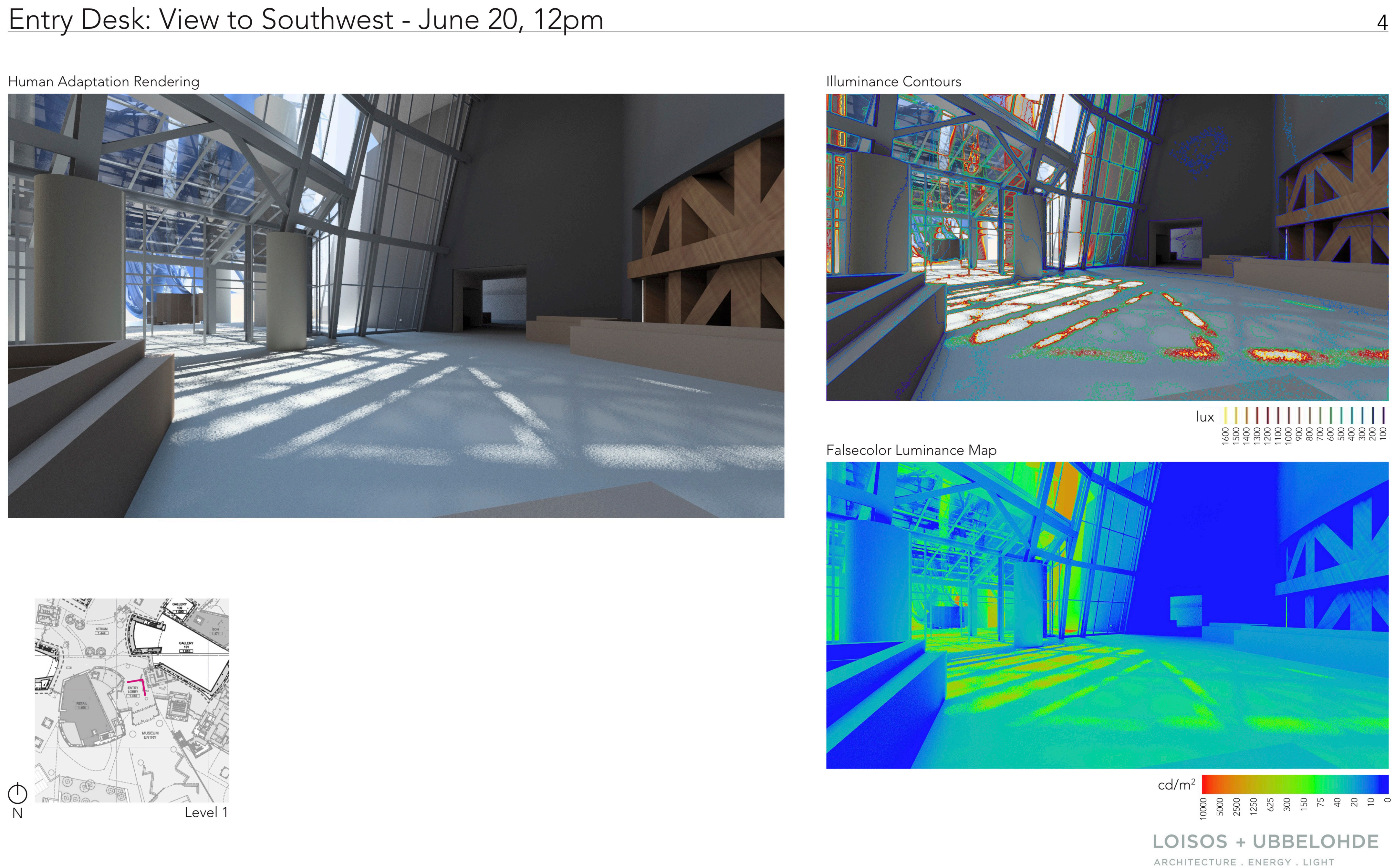
What to do when the sky is blue

notes from practice on the use of colored sky models

Michael Beggs, Loisos + Ubbelohde
19th Annual Radiance Conference, Bilbao, Spain
August 19-20, 2021

This talk presents some of our observations on the use of colored sky models for radiance in the context of our work as a consulting practice that works in a variety of locations, project scales, and levels of analytical complexity.

It is divided into five sections, roughly



Point-in-time view-based simulations are central to our consulting process.

These images are instantly accessible and contain a wealth of data, but the process to produce them accurately requires extensive coordination with designers as well as time-consuming preparation of the simulation model to ensure exactness.

This means that we need our radiance results to be both highly accurate and beautiful.

Sir James Jeans' metaphor for atmospheric scattering from "Why the Sky is Blue", 1931

Sir James Jeans' metaphor for atmospheric scattering from "Why the Sky is Blue", 1931

It is worth reminding ourselves that color is a perceptual phenomenon.

What we call the visible spectrum is the range of wavelengths for which humans have the visual response that we call color.

Radiation, reflection and transmission exist physically in the world, but color as we experience it exists only within the human mind and body.

As such we cannot perceive color as illuminance, we can only percieve it when it is reflected or scattered by something.

In architecture, that more or less happens in three places:

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Reflected or scattered from the outside

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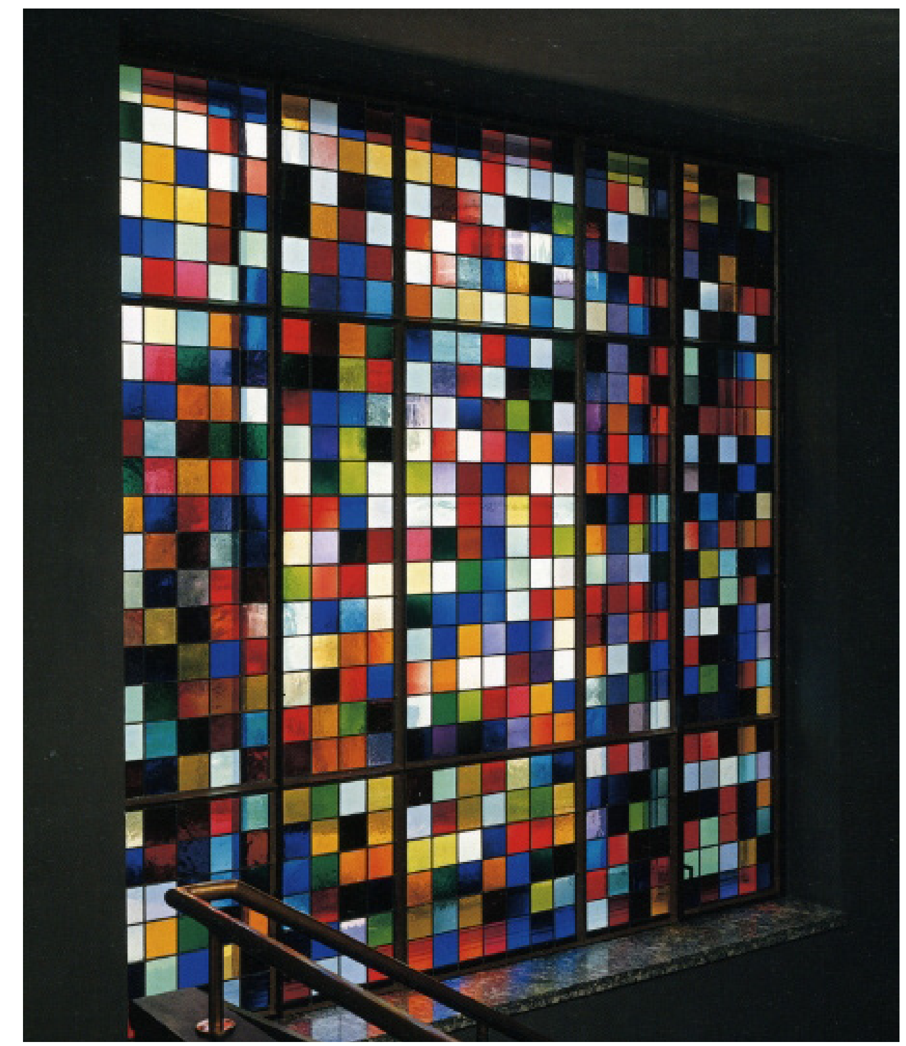
In architecture, that more or less happens in three places:

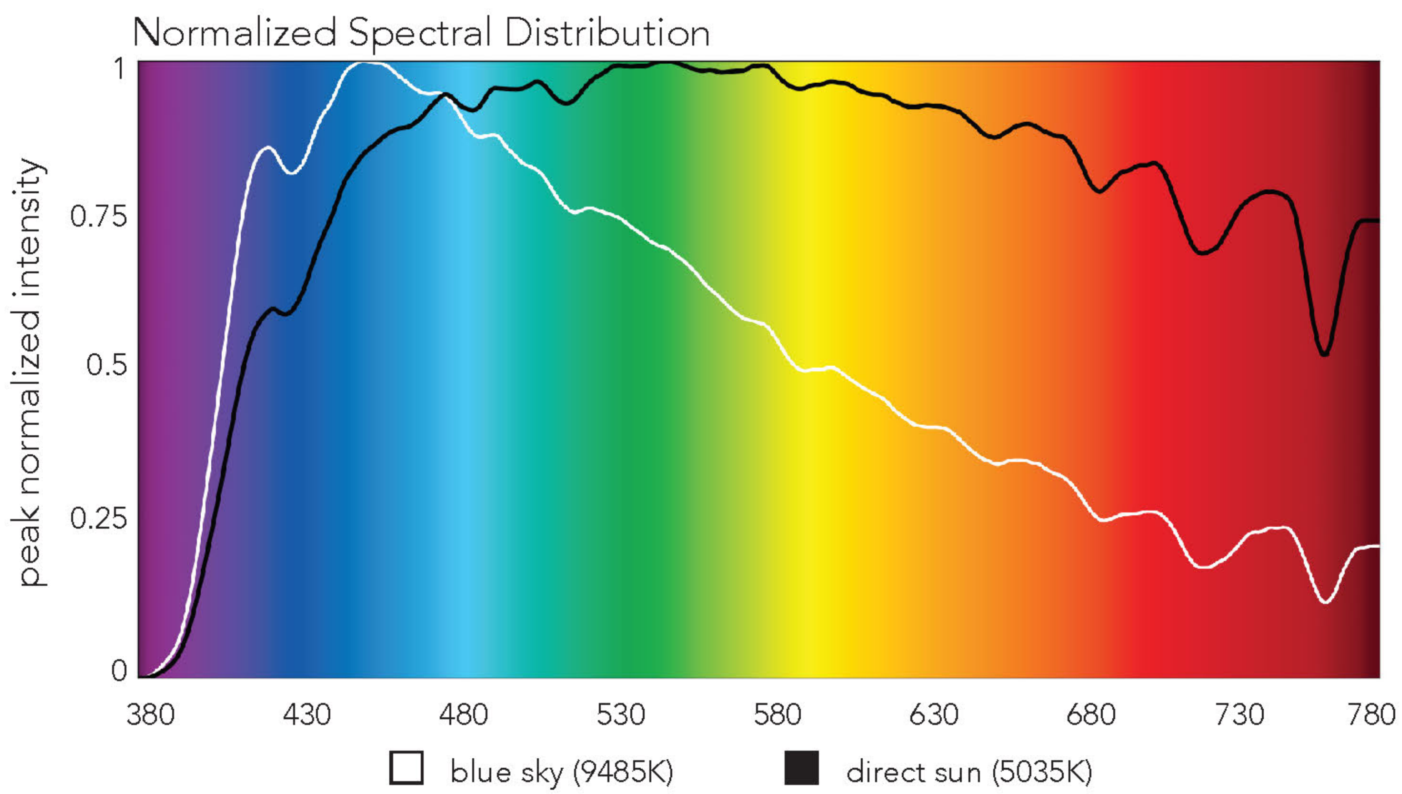
Reflected on (interior) building surfaces

Reflected or scattered from the outside

Scattered within transmissive materials



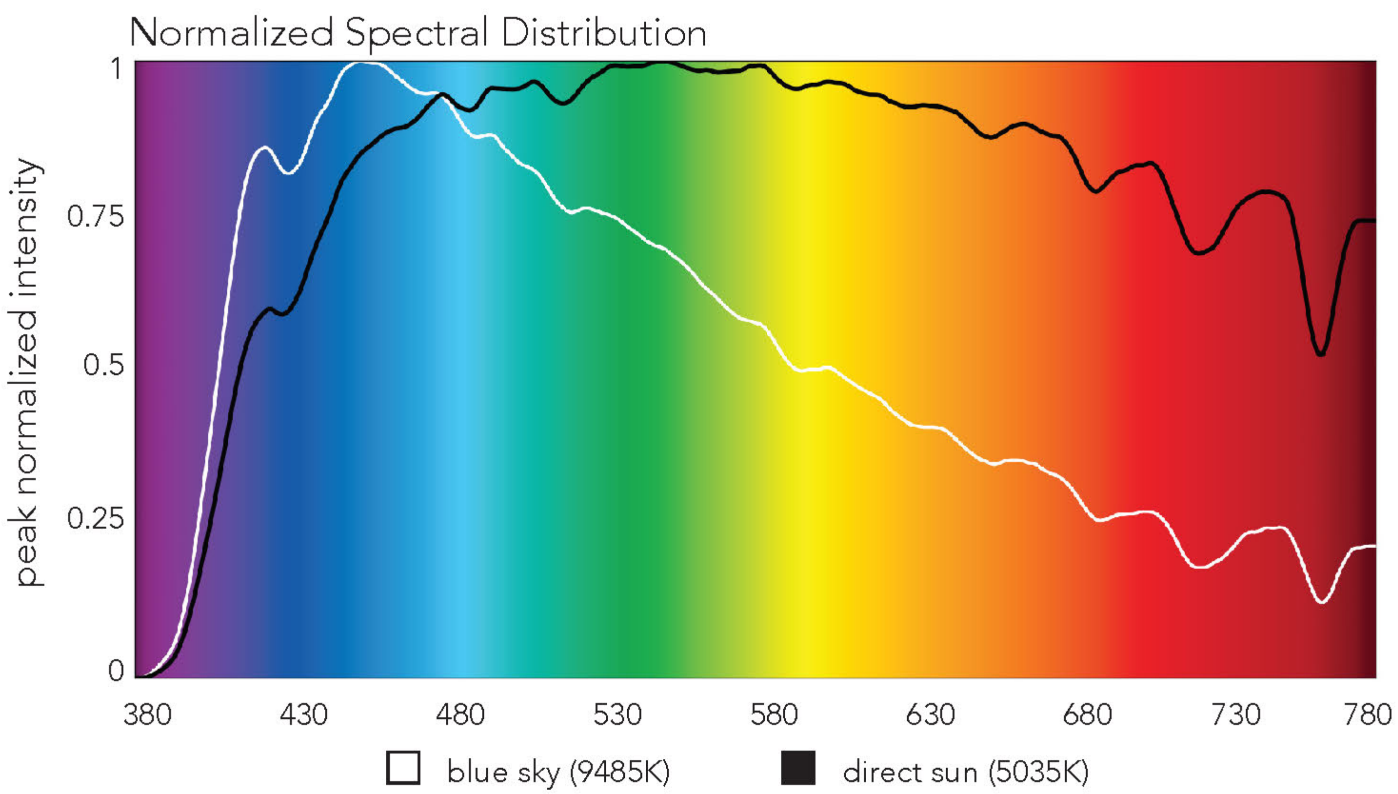
The color of the daylight seen by building interiors varies both by orientation...



Two measurements of the color of daylight taken in the same location at the same time, one pointed directly at the sun, the other at the dark blue sky opposite of the sun, show the greatly varying spectra of daylight.

The color of the daylight seen by building interiors varies both by orientation...

... and by weather condition and time of day



Two measurements of the color of daylight taken in the same location at the same time, one pointed directly at the sun, the other at the dark blue sky opposite of the sun, show the greatly varying spectra of daylight.

5900K Morning Overcast Sky, 9:30 AM

4400K Late Afternoon Sun, 6:30 PM

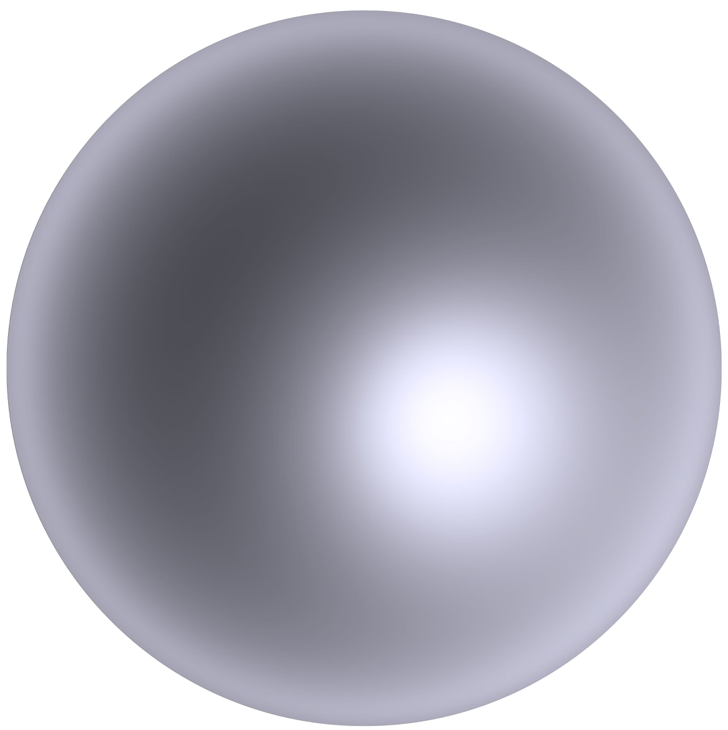
The Sky

The Sky

- The sky models
- Which sky models we prefer
- When we use them
- Special considerations when using the Utah sky model

July 28th, 14:00 - clear sky
Los Angeles, CA (34° N. Latitude)

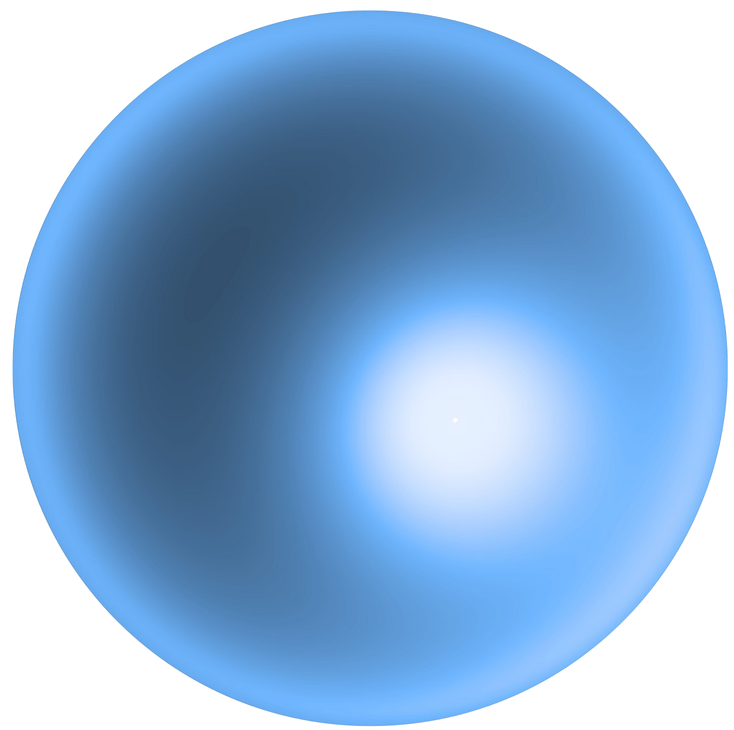
pcond human adaptation renderings



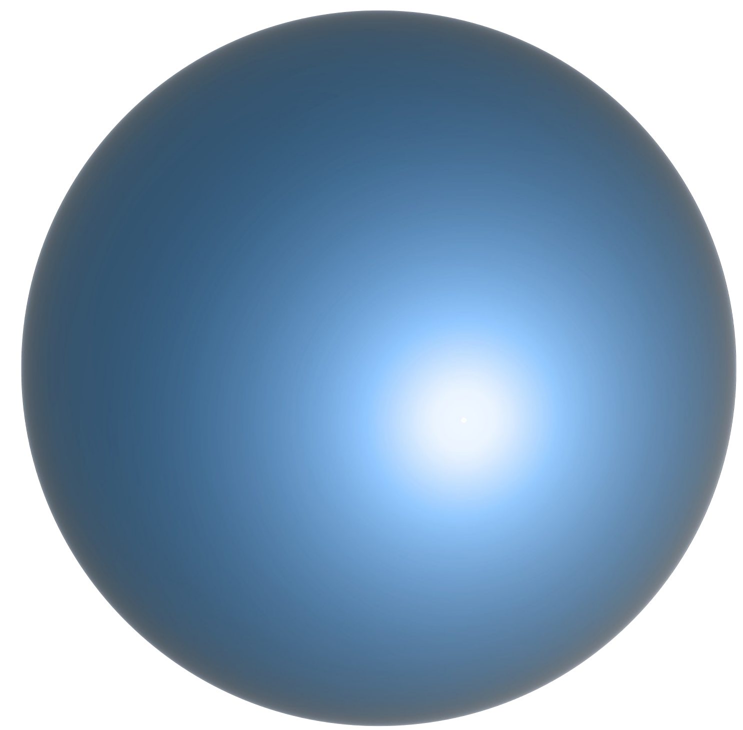
Standard Gendaylit Sky

(!gendaylit 7 28 13.5 -W 769.0 196.0 -a 34.02 -o 118.45 -m 120)

We modify the values of skyfunc to give a slight blue cast to the sky when using gendaylit for clear conditions.

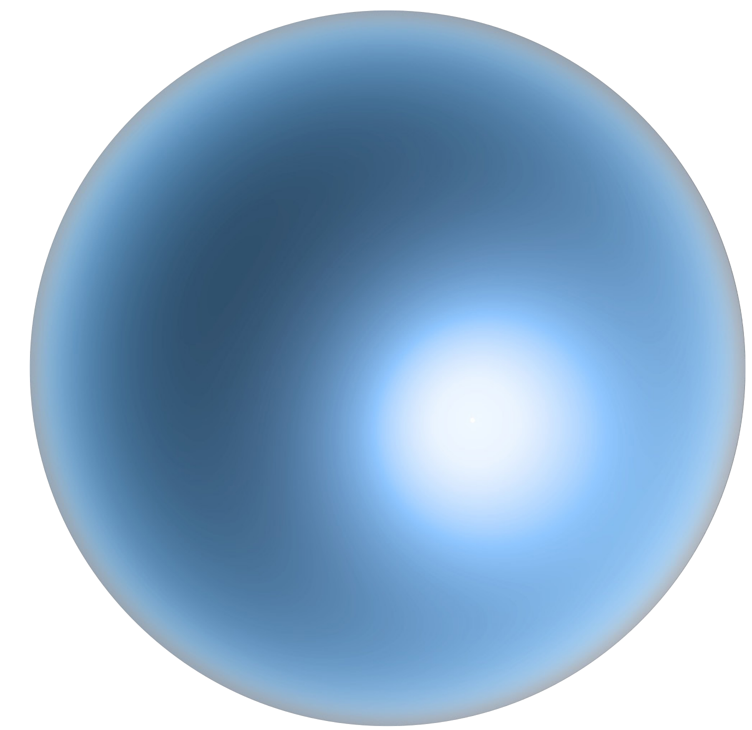


Gendaylit Colored Sky



Standard Utah Sky

gendaylit + colorfunc skyfunc
as described in utah.cal

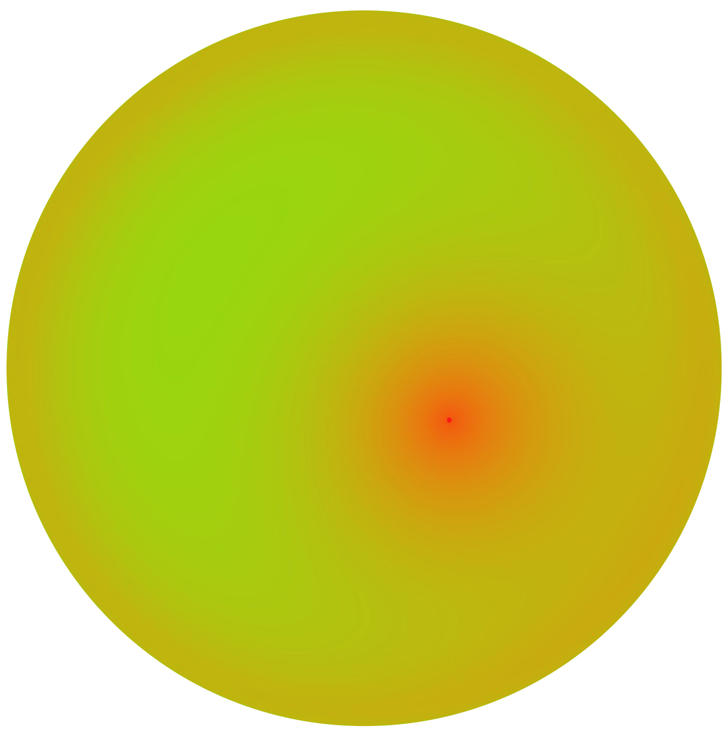


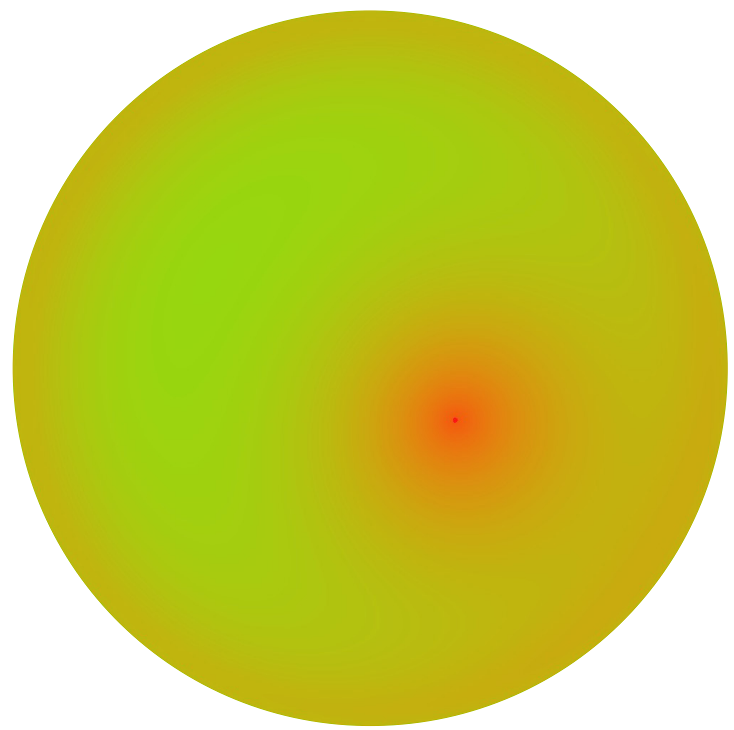
L+U Modified Utah Sky

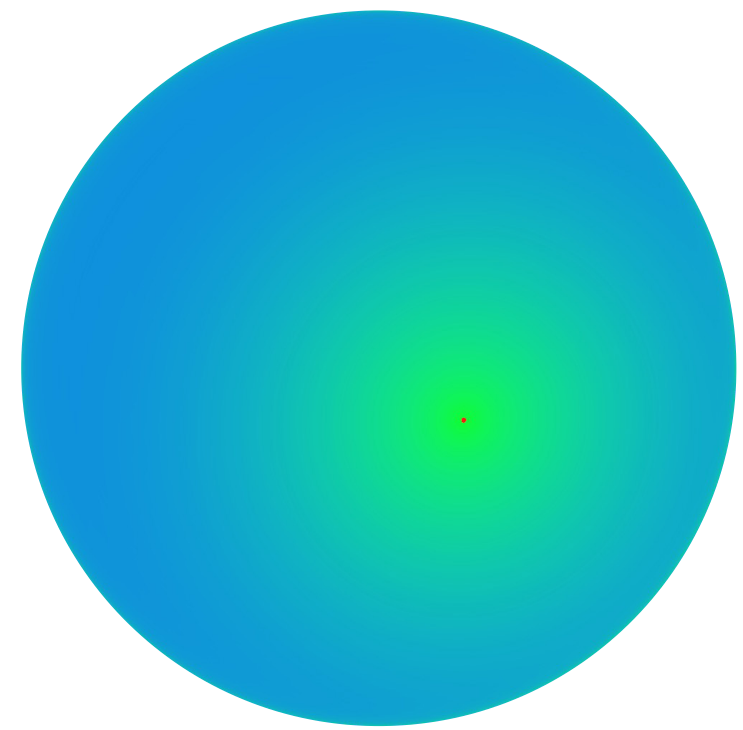
(Utah Sky color model with Perez-based luminance distribution)

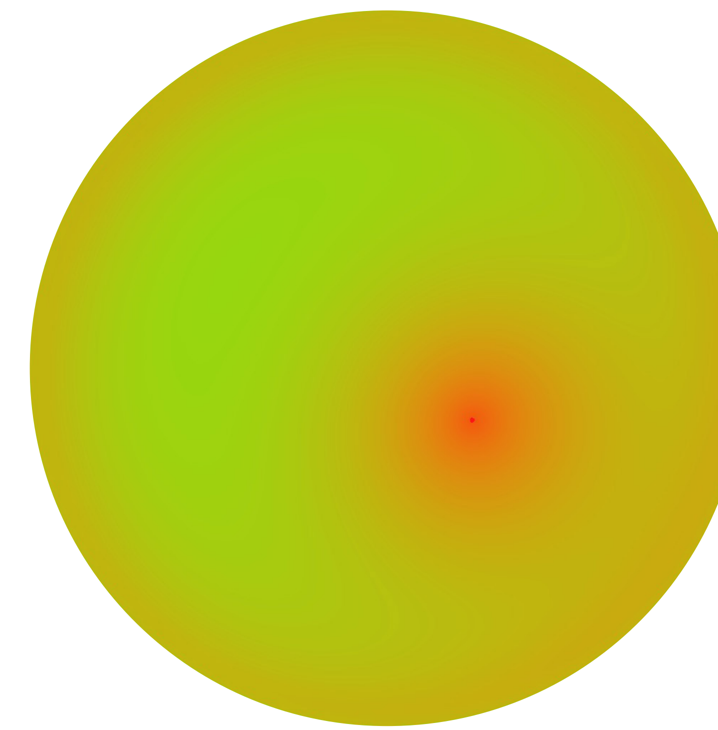
July 28th, 13:00 - clear sky
Los Angeles, CA (34° N. Latitude)

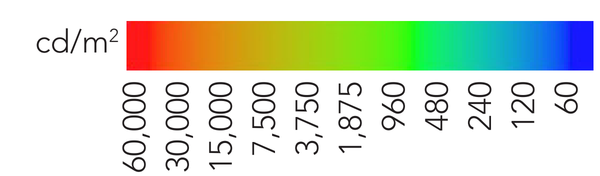
falsecolor luminance maps


Standard Gendaylit Sky


Gendaylit Colored Sky

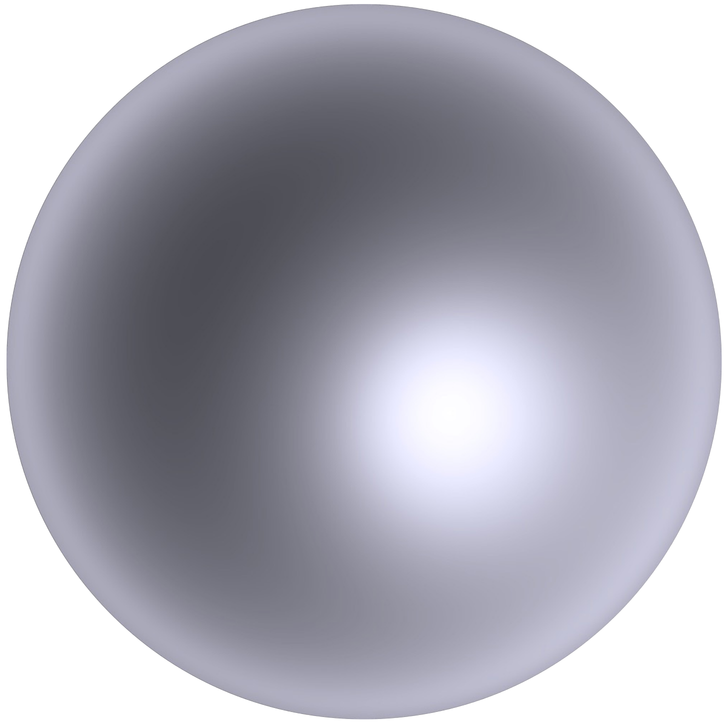

Standard Utah Sky

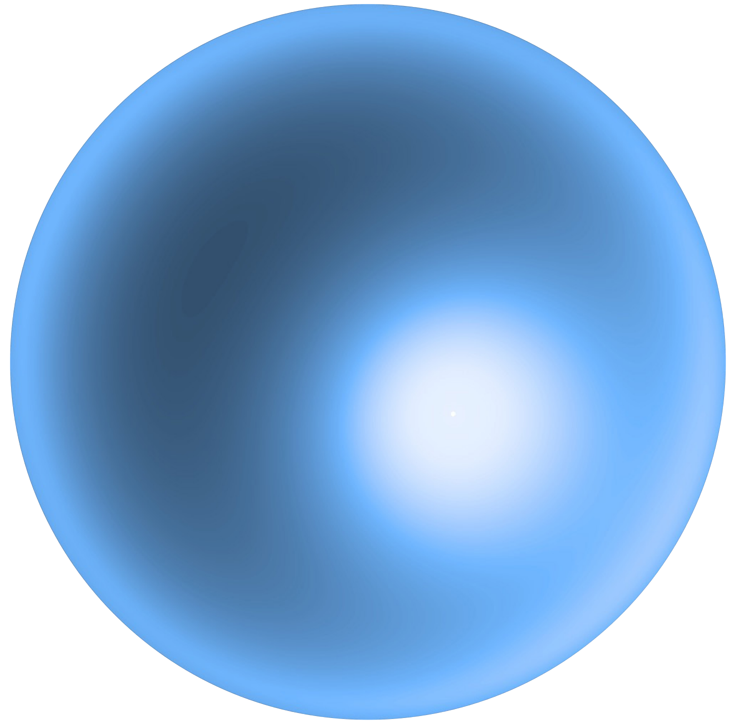

L+U Modified Utah Sky

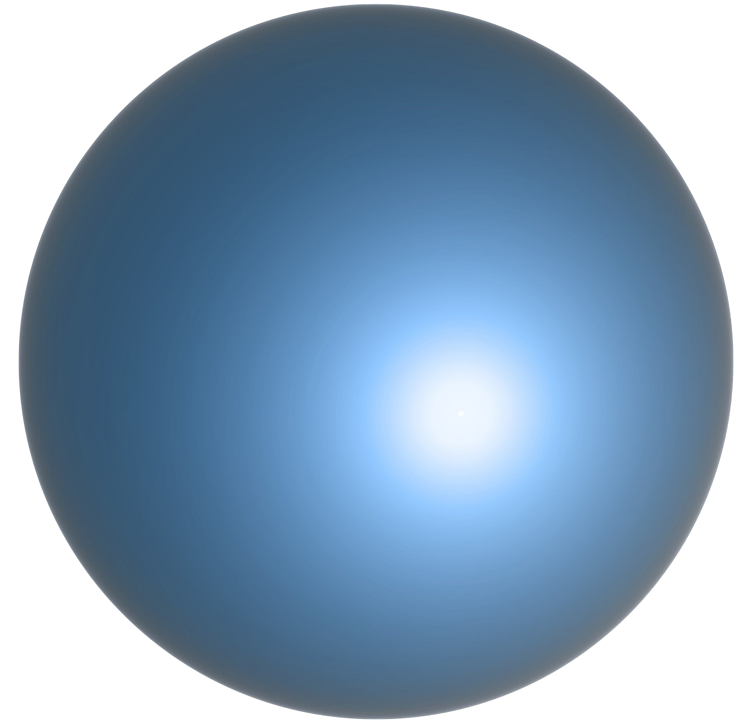


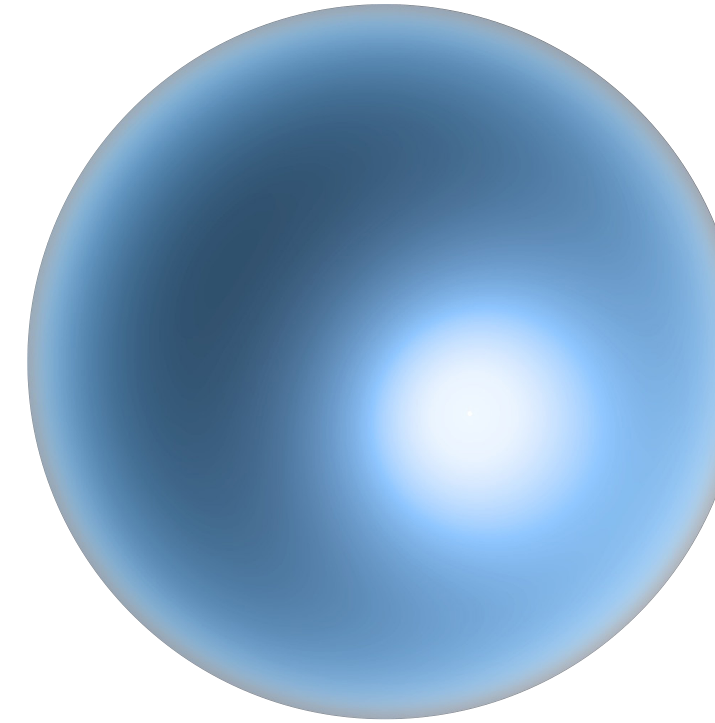
LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

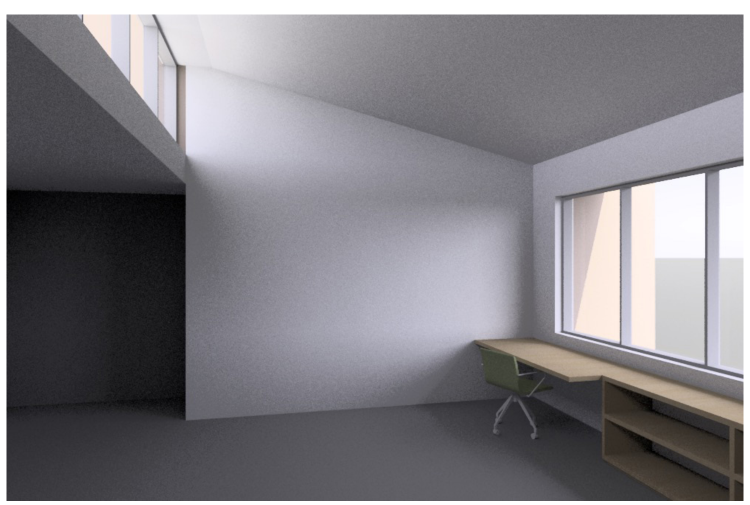
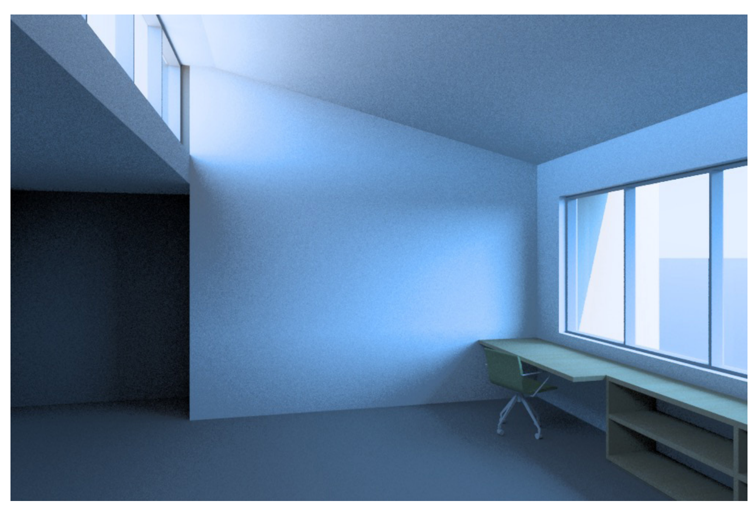
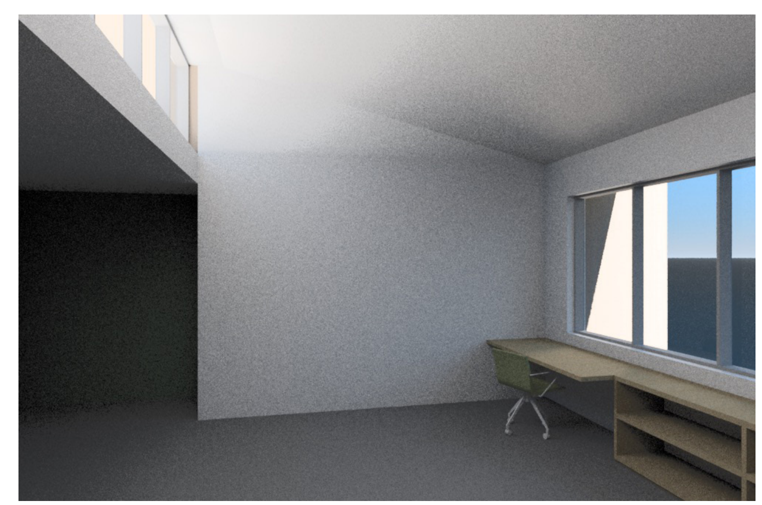
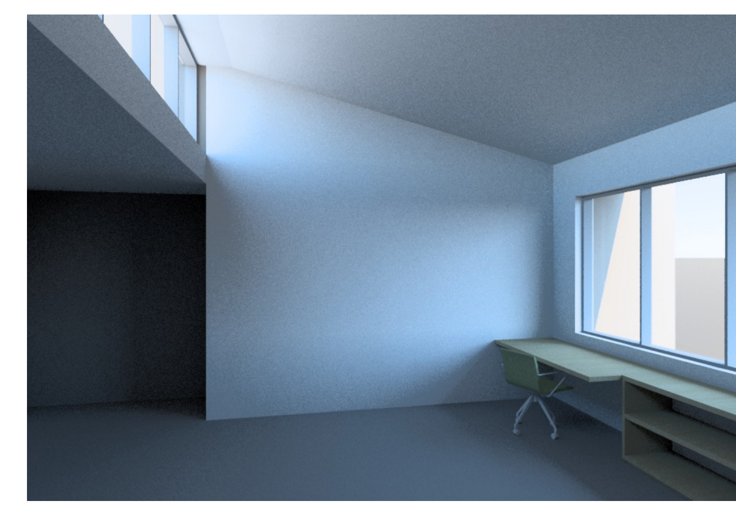
July 28th, 14:00 - clear sky (Los Angeles, 34°N)


Standard Gendaylit Sky

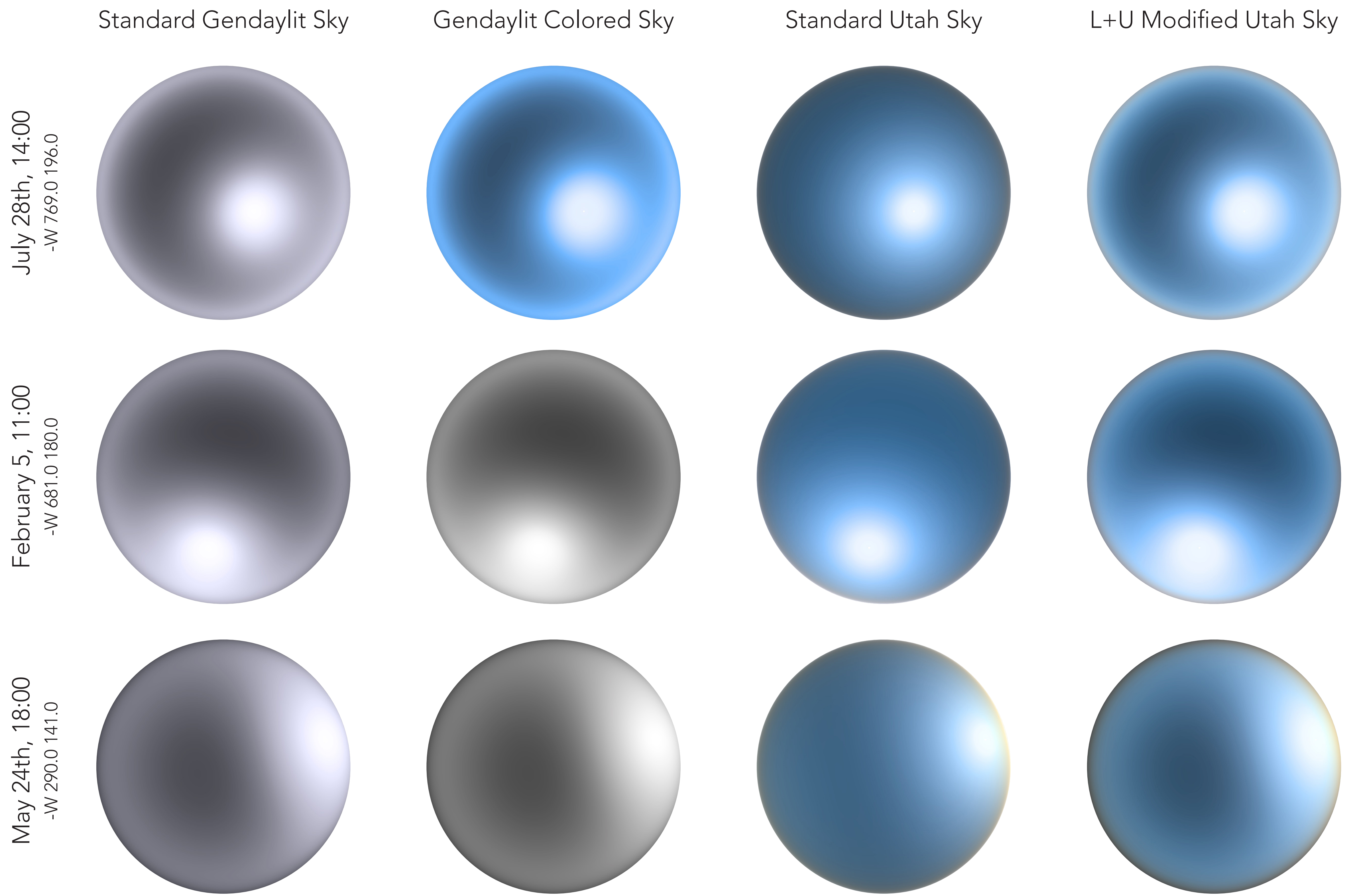

Gendaylit Colored Sky


Standard Utah Sky


L+U Modified Utah Sky

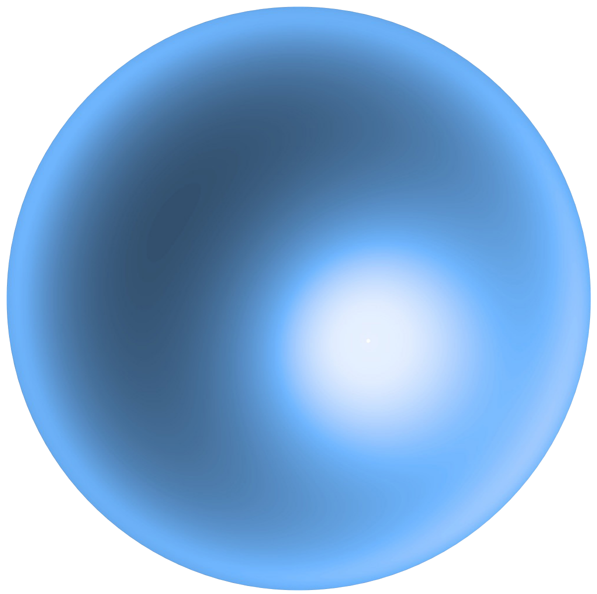





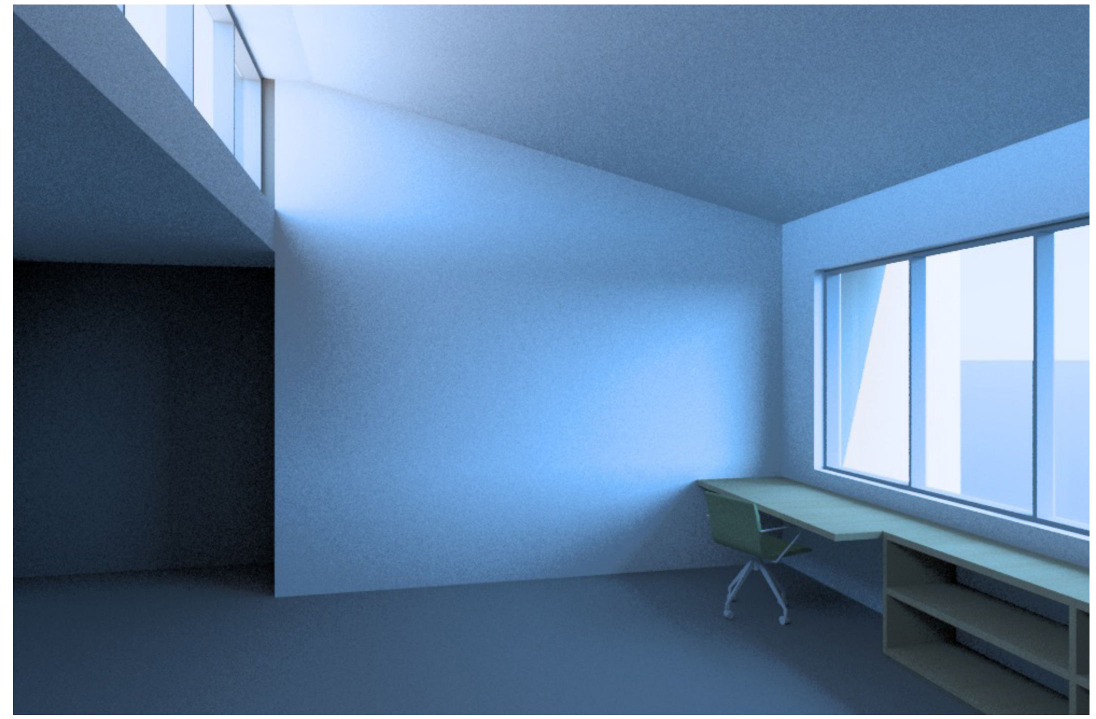
Window faces south


Standard Gendaylit Sky
Gendaylit Colored Sky
Standard Utah Sky
L+U Modified Utah Sky
July 28th, 14:00
-W 769.0 196.0
February 5, 11:00
-W 681.0 180.0
May 24th, 18:00
-W 290.0 141.0

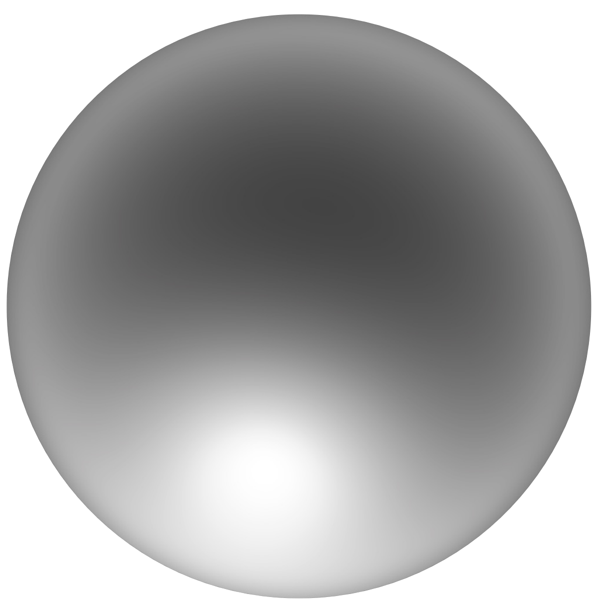
Gendaylit Colored Sky

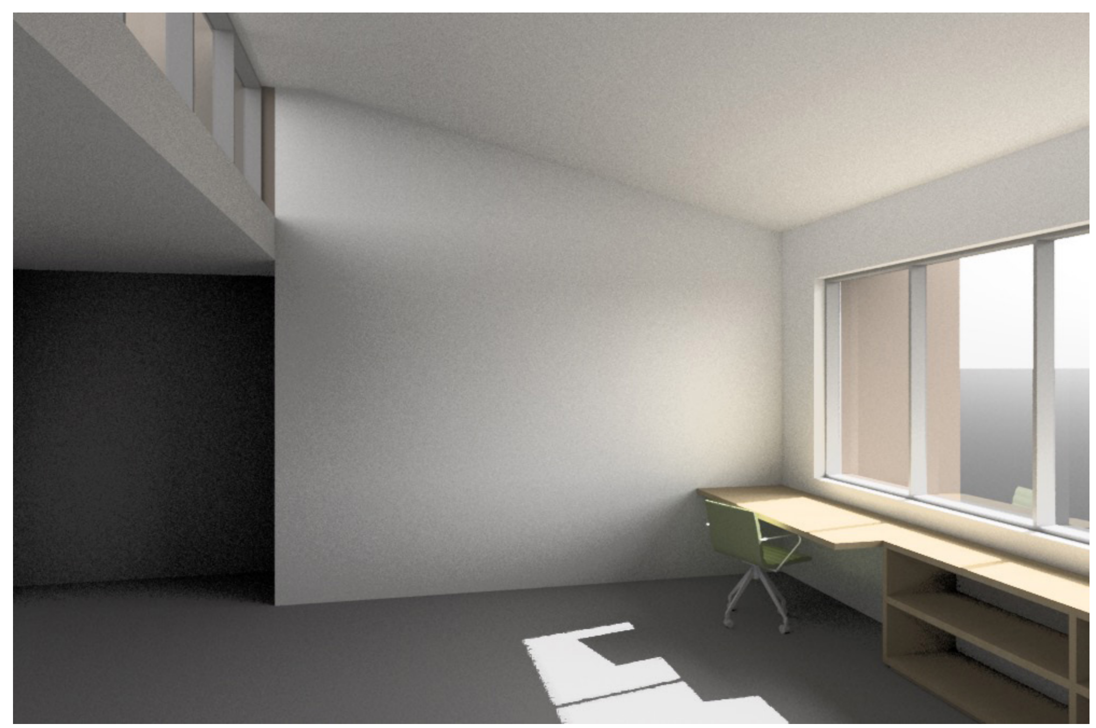
July 28th, 14:00
-W 769.0 196.0





February 5, 11:00
-W 681.0 180.0





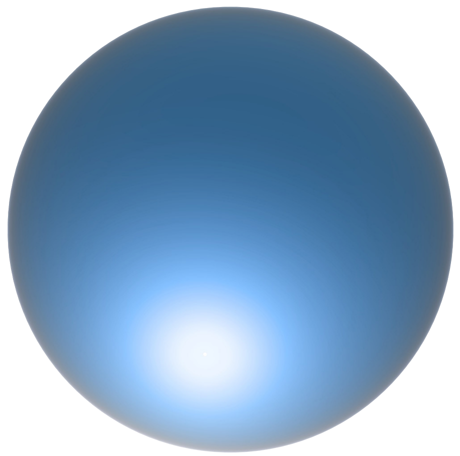
At the moment, the colored gendaylit model is not suitable for most of our applications because:

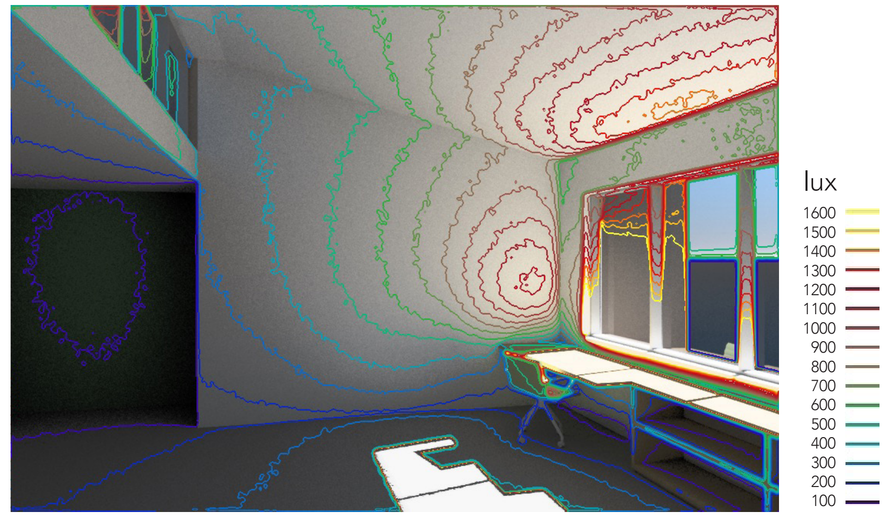
- Lack of support for mixed or intermediate skies limits sky conditions for which the model is practical

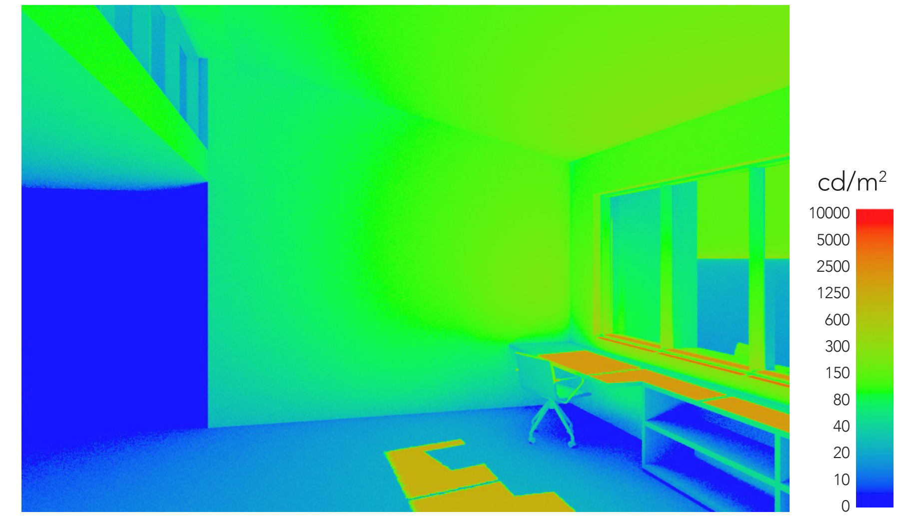
- The sky model is too blue, particularly at the horizon, for the latitudes at which we generally work.

February 5, 11:00

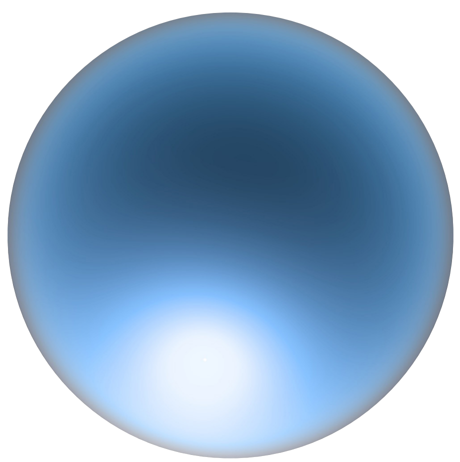
Standard Utah Sky

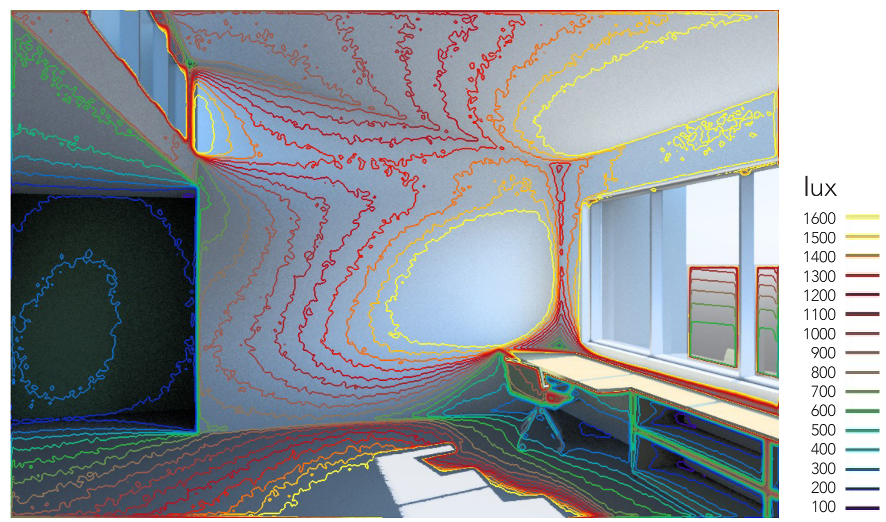


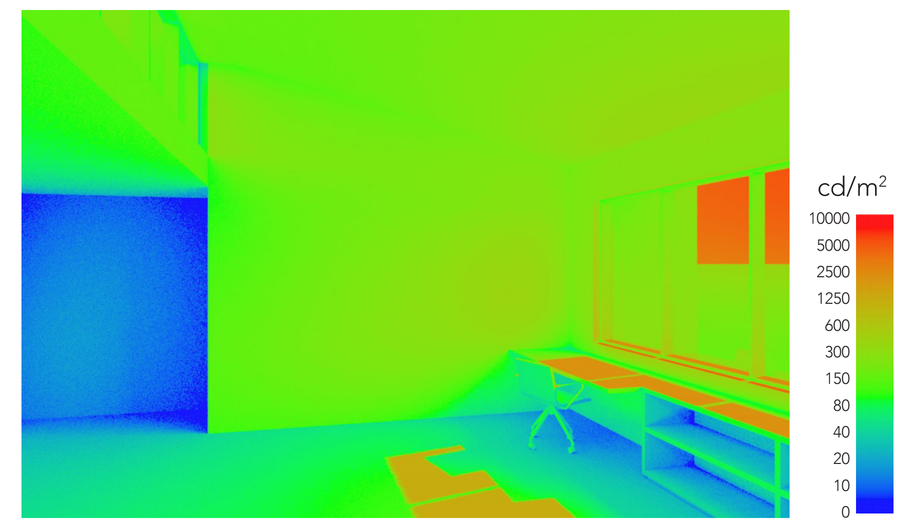




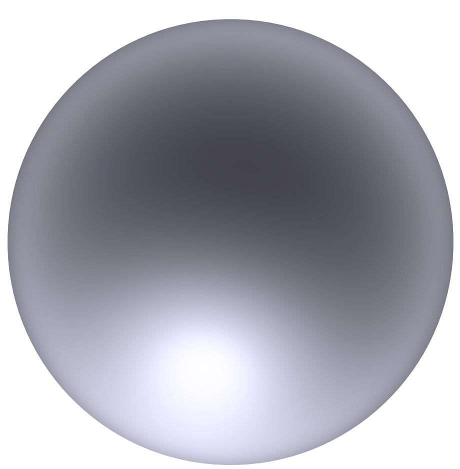
L+U Modified Utah

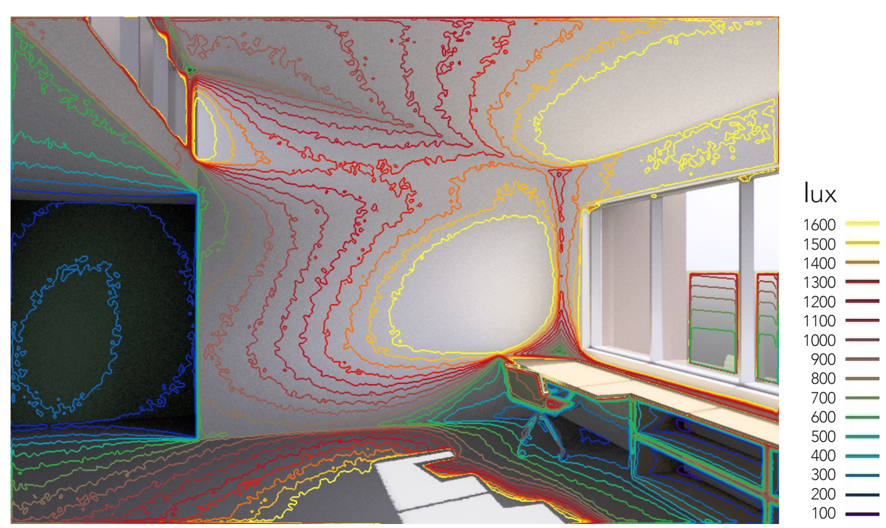


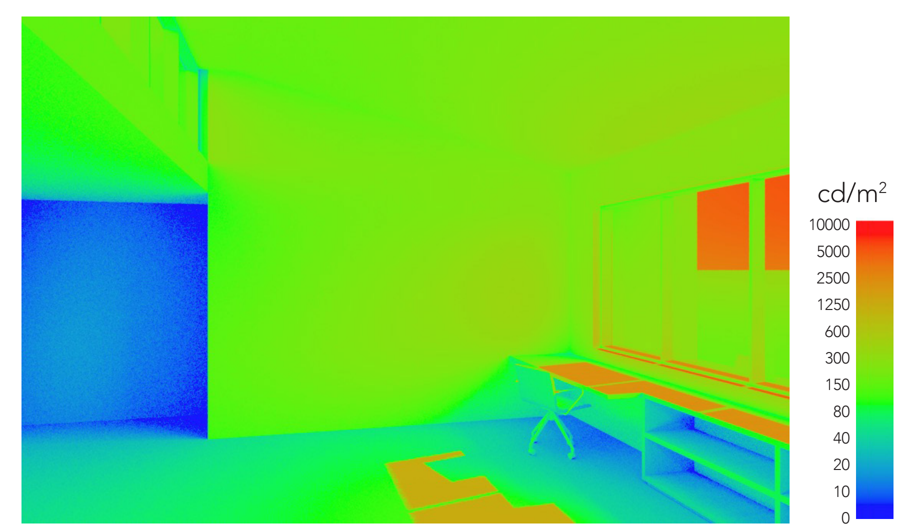




Gendaylit Sky

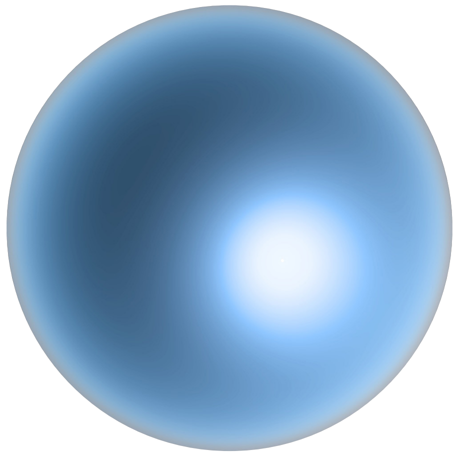


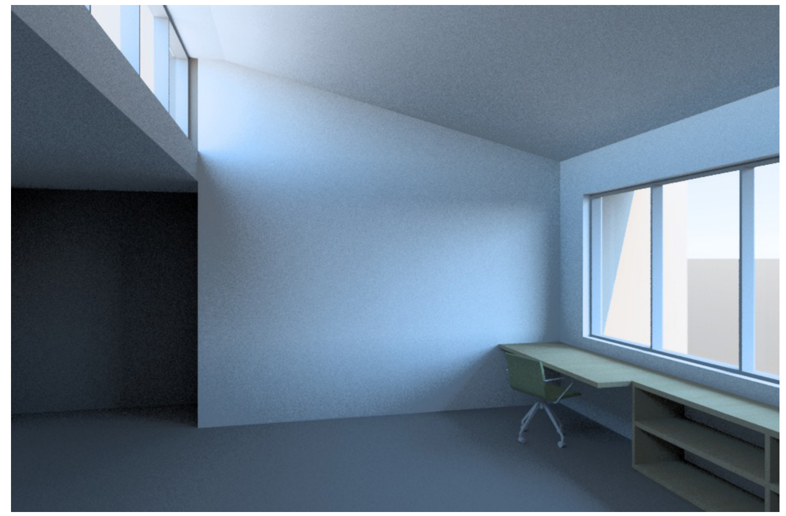




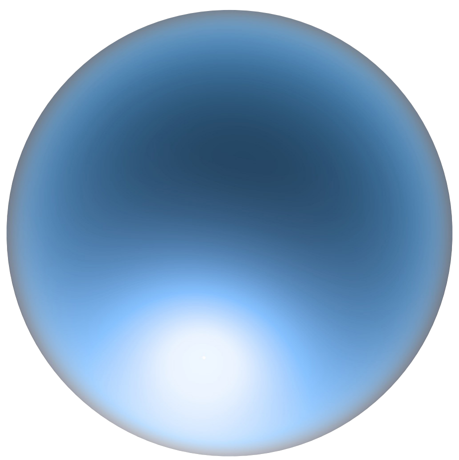
L+U Modified Utah Sky

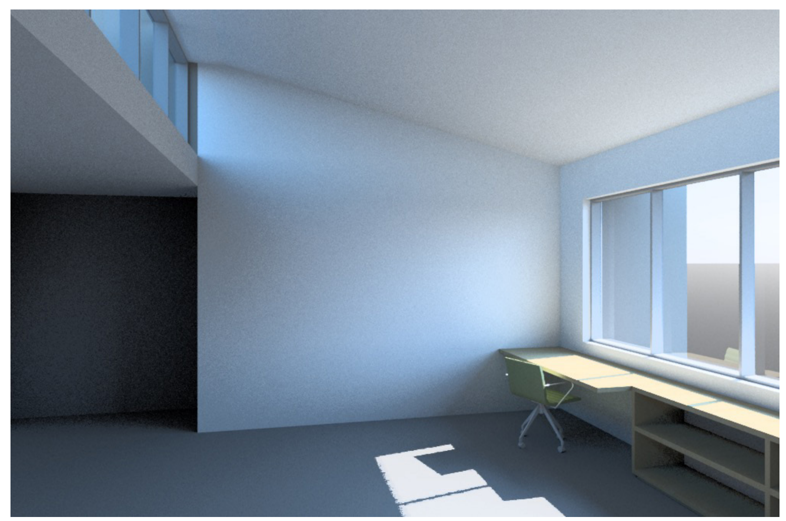
July 28th, 14:00
-W 769.0 196.0



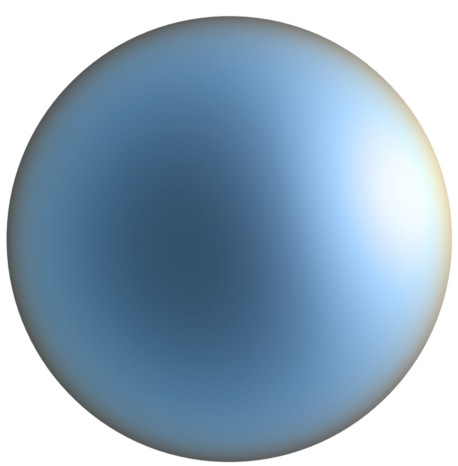


February 5, 11:00
-W 681.0 180.0





May 24, 18:00
-W 290.0 141.0



Some notes on L+U use of the Utah Sky Model

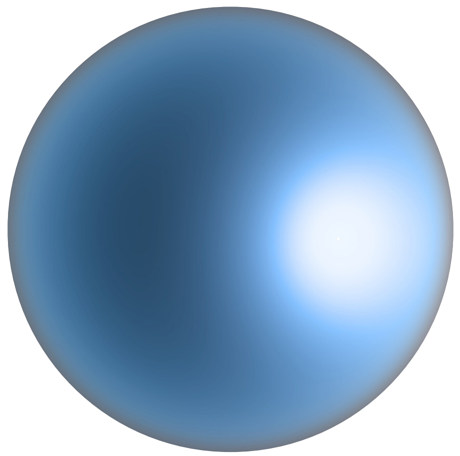
- We use a modified version of the Utah sky model that combines the Utah color model with a perez distribution for luminance and illuminance

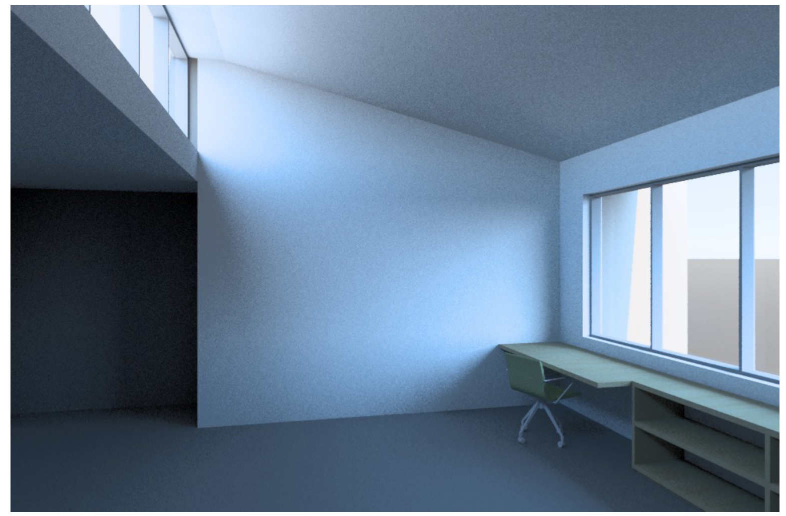
- We do not use the Utah sky for overcast conditions. Typically, we will use the utah sky only for clear conditions (when direct irradiance is more than 2x indirect).

- Otherwise we use gendaylit

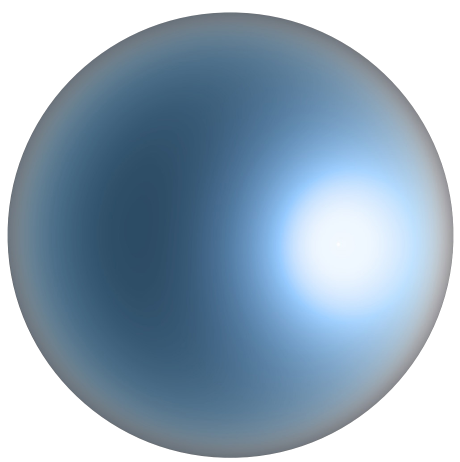
L+U Modified Utah Sky

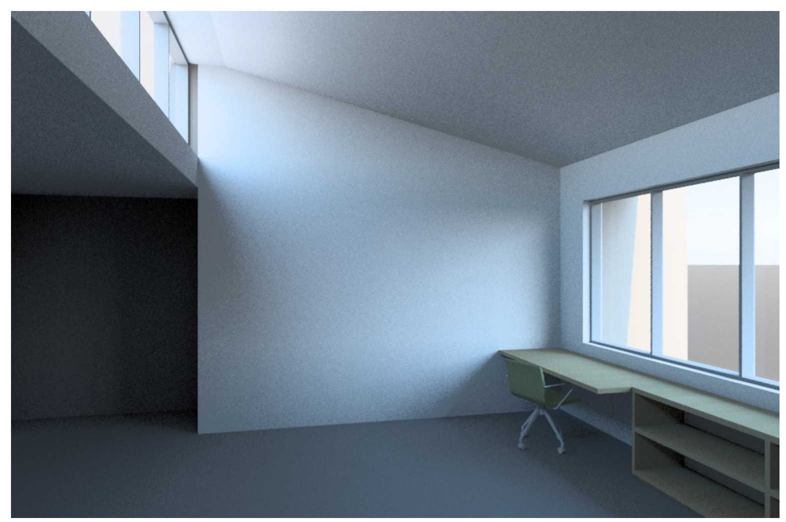
May 24, 15:00
turbidity 0



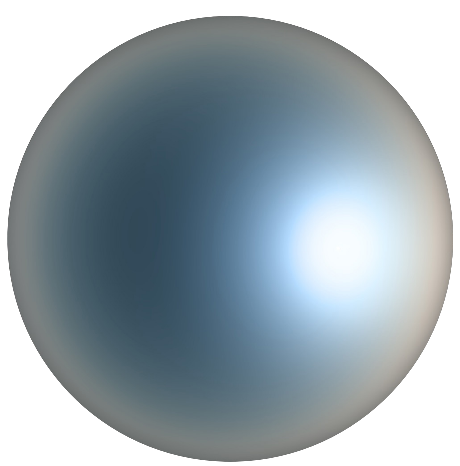


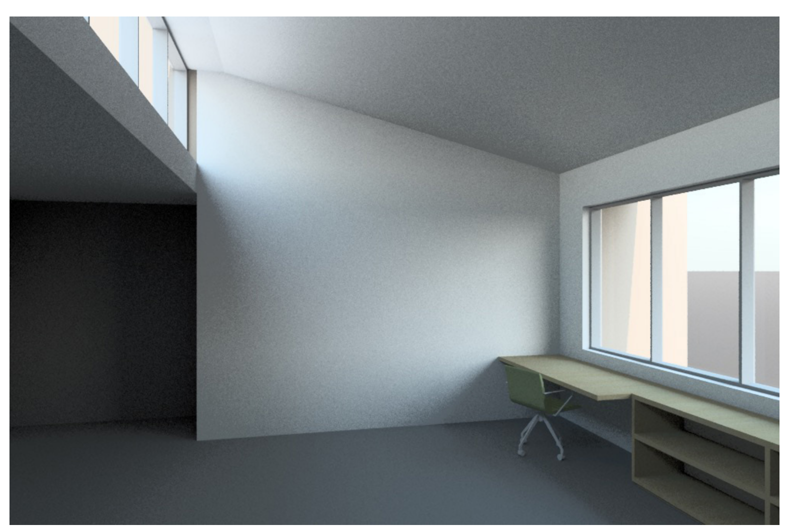
May 24, 15:00
turbidity 3





May 24, 15:00
turbidity 6



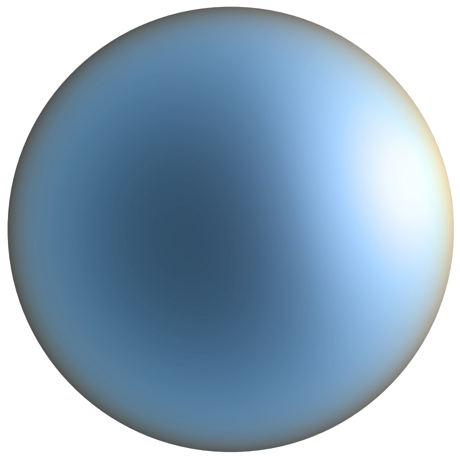


Some notes on L+U use of the Utah Sky Model

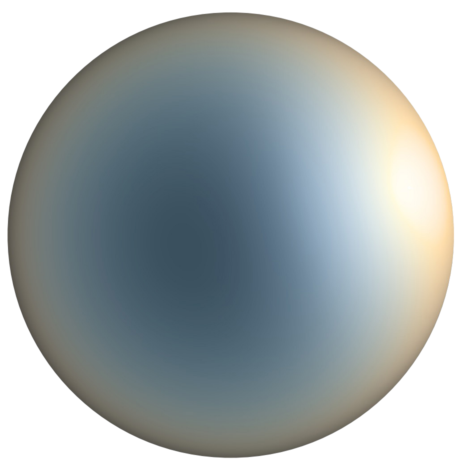
- For clear sky conditions we tend to set the turbidity to 0 as we have found that more turbidity tends to result in overly warm afternoon skies, which can look dirty at the horizon.

L+U Modified Utah Sky

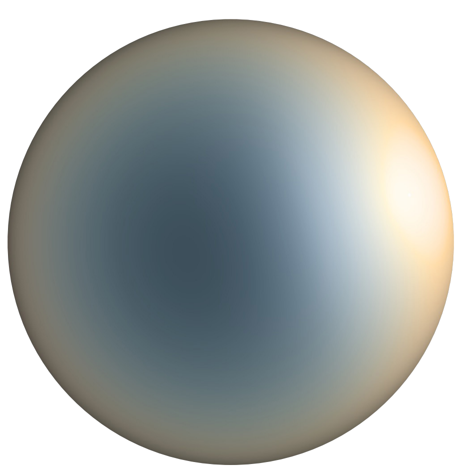
May 24, 18:00
turbidity 0



May 24, 18:00
turbidity 5



May 24, 18:00
turbidity 20



Some notes on L+U use of the Utah Sky Model

- The exception to this rule is in the late afternoon if we need to create a dusk or sunset image.

High-turbidity dusk Utah Sky used in electric lighting integration simulation when sky will have little to no interior contribution.

Schematic Design - June Clear Sky, standard gendaylit sky

Design Development - June Clear Sky, L+U modified Utah sky

Sometimes we will transition from a non-color gendaylit sky to a Utah sky as the project develops and as simulation models become more complex.

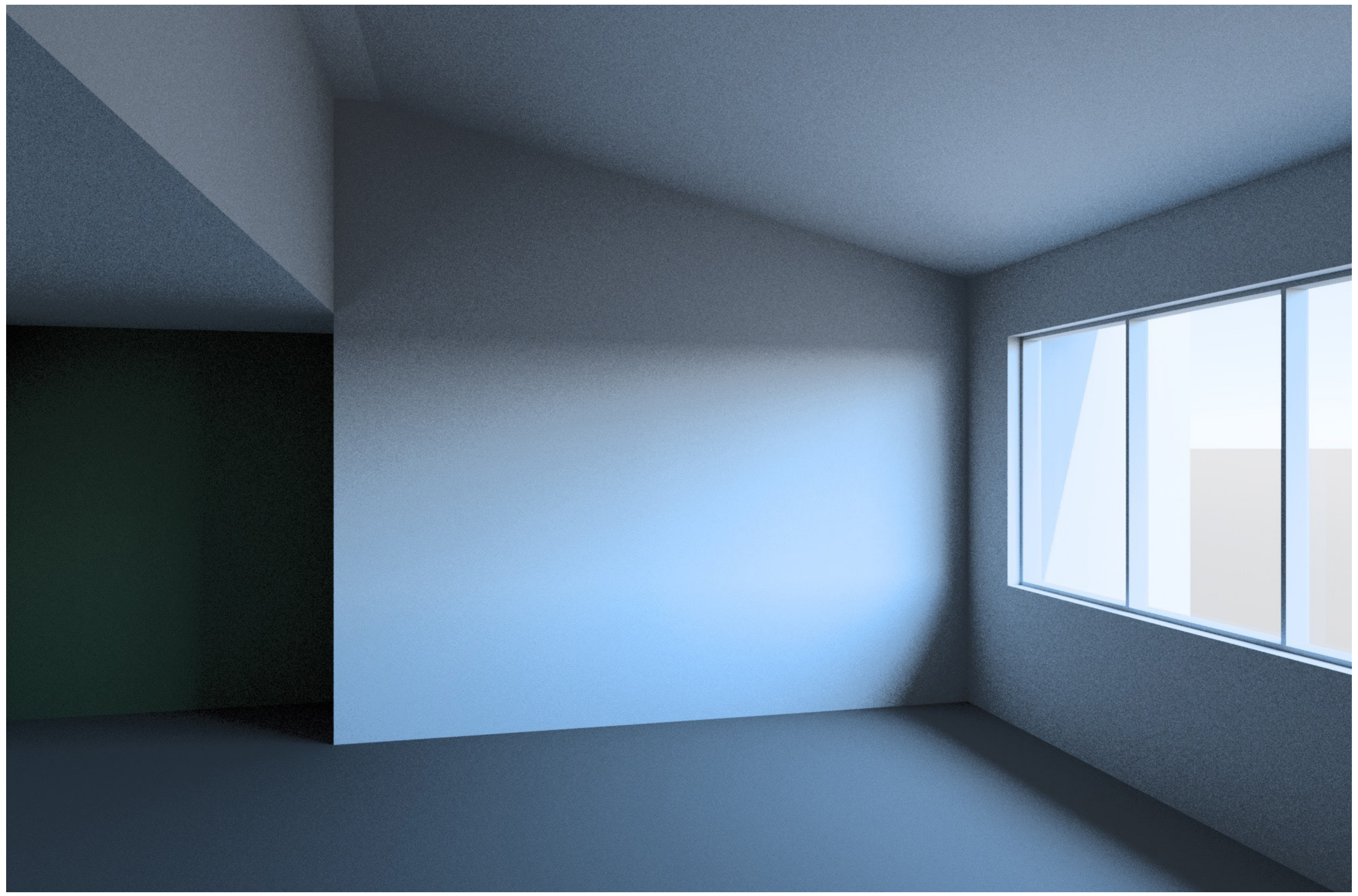
The Model

The Model

Color and orientation

Detail and color

Use of site models



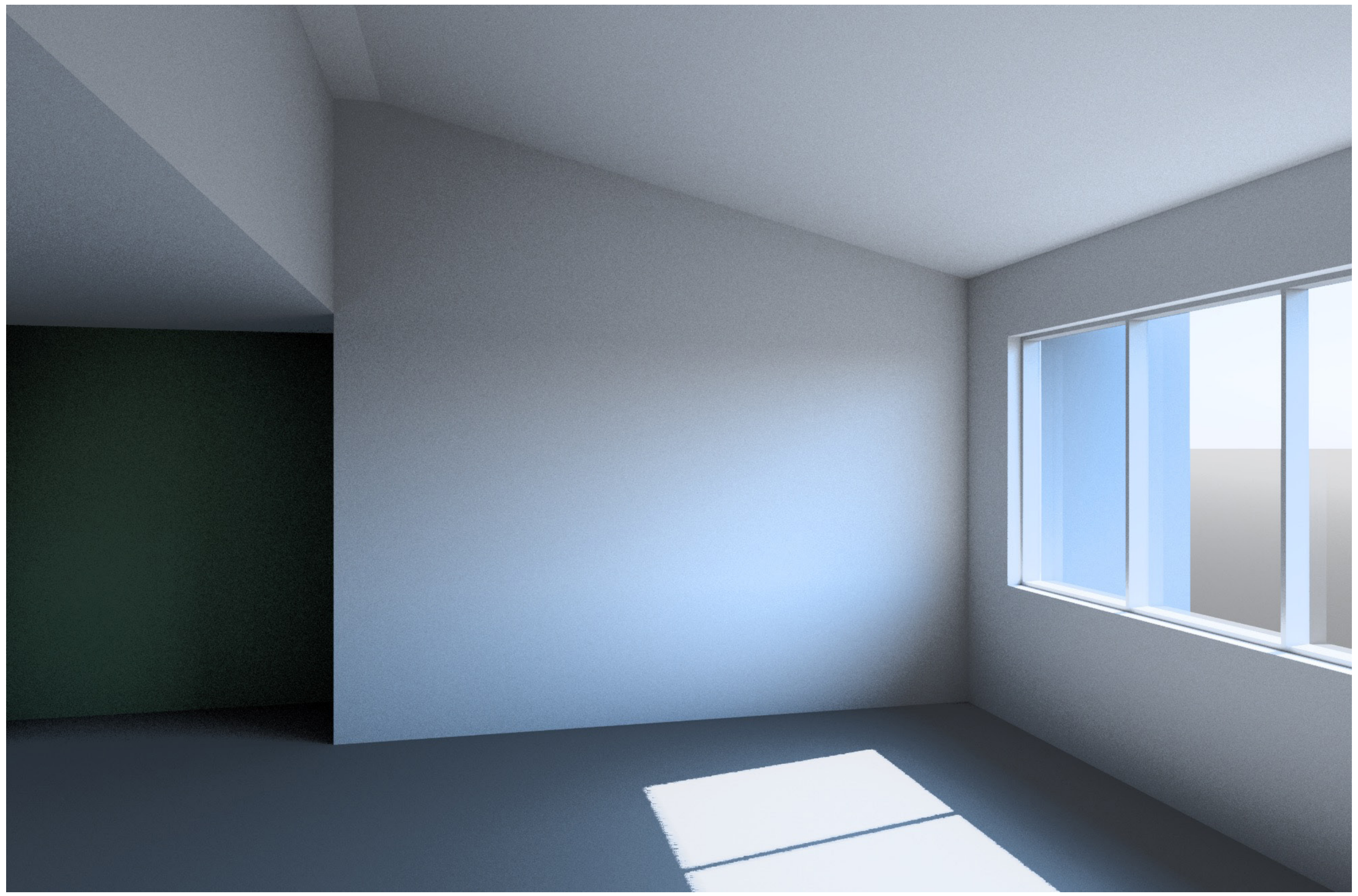
Simple, mostly greyscale model, window faces south

Mostly greyscale model, window wall faces north

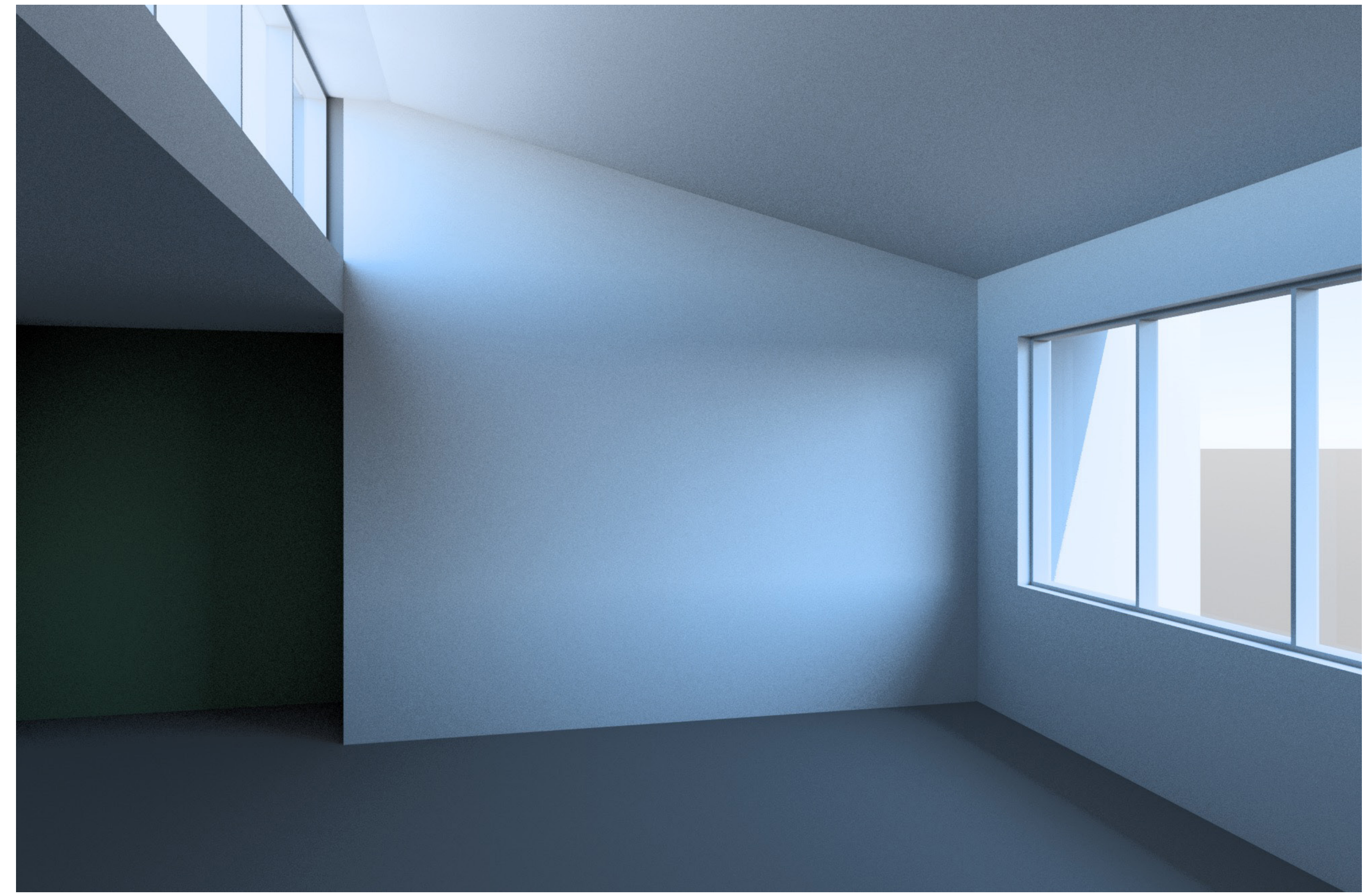
Simulation models that are largely greyscale, particularly greyscale models with one orientation, will be susceptible to the influence of exposure to the blue sky.

Generally both of the images shown above are too blue to match human experience. This level of interior blueness will be distracting to the client and disrupt conversation and comprehension.

There is a dissonance between the level of abstraction of the greyscale model and the specificity of the colored sky model.

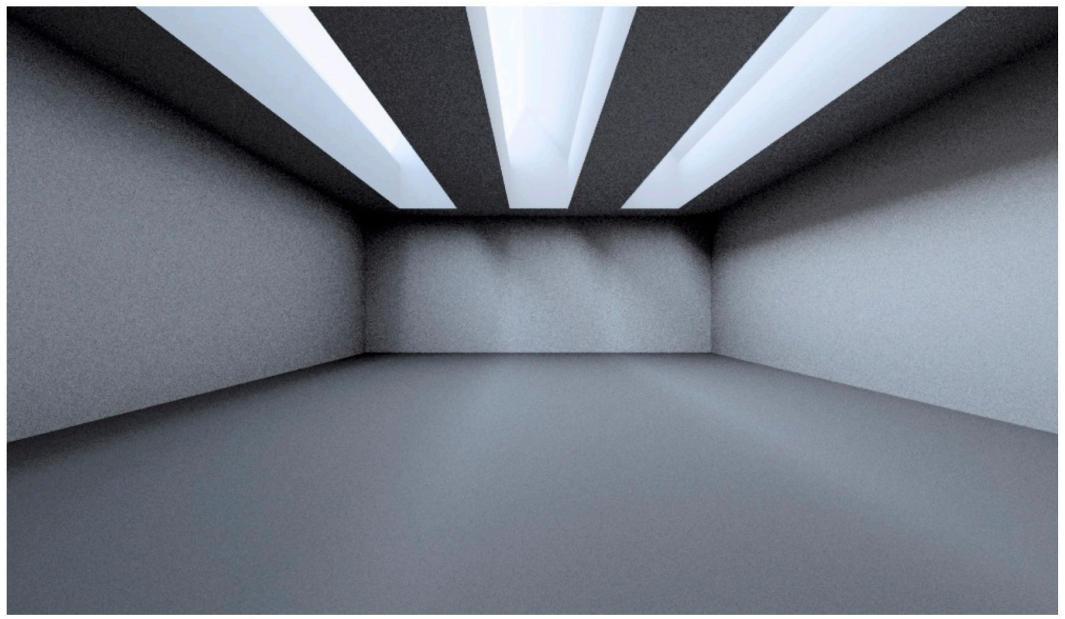


Choosing a time when sun enters the space helps to balance the daylight spectrum within the room, but showing direct sun entry can lead to other potential distractions in conversation with a client

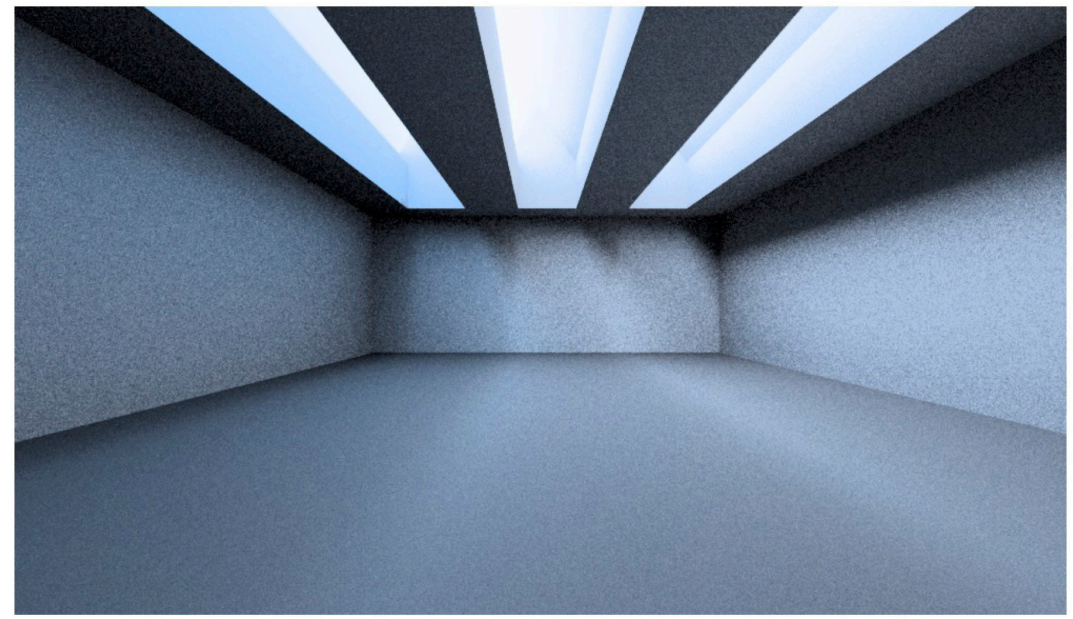


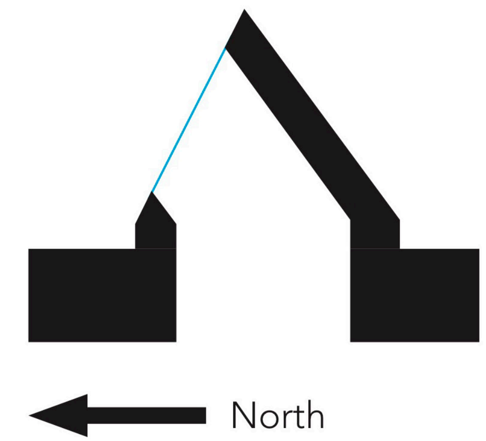
The addition of a second orientation helps here, but since the clerestory faces north, and the building roof is grey, the overall effect is still very blue.

Jun 21 12:00 - Clear Sky

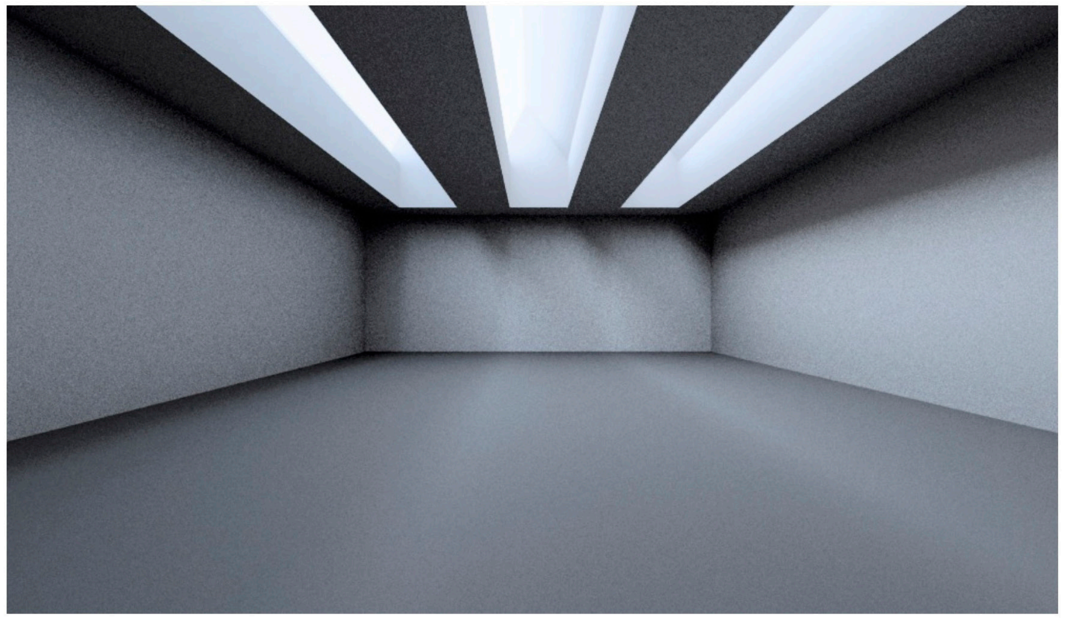


December 12 12:00 - Clear Sky

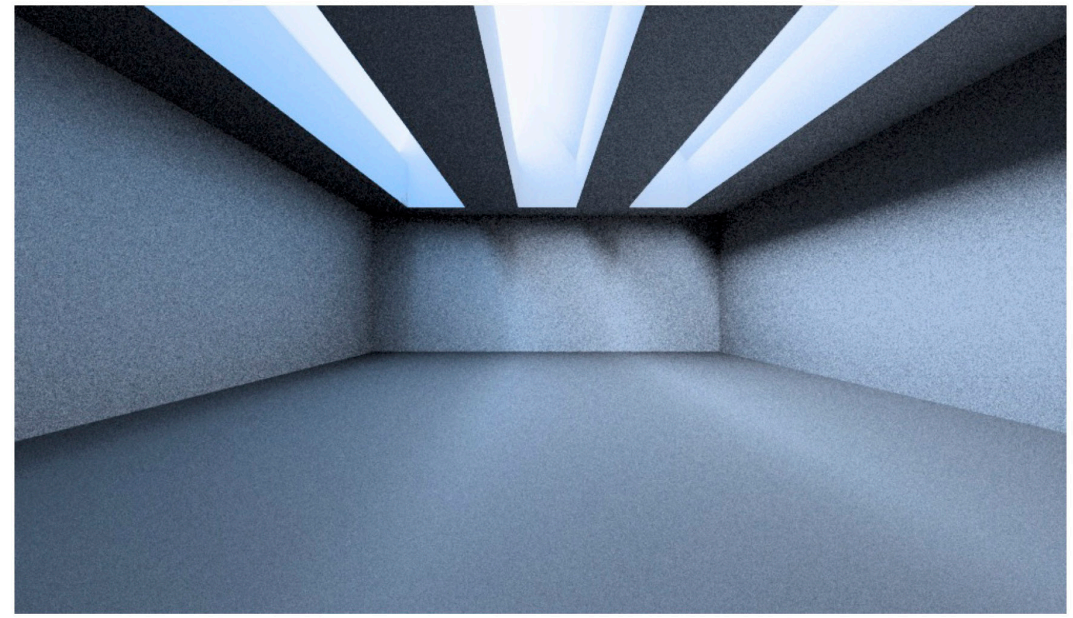


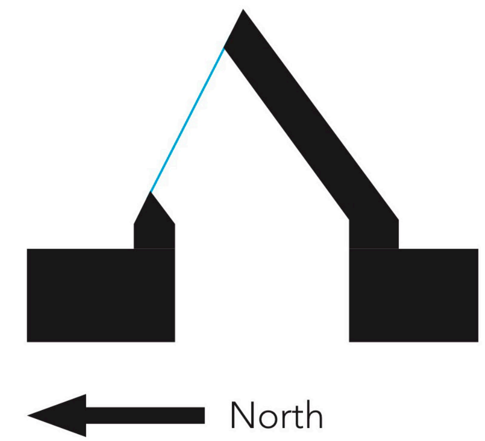


Jun 21 12:00 - Clear Sky



December 12 12:00 - Clear Sky





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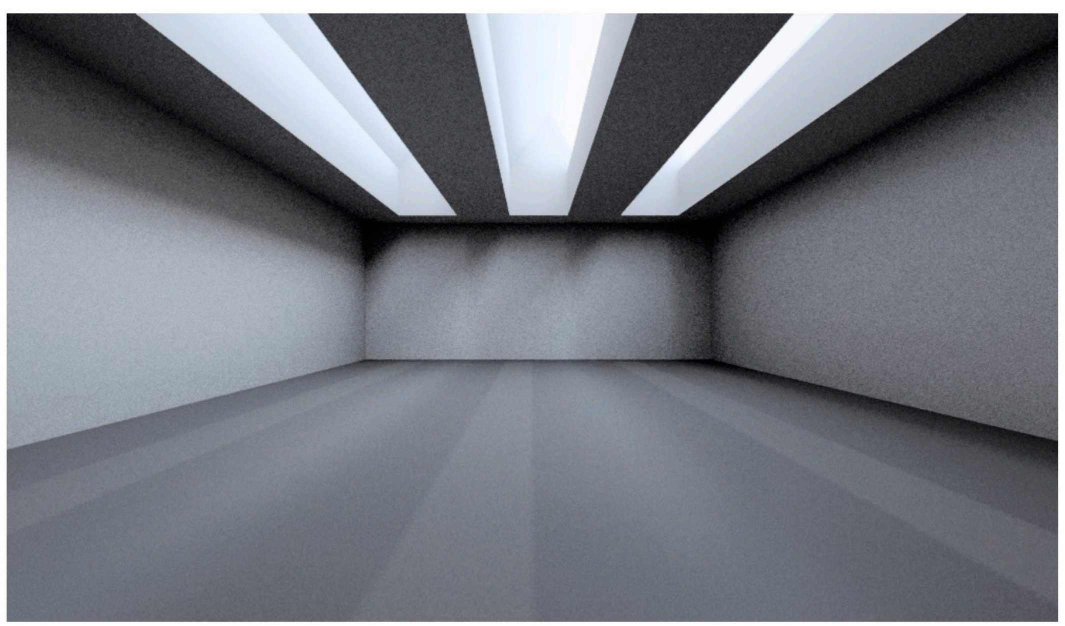
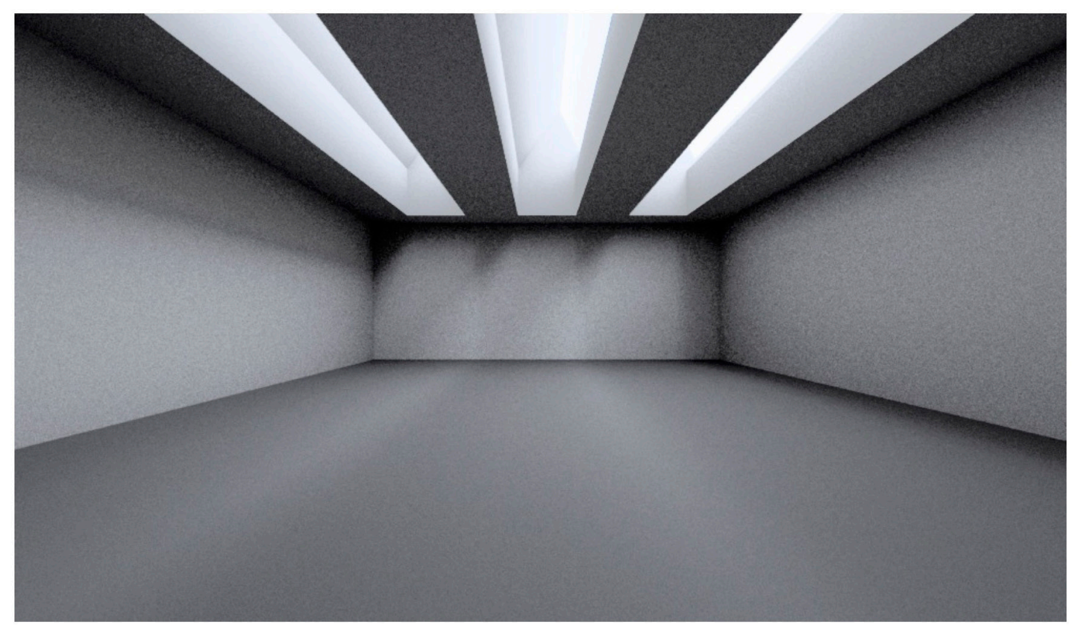
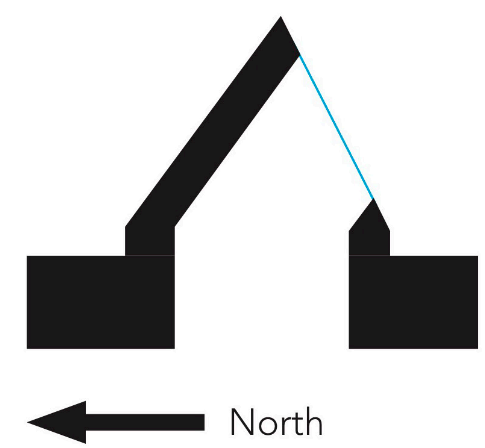
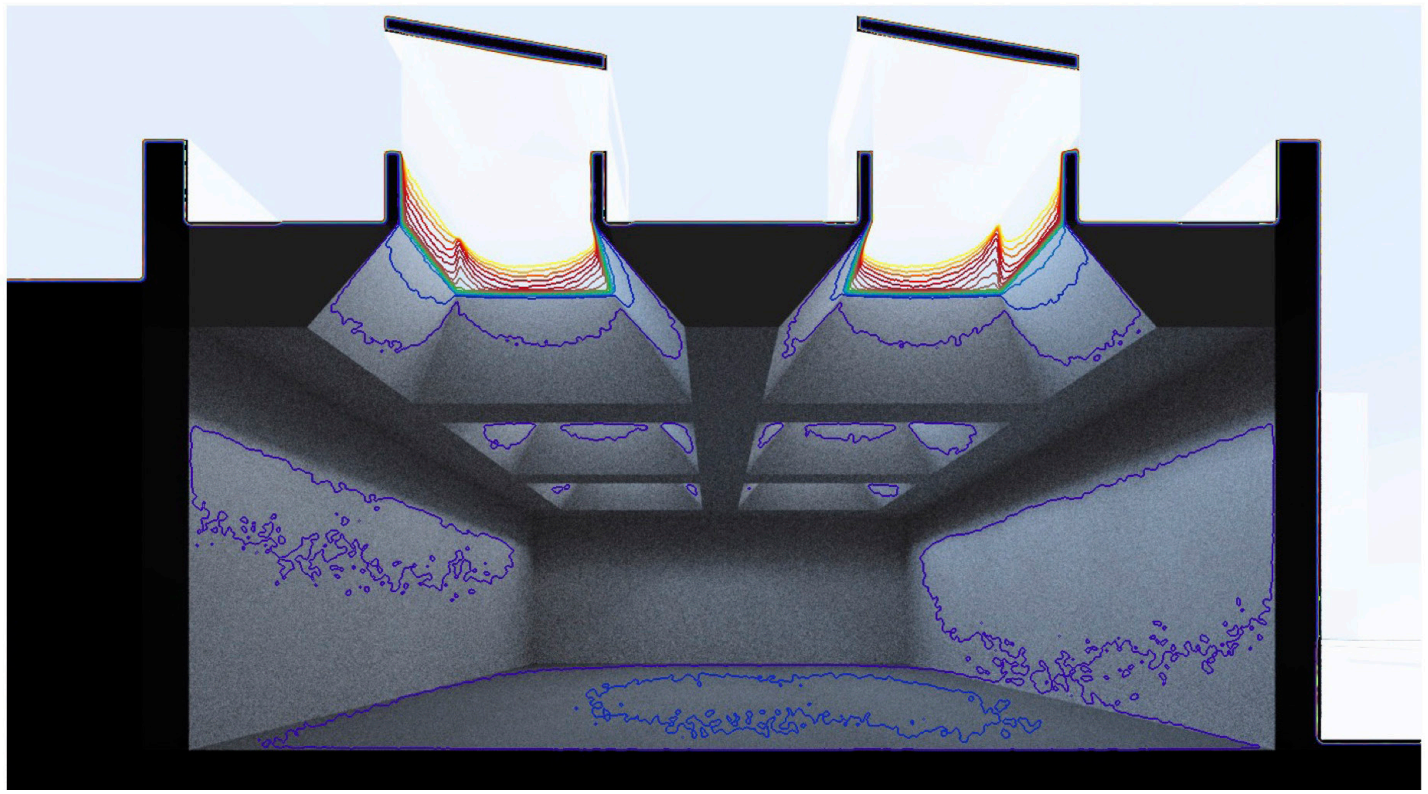


December 12 12:00 - Clear Sky

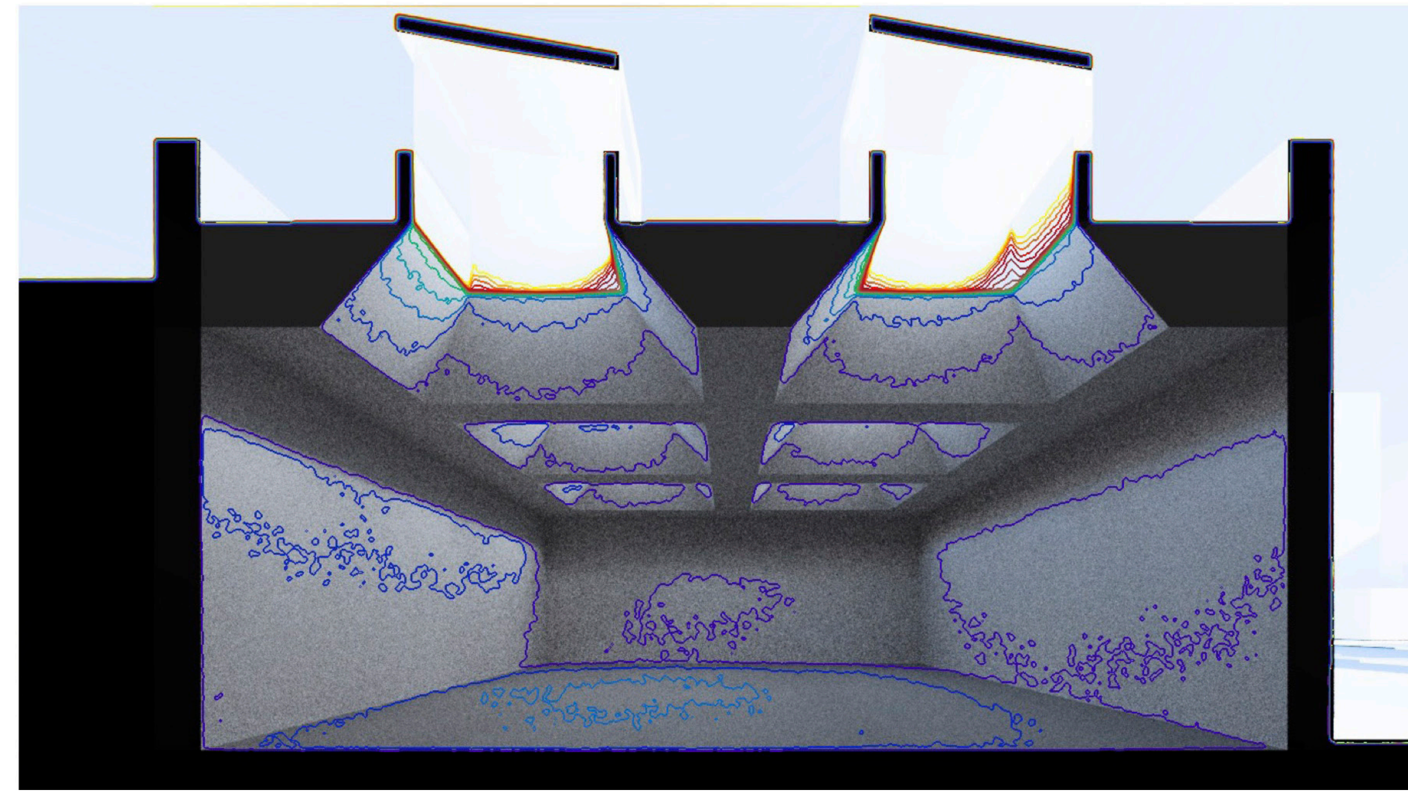




Jun 21 12:00 - Clear Sky



Dec 12 12:00 - Clear Sky



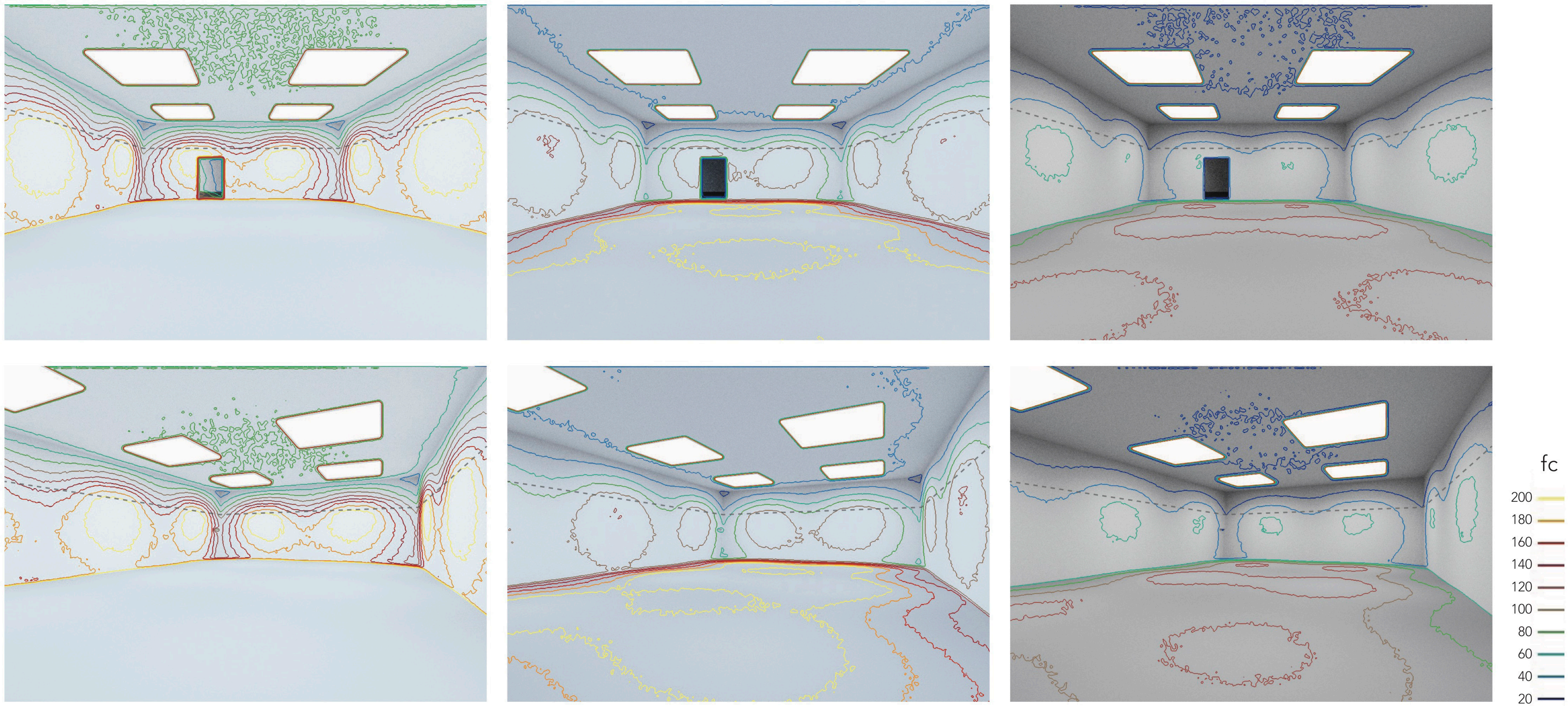
Jun 21 12:00 - Clear Sky (9,800 fc)

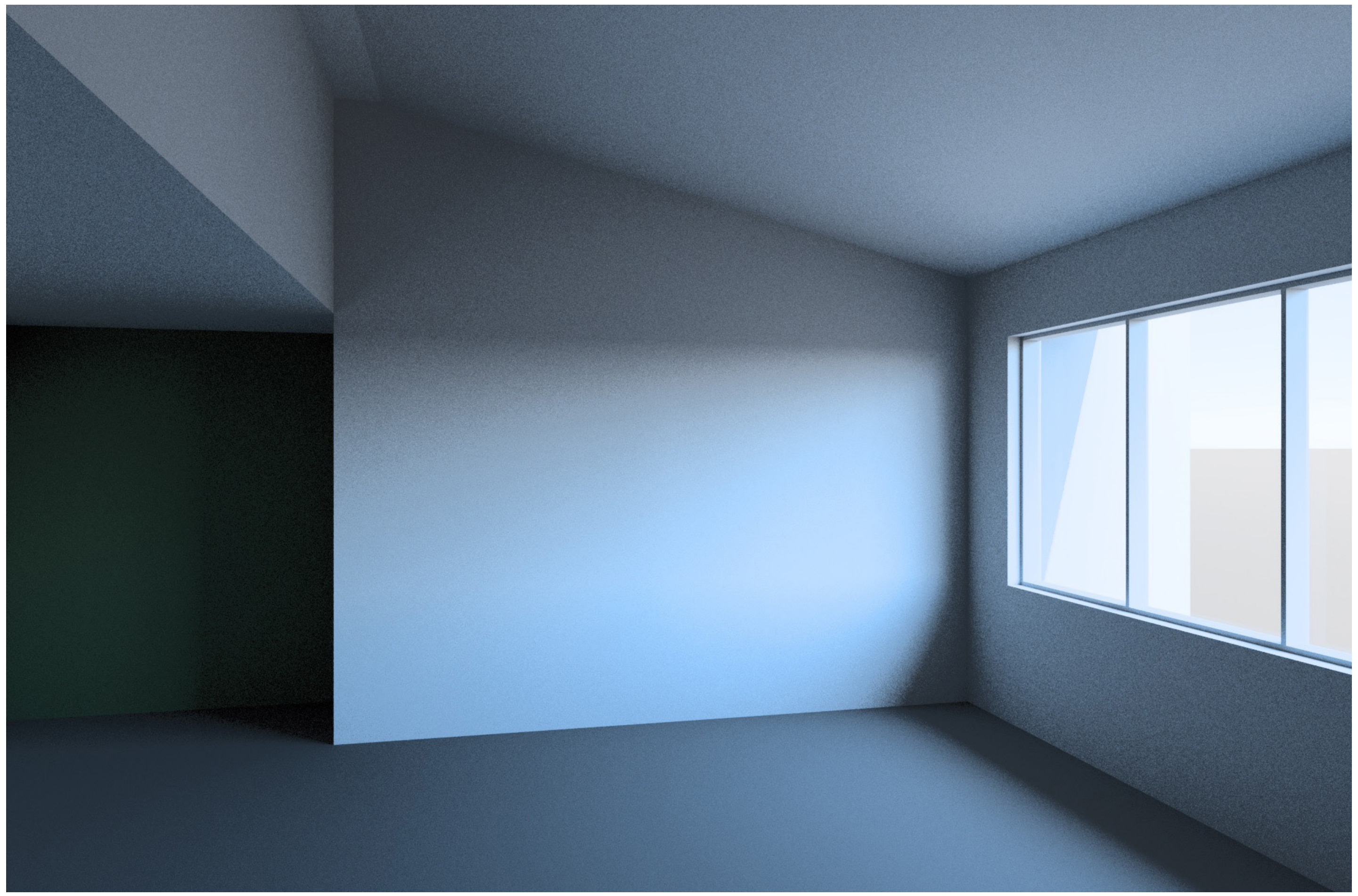
December 12 12:00 - Clear Sky (5,200 fc)

February 24 12:00 - Overcast Sky (3,500 fc)

View from door to East

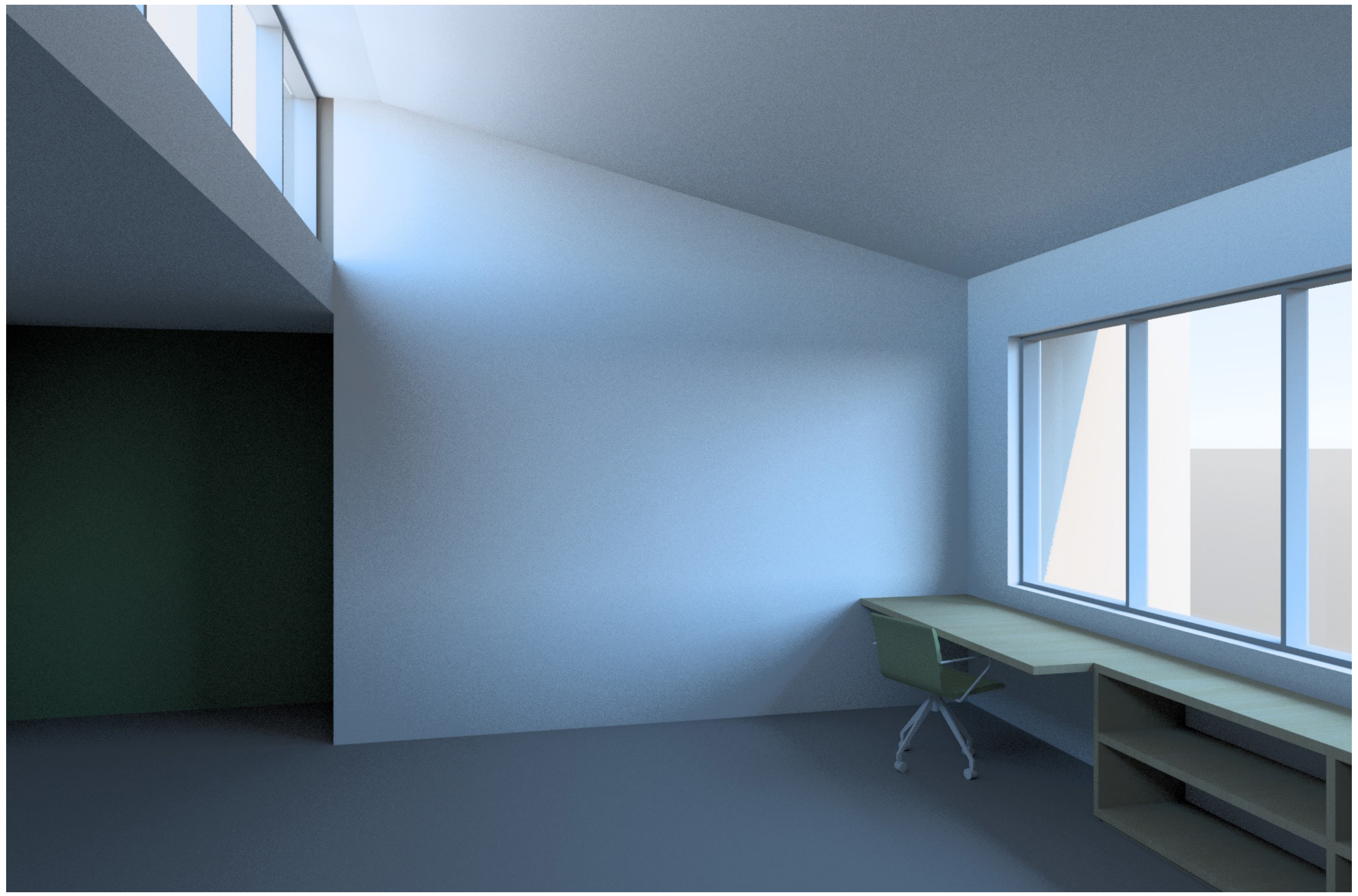
View to West





Simple, mostly greyscale model, window faces south

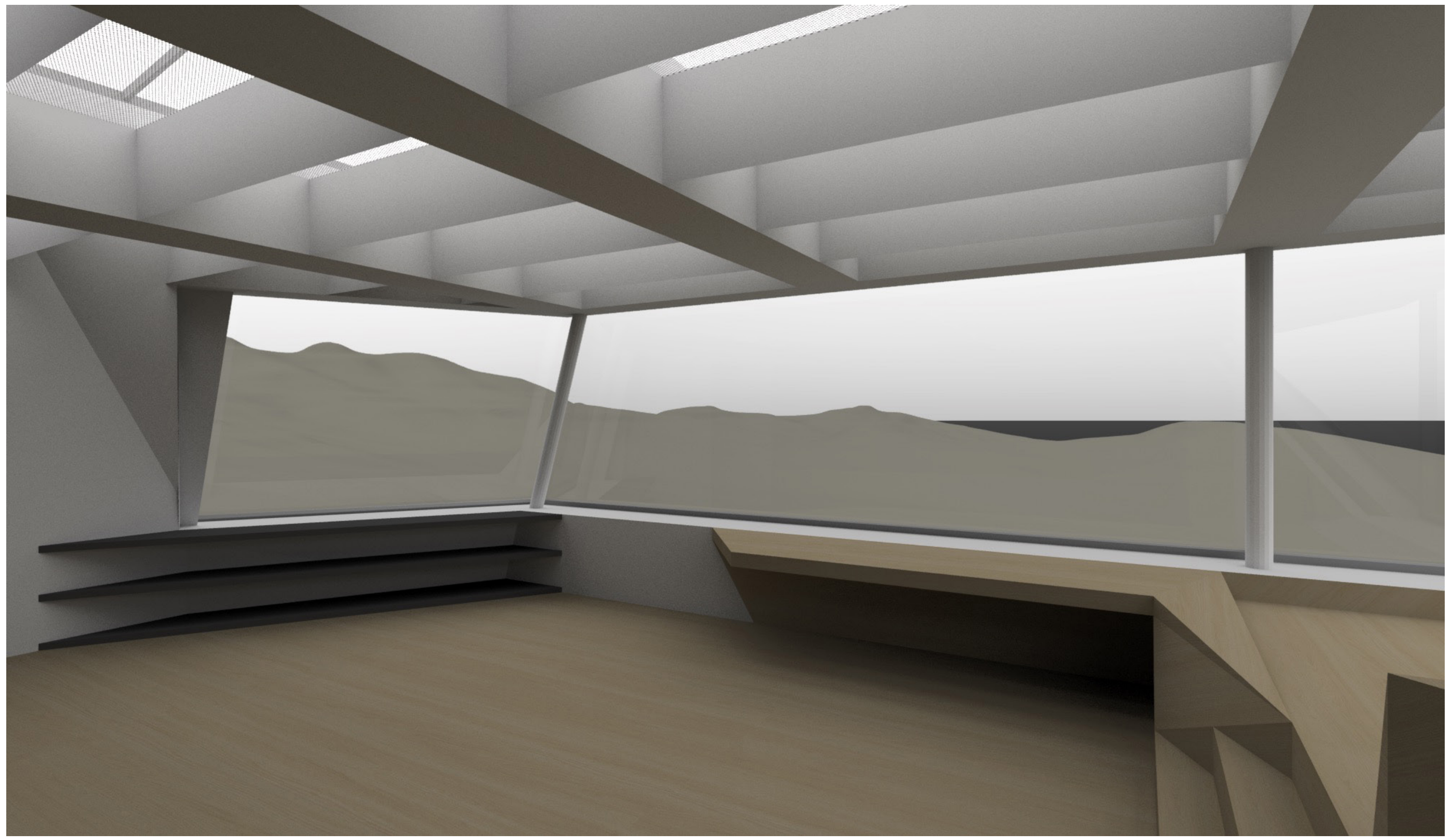
Mostly greyscale model, window wall faces north



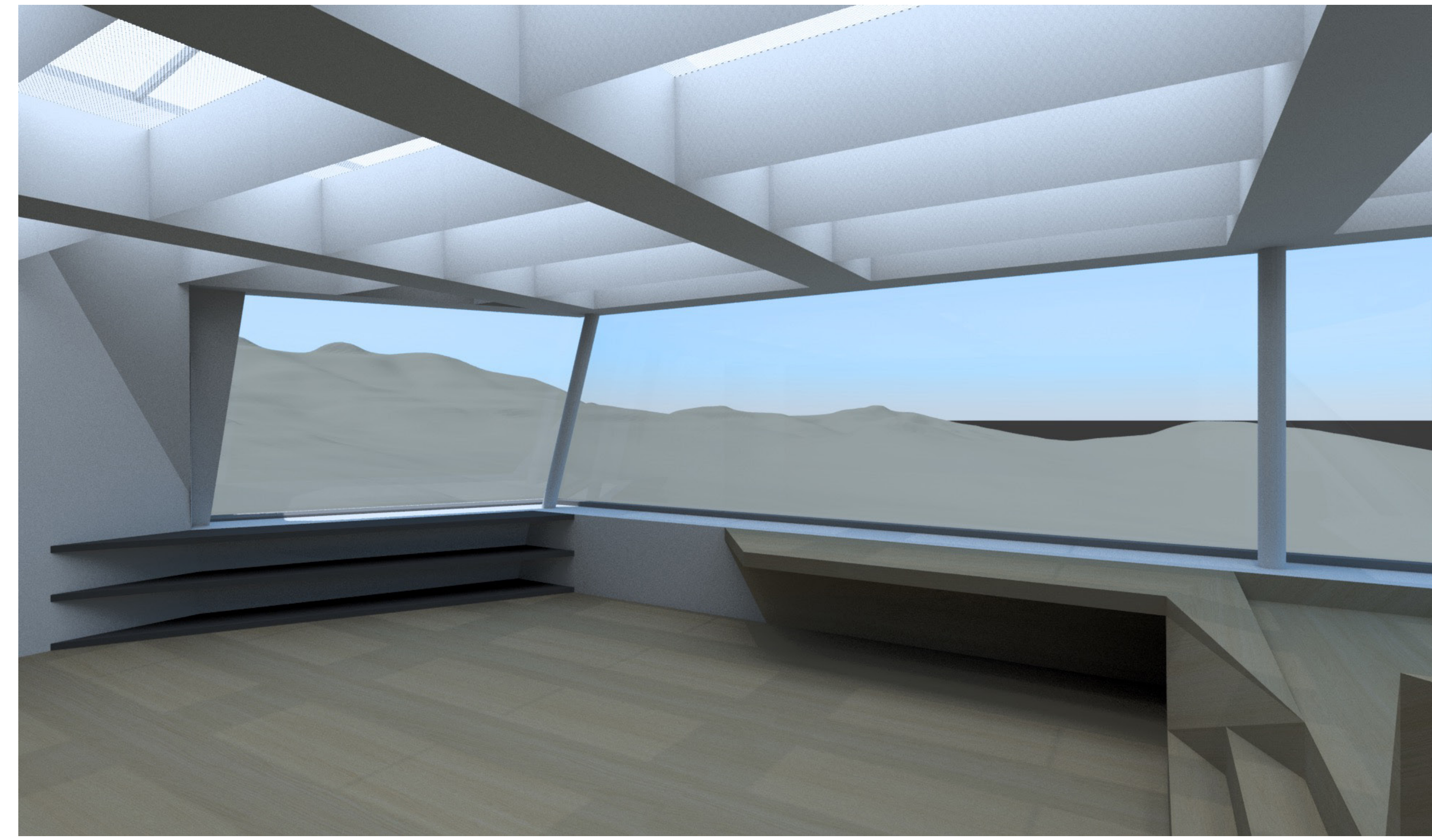
Window faces south

Window wall faces north

Adding color and detail to the simulation model helps to either disguise the blue cast from the sky model or to balance the visual field so that this cast is less noticable.



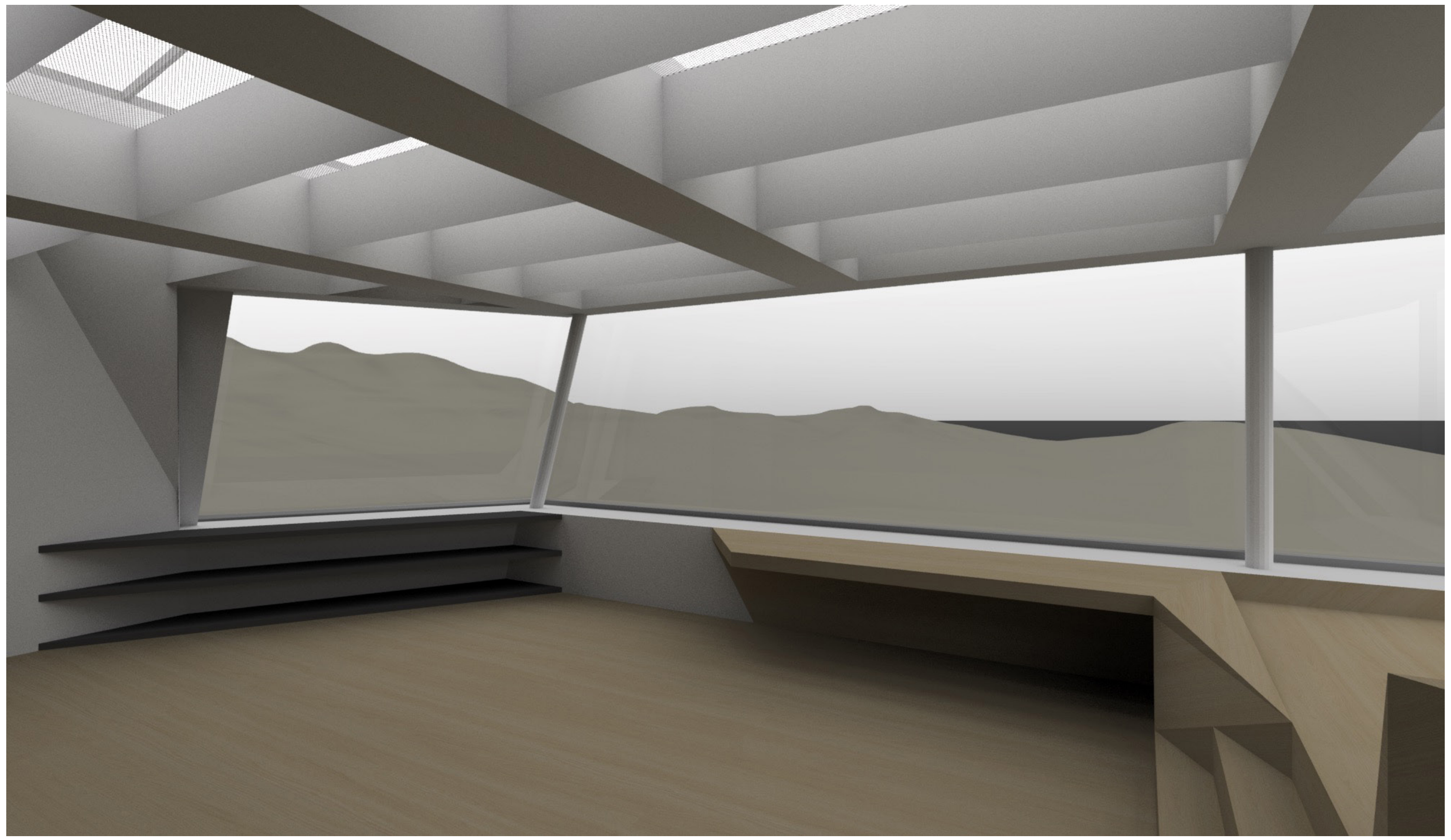
Overcast February sky (gendaylit). View is oriented to north.



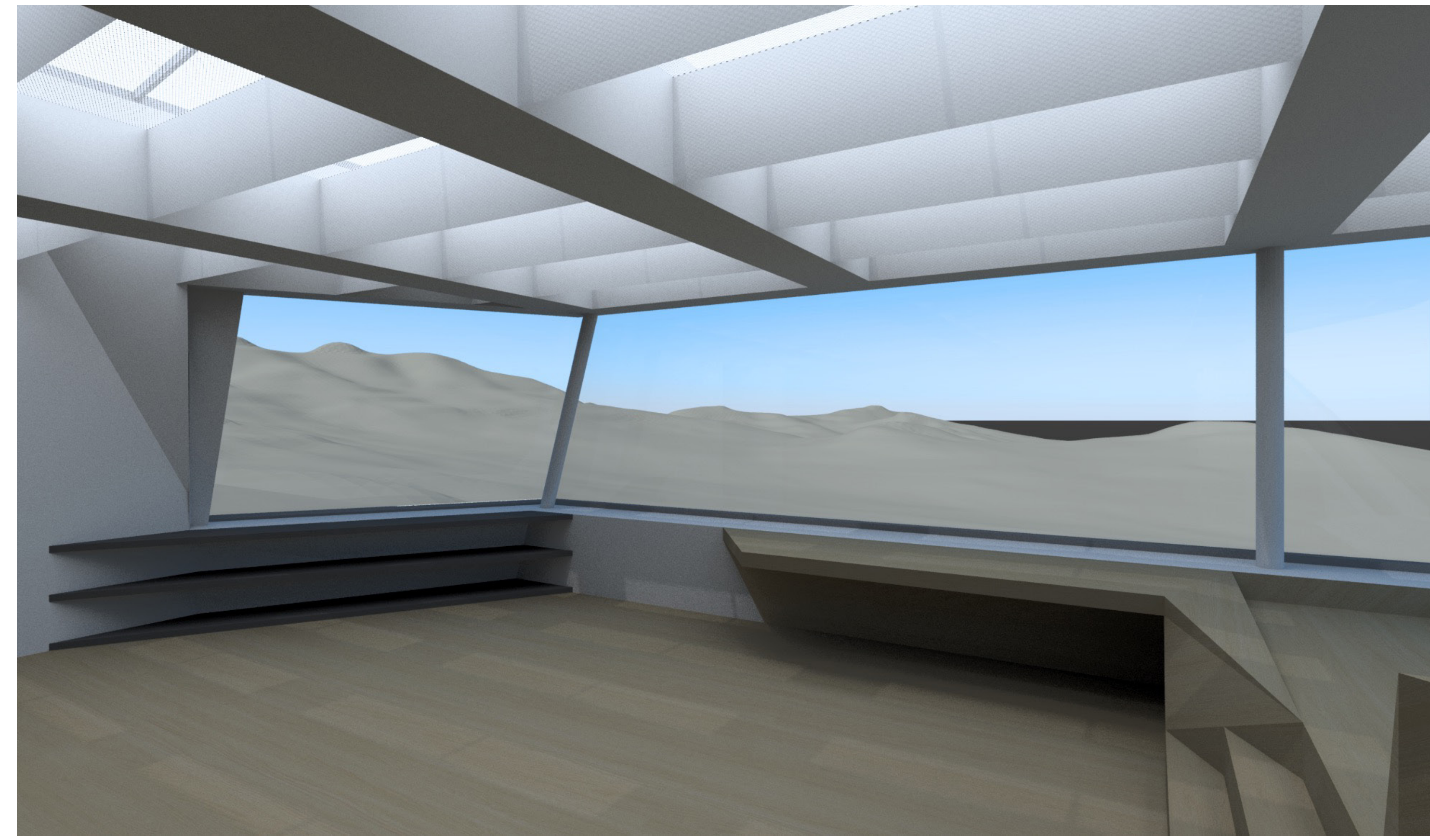
Clear June sky (L+U modified Utah sky)

One potential problem with making the model colored or textured is the potential problem of warm colored materials being located within models that are mostly or entirely north-facing.

In the case of the images here, the overcast sky simulation appears warmer than the clear sky simulation. This is partly a problem of direct comparison and also a problem of white balance, which we will return to later.



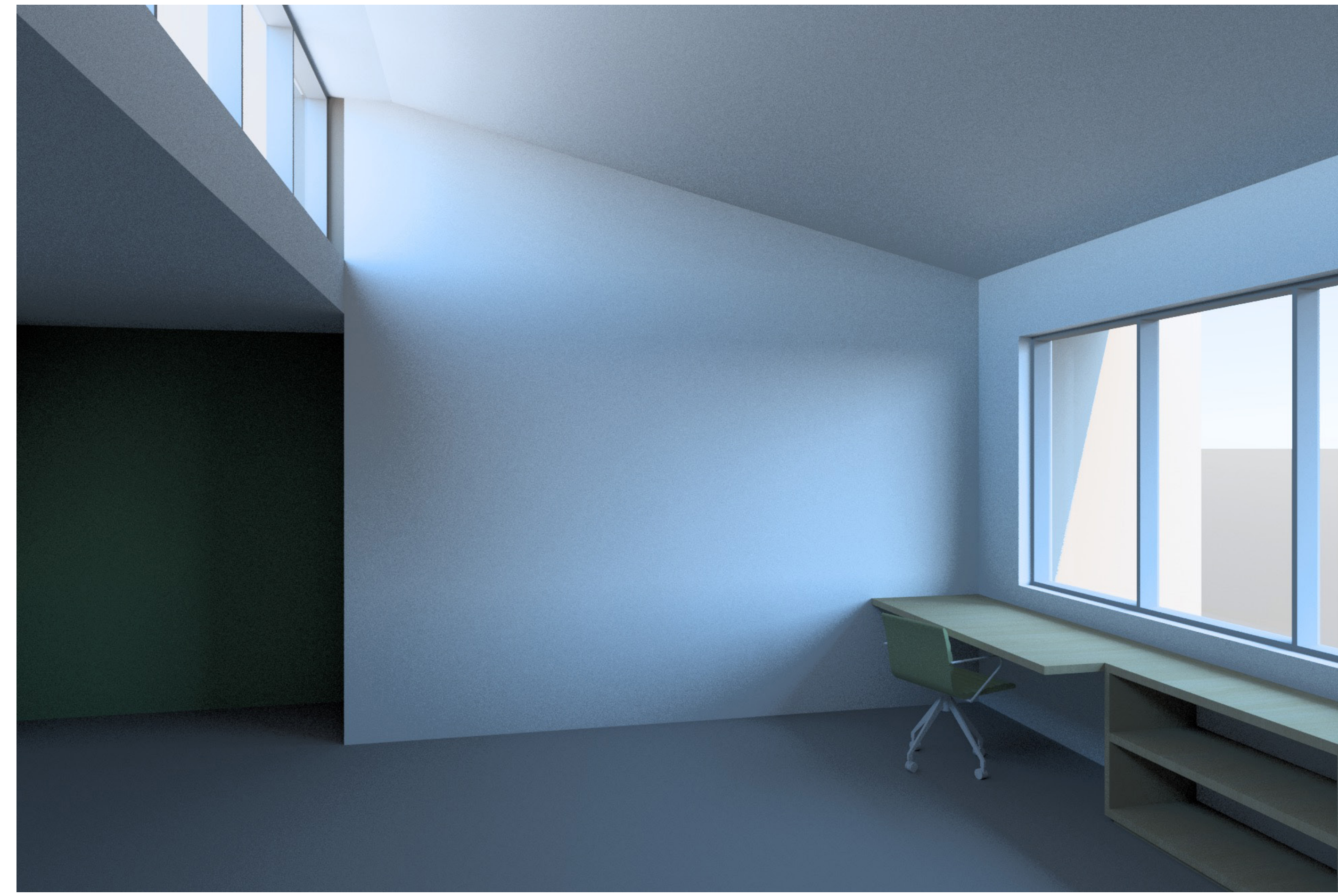
Overcast February sky (gendaylit).



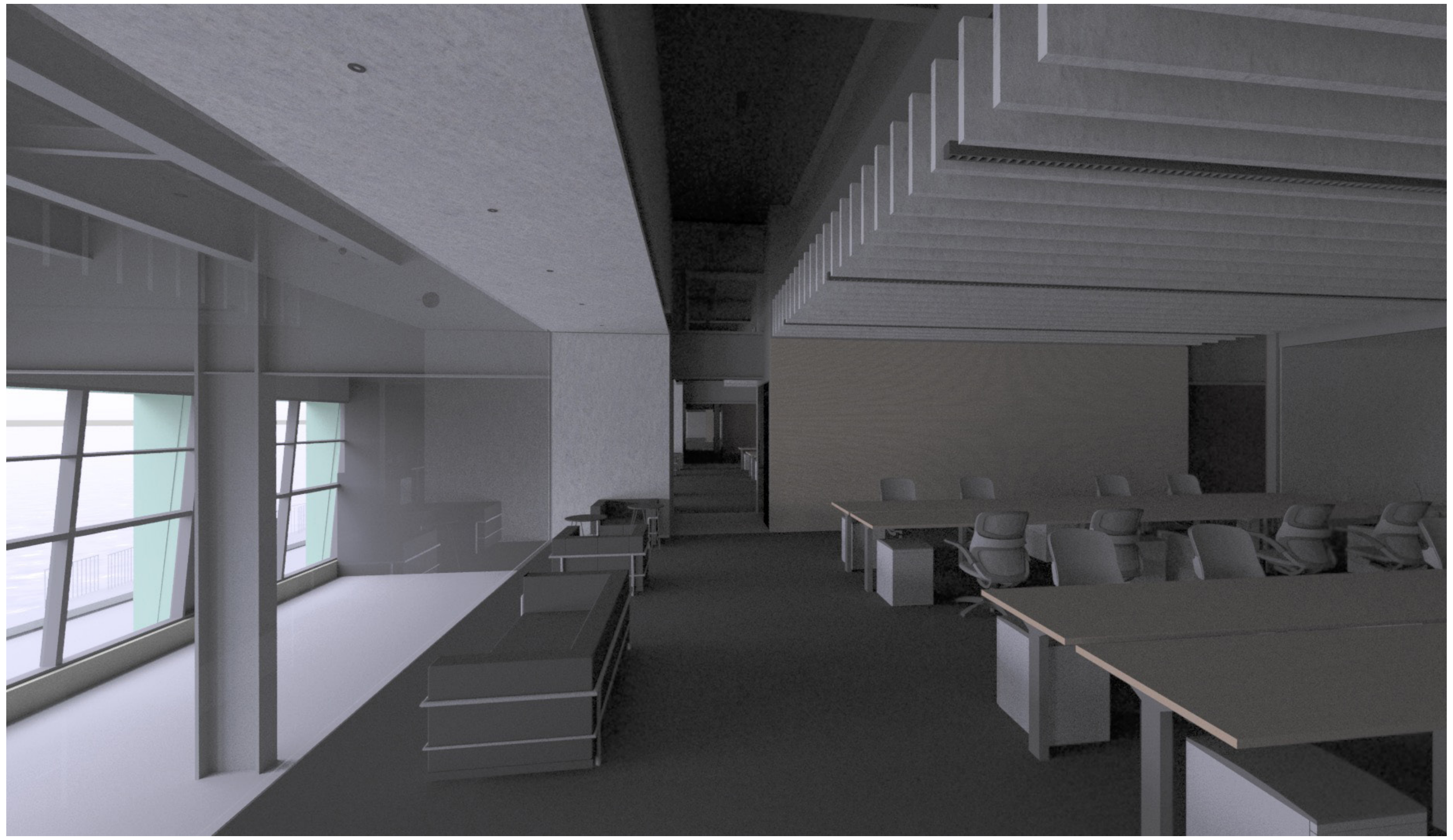
Clear September sky (L+U modified Utah sky)

The comparison is slightly improved by using a lower sun angle, where more directional direct sun strikes the ceiling fins.

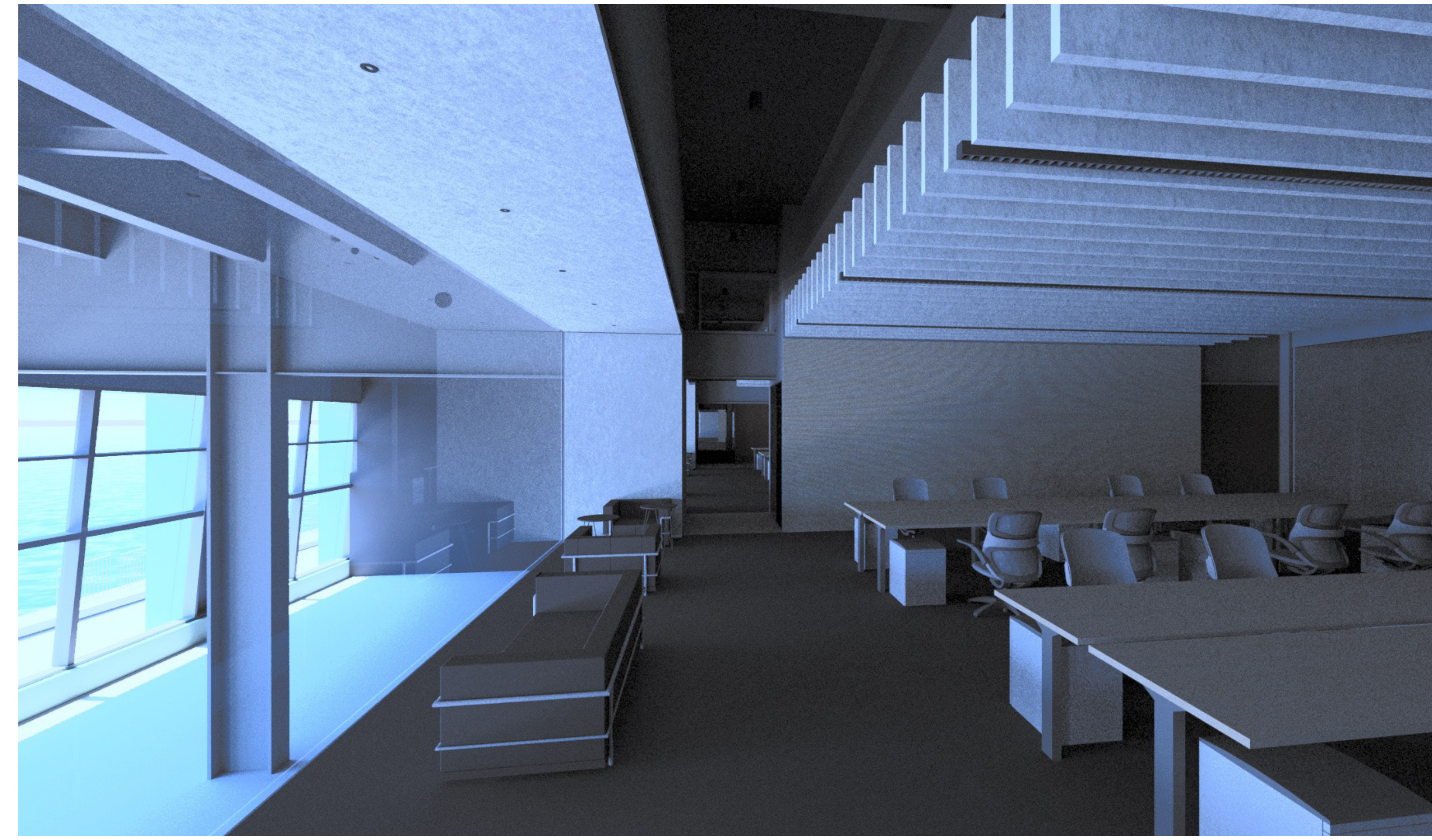
(The trans material used for the skylight glazing has a minute amount of specular transmission to match the specified diffusing interlayer for the skylights.)



Adding a site model, particularly a site model that includes colored elements, will both make the blue cast more believable and also add additional colors to the ambient light spectrum.



Overcast December sky (gendaylit). View is oriented to southwest.

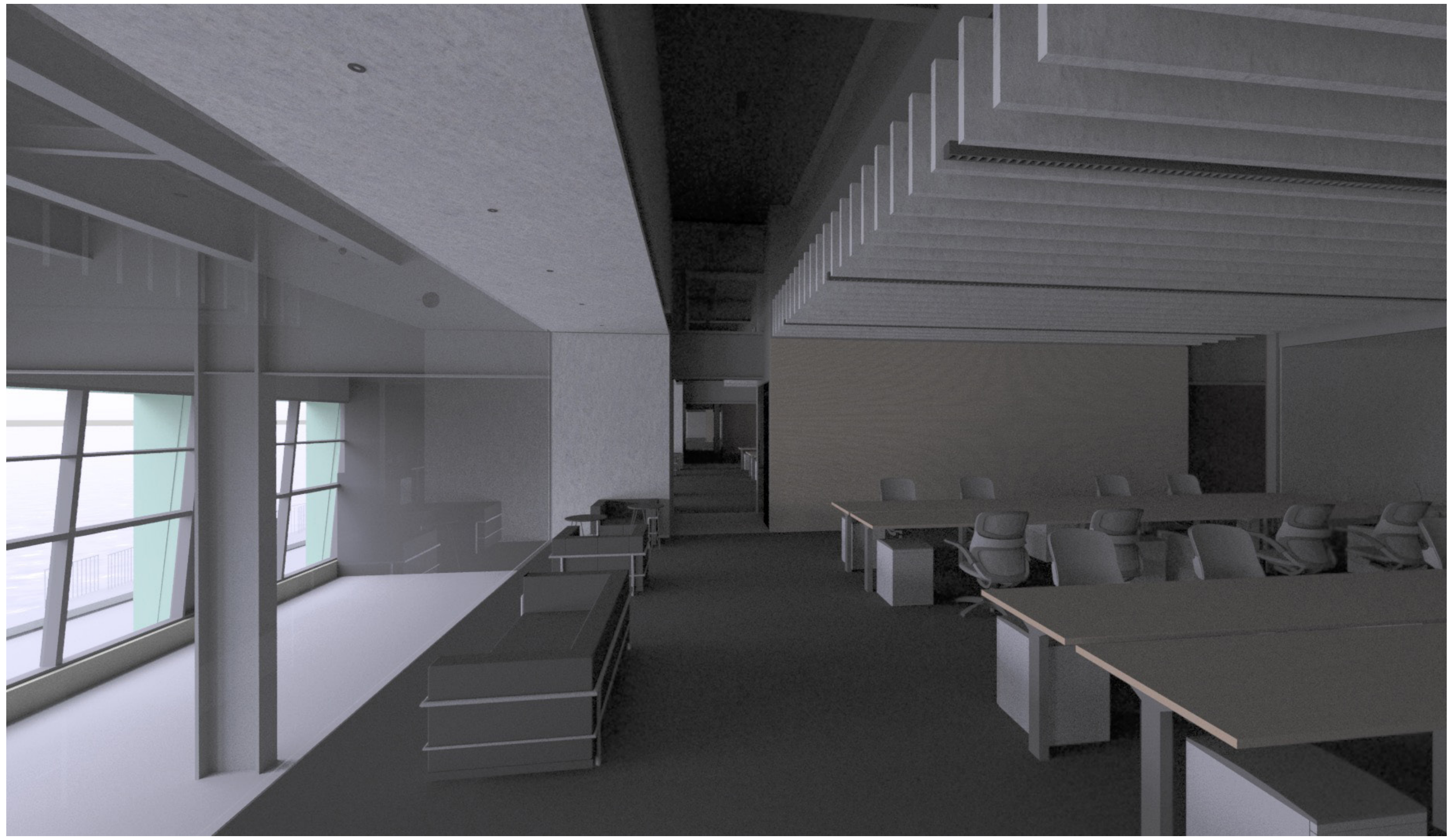


Clear June sky (L+U modified Utah sky)

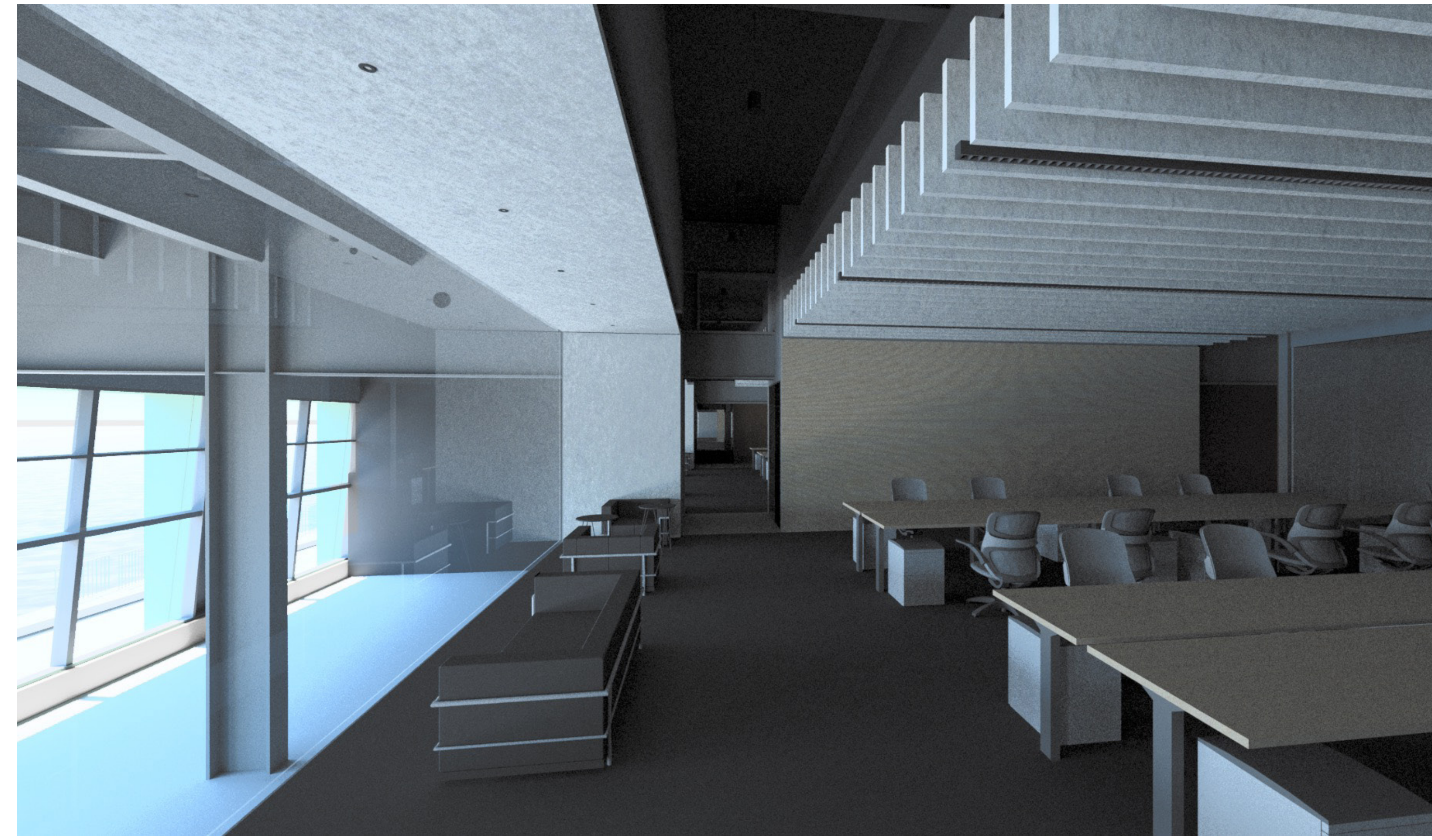
One unexpected consequence of adding a site model was this project for a set of offices located in a renovated pier building.

We used the basin method, as described on the radiance discourse site) for building the water around the pier (surface of the water is dialectric with a functional texture added through wrinkle.cal, with an opaque bottom and sides beneath.

This had the unintended consequence of reflecting the blue of the sky model up onto the ceiling of the offices giving them a very blue cast. The water also appeared very blue, which turned cyan once the image was conditioned.

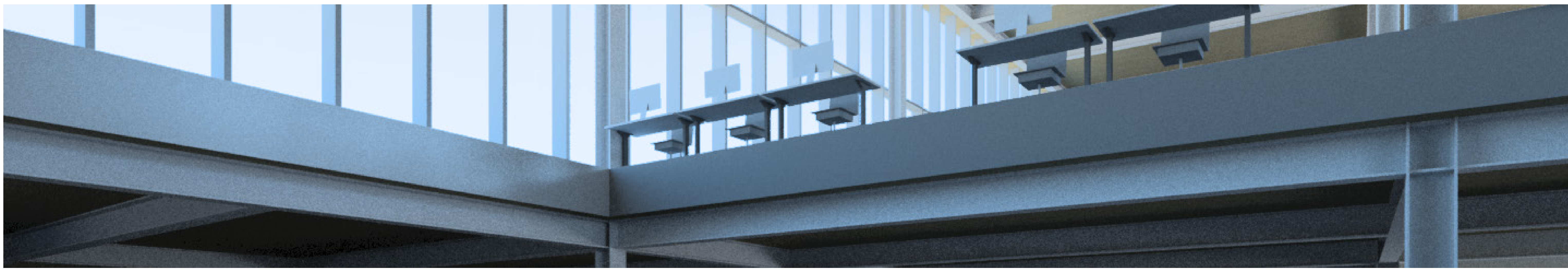


Overcast December sky (gendaylit). View is oriented to southwest.

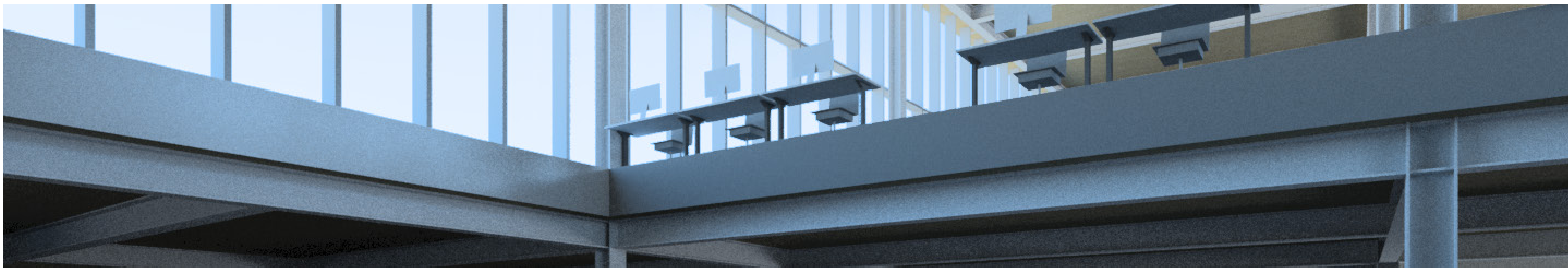


Clear June sky (L+U modified Utah sky) - white balanced and made partially greyscale.

We controlled the appearance of the water by a combination of masking the exterior view and selectively blending in a greyscale (luminance only) version of the same area and carefully white balancing the interior portion of the image.

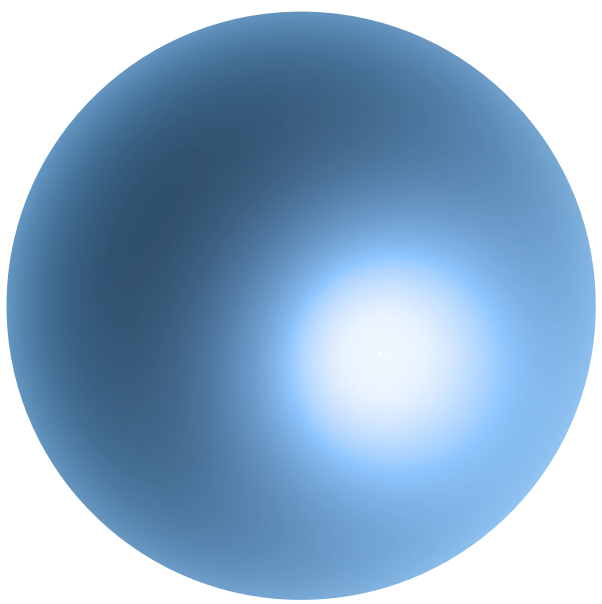


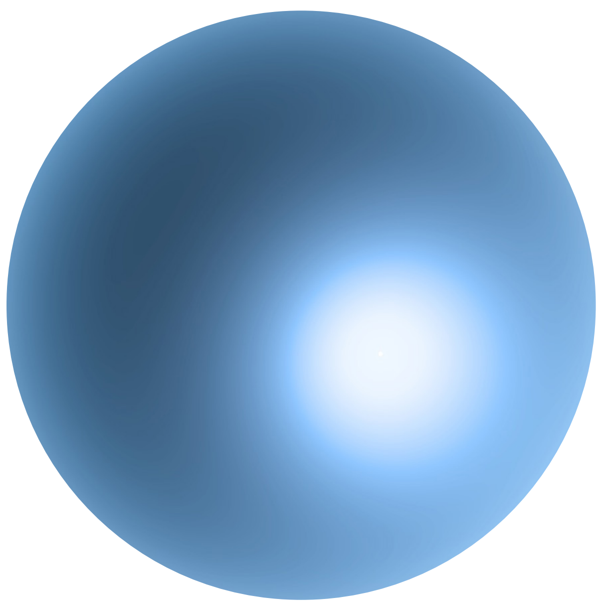
Post Processing



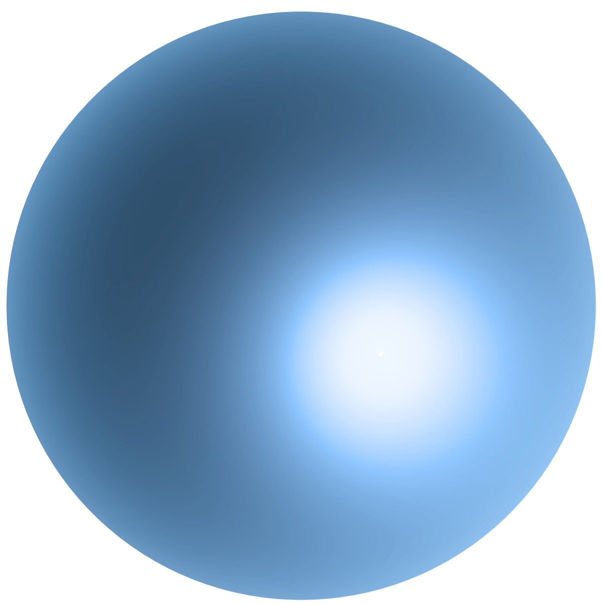
Post Processing

- Pcond and colored skies
- White balancing
- White balance in electric lighting integration



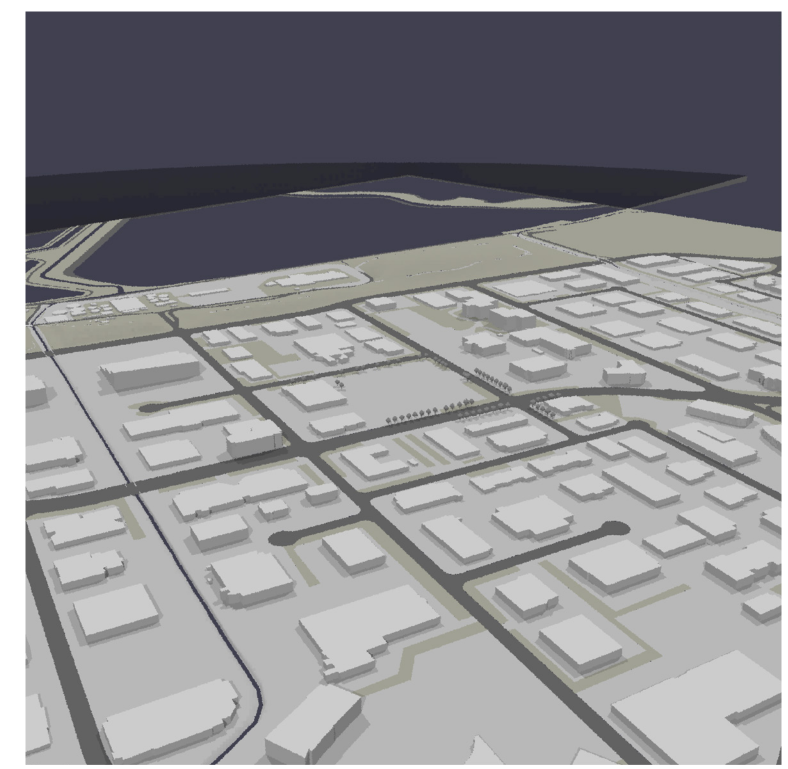


+



+

+



= ?

Yikes! What happened here?

Standard RGB

R : 20
G : 100
B : 81

Radiance RGBE

R : 0.2
G : 1.0
B : 0.81
E : low

Standard RGB

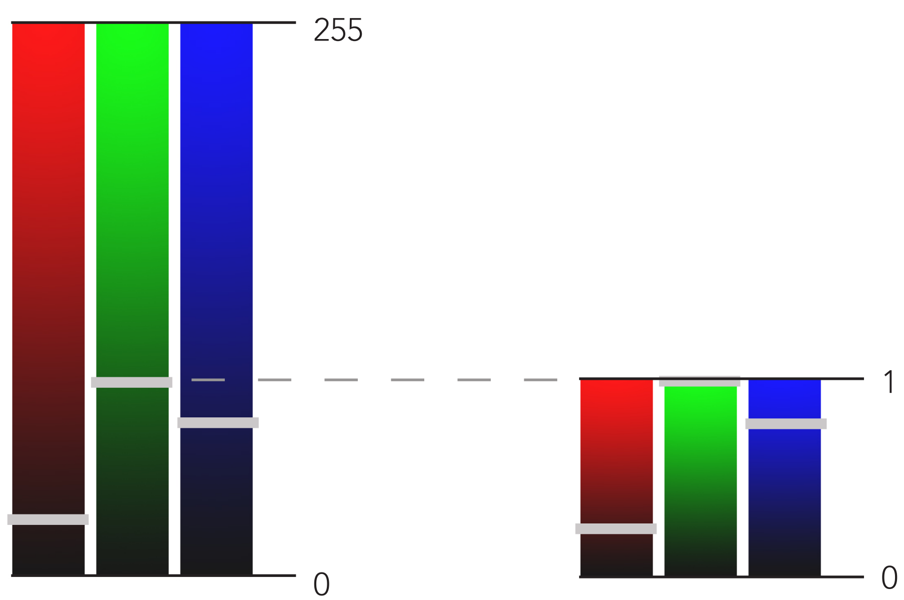
R : 198
G : 214
B : 87

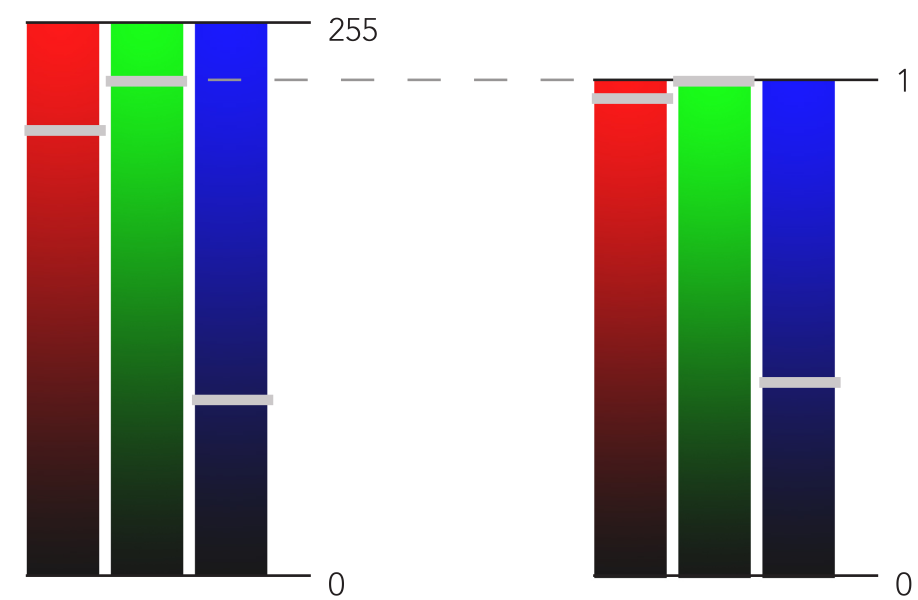
Radiance RGBE

R : 0.92
G : 1.0
B : 0.4
E : higher

if this was a source

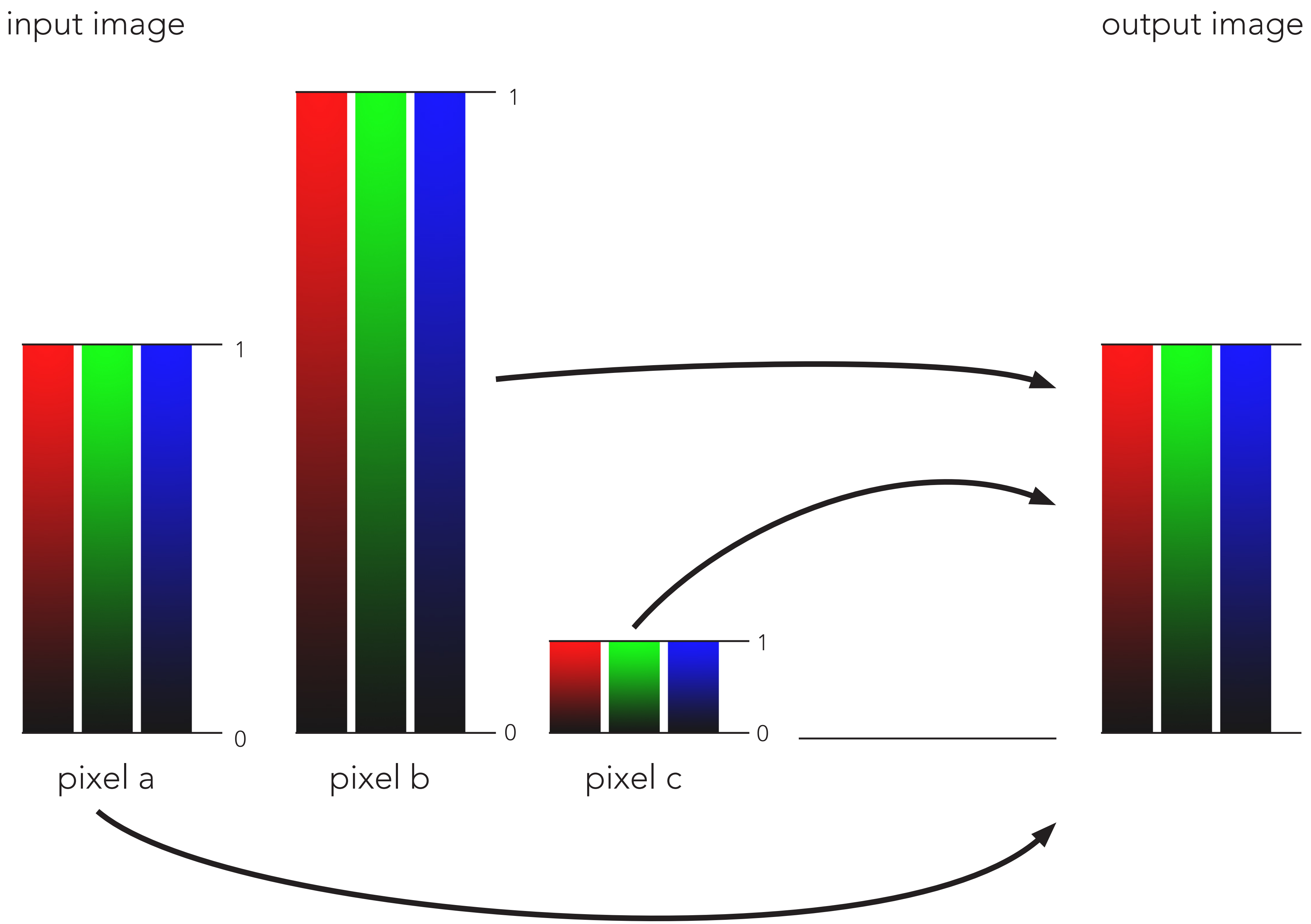
irradiance RGB : 0.92^1, 1.0^1, 0.4^1
illuminance = 179*(0.265r + 0.67g + 0.065b)
illuminance = 179*(0.265*0.92 + 0.67*1 + 0.065b*0.4)
illuminance = 168.26 lux





This is a smart way of handling colors because it allows a very broad range of possible illuminance or luminance values (76 orders of magnitude), al-beit without enhanced color fidelity (you still only have 8-bit color).

However, it poses problems when it comes time to tone or condition images.

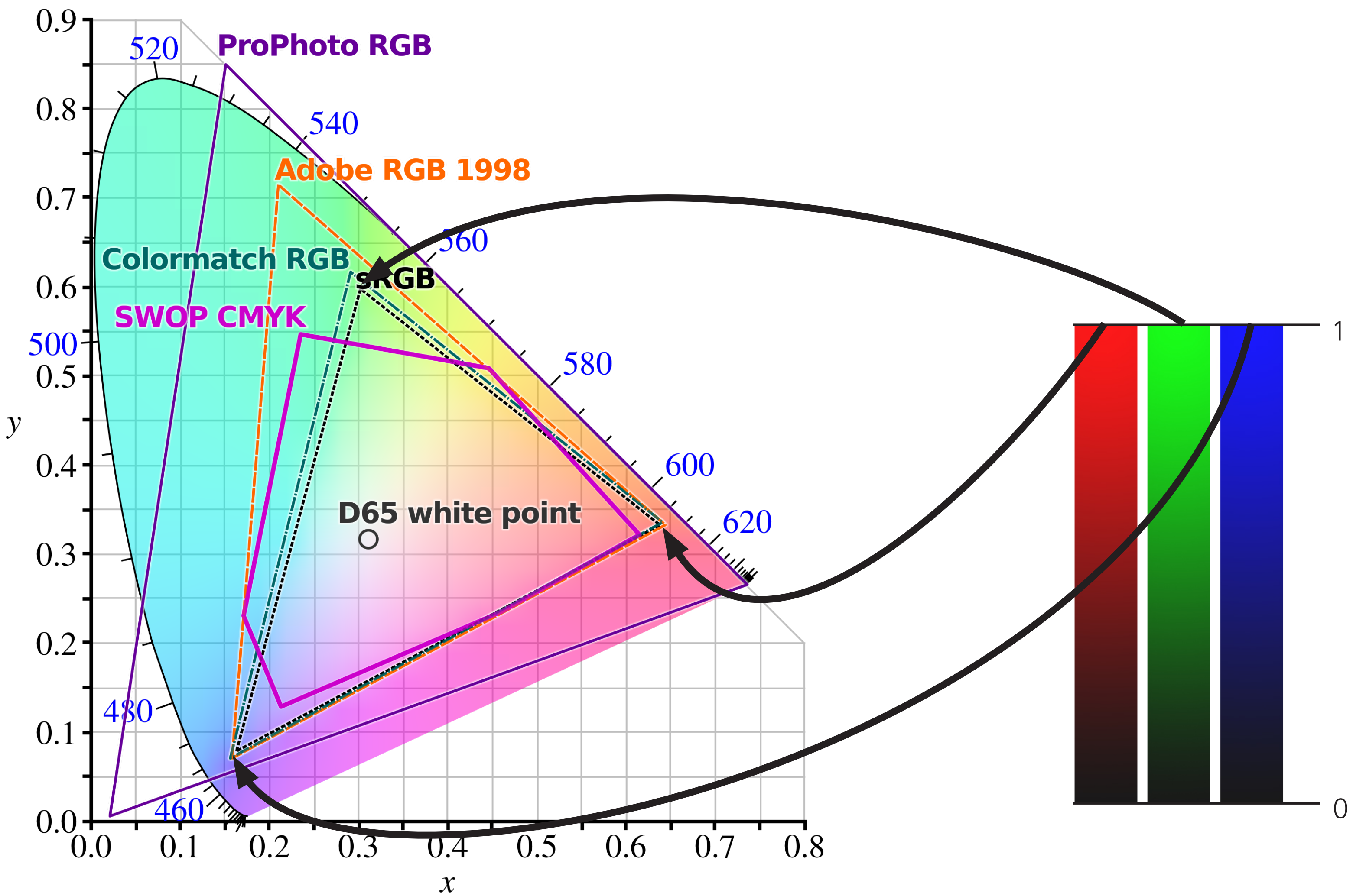


To output a standard dynamic range image, we need to map all these disparate 0-1^{exp} pixels to the same 0-1^{1} scale for display.

pcond -h does this using a mapping that mimics the responses of the human visual system.

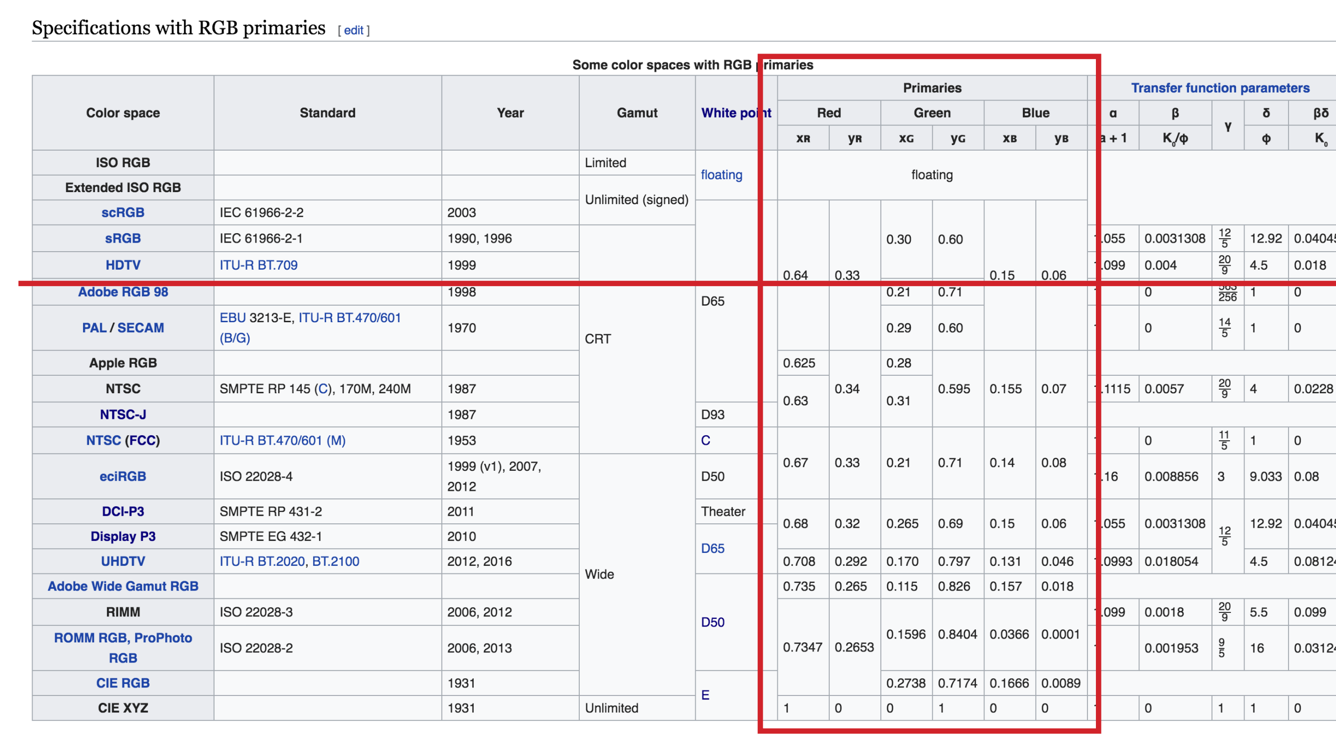
BUT, in order to use it most effectively, you need to tell it what bounds it is mapping to.

Pcond does this to give us some flexibility about what our simulation channels might mean and to enable the process of adaptation to adapt to the capabilities of different output devices.



This means that we need to give pcond a sense of the bounds of red green and blue that our output device supports.

In the digital imaging world, these are called colorspaces.



Specifications with RGB primaries [edit]

Some color spaces with RGB primaries

Color space	Standard	Year	Gamut	White point	Primaries						Transfer function parameters				
					Red		Green		Blue		α	β	γ	δ	βδ
					x_R	y_R	x_G	y_G	x_B	y_B	a + 1	K_0/ϕ		φ	K_0
ISO RGB			Limited	floating	floating										
Extended ISO RGB			Unlimited (signed)												
scRGB	IEC 61966-2-2	2003			0.64	0.33	0.30	0.60	0.15	0.06					
sRGB	IEC 61966-2-1	1990, 1996									.055	0.0031308	12/5	12.92	0.04045
HDTV	ITU-R BT.709	1999									.099	0.004	20/9	4.5	0.018
Adobe RGB 98		1998	CRT	D65			0.21	0.71				0	563/256	1	0
PAL / SECAM	EBU 3213-E, ITU-R BT.470/601 (B/G)	1970					0.29	0.60				0	14/5	1	0
Apple RGB					0.625	0.34	0.28	0.595	0.155	0.07					
NTSC	SMPTE RP 145 (C), 170M, 240M	1987			0.63		0.31				.1115	0.0057	20/9	4	0.0228
NTSC-J		1987		D93											
NTSC (FCC)	ITU-R BT.470/601 (M)	1953		C	0.67	0.33	0.21	0.71	0.14	0.08		0	11/5	1	0
eciRGB	ISO 22028-4	1999 (v1), 2007, 2012	Wide	D50							.16	0.008856	3	9.033	0.08
DCI-P3	SMPTE RP 431-2	2011		Theater	0.68	0.32	0.265	0.69	0.15	0.06	.055	0.0031308	12/5	12.92	0.04045
Display P3	SMPTE EG 432-1	2010		D65											
UHDTV	ITU-R BT.2020, BT.2100	2012, 2016			0.708	0.292	0.170	0.797	0.131	0.046	.0993	0.018054		4.5	0.081243
Adobe Wide Gamut RGB				D50	0.735	0.265	0.115	0.826	0.157	0.018					
RIMM	ISO 22028-3	2006, 2012			0.7347	0.2653	0.1596	0.8404	0.0366	0.0001	.099	0.0018	20/9	5.5	0.099
ROMM RGB, ProPhoto RGB	ISO 22028-2	2006, 2013										0.001953	9/5	16	0.031248
CIE RGB		1931		E			0.2738	0.7174	0.1666	0.0089					
CIE XYZ		1931	Unlimited		1	0	0	1	0	0		0	1	1	0

We primarily produce PDF reports, which inherently use JPEG compression. This means more or less everything we make will get packaged in the sRGB color space, regardless of the output device on which our presentations will be viewed.

This means using these coordinates for RGB:
xr .64 yr .33 xg .30 yg .60 xb .15 yb .06 xw .3127 yw .348

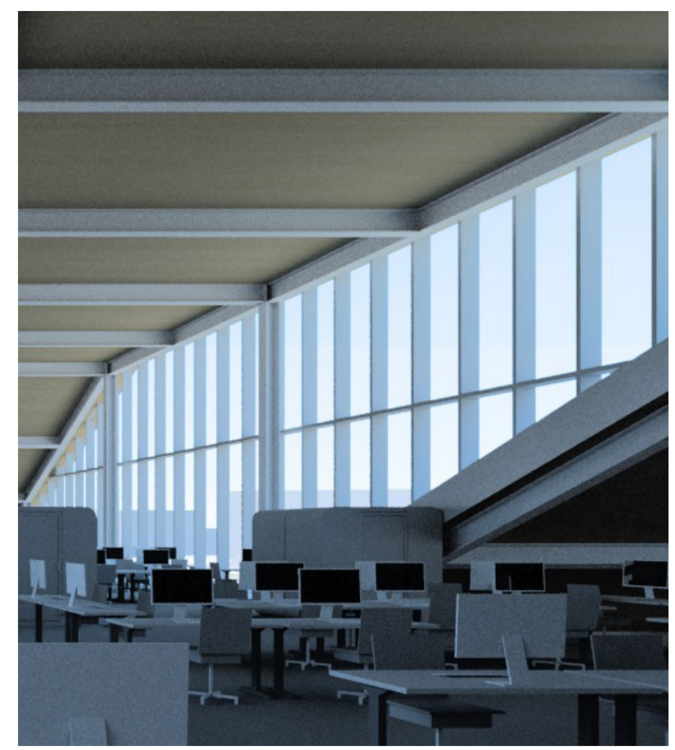
Pcond does not assume a colorspace by default. We can set it using the -p flag.

```
                f-stops  preceeded  by  a  '+' or '-'.  This option implies a
                linear response (see the -l option above).

     -u Ldmax   Specifies the top of the luminance range for the target  out-
                put  device.  That is, the luminance (in candelas/m^2) for an
                output pixel value of (R,G,B)=(1,1,1).  The default value  is
                100 cd/m^2.

     -d Lddyn   Specifies  the  dynamic  range  for the target output device,
                which is the ratio of the maximum and minimum usable  display
                luminances.  The default value is 32.

     -p xr yr xg yg xb yb xw yw
                Specifies  the  RGB  primaries  for the target output device.
                These are the 1931 CIE (x,y)  chromaticity  values  for  red,
                green, blue and white, respectively.

     -f macbeth.cal
                Use  the  given  output file from macbethcal(1) to precorrect
                the color and contrast for the target  output  device.   This
                does  a  more  thorough  job than a simple primary correction
                using the -p option.  Only one of -f or -p may be given.

     -x mapfile
                Put out the final mapping from  world  luminance  to  display
```

So we could run pcond -h -p .64 .33 .30 .60 .15 .06 .3127 .348 to get a human-adapted image conditioned to the sRGB colorspace.

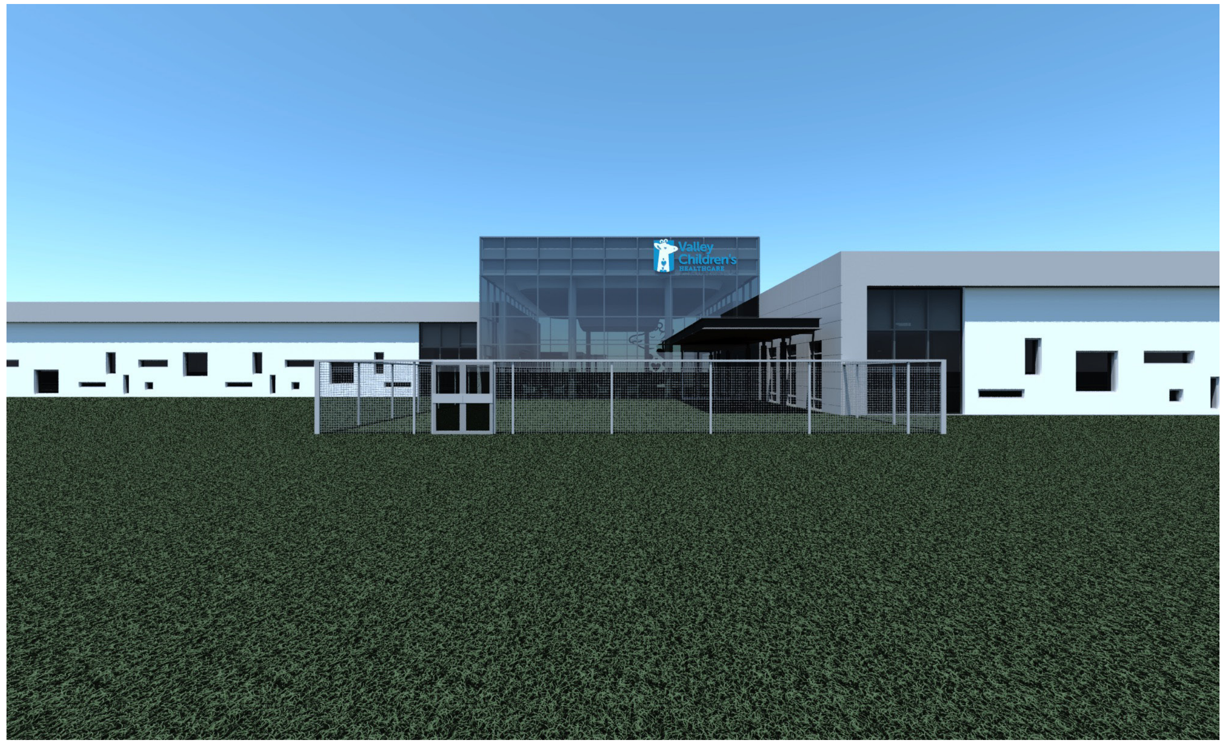
If we want to preserve the equal-energy white point of the Sharp RGBE color model, we can modify the xw and yw coordinates to 0.333 and 0.333 without significantly changing the appearance of the image.

This is a shift from the D65 illuminant to the E illuminant. And is extremeley subtle. Can you tell the difference between the images below?

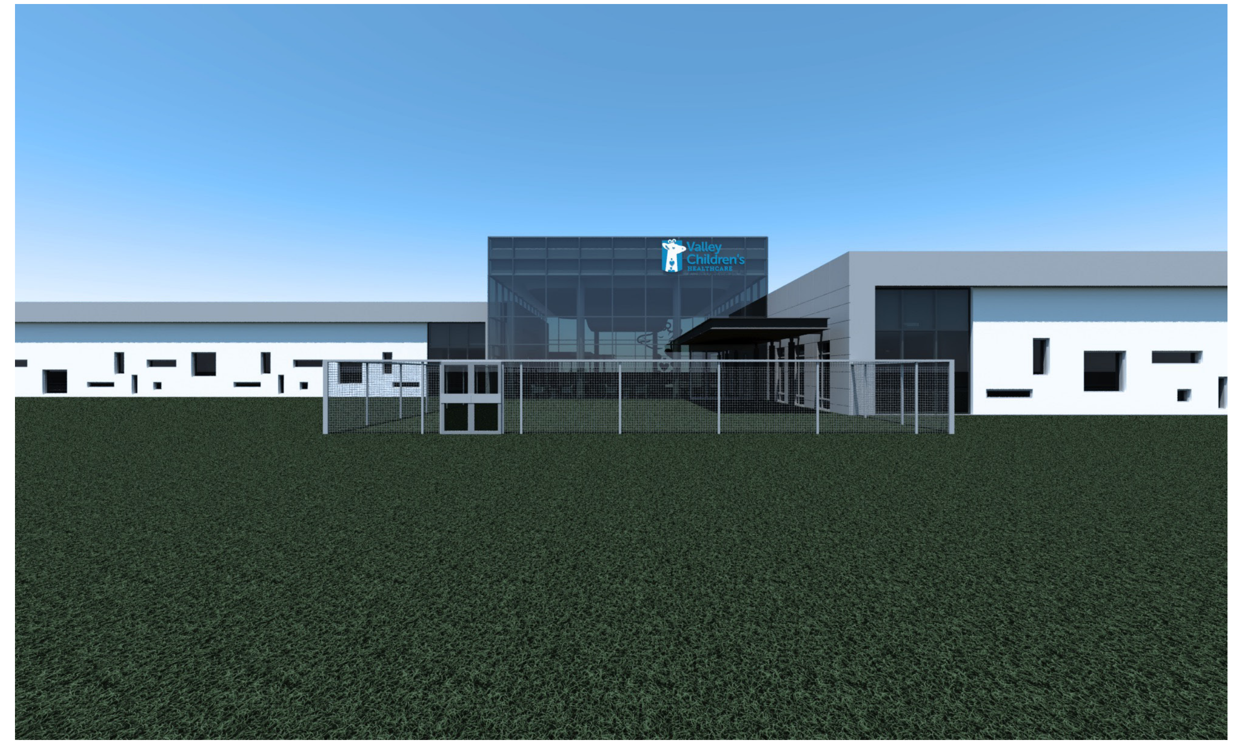


pcond -h -v- without primaries specified

pcond -h -v- with
sRGB primaries specified, modified to use E illuminant
xr .64 *yr* .33 *xg* .30 *yg* .60 *xb* .15 *yb* .06 *xw* .333 *yw* .333
(pcond -h -v- -p .64 .33 .30 .60 .15 .06 .333 .333)

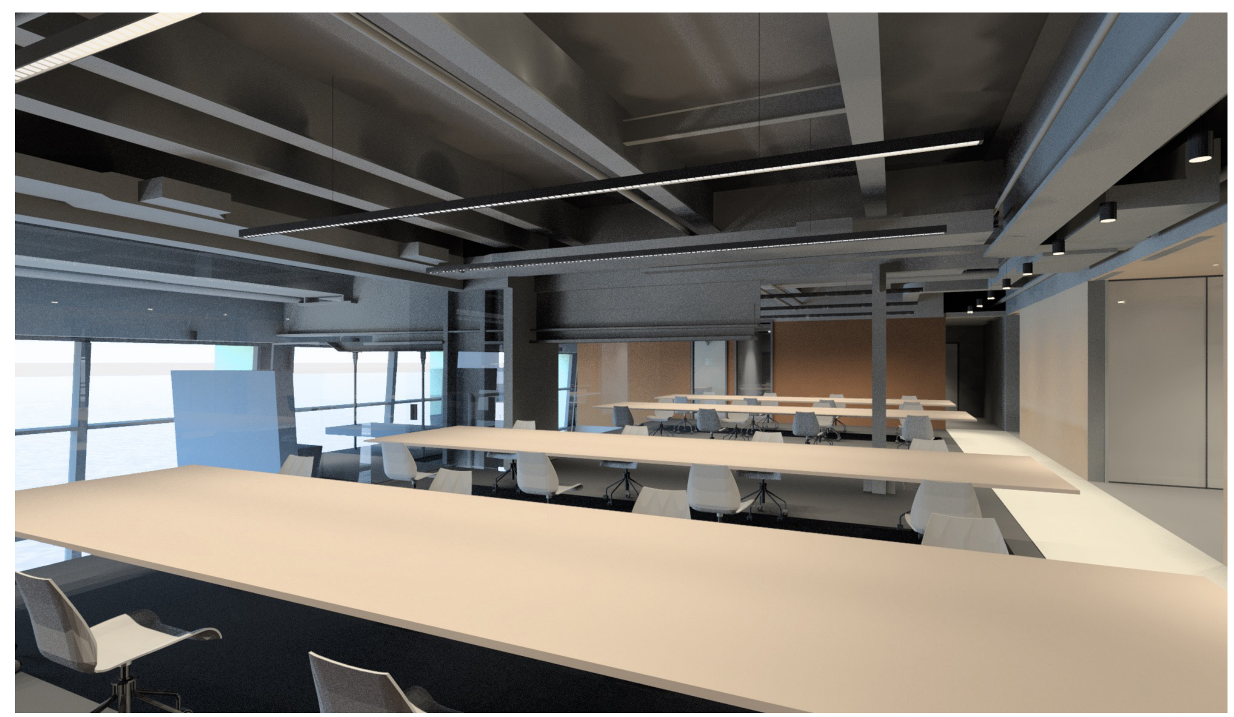


pcond -h -v- no colorspace specified



pcond -h -v- with sRGB + E colorspace

pcond -h -v- no colorspace specified



pcond -h -v- with sRGB + E colorspace

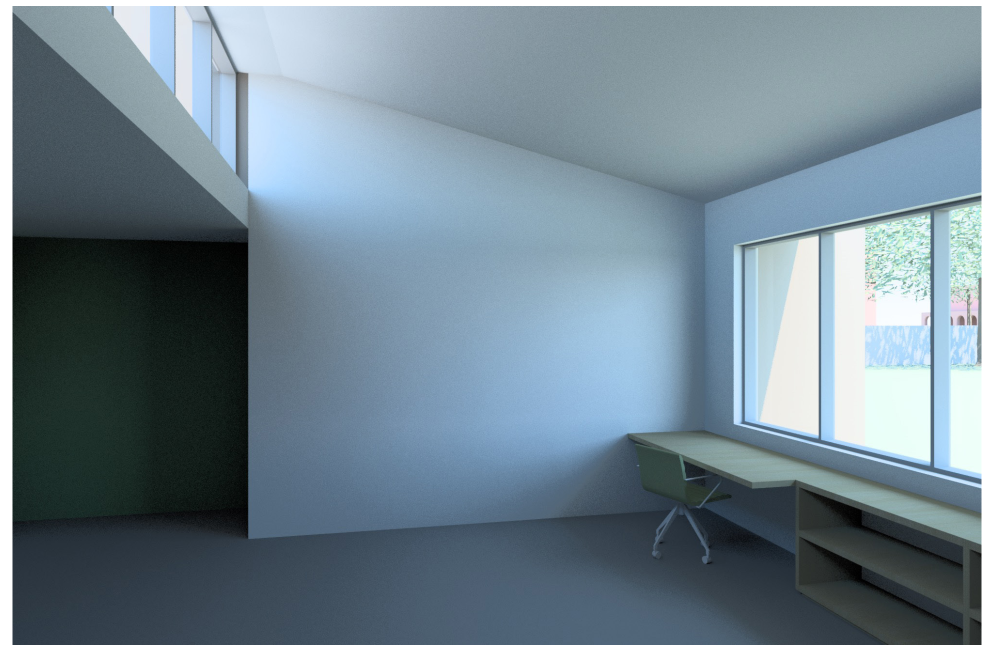
  

A final, related aspect is considering the relationship between the conditioned image and what we would expect the space to look like from experience. We will sometimes use custom gaussian distribution inputs to pcond to modify the exposure and conditioning of the image.

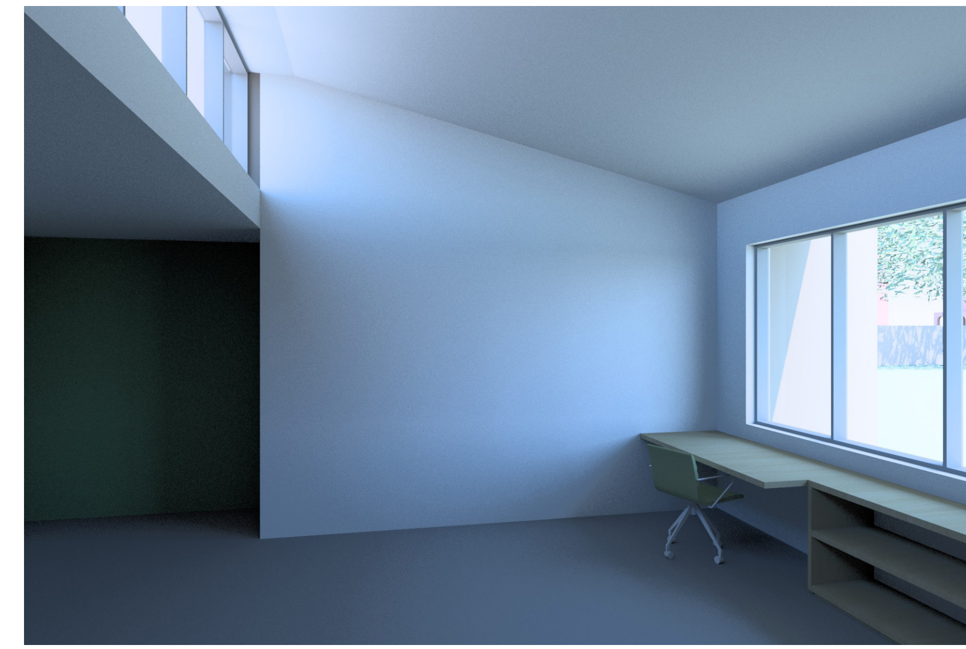
We also use this method to give exactly the same exposure to different sky conditions, to show difference (remove the variable of local adaptation).

This can also be accomplished, though without the advantages of the gaussian distribution, using the exposure flag in pcond.

5000k > 4000k



5000k > 5000k



5000k > 6000k

We use pfilt to colorshift images along the black-body curve without changing the absolute luminance of the output image. This gives us control over the white point of the image, so that we can consider local color adaptation alongside adaptation to luminance.

no shift, standard pcond

5000k > 4000k, standard pcond

5000k > 3500k, standard pcond

no shift, sRGB + E pcond

5000k > 4000k, sRGB + E pcond

5000k > 3500k, sRGB + E pcond

Equal-energy - no white balancing applied
(5000k daylight + 5000k electric lighting)

Warm electric lighting, neutral daylighting
(5000k daylight + 3000k electric lighting)

Warm electric lighting, cold daylighting
(6000k daylight + 3000k electric lighting)

White balance is also an important consideration in electric lighting integration simulations, where we want to show that the light sources are of different color temperatures, while keeping in mind that an occupant of the room will rapidly adapt to both color temperatures without noticing it.

Daylight only (clear sky with no direct sun entry)

Daylight + electric lighting (standard pcond)

Daylight + electric lighting (sRGB + E pcond)

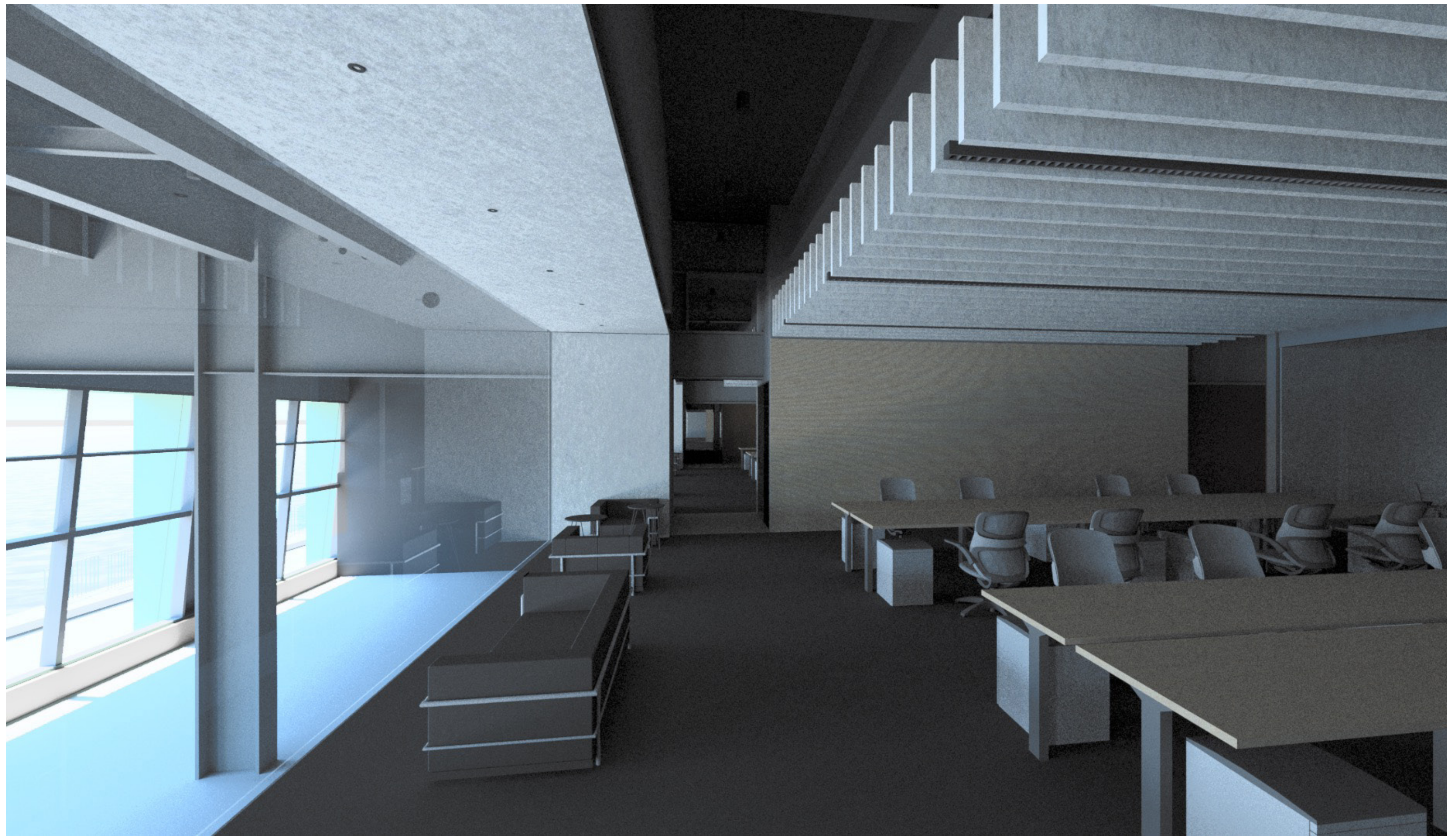
In this room, which faces directly east, the bluish cast of an uncorrected midday-afternoon sky is understandable in a daylight-only simulation, but looks green and harsh when the warmer electric lighting is added. The multiple colors of light are particularly noticable and distracting on the all-grey furniture.

The effect is somewhat reduced by the use of appropriate colorspace primaries, but this remains a difficult scene to understand.

Clear sky + electric lighting (sRGB pcond)

Overcast sky + electric lighting

By comparison, the scene is more coherent with a greyscale gendaylit overcast sky.



Daylight only (clear summer sky)

Daylight + electric lighting

In other cases, the addition of electric lighting, even of strongly different color temperature, makes the blue cast of daylight look more natural. Here the simulation produces an image that is consistent with our experiences of daylight within electrically-lit spaces.

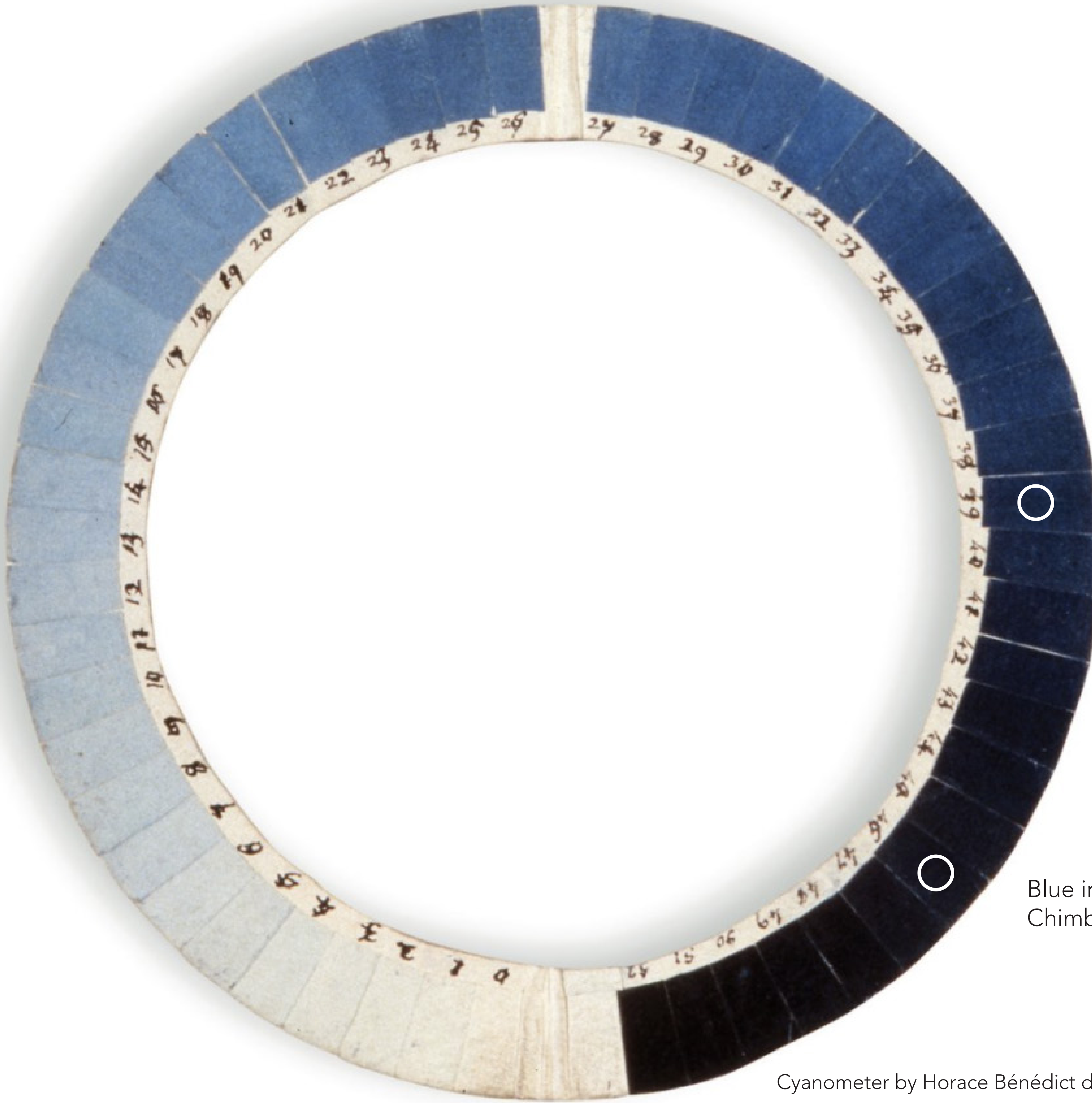
The Future

Cyanometer by Horace Bénédict de Saussure, 1789

Cyanometer by Horace Bénédict de Saussure, 1789

The Future

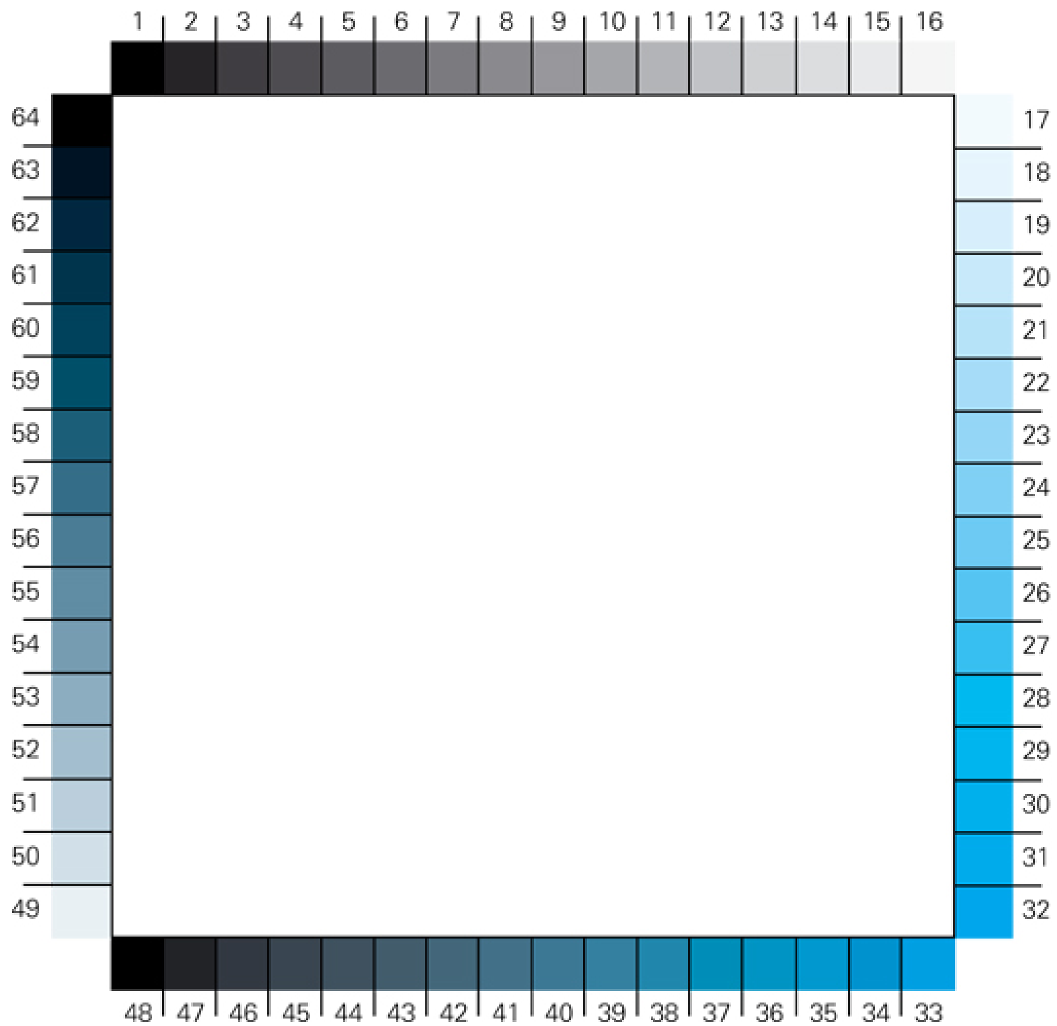
- Localized color
- Fine control of daylight color
- Into the unknown

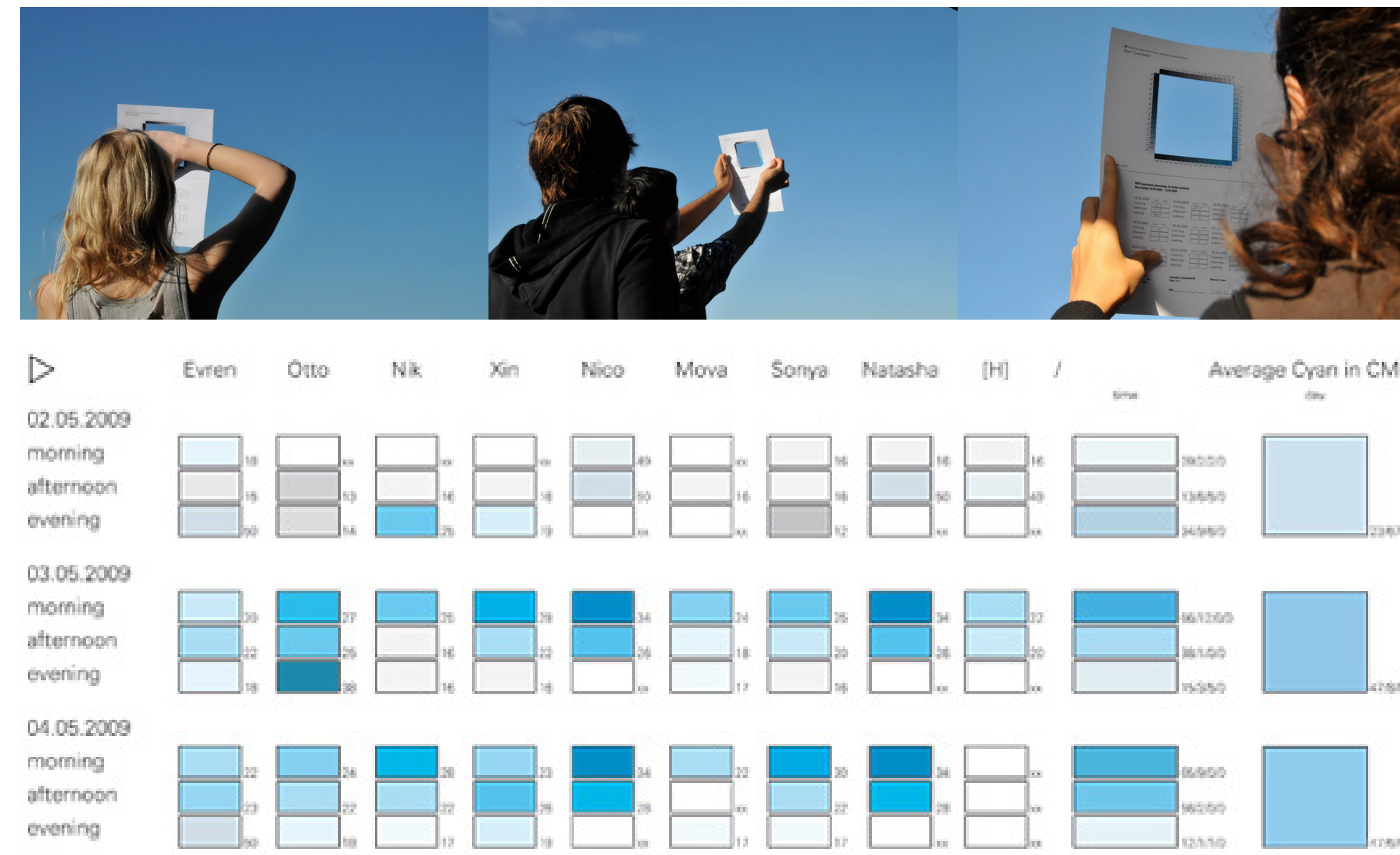


Blue in the 39th degree measured on
Mont Blanc by de Saussure in 1786

Blue in the 46th degree measured on
Chimborazo by Alexander von Humboldt in 1802

Cyanometer by Horace Bénédict de Saussure, 1789





"New Cyanometer" Otto von Busch and Evren Uzer, 2009
under the auspices of the Institut für Allgemeine Theorie.
All images from the Institut's website:
http://www.iat-research.com/index.php/archive/47-work/95-new-cyanometer

Mojave Desert, California
December 16, 2020

Boulder, Colorado
December 26, 2020

Central Utah
January 6, 2021

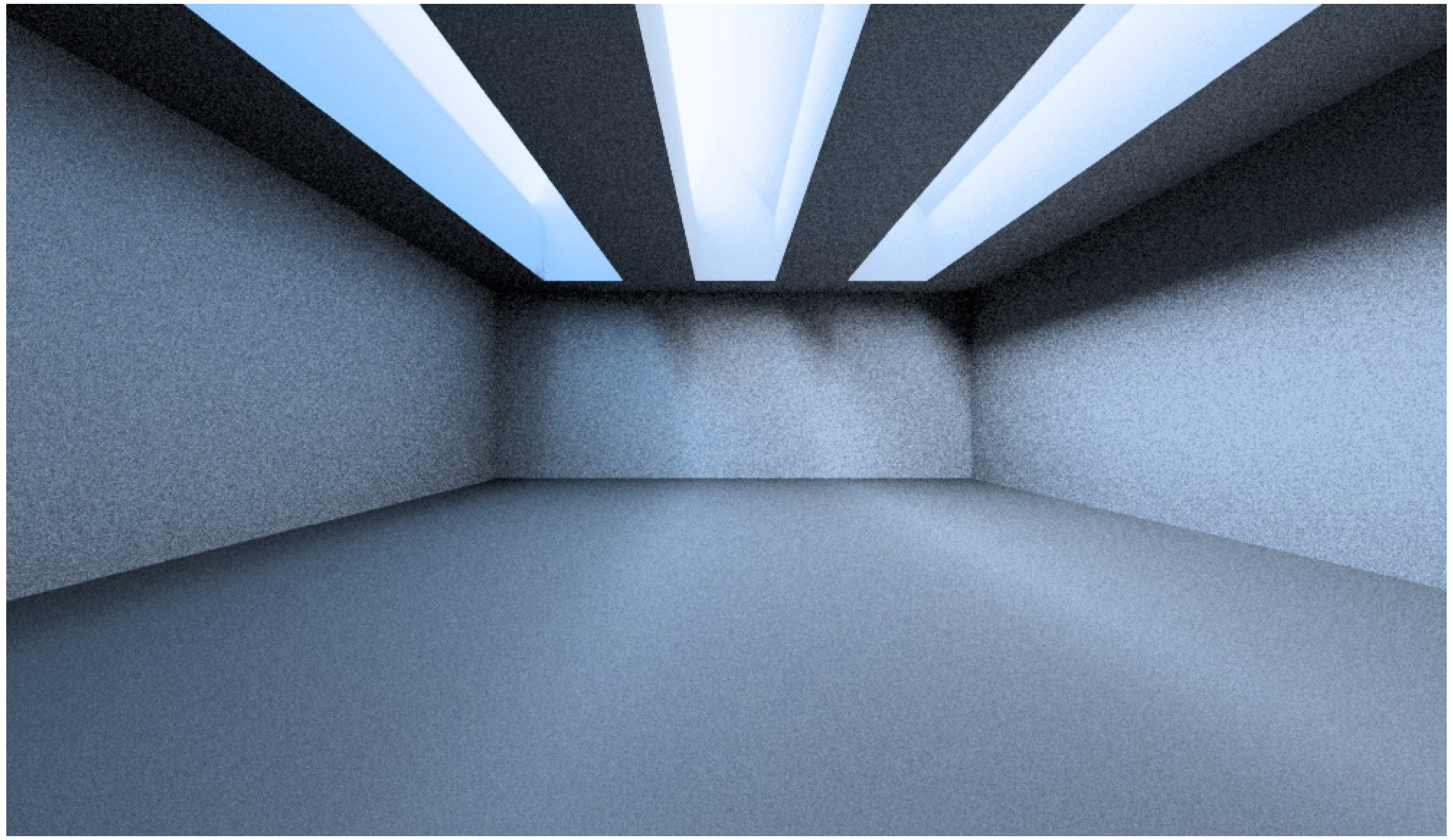
Los Angeles, California
July 1st, 2021

Alameda, California
March 7, 2021

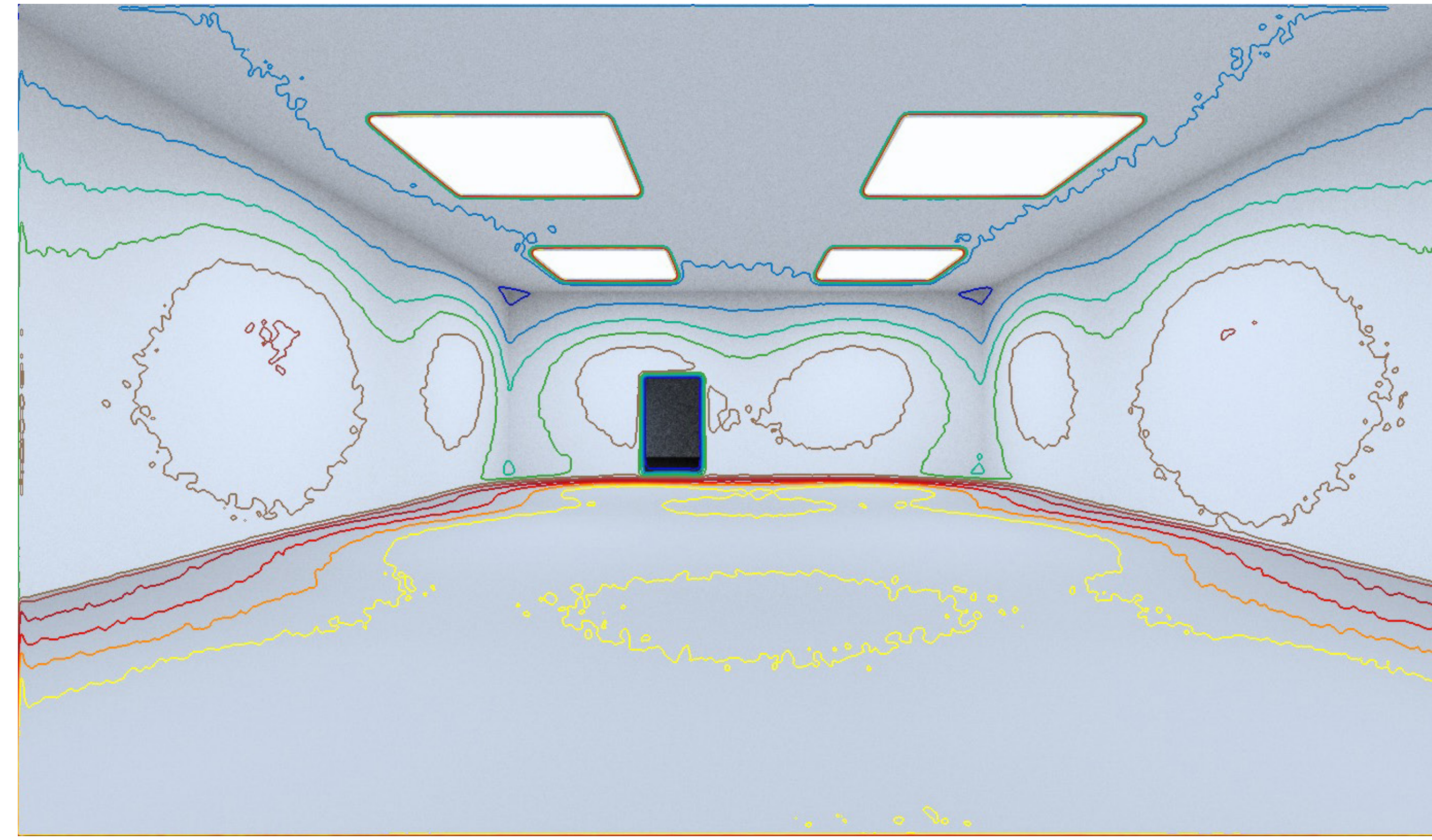
Seaside, California
August 8, 2021

Alameda, California
April 18, 2021

We are considering ways to more accurately describe the subtle differences in the colors of daylight between locations and climates. This involves creating methods in which there is a useful feedback between simulation sky models and measured or monitored data.

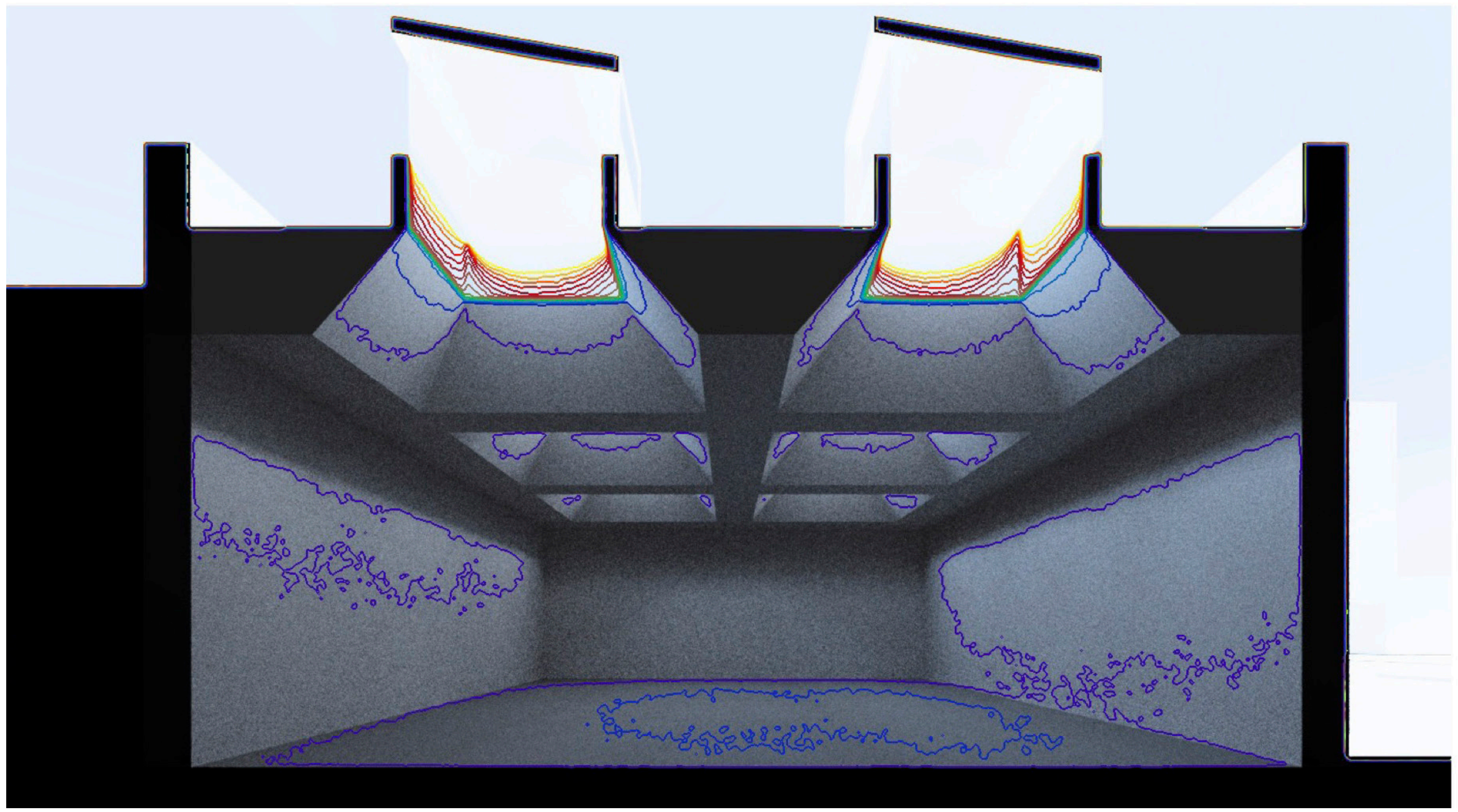


December clear sky with north-facing diffusing sawtooths

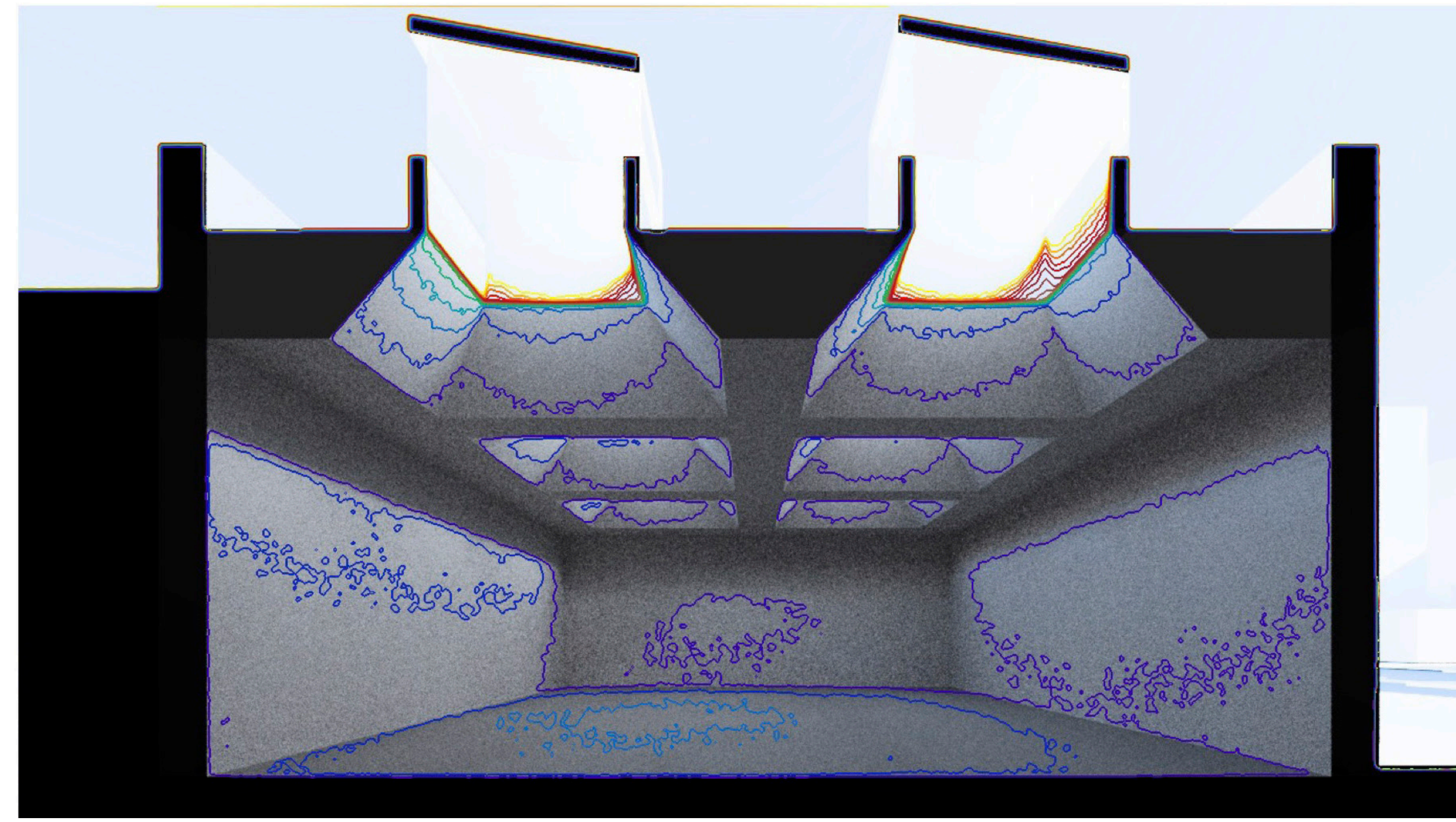


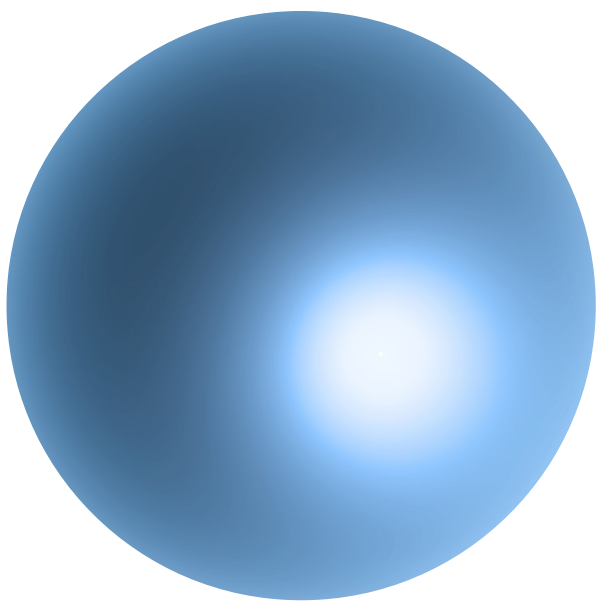
December clear sky with louvered horizontal diffusing skylights

Jun 21 12:00 - Clear Sky



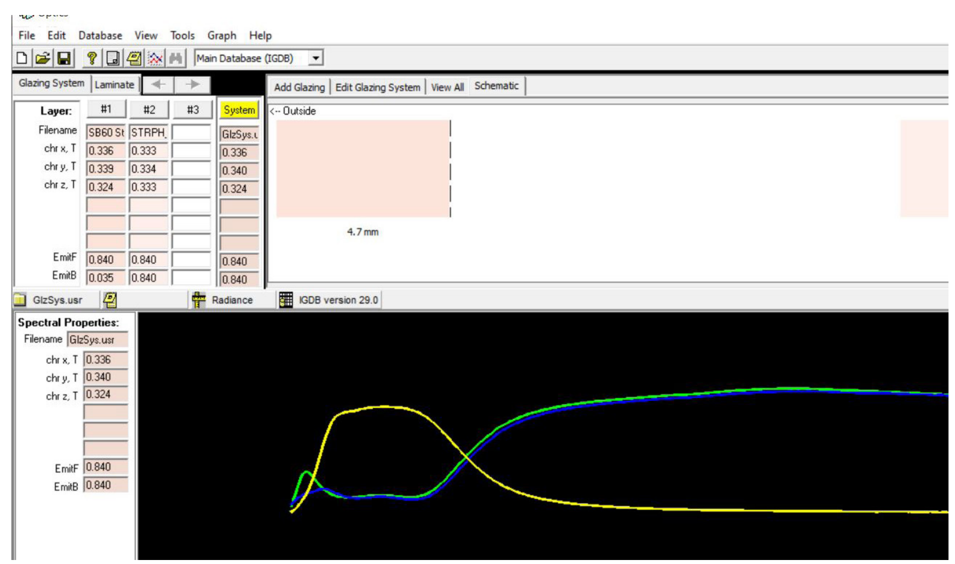
Dec 12 12:00 - Clear Sky





Colored sky model

+



Optics glazing definitions

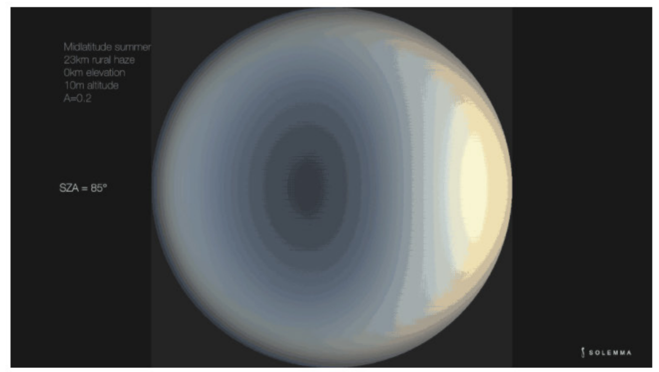
=

Model with glazing specific color reflectance and transmittance

ALFA

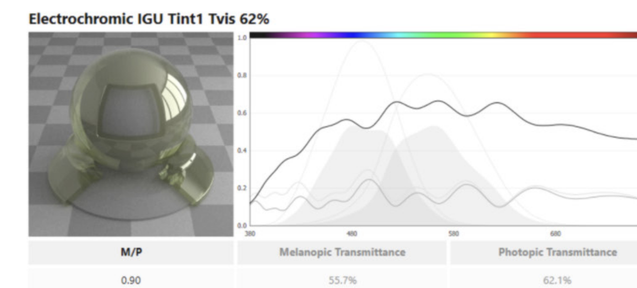
SPECTRAL SKIES

The daytime sky is a powerful driver of circadian biology. Unlike (most) man-made light sources, it varies in color not only by time of day, but also by direction of view. To simulate it accurately, ALFA deploys spectral calculations using the best-in-class radiative transfer library, **libRadtran**. This lets ALFA users pull up physically-accurate clear, hazy, or overcast skies for any location on Earth.



SPECTRAL MATERIALS

Between emission from a source and arrival at the eye, light spectra are modified by transmission and reflection off material surfaces. To ensure realistic results, ALFA comes with a catalog of over 500 measured spectral materials, based on spectrophotometric measurements of real architectural objects. The software is also compatible with the **International Glazing Database**, making it easy to import any of the IGDB's tens of thousands of spectrally measured glazing products.



We are aware of the work Solemma has done building upon radiance to create Alfa to simulate circadian-related lighting conditions, amongst other uses. We have not done this kind of simulation because we have not had clients ask for it. For 99% of architectural daylighting services, 3 channel RGB is more than enough information, and presents more than enough potential gaps and pitfalls in creating accurate simulations.

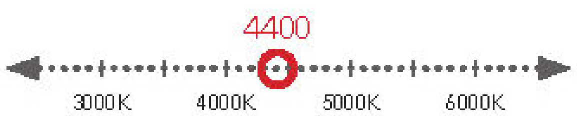
Openness : 3%

Color : 1519 Silver Birch

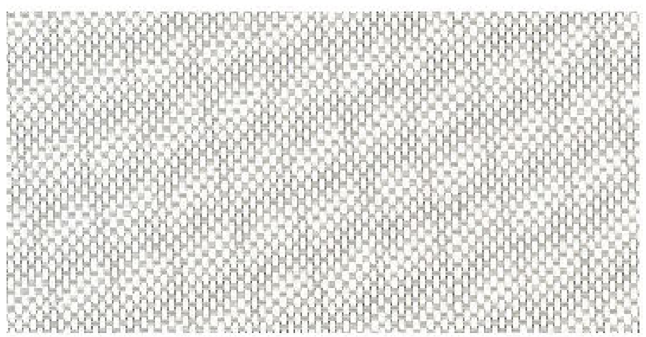
VLT (measured) : 8.8%

VLT (per manufacturer) : 8%

Transmitted Color Temperature*

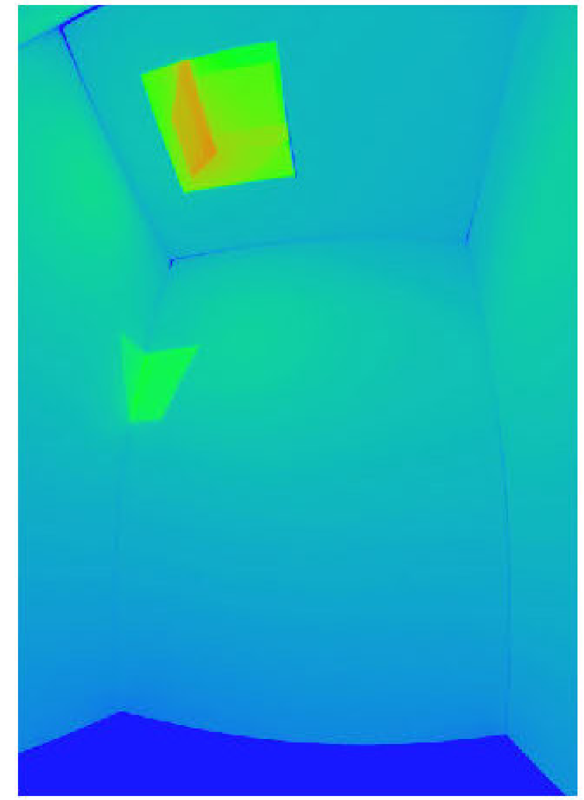


* with 5000K direct sun source



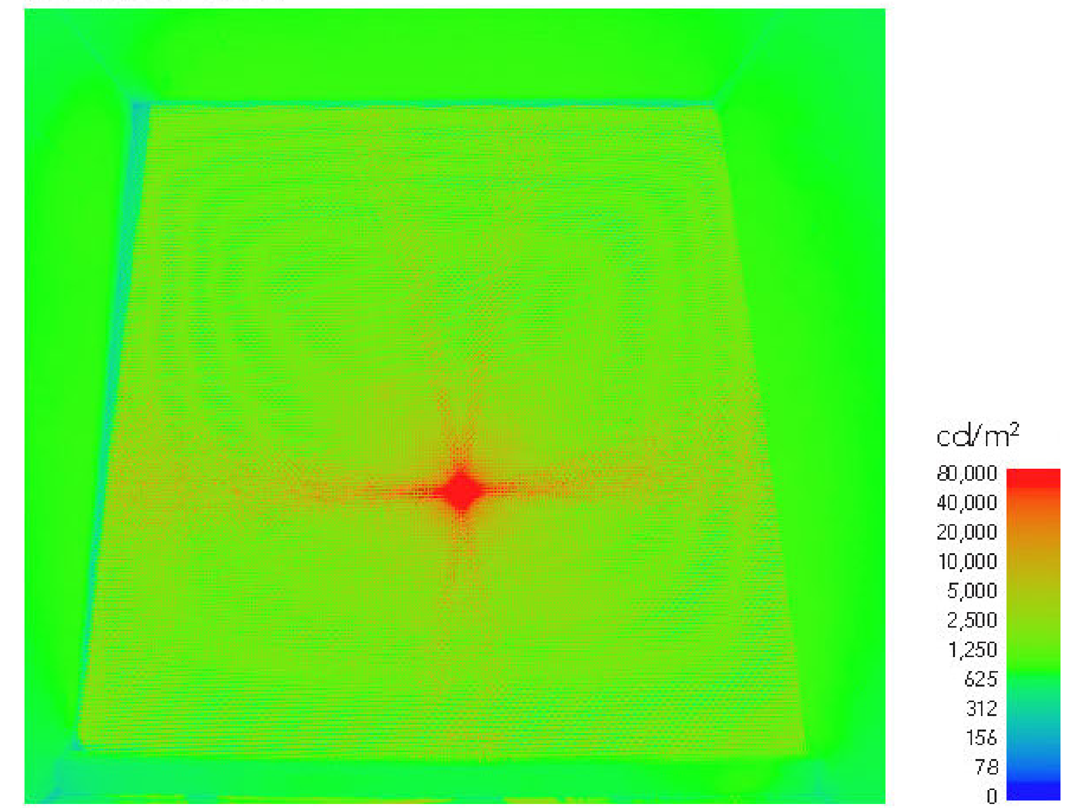
Skylight Appearance

human adaptation processed HDR image



falsecolor luminance map (scale at right)

Direct Sun / Glare



falsecolor luminance map

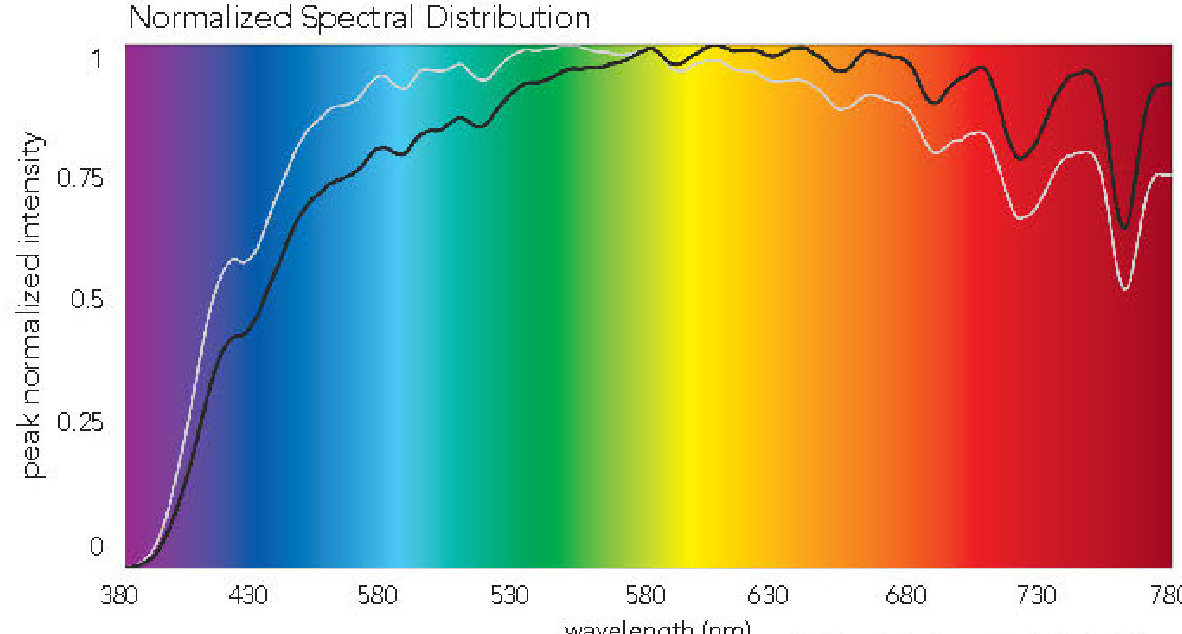
Notes

Pros:
Low contrast within shadecloth
Medium screening of bright objects / sun
High VLT

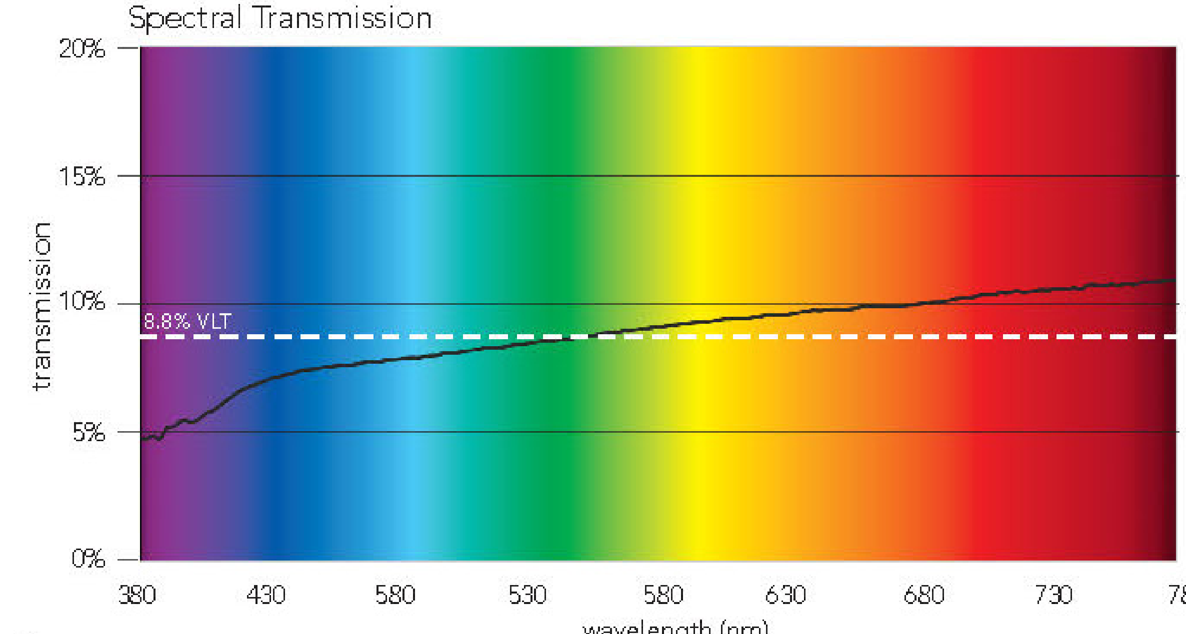
Cons:
Moderate warm color shift

Color Transmission

Normalized Spectral Distribution



Spectral Transmission

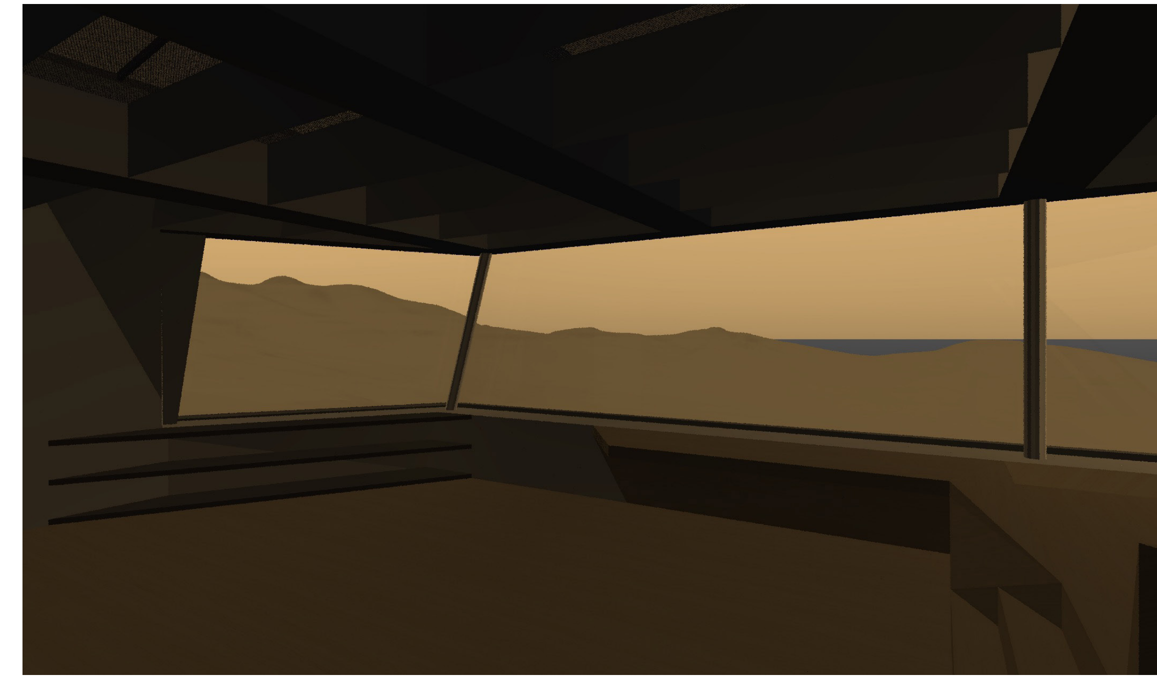


What to do when the sky is blue - Michael Beggs
19th Annual Radiance Conference, August 19-20th 2021

View of San Francisco, Midday, September 9, 2020

Berkeley, California, September 9, 2020, 12:16pm

View of San Francisco, Midday, September 9, 2020



Climate change will reshape local climates in ways that will take us completely by surprise. We may not find ourselves simulating wildfire skies anytime soon, but we are, even anecdotally, already seeing increasing variability in sky conditions.

In this context, maintaining flexibility, and developing simple methods for calibrating simulation skies to measured or monitored data, may become essential parts of good daylighting practice.

And for some projects, that will also mean understanding the color of the sky.