Feasibility and Design of a Daylighted Artificial Sky

Bruce Haglund, Professor of Architecture, Associate AIA, FASES

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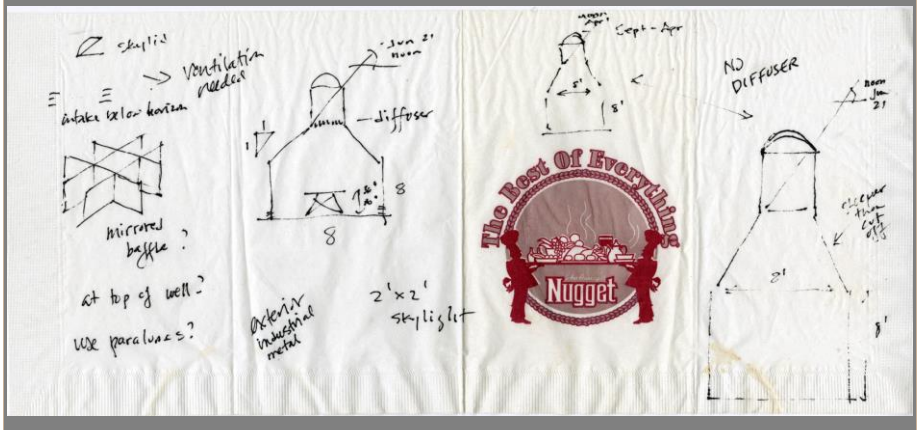

…from napkin sketch to realization?

Introduction.

To achieve highly successful results, daylighting schemes for both new and existing buildings must be tested for light levels, light distribution, and glare, as well as be visually assessed for architectural quality before the building is actually built or remodeled. This type of testing is also valuable in architectural education where students can verify the fitness of their proposals for building designs. The design, testing, and re-design of their projects provide opportunities to gain practical skills applicable in their professional careers as well as experience with research methodology.

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Models in the Design Process.

Testing physical scale models of architectural spaces is an accurate means to evaluate daylighting schemes for buildings. An effective daylighting model allows the designer to record and compare daylight aperture design options quickly and reliably. Useful comparisons can be achieved only under reliably consistent sky conditions. The natural sky poses a problem: Natural skies are dynamically variable, not only from day-to-day, but minute-to-minute, defeating the principle of consistency required for accurate comparisons.

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Artificial skies must be able to simulate a standard uniform overcast sky condition where the zenith is about three times brighter than the horizon with gradual darkening from zenith to horizon. To achieve this goal two basic types of electrically lighted skies have been used—mirror box and hemispheric skies.

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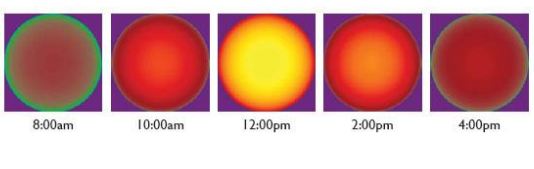
As a point of reference, the following images are a series of hemispherical fisheye images simulated in Radiance. The simulation was run on September 21 under overcast conditions.



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The brightness of even the ideal overcast sky varies significantly during each day.

However, the distribution of light is constant—3x brighter at the apex.

So our goal is to provide proper distribution, not specific luminance.

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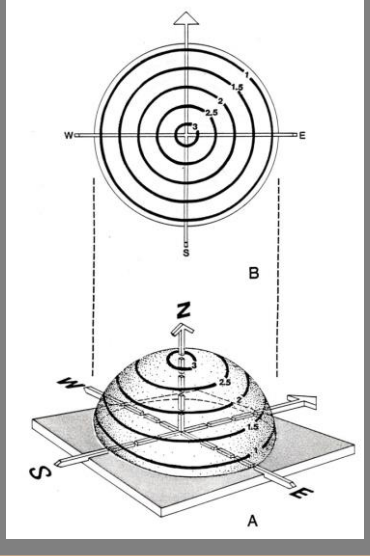

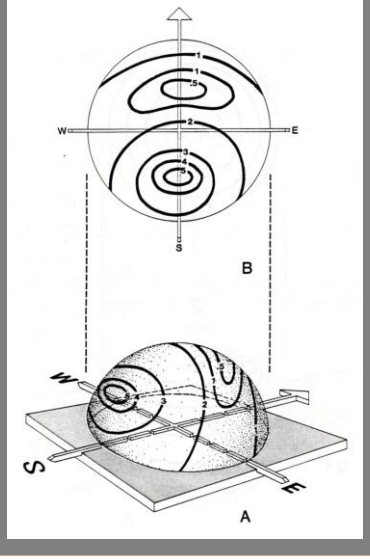

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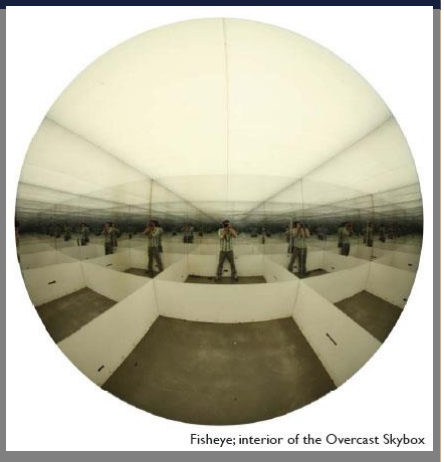

Fisheye; interior of the Overcast Skybox

Inside Hemispheric Sky (Michigan) vs. Mirror Box Sky (Seattle IDL)

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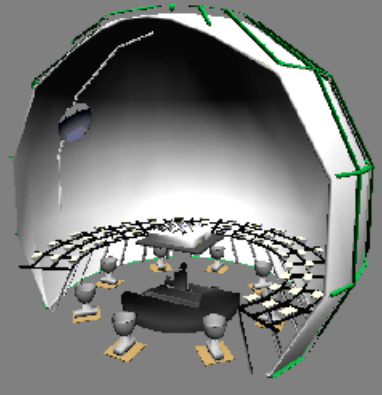

University of Michigan Hemispheric Sky

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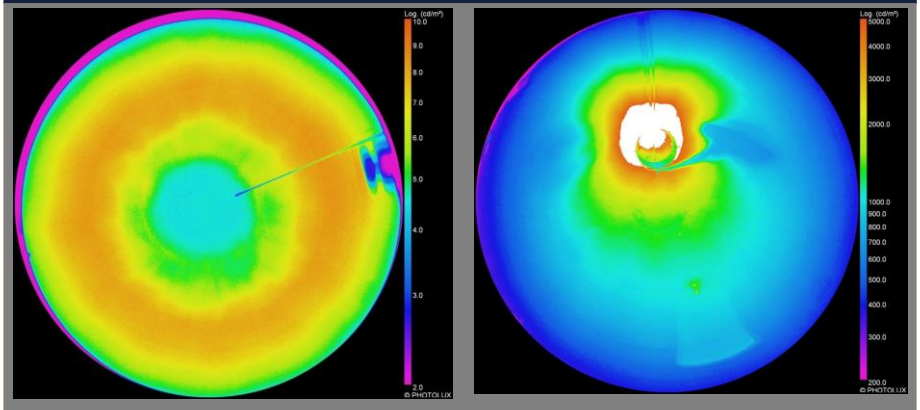

University of Michigan Sky: Overcast vs. Clear Sky Conditions

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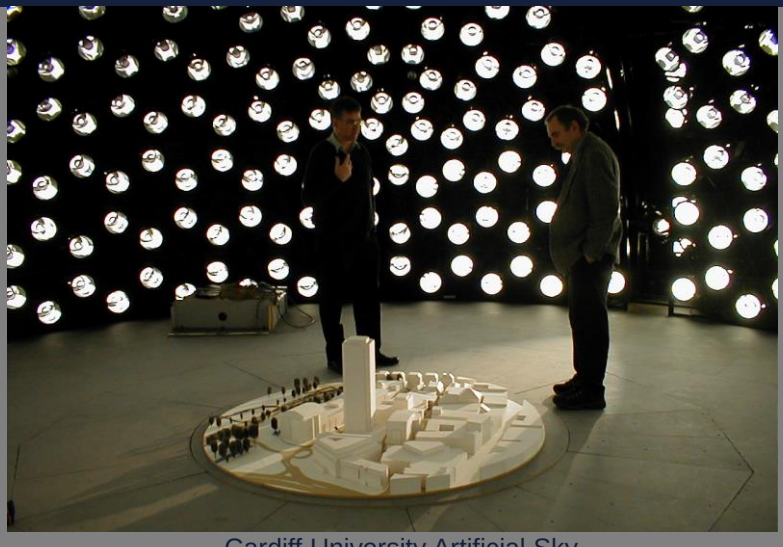

Cardiff University Artificial Sky

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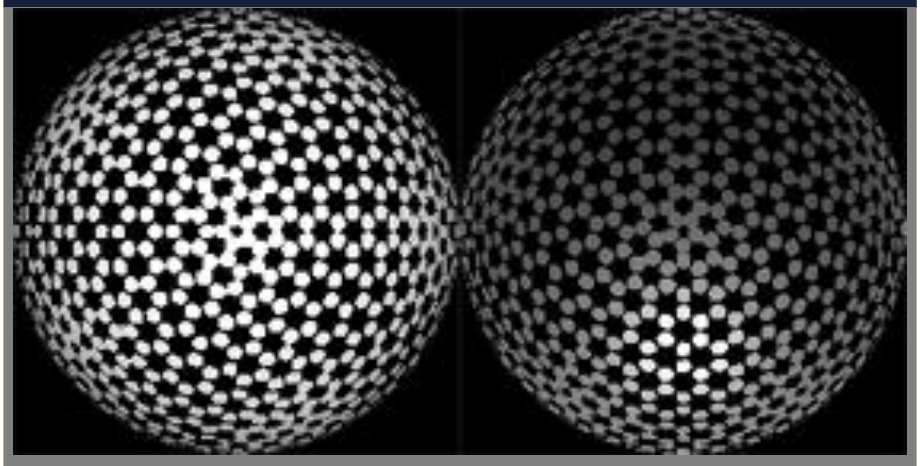

University of Cardiff Sky: Overcast vs. Clear Sky Conditions

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Cardiff Sky 8m diameter: 640 luminaires (20-watt Philips CL 4500K) CFLs (12,800 watts total)

Bartlett Sky 5.2m diameter: 270 CFLs (5,400 watts total).

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Mirror-Box Artificial Sky at IDL, Boise, ID
uses twenty-two 59-watt fluorescent lamps (1,298 watts total)

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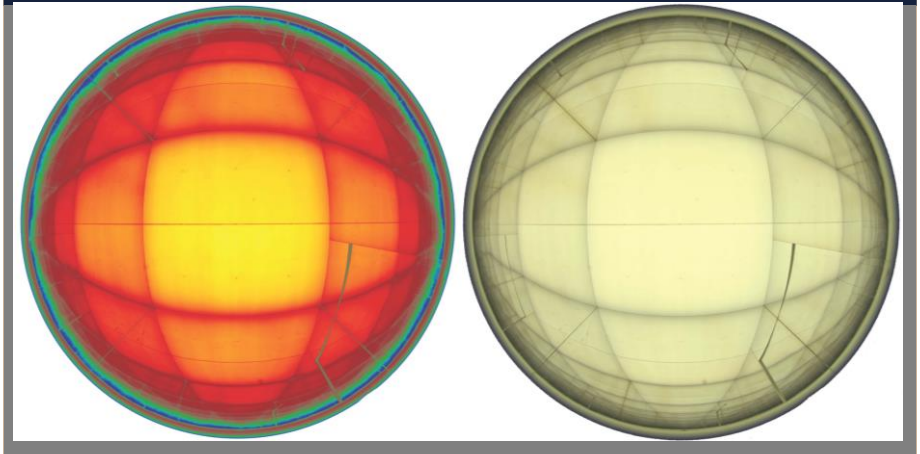

Mirror Box Sky: False Color Fisheye vs. HDR Fisheye

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Computer-driven Heliodon at IDL, Boise, ID

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Three reasons.

- **Philosophical:** Is there a passive tool that could encourage this mindset and be used to test daylighting models?
- **Qualitative:** Could natural light be used for model testing?
- **Environmental:** Is there a zero-energy alternative to electrically lighted artificial skies?

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Daylighted space vs. Electrically lighted space in the Great Court of the British Museum.

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Methodology. We were inspired to begin this project by two precedents—

- University of Oregon's cutting edge classroom for the Mt. Angel Abbey School in Eugene, OR
- Ball State University's use of digital cameras to analyze glare by charting relative brightness in the field of view.

Our sky will be similar to a mirror-box sky in that it will simulate overcast sky conditions and feature no heliodon.

Our heliodon, which uses a tilt table, sun peg, and the actual sun, will continue to be used to test sun penetration for daylighting models.

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Pattern 11: Toplighting (Classroom)

Center Skylight (14%SFAR): Angled Alluminum Cloud (As Built)

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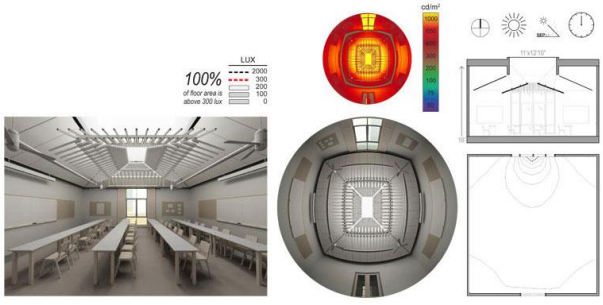
Slideshow
To Overview

These data represent a single view window with a single skylight (11' x 12'10") representing 14% of the floor area, set within a 16' tall ceiling with sloping t-bar trays, with an angled and staggered aluminum reflector hung below the skylight. The sloped ceilings improve the distribution of light from the skylights and increase the visual perception of brightness while minimizing shadows. The angled reflector is intended to decrease the illumination directly below the skylight, redirect the brightness onto the sloped ceiling and walls, and minimize the line of sight to the skylight aperture for students seated within the classroom, thus reducing the potential for glare. The floor area above 300 lux is 100%.



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Model testing under the translucent barrel vault at PUCE.

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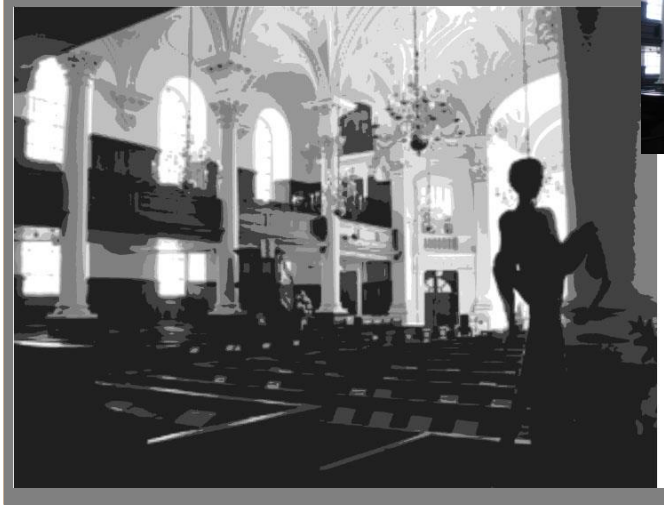
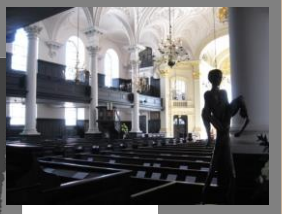
Culplite analysis of St. Martin's, London





RAW format of the image is used.

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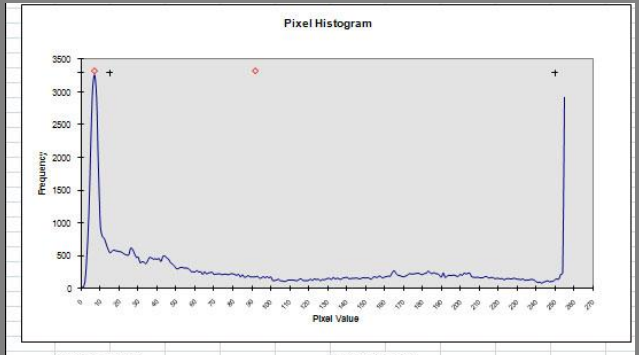

Overall Image		**Indiviual Pixel**		
Weighted Ave Pixel Intensity	105.12	Individual Pixel Value	40	
Total Number of Pixels	76800	Corresponding Luminance	58.12	footlamberts
Background Bell Curve		**Spike**		
Low End Pixel Value	15	Low End Pixel Value	0	
High End Pixel Value	250	High End Pixel Value	15	
Background Median Value	92	Spike Median Value	7	
Number of Background Pixels	53915	Number of Spike Pixels	19753	
Background Percentage of View	70.20	% Spike Percentage of View	25.72	%

"When a digital camera makes an exposure the imaging chip records the amount of light that has hit each pixel, or photo site."

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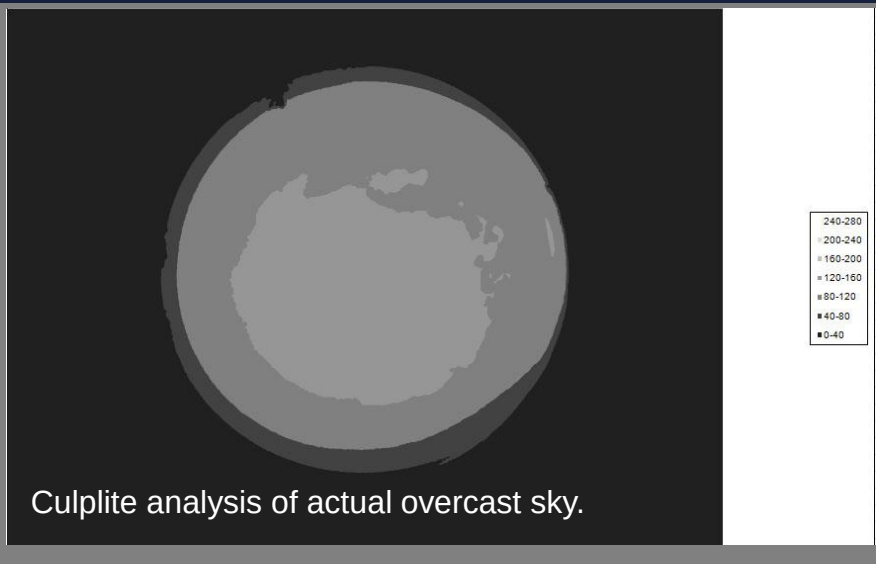

Culplite analysis of actual overcast sky.

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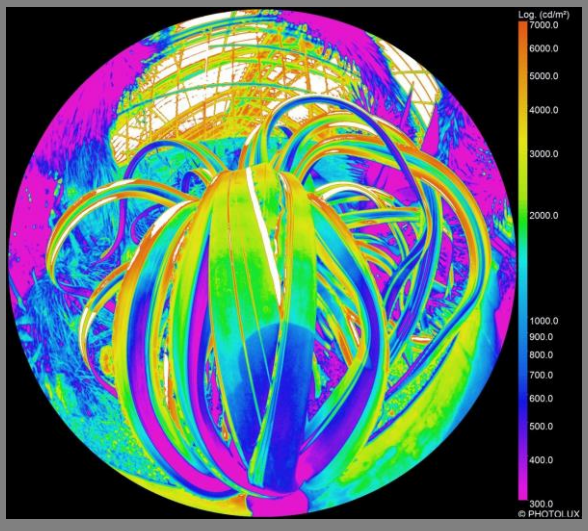

More sophisticated camera systems can be calibrated to cd/m^2 or footlamberts.

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Sky Dome Luminance - Overcast Sky Box
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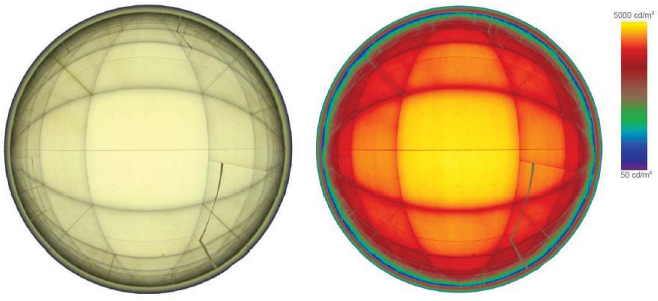

HDR Hemispherical Sky
Taken with Fisheye lens pointed straight up.

False Color Image
Taken with Fisheye lens pointed straight up.

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	Rectilinear	Cylindrical
Matte white surfaces	Model A	Model C
Mirrored surfaces	Model B	Model D

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Early days test of one model before circular fisheye lens was available.

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Sigma 4.5mm f/2.8 EX DC HSM circular fisheye lens mounted on a Nikon D-5000 Digital SLR camera

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Heliodon with sunpeg.

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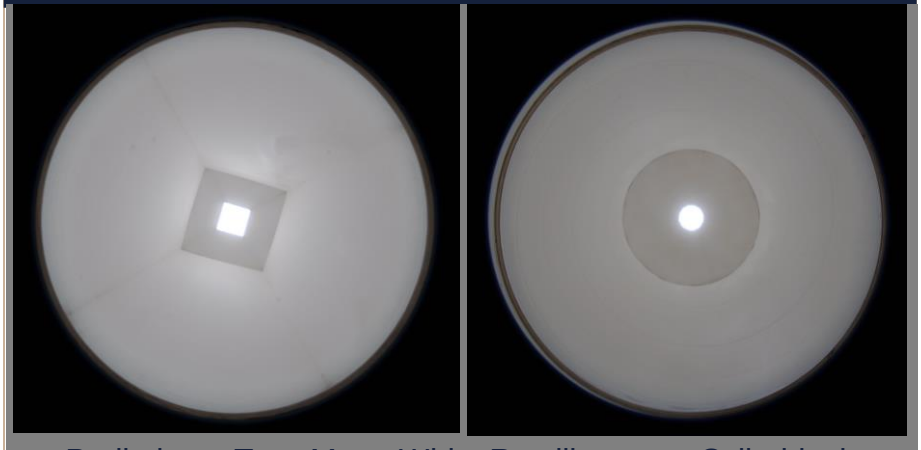

Preliminary Test: Matte White Rectilinear vs. Cylindrical

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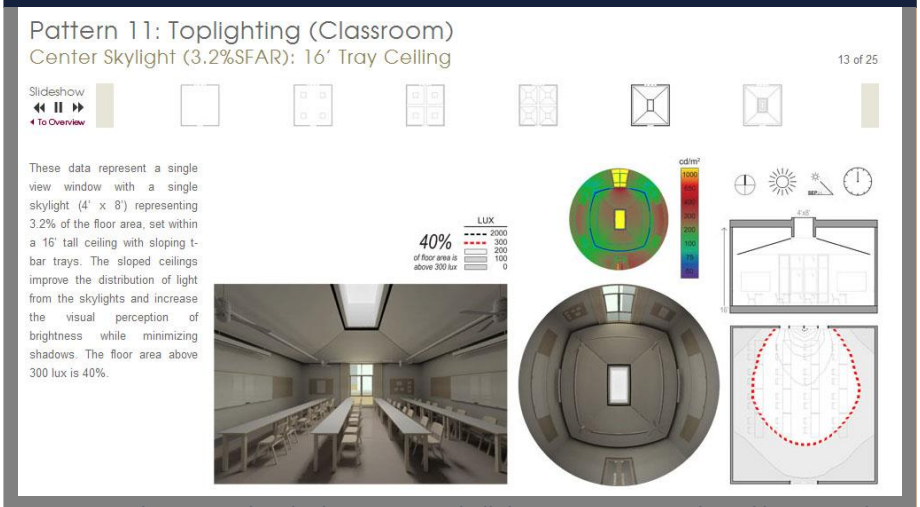

CPI ControLite Dynamic Glazing System skylight uses a succession of integrated 'rota-blade' louvers that adjust to capture and distribute light evenly .

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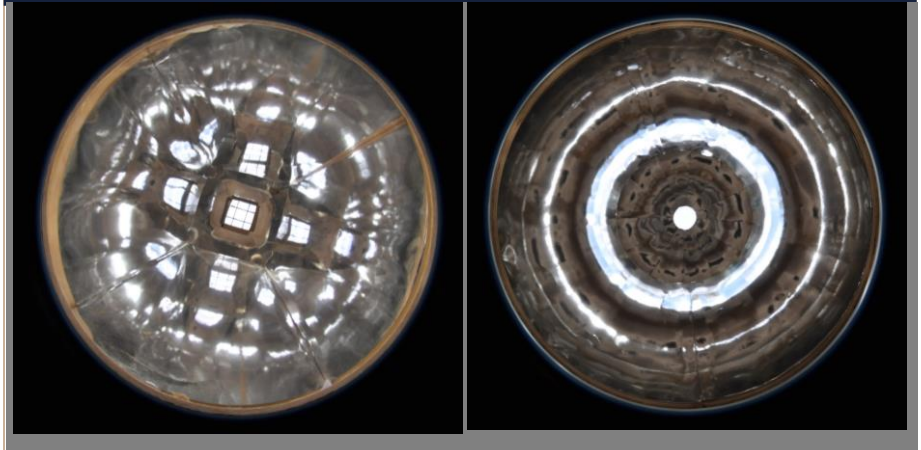

Preliminary Test: Mirrored Rectilinear vs. Cylindrical

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Center Skylight (6.4%SFAR): Translucent Cloud

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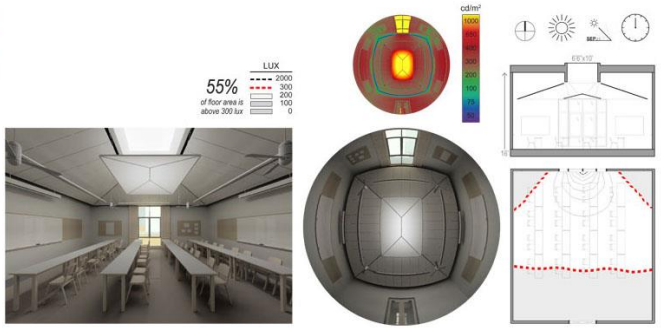
Slideshow
To Overview

These data represent a single view window with a single skylight (6'6" x 10') representing 6.4% of the floor area, set within a 16' tall ceiling with sloping t-bar trays, with an translucent reflector hung below the skylight. The sloped ceilings improve the distribution of light from the skylights and increase the visual perception of brightness while minimizing shadows. The reflector is intended to decrease the illumination directly below the skylight, redirect the brightness onto the sloped ceiling and walls, and minimize the line of sight to the skylight aperture for students seated within the classroom, thus reducing the potential for glare. The floor area above 300 lux is 55%.



From *Advanced Buildings Daylighting Pattern Guide*

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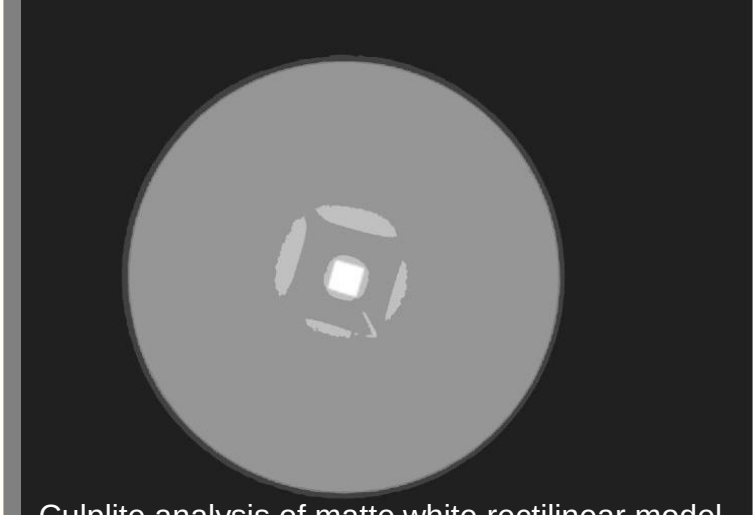

Culplite analysis of matte white rectilinear model.

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Prototype daylighted sky.

If our research and testing proves the naturally lighted artificial sky viable, we intend to build a full-scale prototype (~10 ft x 10 ft) for eventual installation at our new interdisciplinary design laboratory on campus in Moscow, Idaho. The design and construction of the prototype will be a hands-on research project for a group of students from both architecture and interior design. The team of student researchers will construct, instrument, test, and analyze the results of the prototype in a non-thesis research class.

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