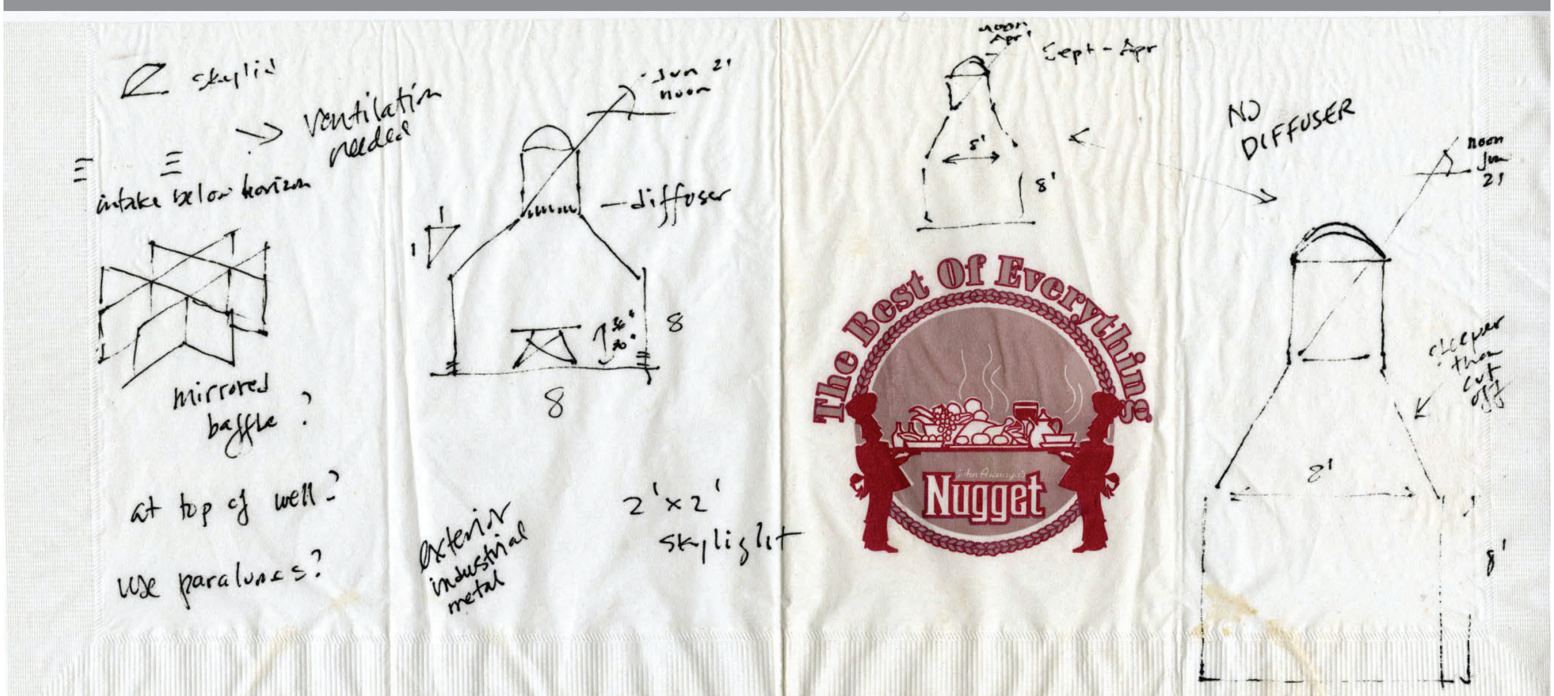
Feasibility and Design of a Daylighted Artificial Sky

Bruce Haglund, Professor of Architecture, Associate AIA, FASES



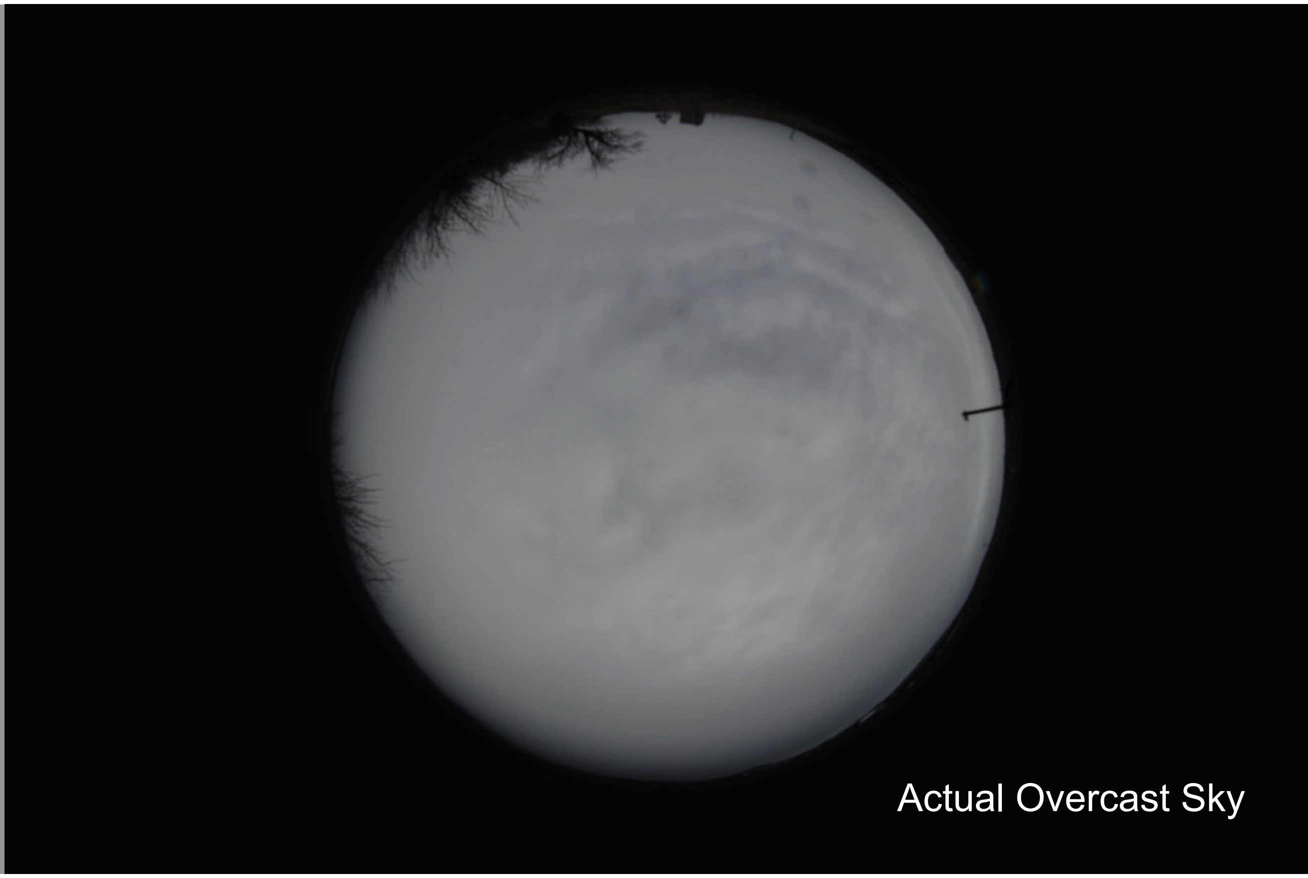
…from napkin sketch to realization?

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.

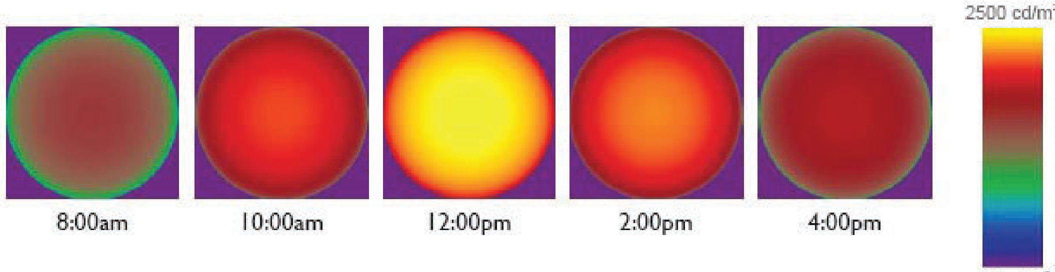
Models in the Design Process.

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.



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.

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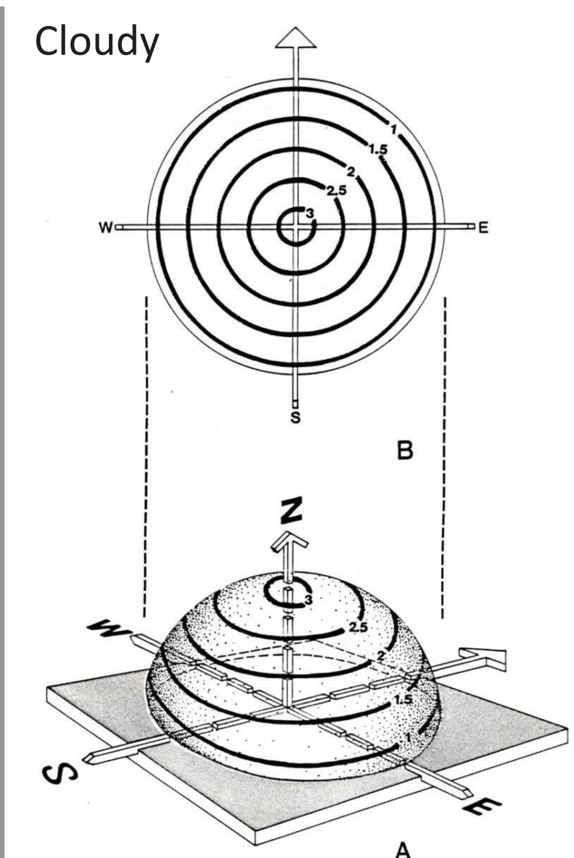
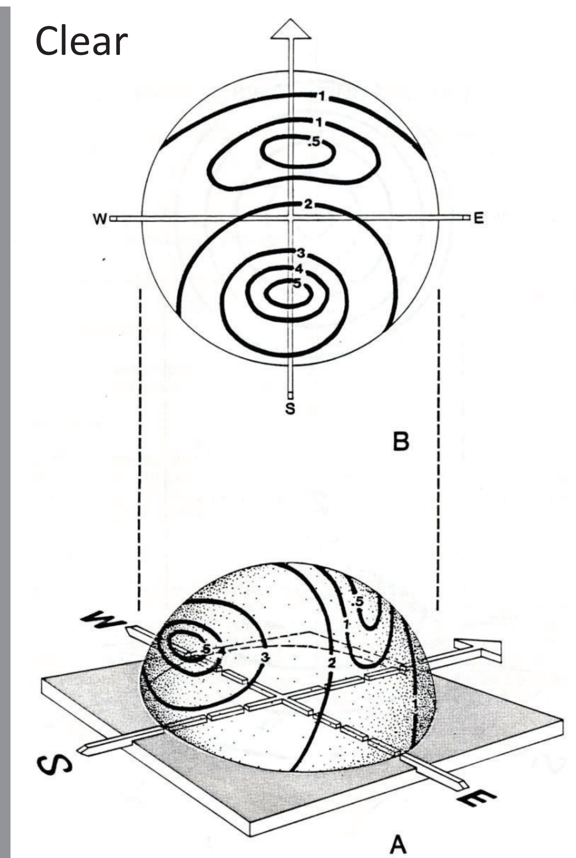
The brightness of even the ideal overcast sky varies significantly during each day.

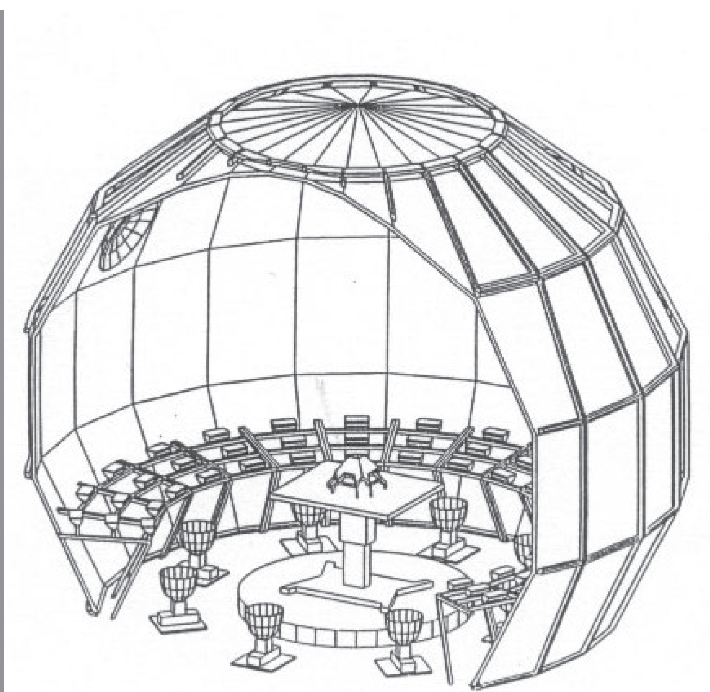
However, the distribution of light is constant—3x brighter at the apex.

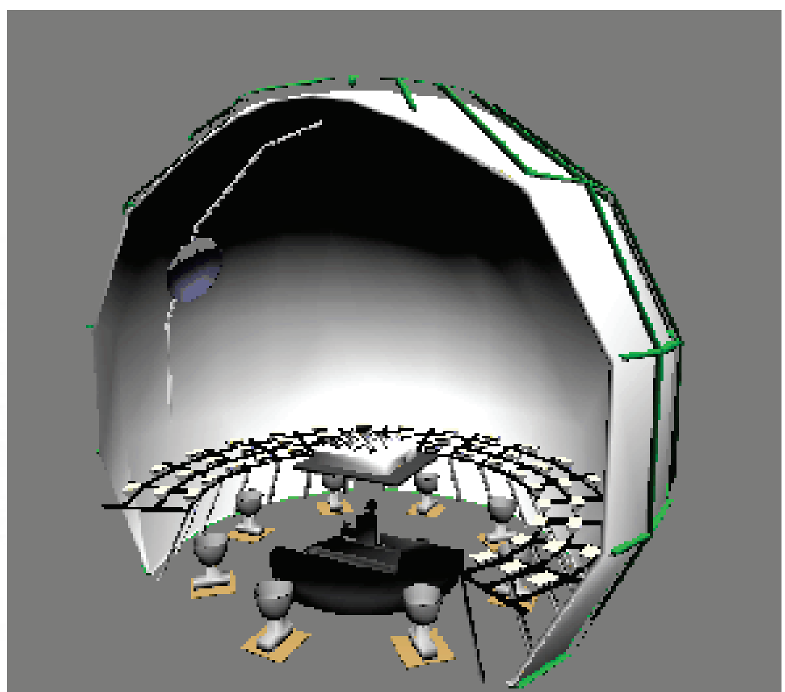
So our goal is to provide proper distribution, not specific luminance.



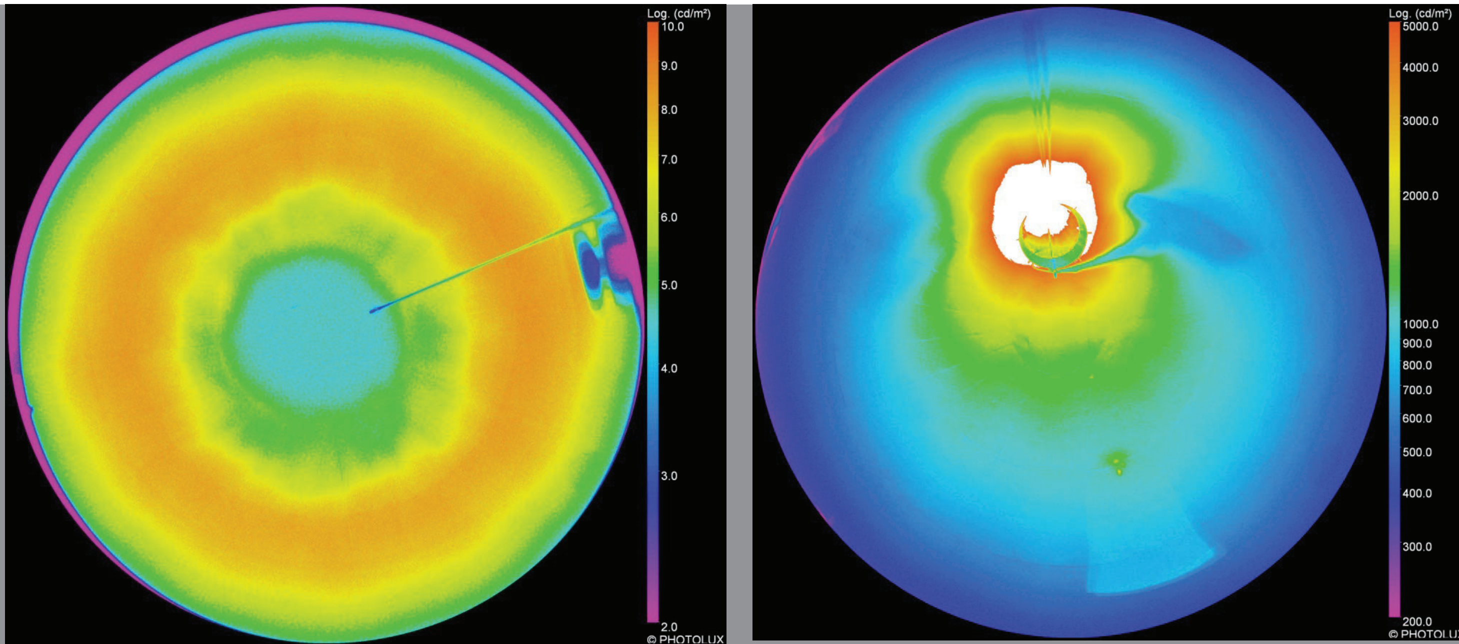


Inside Hemispheric Sky (Michigan) vs. Mirror Box Sky (Seattle IDL)

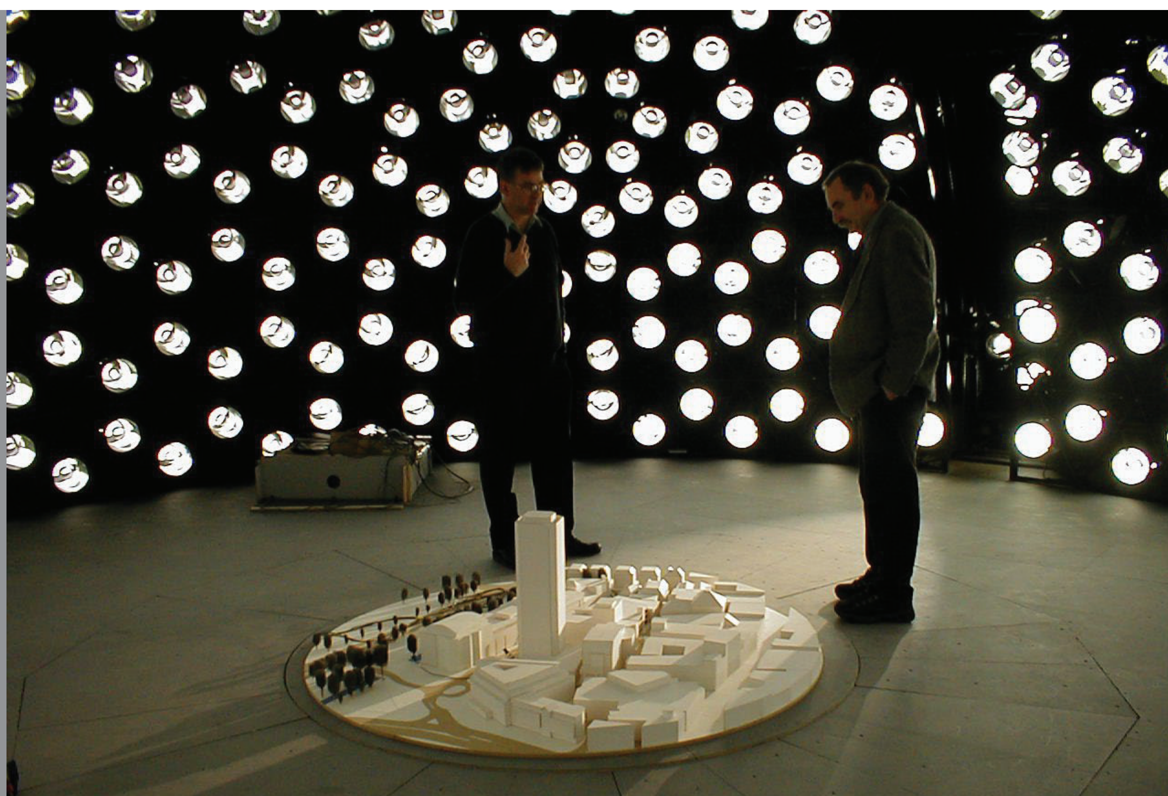




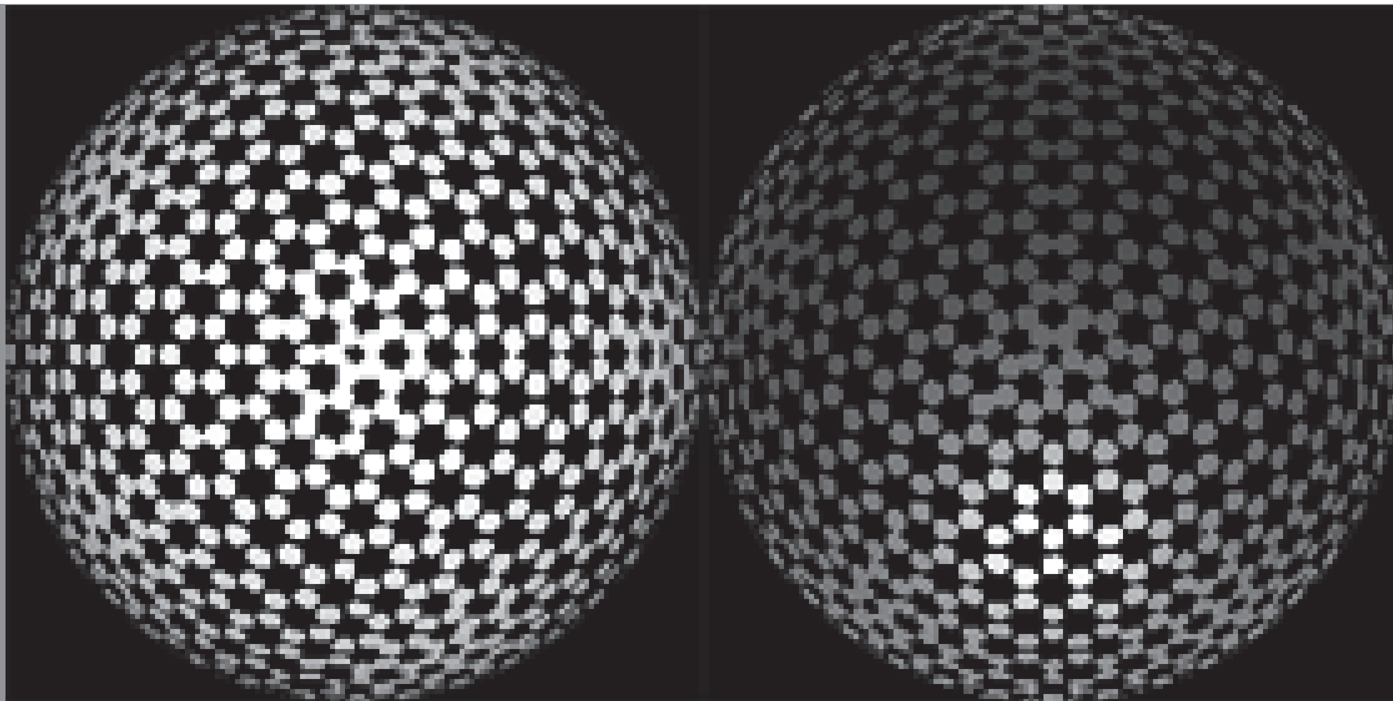
University of Michigan Hemispheric Sky



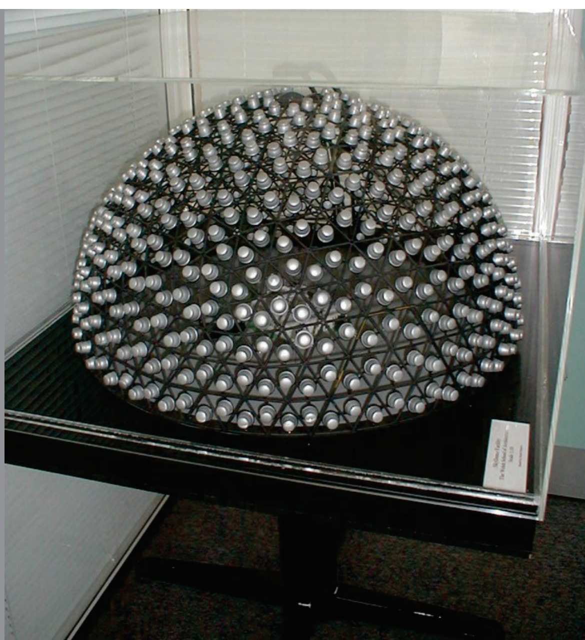
University of Michigan Sky: Overcast vs. Clear Sky Conditions



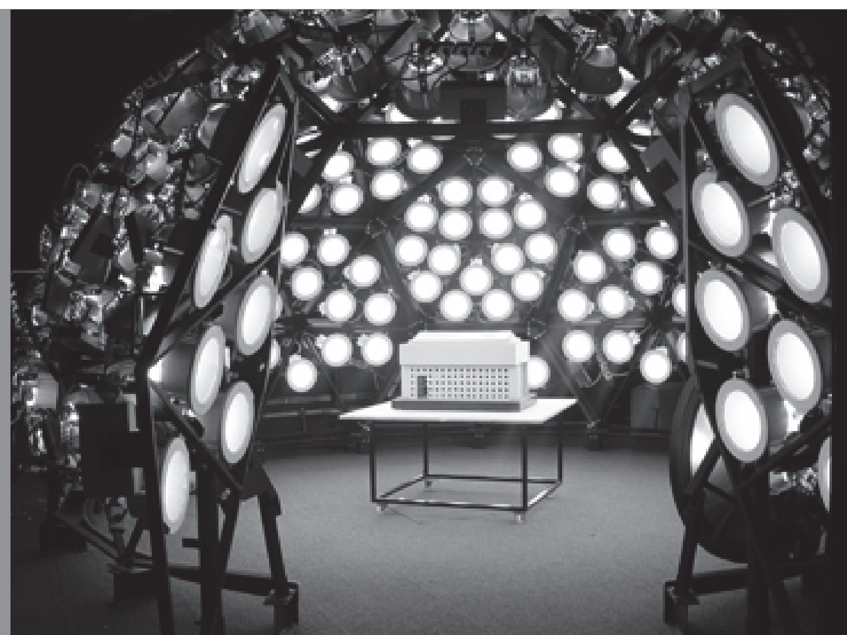
Cardiff University Artificial Sky



University of Cardiff Sky: Overcast vs. Clear Sky Conditions

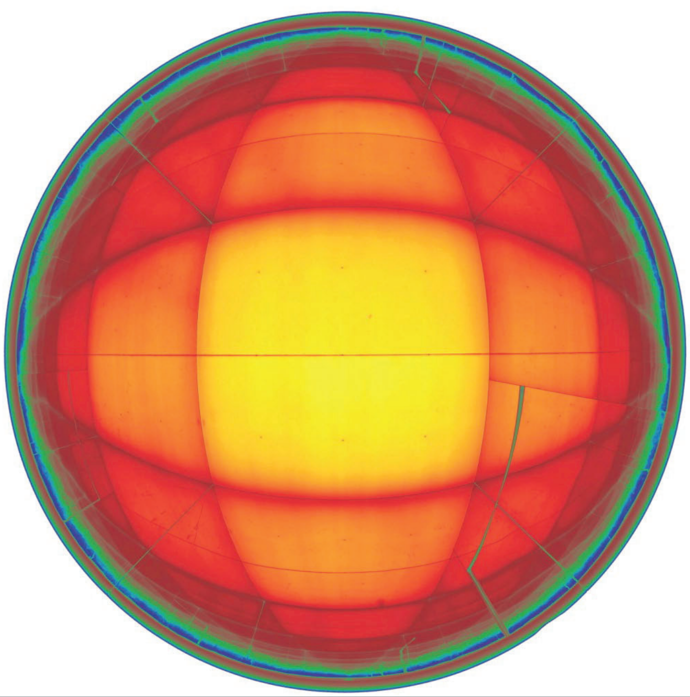


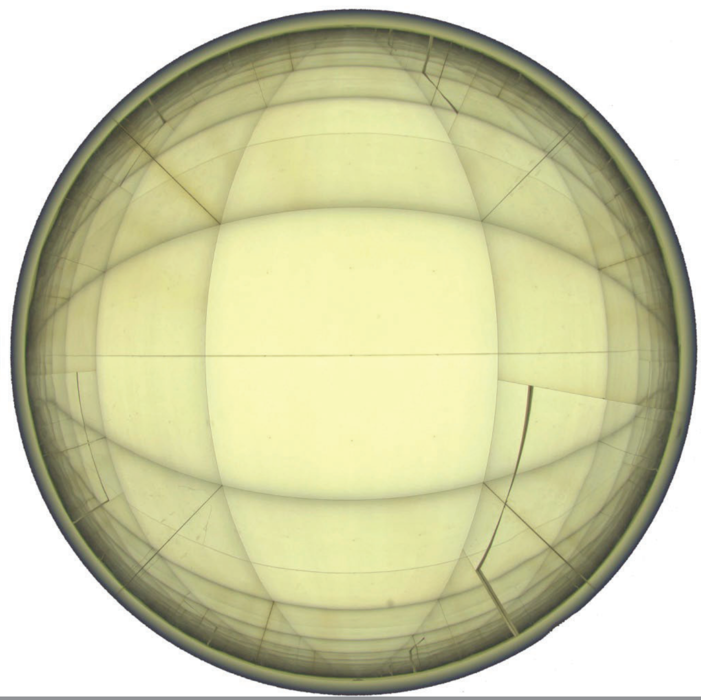
Cardiff Sky 8m diameter: 640 luminaires (20-watt Philips CL 4500K) CFLs (12,800 watts total)



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

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

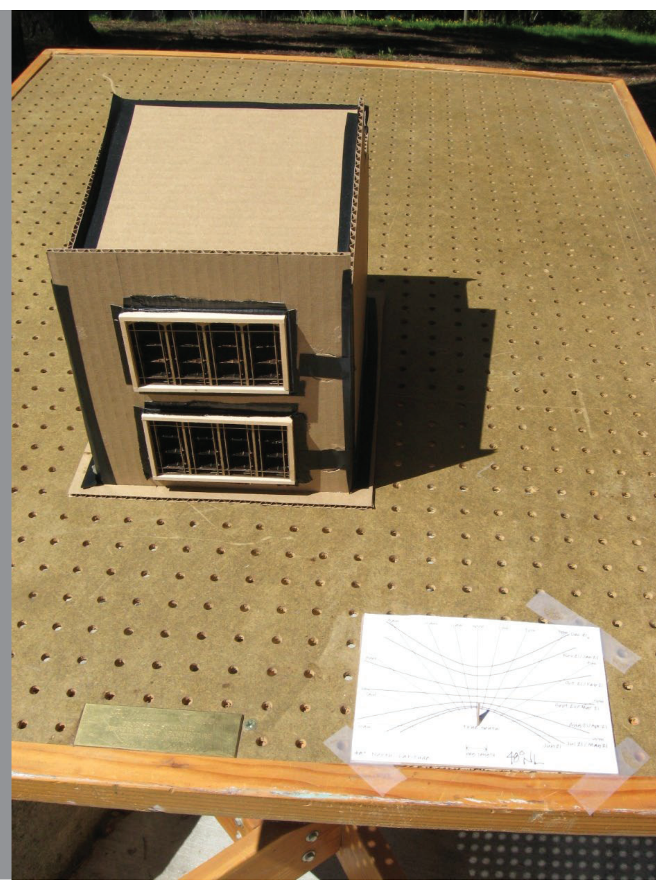




Mirror Box Sky: False Color Fisheye vs. HDR Fisheye

Computer-driven Heliodon at IDL, Boise, ID

Heliodon with sunpeg.



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?

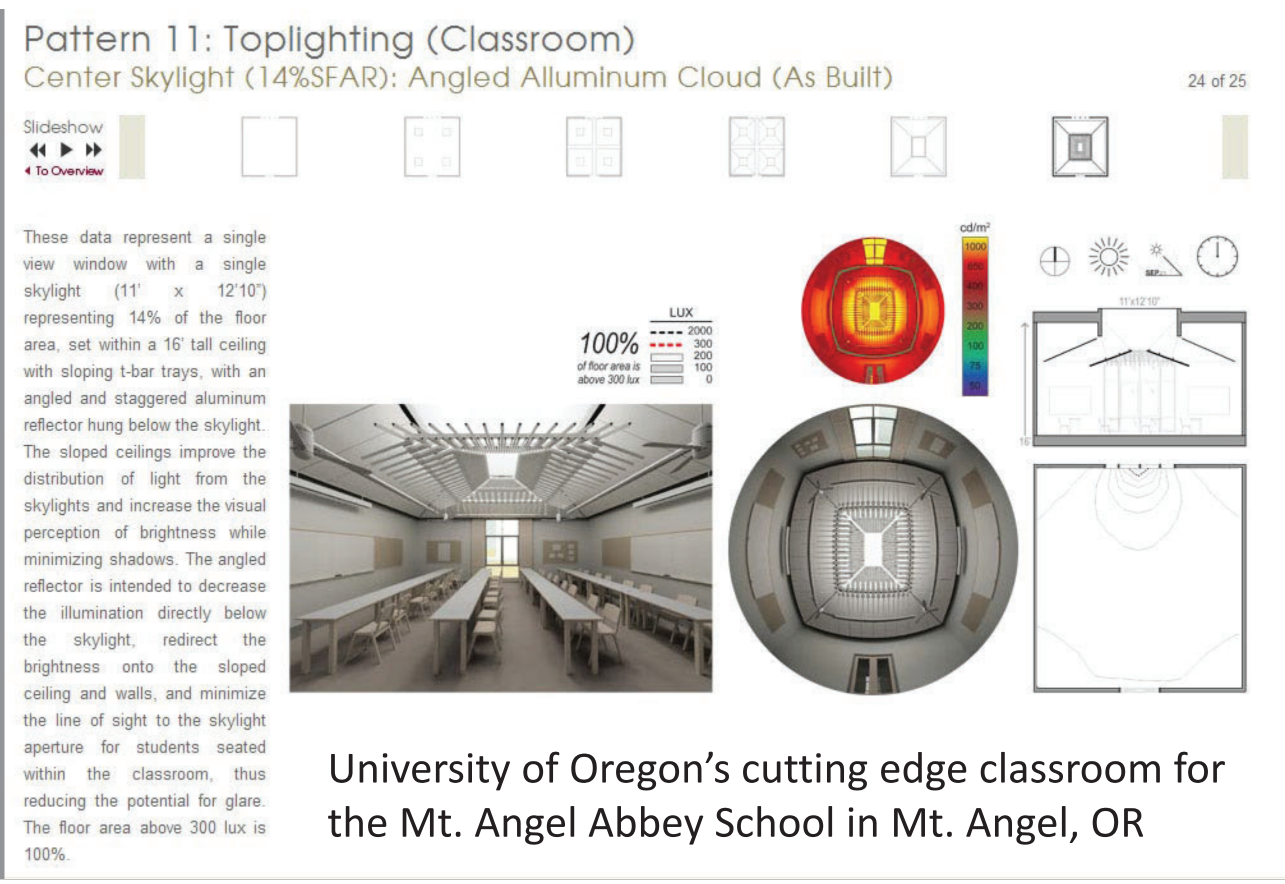
Daylighted space vs. Electrically lighted space in the Great Court of the British Museum.

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 Mt. Angel, 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.

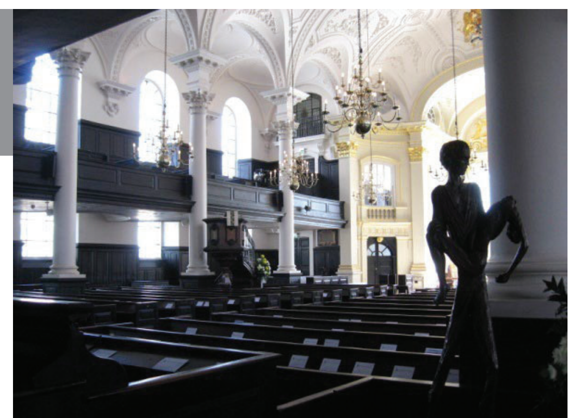
Our heliodon, which uses a tilt table, sun peg, and the actual sun, will continue to be used to test sun penetration for daylighting models.

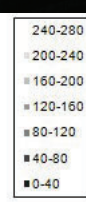


University of Oregon's cutting edge classroom for the Mt. Angel Abbey School in Mt. Angel, OR

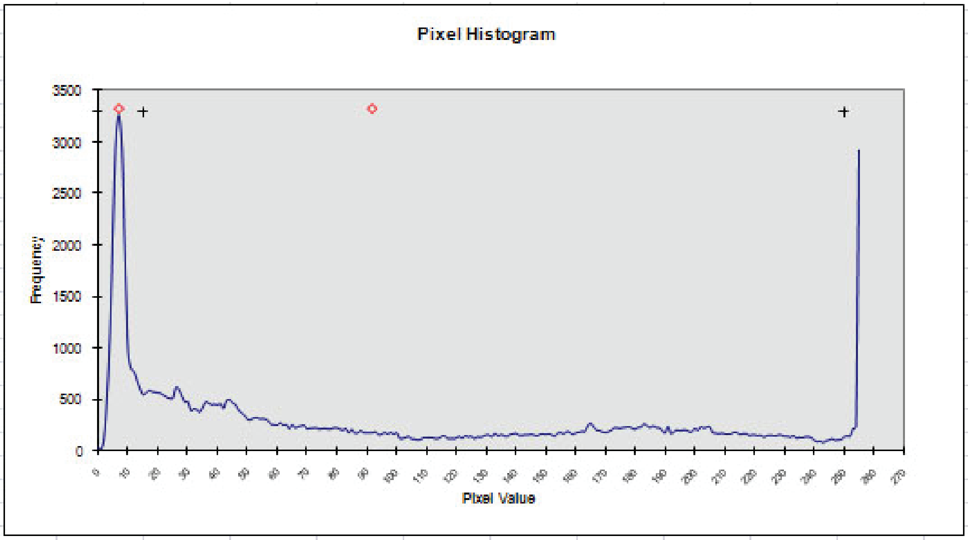
Model testing under the translucent barrel vault at PUCE.

Culplite analysis of St. Martin’s in the Field, London





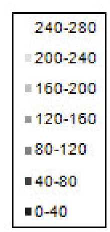
RAW format of the image above is used.

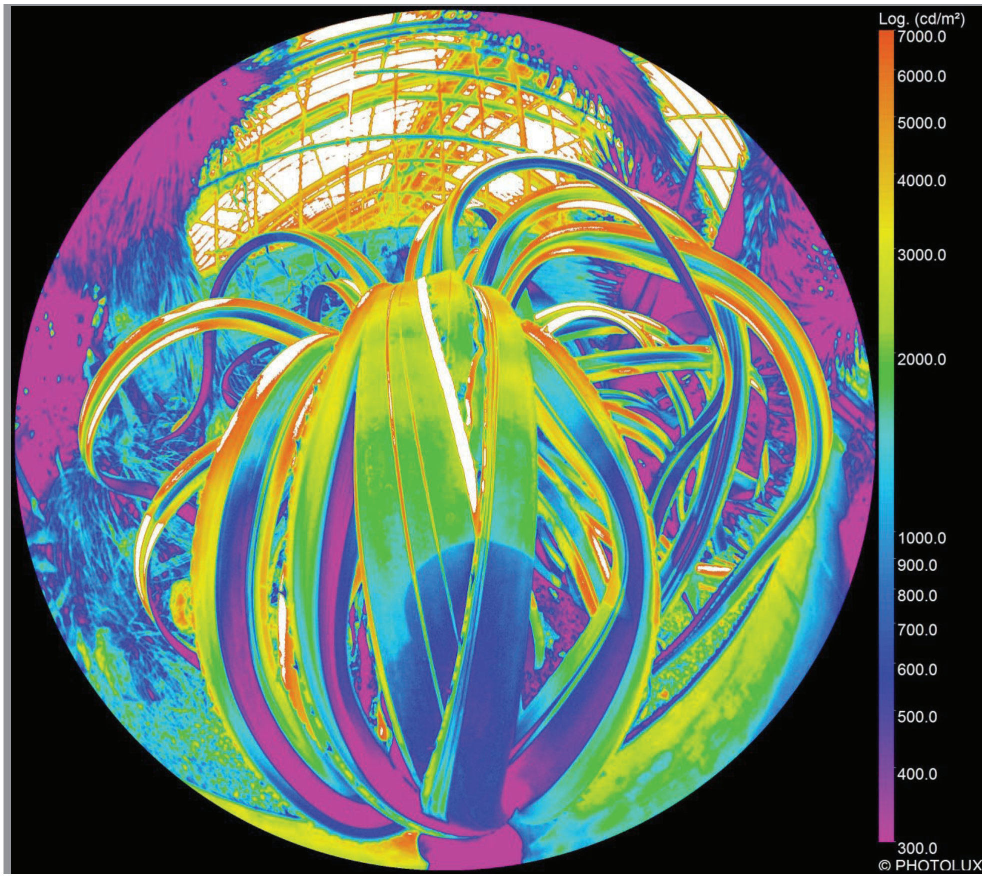


Overall Image			**Indiviual Pixel**		
Weighted Ave Pixel Intensity	105.12		Individual Pixel Value	40	
Total Number of Pixels	76800		Corresponding Luminance	58.12	footlamberts
Background Bell Curve			**Spike**		
Low End Pixel Value	15		Low End Pixel Value	0	
High End Pixel Value	250		High End Pixel Value	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."

Culplite analysis of actual overcast sky.





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

False color image.

Sky Dome Luminance - Overcast Sky Box

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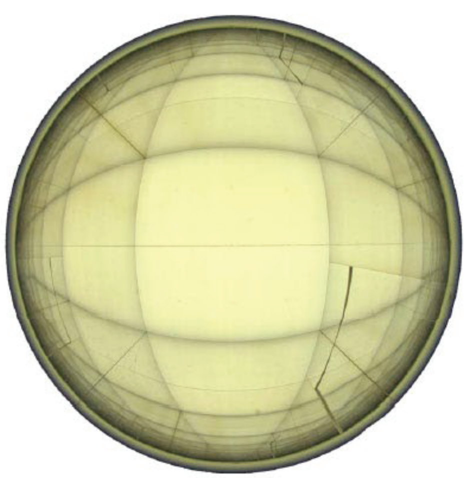
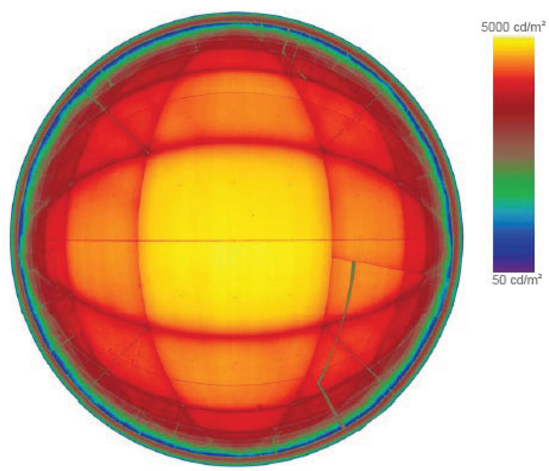


HDR Hemispherical Sky
Taken with Fisheye lens pointed straight up.



False Color Image
Taken with Fisheye lens pointed straight up.

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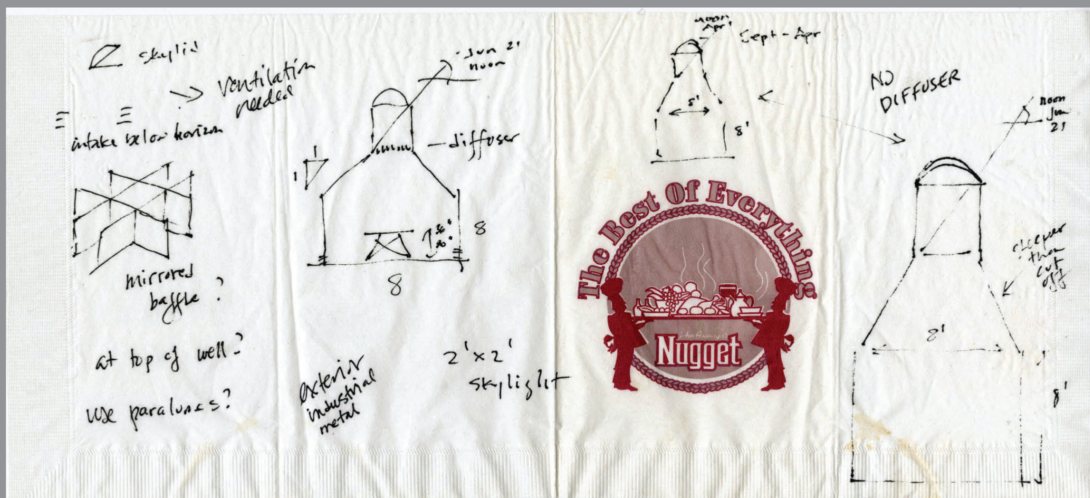
Changing Mindsets:
A Passive-First Artificial Sky

Bruce Haglund, Emilie Edde, Daniel Flesher, and Brenda Gomez
University of Idaho, Moscow, Idaho



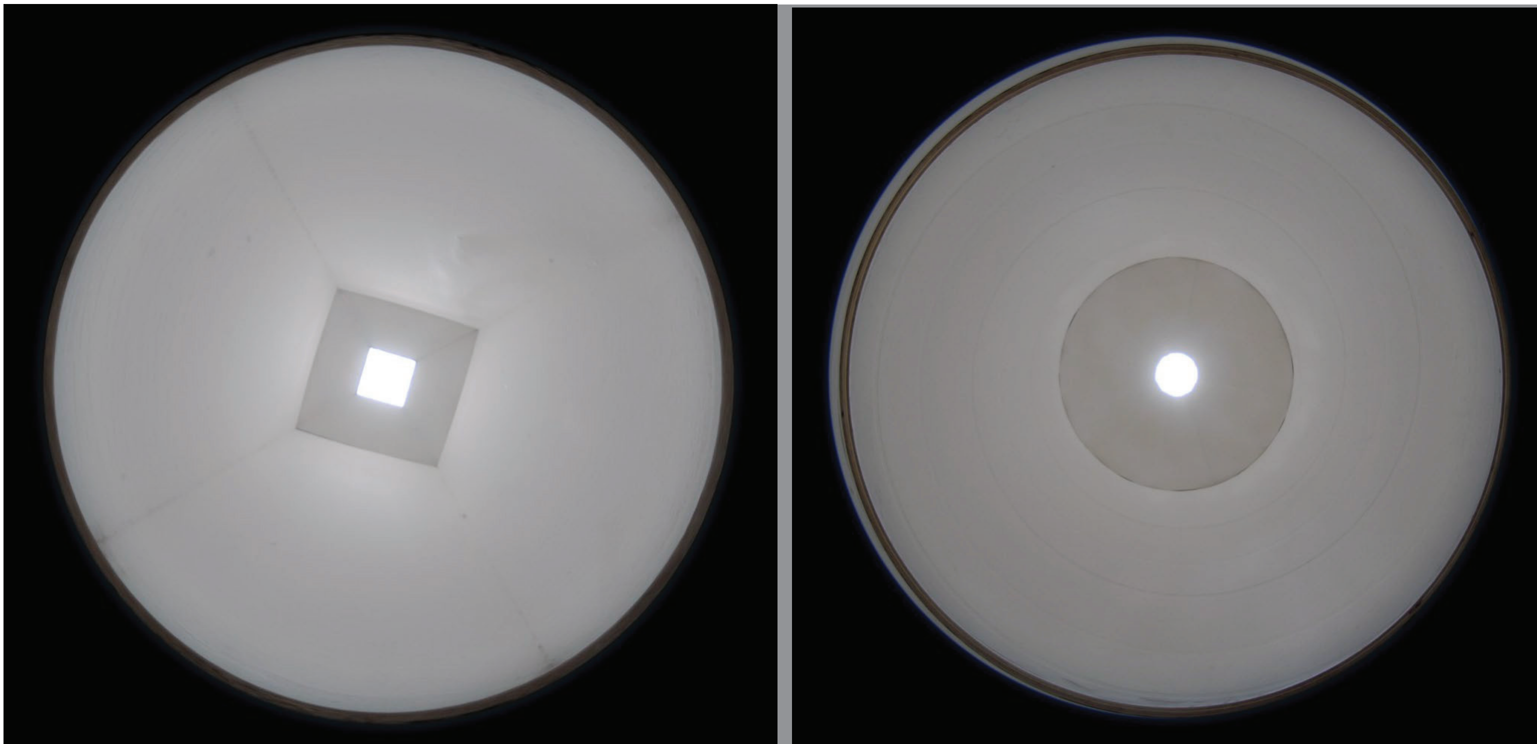
…from napkin sketch to realization?

4 models assigned to Arch 570

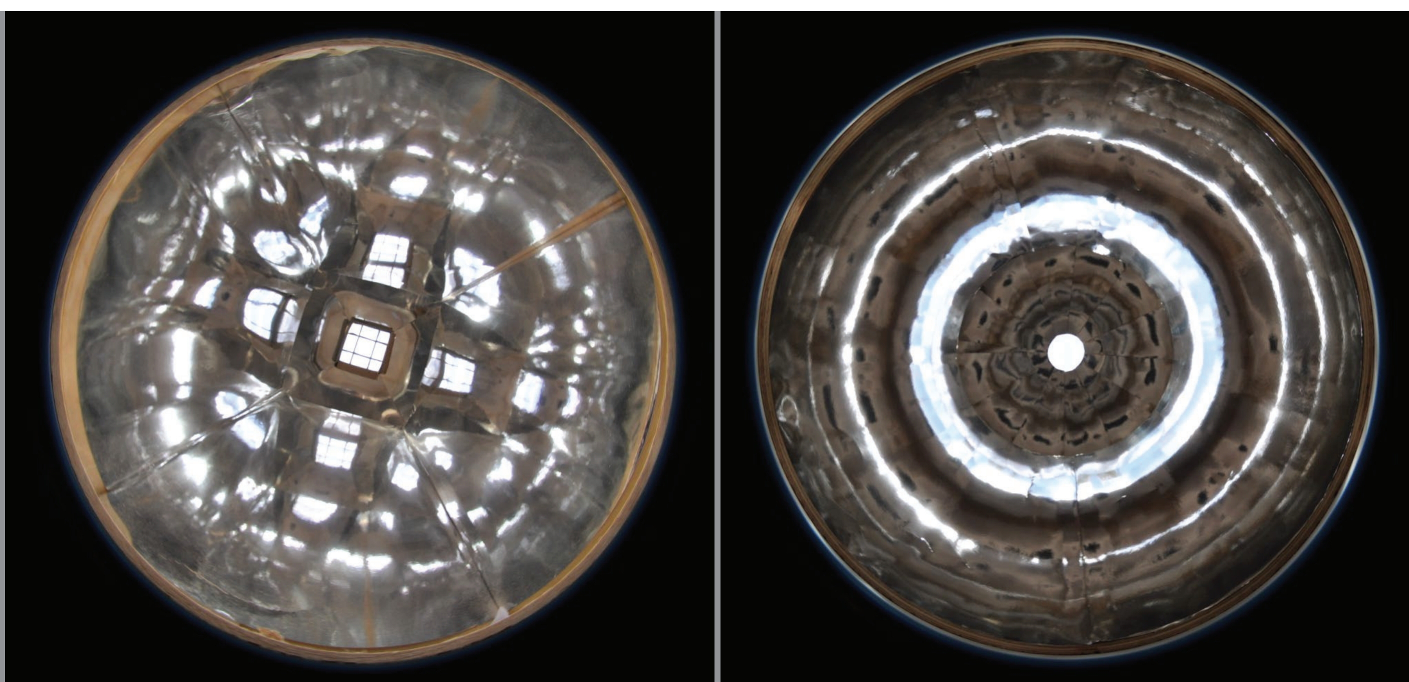
	Rectilinear	Cylindrical
Matte white surfaces	Model A	Model C
Mirrored surfaces	Model B	Model D

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

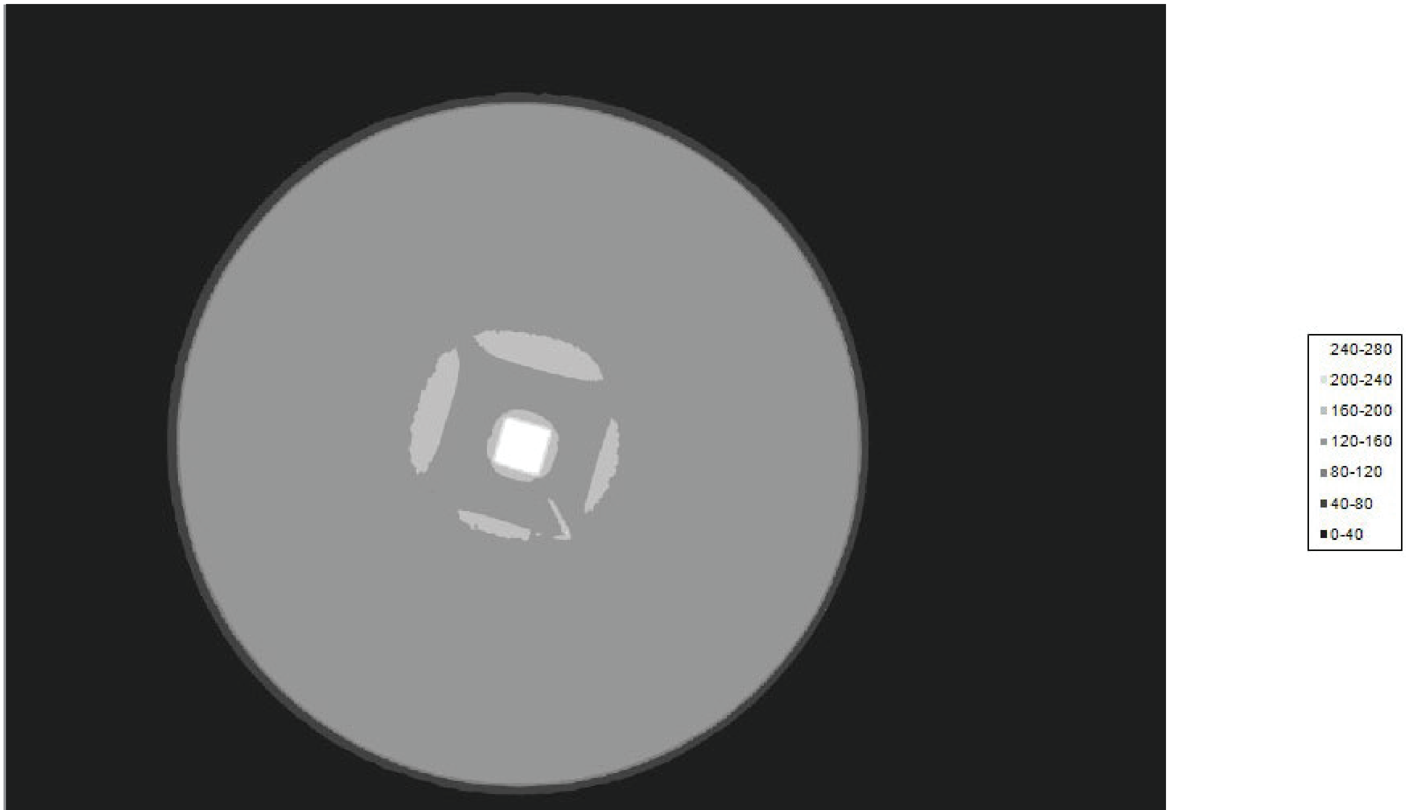
Sigma 4.5mm f/2.8 EX DC HSM circular fisheye lens mounted on a Nikon D-5000 Digital SLR camera.



Preliminary Test: Matte White Rectilinear vs. Cylindrical



Preliminary Test: Mirrored Rectilinear vs. Cylindrical



Culplite analysis of matte white rectilinear model.

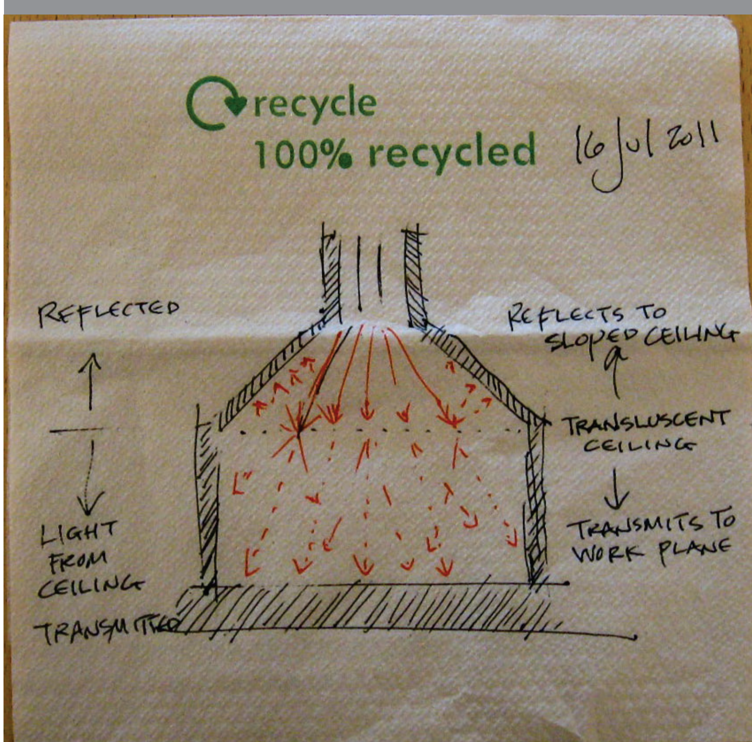
Prototype daylighted sky.

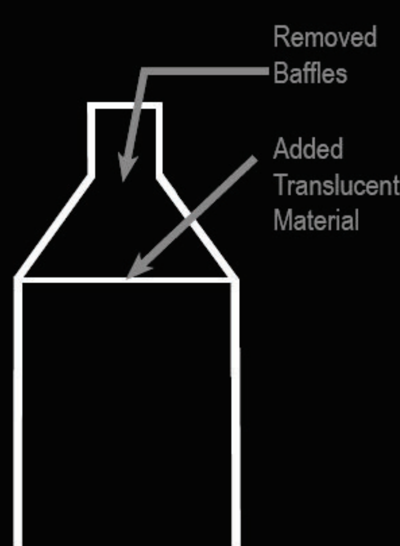
If our research and testing proves the naturally lighted artificial sky viable, we intend to build a full-scale prototype (~10 ft x 10 ft) for eventual installation at our new interdisciplinary design laboratory on campus in Moscow, Idaho. The design and construction of the prototype will be a hands-on 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.

Remember these? They needed redesign!

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

Arch 570 Redesign:

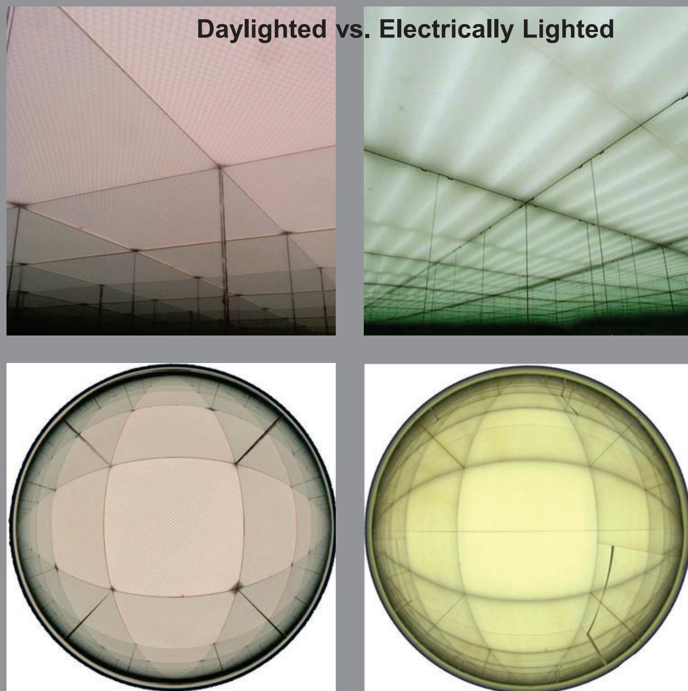




Experimenting with translucent ceiling and neutral floor materials. And, ultimately with different shapes.

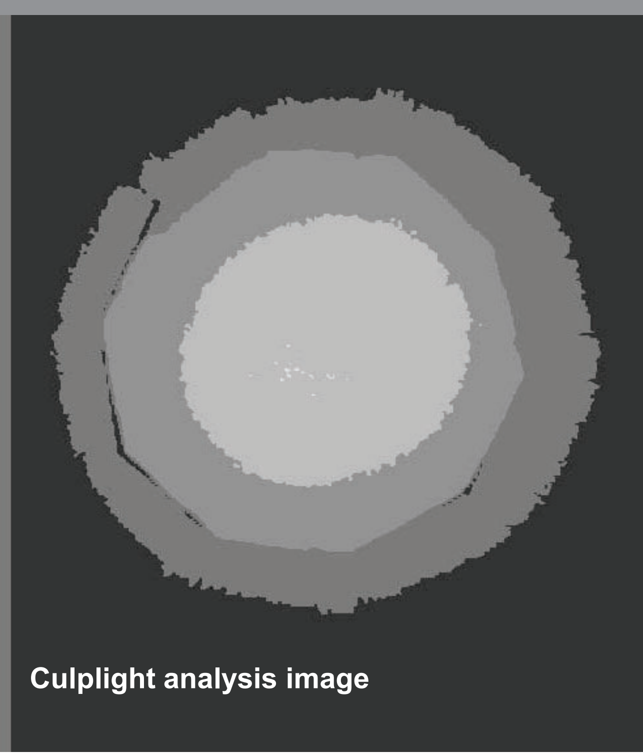
First Feasible Option:

Two teams proposed Mirror-Box Sky w/Kalwall Skylight.



Second Feasible Option:

Two teams proposed Conical Sky w/matte white interior.



Seed Grant for construction and instrumentation awarded

Funding: 1 July 2012 - 31 July 2014.

We've built option #2.

SketchUp model

Fall term Solatube installation

Spring term construction sequence

Using Photography for Testing and Calibration:

Pros.

1. Photography can collect luminance data for all points simultaneously

2. Photography can act as a per pixel luminance meter when calibrated properly, resulting in extremely high-resolution measurements

Using Photography for Testing and Calibration:

Cons.

1. All lenses exhibit vignetting, or the darkening of pixels at the corners of the photos. This phenomena must be accurately corrected for in order to be used for analysis.

2. Vignetting affected not only by lens, but by aperture size, so all photos must be taken at same aperture for correction to remain constant.

http://upload.wikimedia.org/wikipedia/commons/1/1f/Example_of_vignetting_and_dusty_scan.jpg

Calibration Process:

Area of interest defined within white partition. Light level measured 26.4fL at top and 20.3fL at bottom

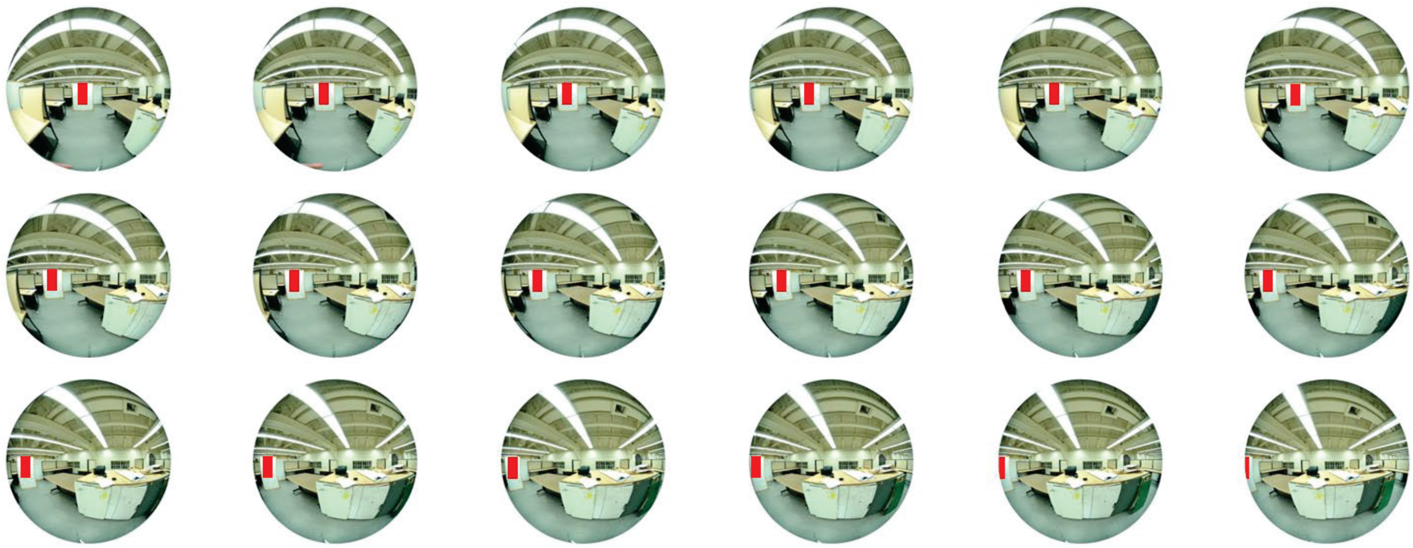
Relatively even distribution.

Value will be averaged in 5° increments to determine light falloff, expressed as a quartic function.

Calibration Process:

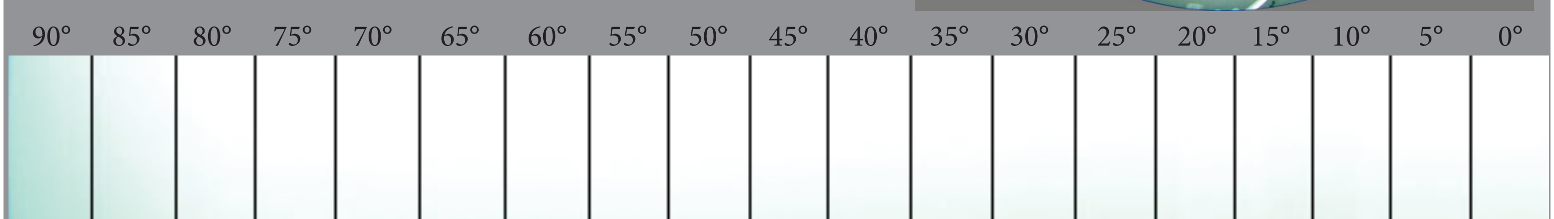
Camera placed on a tripod and rotated 5˚ between exposures.

F-4 with 1/6s exposure.



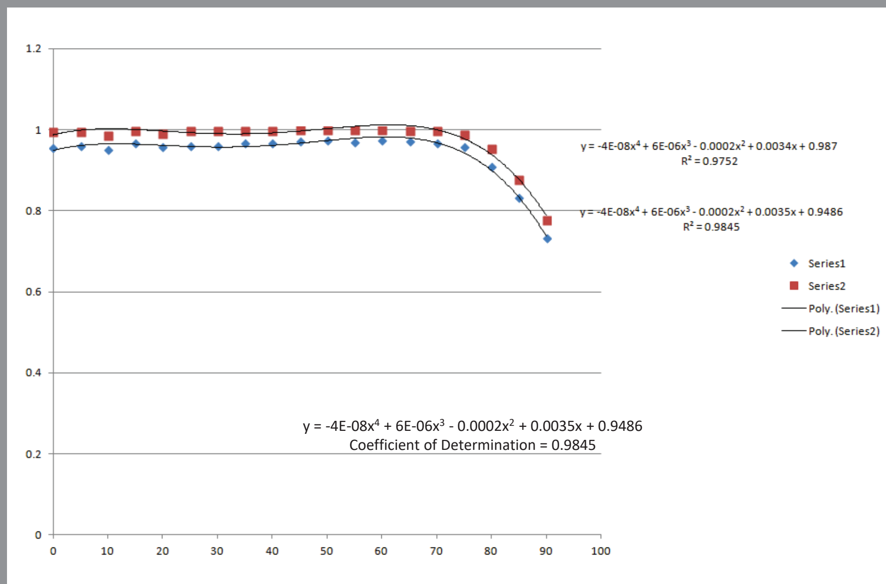
Calibration Process:

Area of interest cropped in Photoshop, resulting in a continuous image of the same spot from 0-90˚



Calibration Process:

Image analyzed using Grasshopper for Rhino, giving quartic equation of light falloff.



Calibration Process:

Quartic function used to create filter to be applied in Photoshop.

http://lemieuxster.com/dev/gradient/

$y = -4E\text{-}08x^4 + 6E\text{-}06x^3 - 0.0002x^2 + 0.0035x + 0.9486$

$R^2 = 0.9845$

Layer will be set to Linear Dodge blend mode in Photoshop, which adds the brightness of the pixels to the layer below.

Calibration Process:

The filter was tested to see if it corrected for our baseline.

Before:

After:

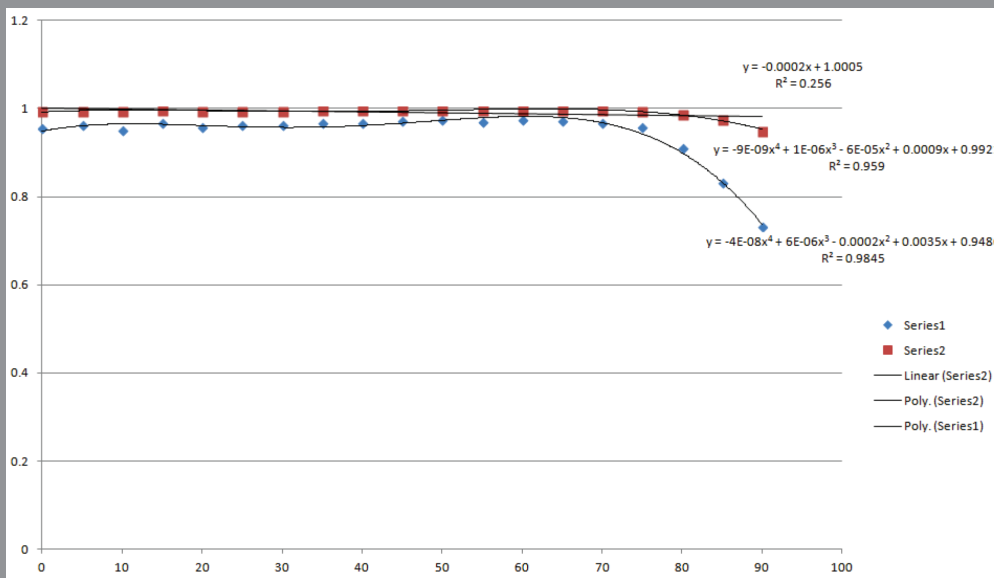
Calibration Process:

Before:

After:

Calibration Process:

The image with applied filter was analyzed in Grasshopper to see if light fall off had actually been corrected.



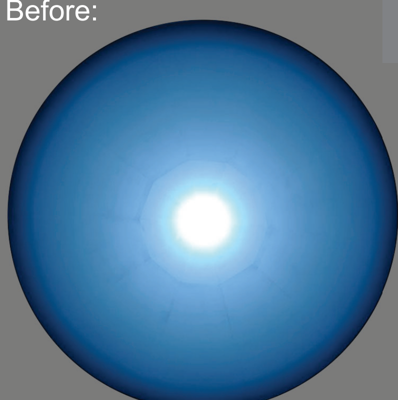
Testing the Sky Using Photography

Photo taken using fisheye lens inside artificial sky on Oct 14th 2013 at 2:20PM; Clear sky conditions.

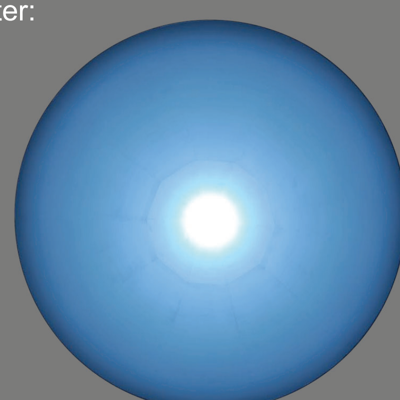
Lens pointed directly at zenith and positioned at the height of the horizon.

Photo corrected for vignetting.

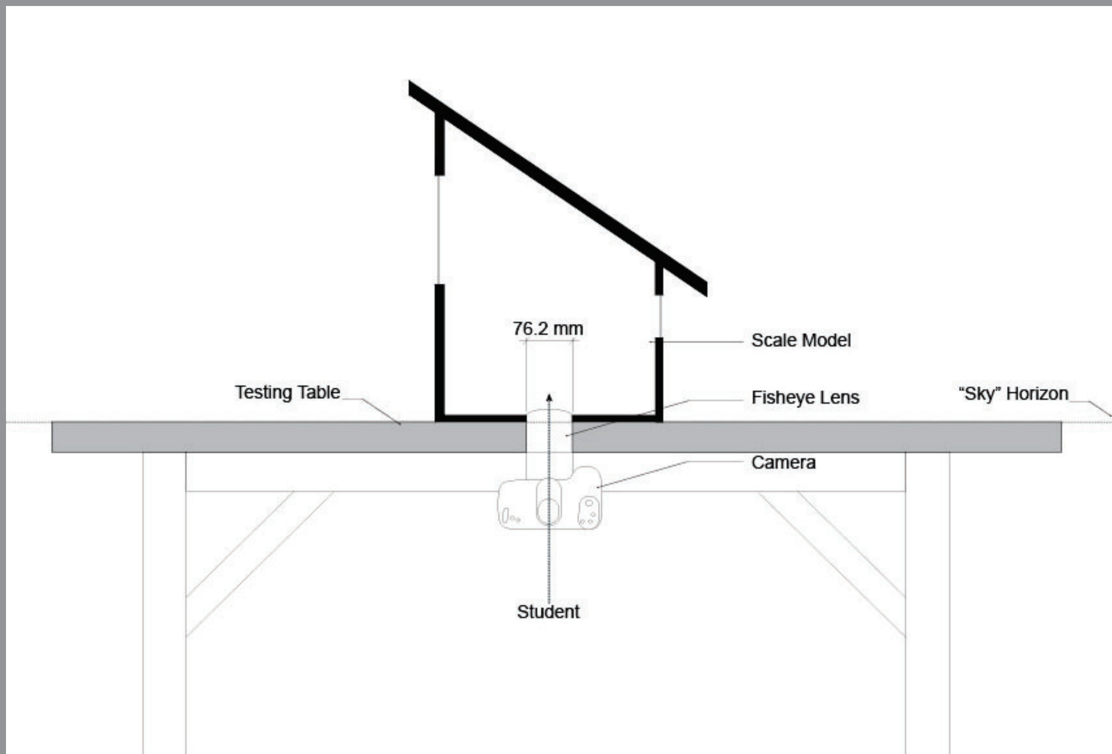
Before:



After:

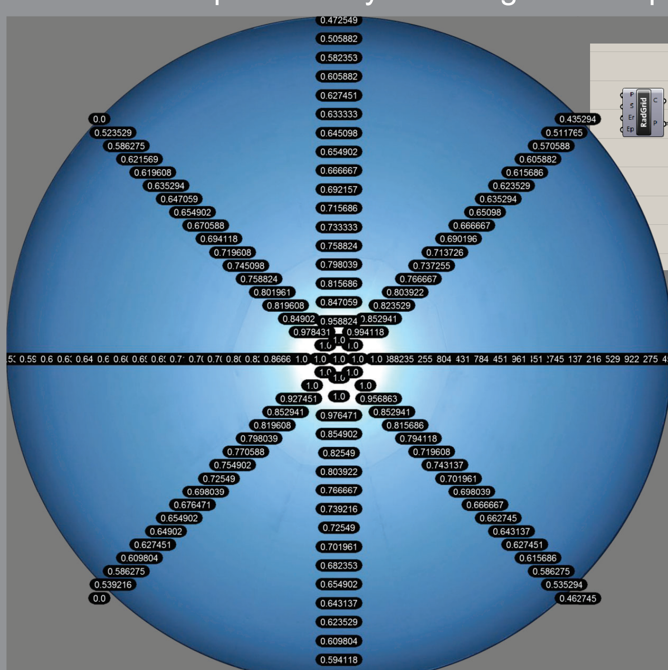


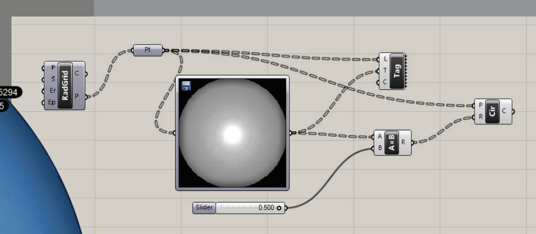
Fisheye Lens:



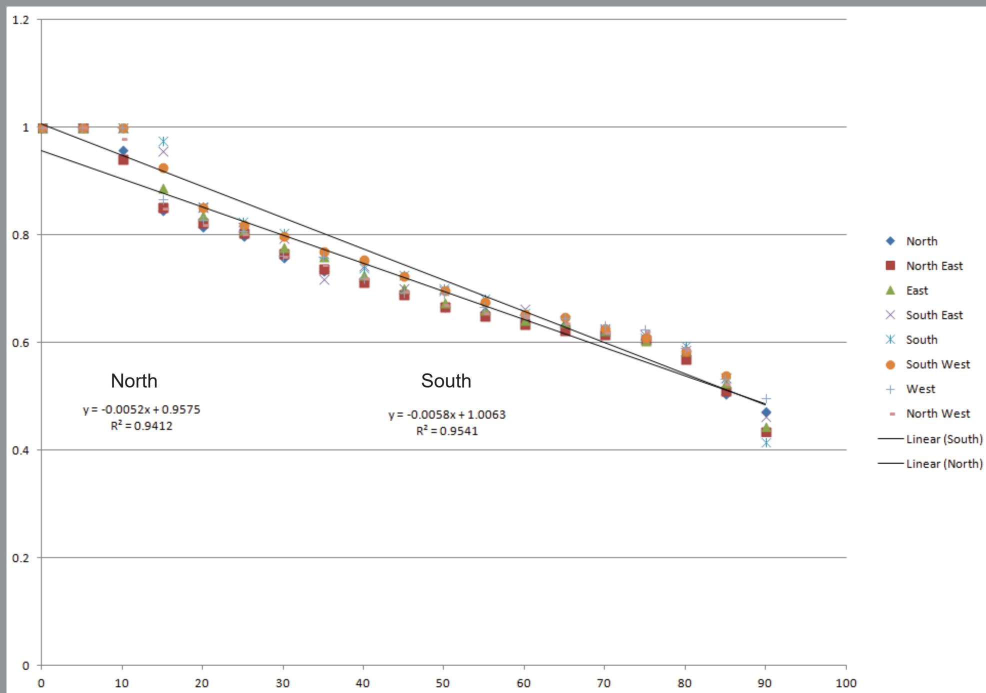
Testing the Sky Using Photography

Corrected photo analyzed using Grasshopper plug-in for Rhino





Testing the Sky Using Photography



Epilogue

Physical model for use in artificial sky

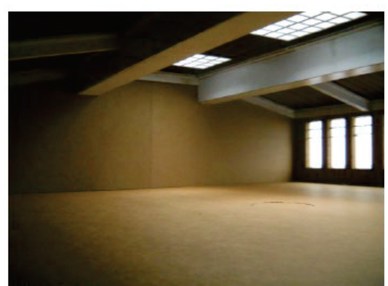
Filip Fichtel, Ryan McColly, Clay Reiland

Comparing physical model in sky with outdoors:

Model Photos

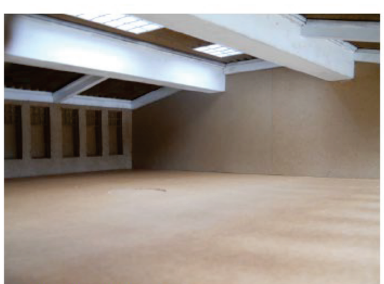
In Sky

In the dome 1

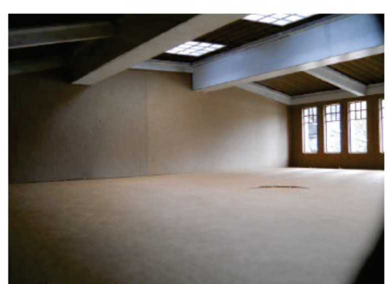


In the dome 2

Outdoors

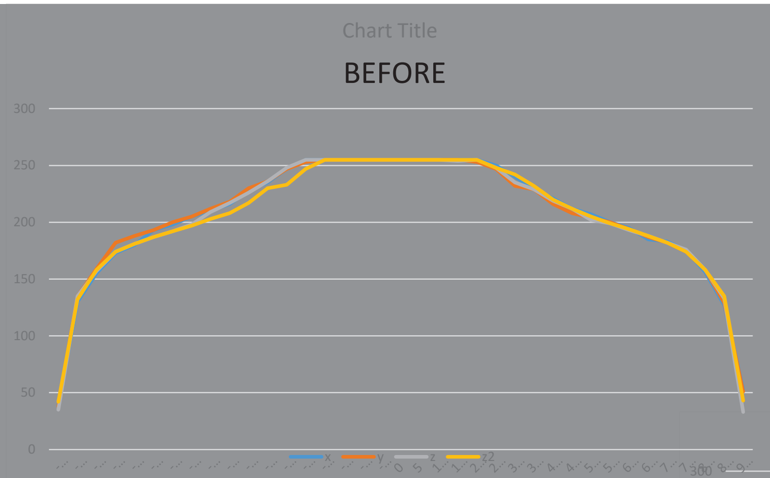


Outside Cloudy Day 1

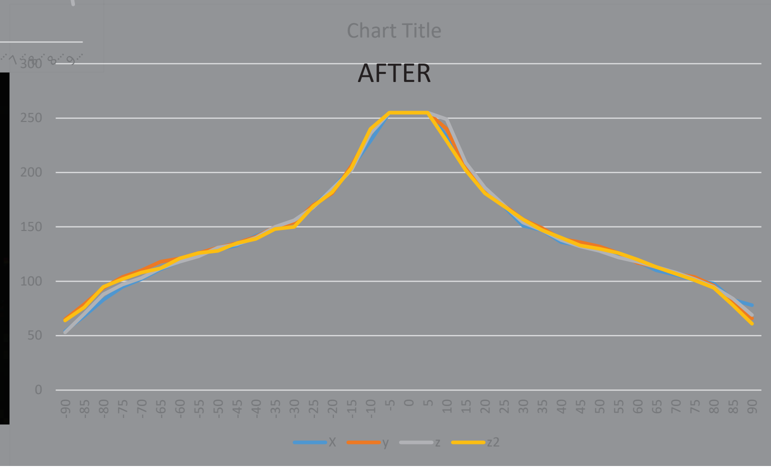


Outside Cloudy Day 1

Tom Kearns, Ryan Ivie, Ben Ferry, Clay Cravea



Before and after installation of temporary baffle.



More work to do:

1. **Analyze photos from different seasons and sky conditions**
2. **Adjust sky aperture (the baffle) as needed**
3. **Retest and reanalyze**
4. **Write Users' Manual**
5. **Distribute plans worldwide**