one or more facades
  - Interior surface colors
- Furniture layout
  - High partition
  - Low partition
- Blinds/Shades
  - Usage
  - Type



We found that these were a big deal! … typically not even modeled in daylighting or energy simulations!

The new metrics reward …

- Rewards spaces with less sun penetration
  - Spaces with well designed overhangs
  - Spaces with North orientation.
- Rewards spaces with deep daylight penetration
  - Higher window head height
  - Light redirecting technologies
- Rewards spaces with multi-directional daylight
  - Spaces with windows on more than one wall
  - Spaces with windows and skylights

The new metrics penalize …

- Penalizes spaces with no blinds/shades (and no overhangs)
  - Spaces that admit too much direct sun
- Penalizes deep spaces
  - Spaces with large floor plans where a large portion of the occupied space is away from a daylight source
- Penalizes spaces with low daylight levels
  - Spaces with dark windows
  - Spaces with small windows

Metrics limitations 

- Quantifying visual discomfort
  - Annual Sunlight Exposure is a proxy for visual discomfort
    - Not a luminance based metric
    - A luminance based glare metric likely to provide better correlation to visual discomfort
  - No luminance based glare metric (yet …)
- A space-level metric
  - Needs to be calculated for each space in a building
  - Cannot be very easily translated to the whole building

Simulation tools for daylight metrics

- To calculate the new metric, the simulation tool needs some **minimal capabilities**
  - Annual hourly simulation - using a weather file
  - Report results for a sensor grid
  - Model blinds/shades operation based on sun penetration
  - Assign blinds/shades to window groups in a space
  - Minimum sky patch resolution
  - Minimum solar disc resolution

Simulation tools for daylight metrics

- Radiance 3-Phase method (aka. Dynamic Radiance)
- Open Studio
- DaySim
- Autodesk 360 Rendering
- IES-VE
- And others …

Radiance

- *Radiance* is a set of lighting simulation and rendering tools made freely available by LBNL since about 1990
  - Considered the 'gold standard' for simulation accuracy
  - Uses ray-tracing (slow, but powerful)
    - Point calculations are pretty fast
    - Nice images take longer
    - Annual simulation even longer …

For more information:

- http://www.radiance-online.org/

Radiance 3-Phase Method

- Also known as ‘Dynamic Radiance Approach’
  - Is a new method to use *Radiance* for **fast**, matrix-based annual daylighting calculations
    - Uses annual analysis with weather files
    - Parametric simulation runs capabilities
    - Realistic blinds and shade modeling assumptions with BSDFs
- Daylight Metrics:
  - *Radiance 4.1* includes all scripts needed to run 3-phase (and 5-phase) simulations and calculate sDA and ASE

For more information:

- SimBuild Paper: http://www.ibpsa.us/pub/simbuild2010/papers/SB10-DOC-TS08A-01-Saxena.pdf
- Tutorial: http://www.radiance-online.org/learning/tutorials/Tutorial-ThreePhaseMethod.pdf

DAYSIM & DAYSIMps

- *Radiance*-based annual daylighting analysis software with an easy to use user-interface

- Daylight Metrics:
  - Outputs sensor grid illuminance, sun penetration hourly results
  - Capable of outputs range from climate-based daylighting metrics
  - 'DAYSIMps' developed by Penn State will have capability to calculate and output sDA and ASE in near future

For more information:
- http://daysim.ning.com/
- About DAYSIMps: http://www.radiance-online.org/community/workshops/2013-golden-co/Mistrick_Daysim-Development.pdf

Open Studio (NREL)

- A collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using *Radiance*
  - Currently all *Radiance* functionality is accessed via the command line interface (CLI)

- Daylight Metrics:
  - Capable of performing an annual climate-based daylight simulation, using the 3-phase method with BSDFs, and calculate sDA and ASE

For more information:

- https://openstudio.nrel.gov/downloads
- Radiance in Open Studio: https://openstudio.nrel.gov/getting-started-developer/getting-started-radiance/openstudio's-radiance-functionality-documentation

Autodesk 360 Rendering Illuminance

- A cloud-based rendering service that can generate illuminance images for Revit models to quantify the effects of natural and artificial lighting on rendered surfaces or sensor points

- Daylight Metrics
  - Capabilities limited to generating rendered scenes and sensor outputs for now
  - sDA and ASE calculation from within UI coming soon …

For more information:
- http://rendering.360.autodesk.com/index.aspx
- About sDA and ASE: http://autodesk.typepad.com/bpa/2013/04/illuminance-learning-about-lightingdaylighting-analysis-1.html

IES-VE

- A whole building energy performance modeling software, with a *Radiance* module (*RadianceIES*) that allows detailed daylight calculation and rendering
  - http://www.iesve.com/software/download-centre

- Daylight Metrics
  - Annual daylighting simulations with weather files can now be done with latest version
  - However blinds/shades can only be modeled as “static”. sDA calc per LM-83 requires hourly operation based on solar penetration

For more information:
- http://www.iesve.com

Which simulation tools will NOT work …

- DOE 2 based simulation programs
  - eQUEST
  - Visual DOE
  - EnergyPRO, etc.
- EnergyPlus (Split flux)
  - DesignBuilder
- Sketchup
- Ecotect

A great building must begin with
the unmeasurable,
must go through measurable
means when it is being designed,
and in the end must be
unmeasurable.

- Louis Kahn

Thank You

Question / comments are welcome!

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