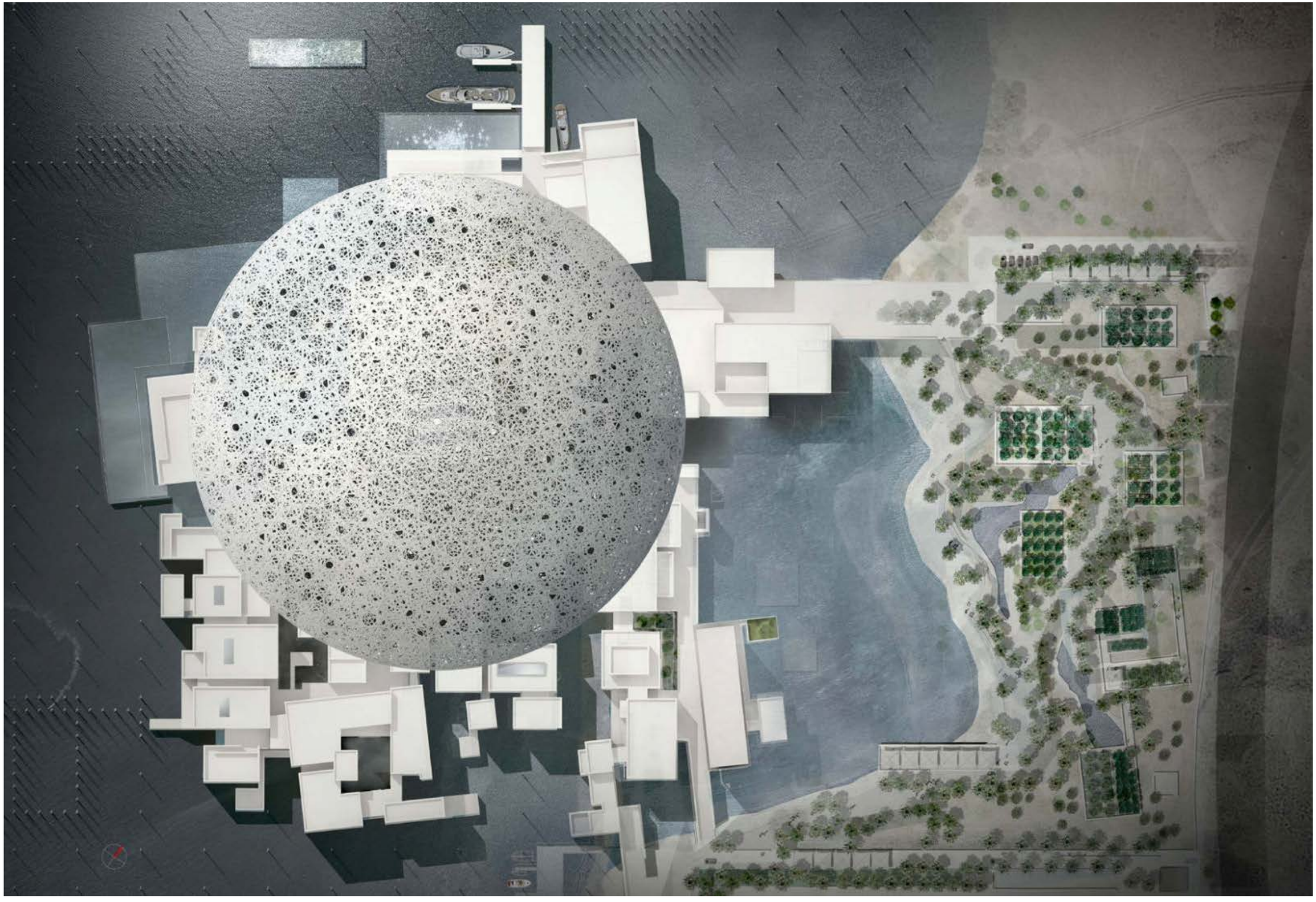
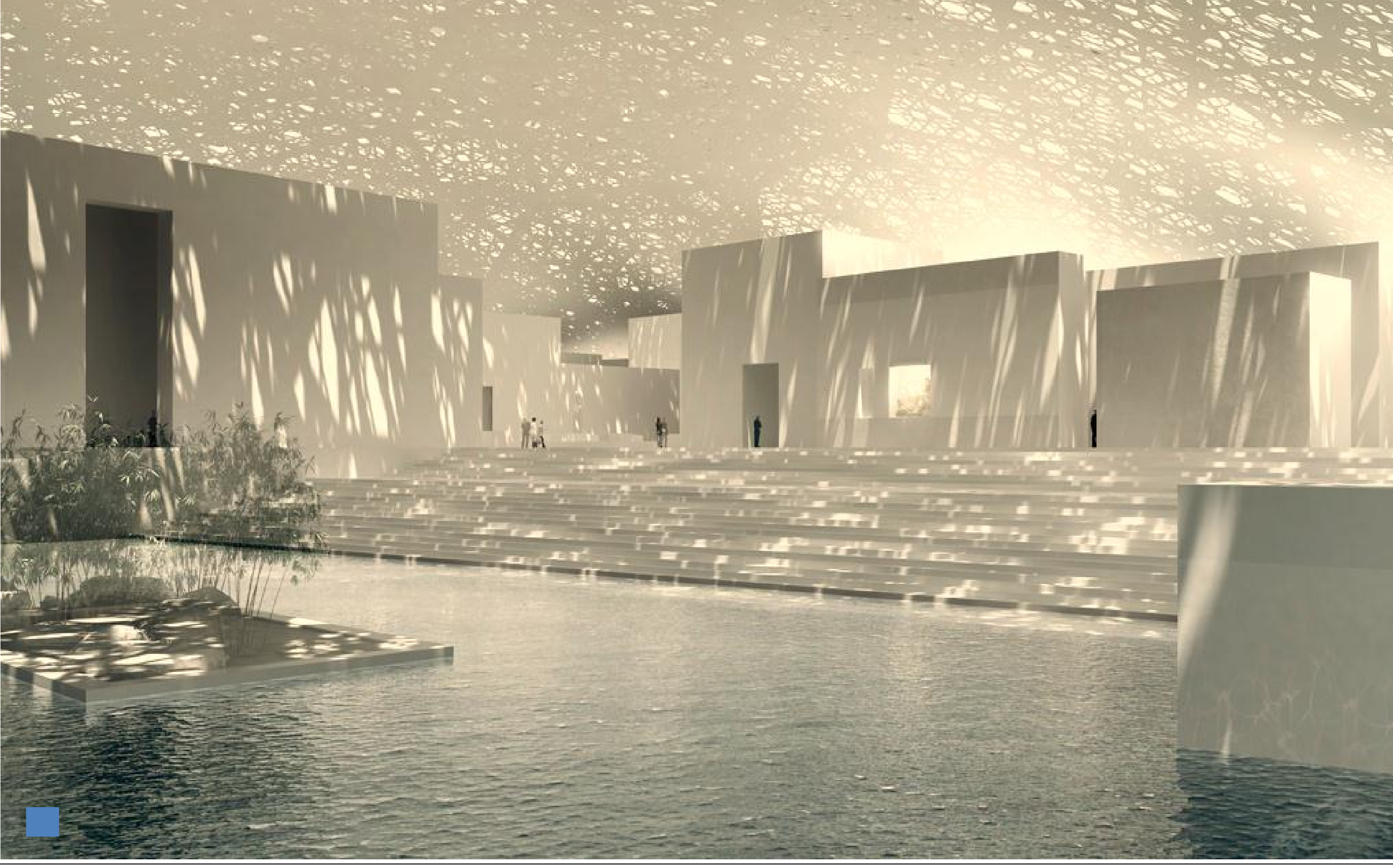
12th International Radiance Workshop – NREL Golden, CO

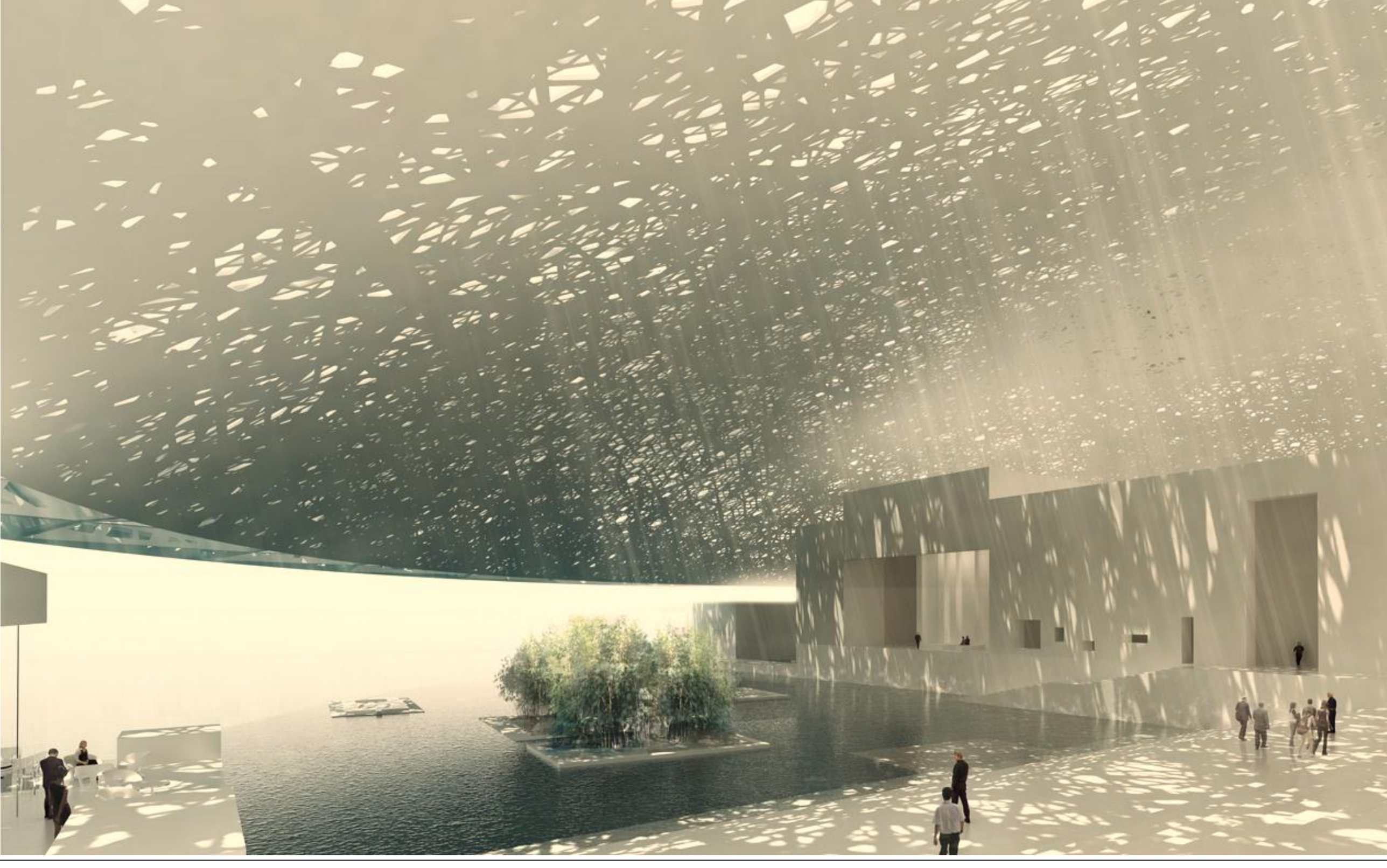
Daylighting Case Studies:

L O U V R E A B U D H A B I

Chris Coulter, Buro Happold







WORKS OF ART ON PAPER:	AVERAGE ILLUMINANCE
Works on paper with colored media Any media on a degraded support Color photo prints and transparencies	50 lux
Works on paper with black and white media only Black and white photographs	100 lux
TEXTILES:	
All textiles (costumes, tapestries, etc)	50 lux
PAINTINGS:	
Oil and tempera paintings	200 lux
Thinly covered paintings on unprimed canvas Paintings in distemper media or gouache, miniatures	50 lux
OBJECTS:	
Objects with painted, dyed or polychromed surfaces Upholstered furniture Unstable glass	50 lux

Basis of analysis: oil paintings with 200 lux sensitivity.

Typically, we would design for cumulative annual exposure (lux-hrs/yr).

200 lux x 3000 hours = 600,000 lux-hrs

300 lux x 2000 hours = 600,000 lux-hrs

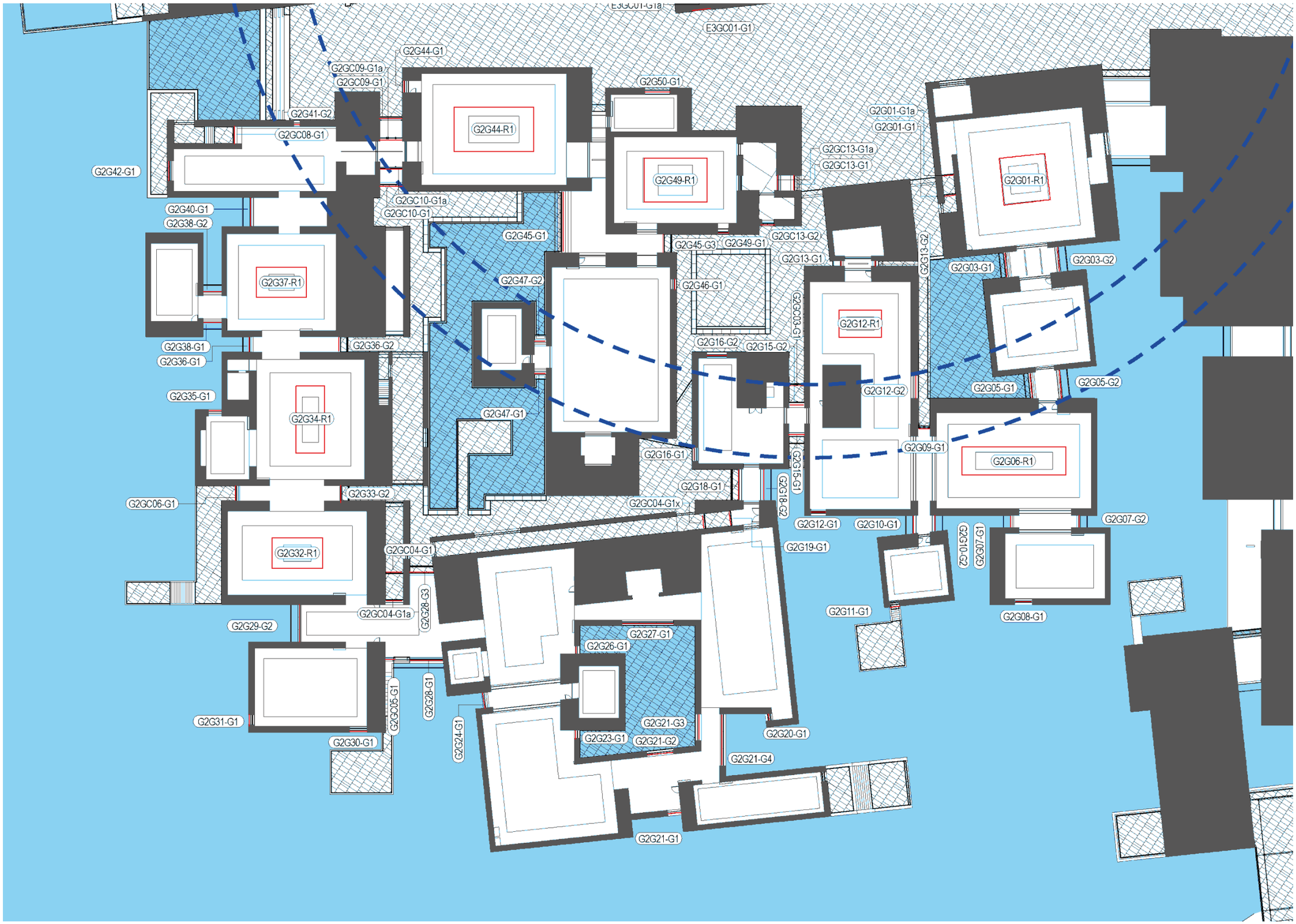
Client's museography team requested that exposure be represented as average annual illuminance.

This both simplified and complicated the analysis.
Depending on the museum's open hours, the average illuminances can change significantly.

Original assumption museum open 9a-6p 4 days/wk, 9a-10p 2 days/wk
~ 3250 hours annually

2 months ago, told open '10a-10p'
~ 4400 hours annually

Apertures Under Study



Master Glazing Schedule

Aperture ID	Glass Type	Glass VLT	Dome Reduction Factor	Mashrabiya	Diffusing Shade VLT	Screening Shade VLT
G2G01G1	GL-2A	5%	3.1%	N	42%	29%
G2G01R1	GL-R2	60%	3.9%	N	42%	29%
G2G03G1	GL-3	60%	3.6%	Y	42%	29%
G2G03G2	GL-3	60%	12.5%	Y	42%	29%
G2G05G1	GL-3	60%	13.6%	Y	17%	29%
G2G05G2	GL-3	60%	58.5%	Y	17%	29%
G2G06R1	GL-R1	60%	95.1%	N	8%	29%
G2G07G1	GL-3	60%	100.0%	Y	17%	29%
G2G07G2	GL-3	60%	98.0%	Y	17%	29%
G2G08G1	GL-1	60%	100.0%	N	17%	29%
G2G09G1	GL-5A	5%	12.4%	N	42%	29%
G2G10G1	GL-3	60%	99.9%	Y	17%	29%
G2G10G2	GL-3	60%	100.0%	Y	17%	29%
G2G11G1	GL-1	60%	100.0%	N	17%	29%
G2G12G1	GL-1	60%	100.0%	N	17%	29%
G2G12G2	GL-2	60%	11.2%	N	42%	29%
G2G12R1	GL-R2	60%	4.6%	N	42%	29%
G2G13G1	GL-3	60%	3.4%	Y	42%	29%
G2G13G2	GL-3	60%	5.3%	Y	42%	29%
G2G15G1	GL-3	60%	63.1%	Y	17%	29%
G2G16G1	GL-1	60%	70.2%	N	17%	29%
G2G16G2	GL-1	60%	5.3%	N	42%	29%
G2GC03G1	GL-2	60%	6.8%	N	42%	29%
G2G18G1	GL-3	60%	95.5%	Y	17%	29%
G2G18G2	GL-3	60%	92.2%	Y	17%	29%
G2G19G1	GL-1	60%	86.9%	N	17%	29%
G2G20G1	GL-1	60%	100.0%	N	17%	29%
G2G21G1	GL-1	60%	100.0%	N	17%	29%
G2G21G2	GL-1	60%	100.0%	N	17%	29%
G2G21G3	GL-1	60%	100.0%	N	17%	29%
G2G21G4	GL-1A	60%	100.0%	N	17%	29%
G2G22G2	GL-1	60%	100.0%	N	17%	29%
G2G23G1	GL-1	60%	100.0%	N	17%	29%
G2G24G1	GL-3	60%	100.0%	Y	17%	29%
G2G26G1	GL-1	60%	100.0%	N	17%	29%
G2G27G1	GL-1	60%	100.0%	N	17%	29%

Aperture ID	Glass Type	Glass VLT	Dome Reduction Factor	Mashrabiya	Diffusing Shade VLT	Screening Shade VLT
G2G44G1	GL-2	60%	14.9%	N	42%	29%
G2G44R1	GL-R2A	60%	2.3%	N	42%	29%
G2G50G1	GL-2	60%	5.9%	N	42%	29%
G2G49G1	GL-2	60%	2.3%	N	42%	29%
G2G49R1	GL-2	60%	1.7%	N	42%	29%
G2GC13G1	GL-2A	5%	3.1%	N	42%	29%
G2GC13G2	GL-2	60%	4.8%	N	42%	29%
G2G45G1	GL-3	60%	4.3%	Y	42%	29%
G2G45G2	GL-3	60%	7.6%	Y	42%	29%
G2G45G3	GL-3	60%	4.8%	Y	42%	29%
G2G46G1	GL-2	60%	5.2%	N	42%	29%
G2G47G1	GL-3	60%	75.2%	Y	17%	29%
G2G47G2	GL-3	60%	7.1%	Y	42%	29%
G2G28G1	GL-3	60%	100.0%	Y	17%	29%
G2G28G3	GL-3	60%	97.4%	Y	17%	29%
G2G29G2	GL-1	60%	100.0%	Y	17%	29%
G2GC05G1	GL-1	60%	100.0%	N	17%	29%
G2G30G1	GL-1	60%	100.0%	N	17%	29%
G2G31G1	GL-1	60%	100.0%	N	17%	29%
G2G33G2	GL-3	60%	99.6%	Y	17%	29%
G2G32R1	GL-R1	60%	100.0%	N	13%	29%
G2GC06G1	GL-1	60%	100.0%	N	17%	29%
G2G34R1	GL-R1	60%	100.0%	N	13%	29%
G2G36G1	GL-3	60%	100.0%	Y	17%	29%
G2G36G2	GL-3	60%	87.4%	Y	17%	29%
G2G35G1	GL-1	60%	100.0%	N	17%	29%
G2G37R1	GL-R1	60%	100.0%	N	13%	29%
G2G38G1	GL-3	60%	100.0%	Y	17%	29%
G2G38G2	GL-3	60%	99.9%	Y	17%	29%
G2G40G1	GL-3	60%	100.0%	Y	17%	29%
G2GC09G1	GL-2	60%	9.0%	N	17%	29%
G2GC10G1	GL-5	5%	10.2%	N	17%	29%
G2G41G2	GL-1	60%	36.2%	N	17%	29%
G2G42G1	GL-1	60%	100.0%	N	17%	29%
G2GC08G1	GL-1	60%	80.7%	N	17%	29%

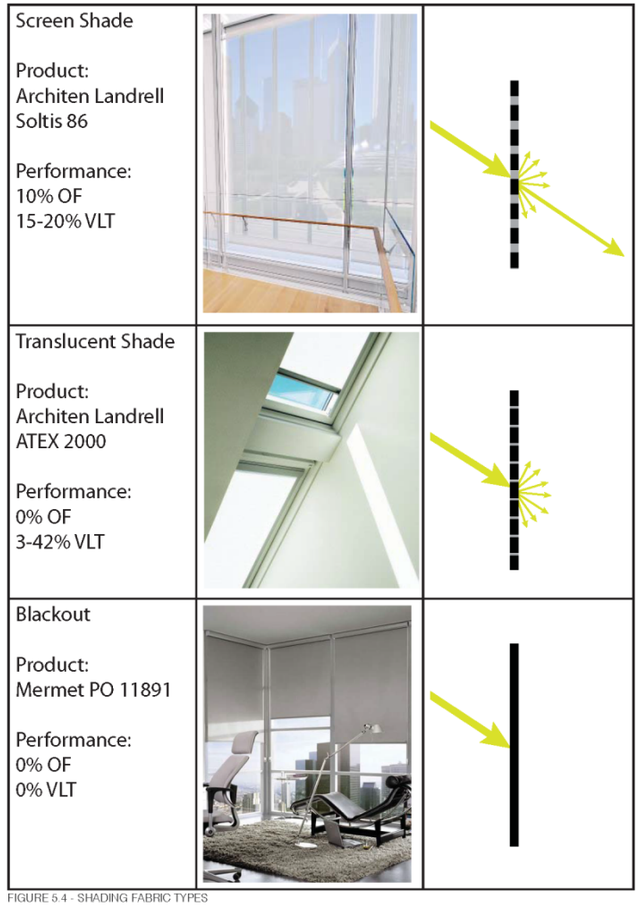
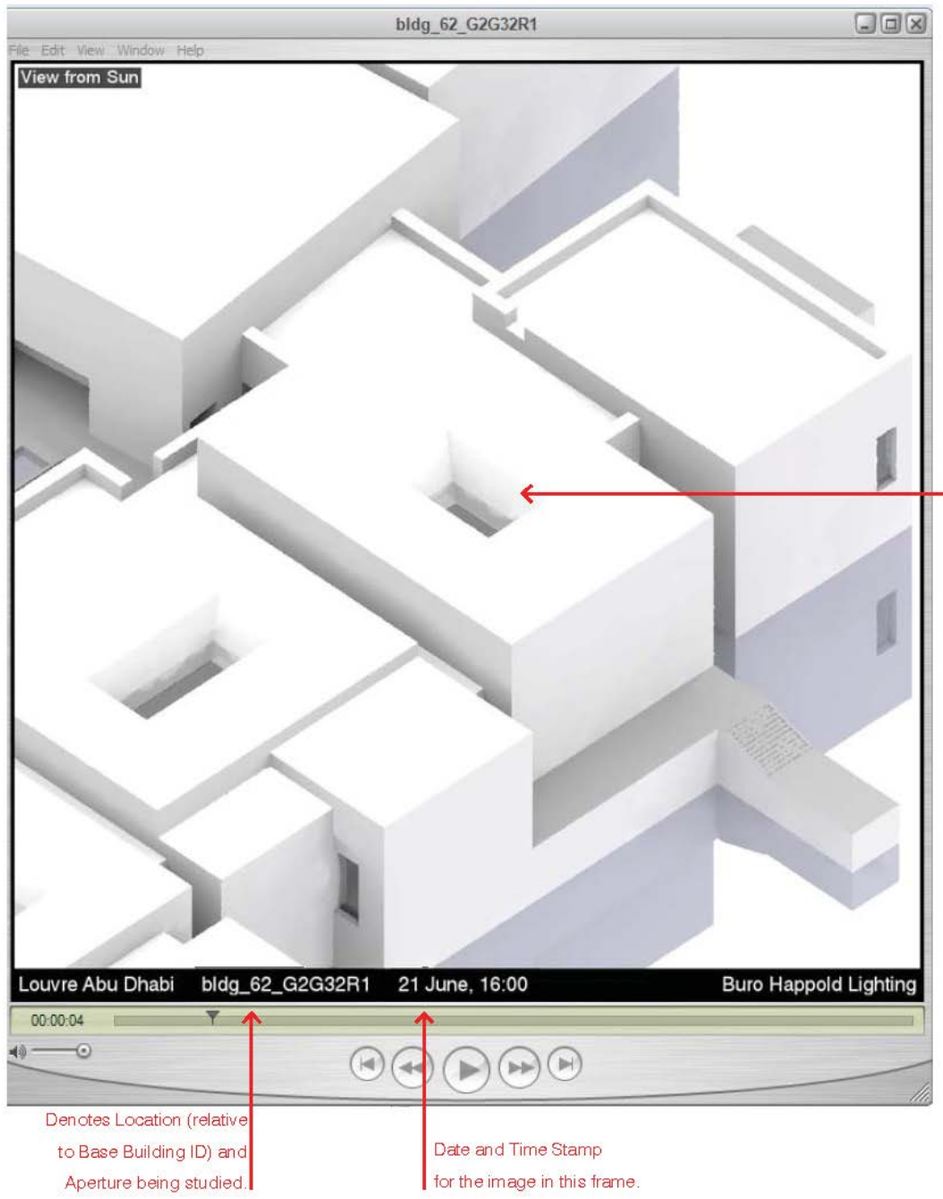
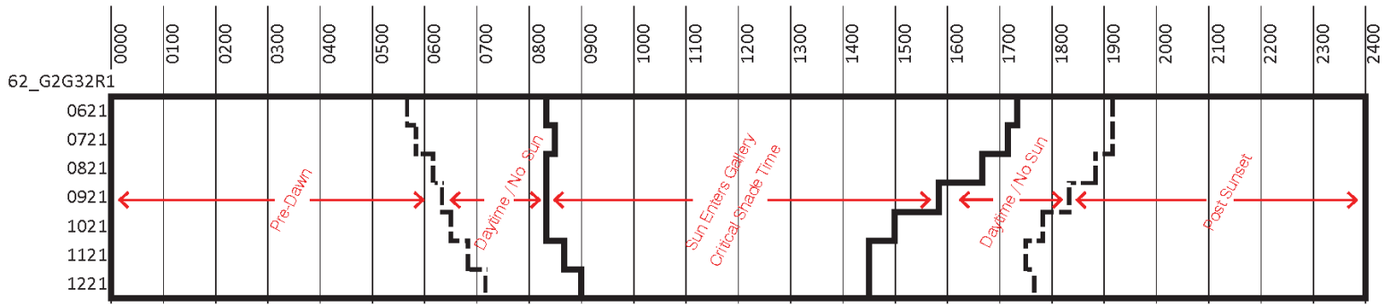
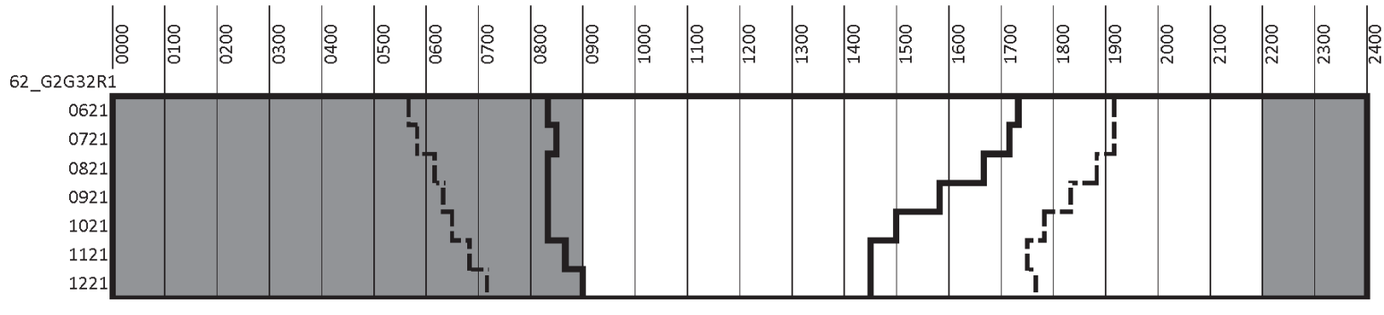


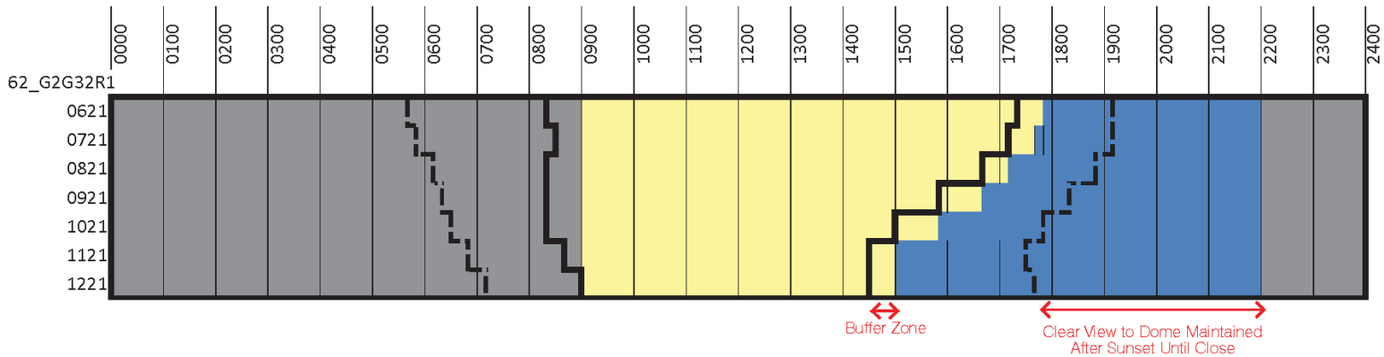
FIGURE 5.4 - SHADING FABRIC TYPES

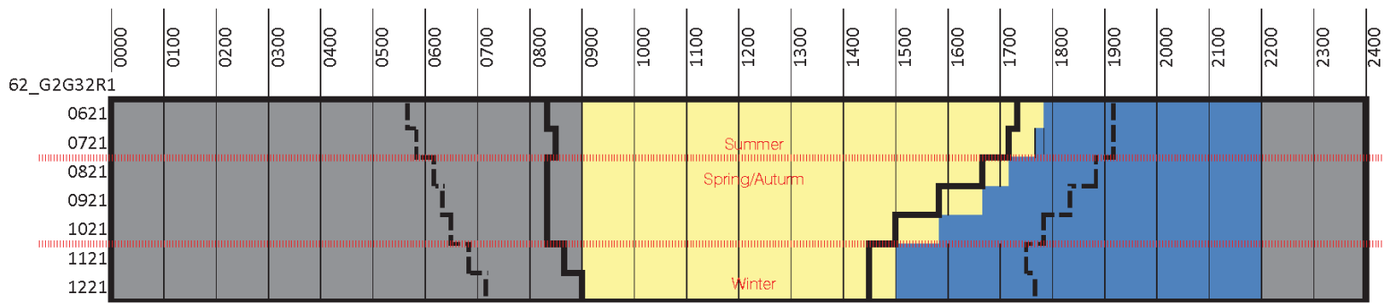
Aperture Shading Schedules



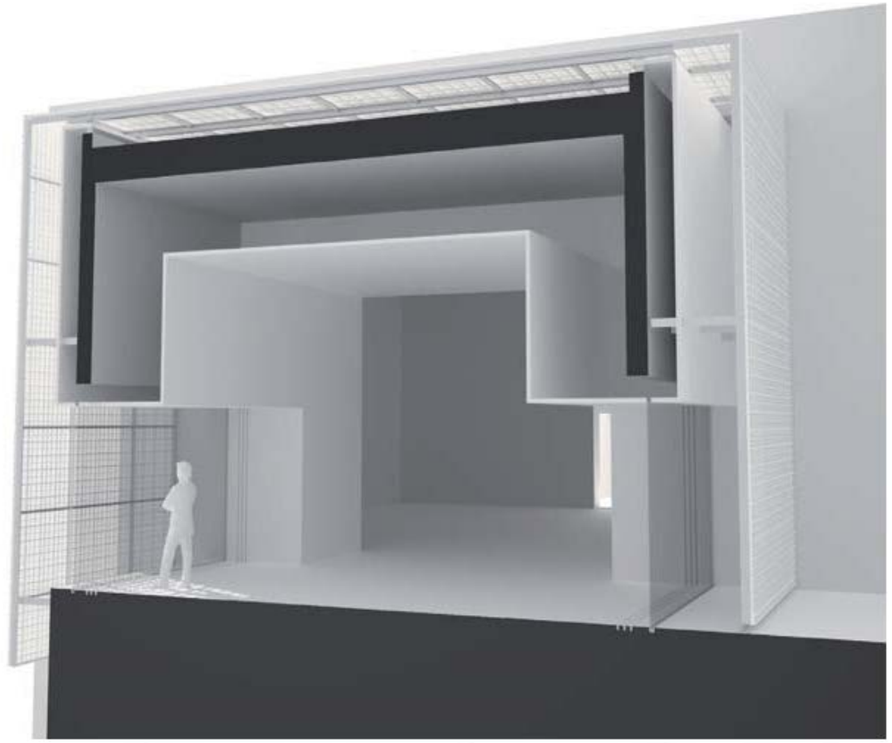




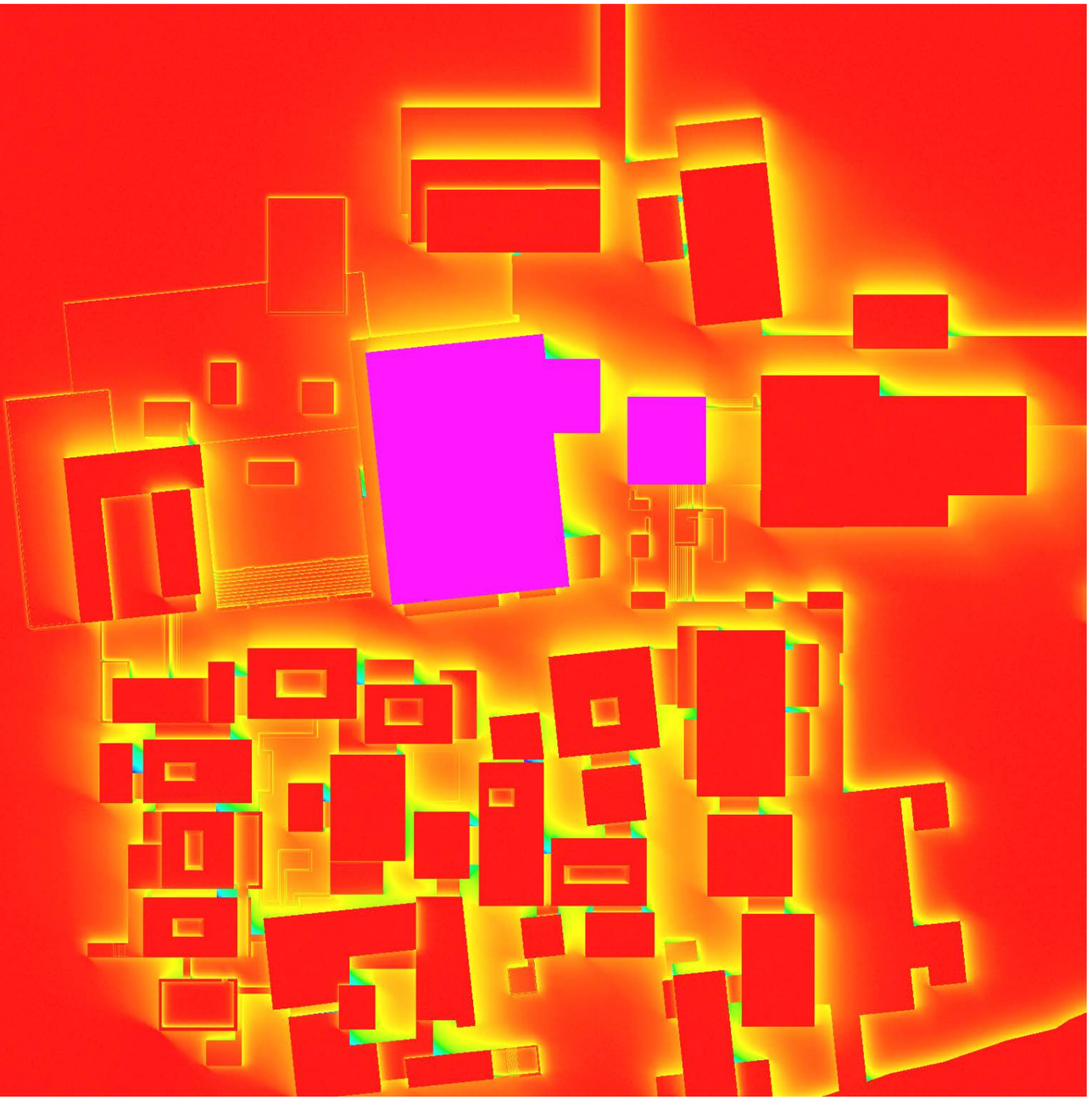


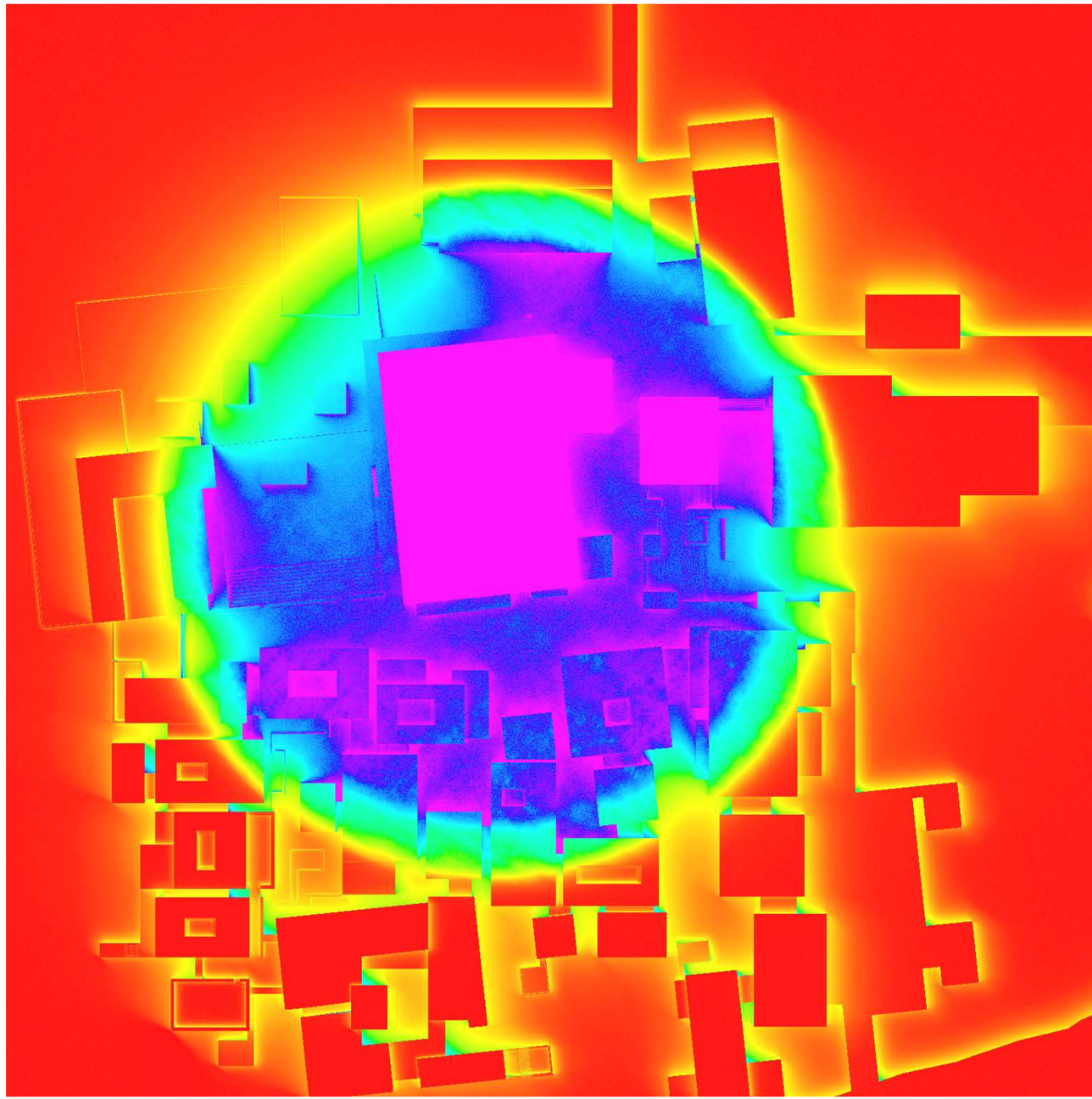


Mashrabiya Shading Impact

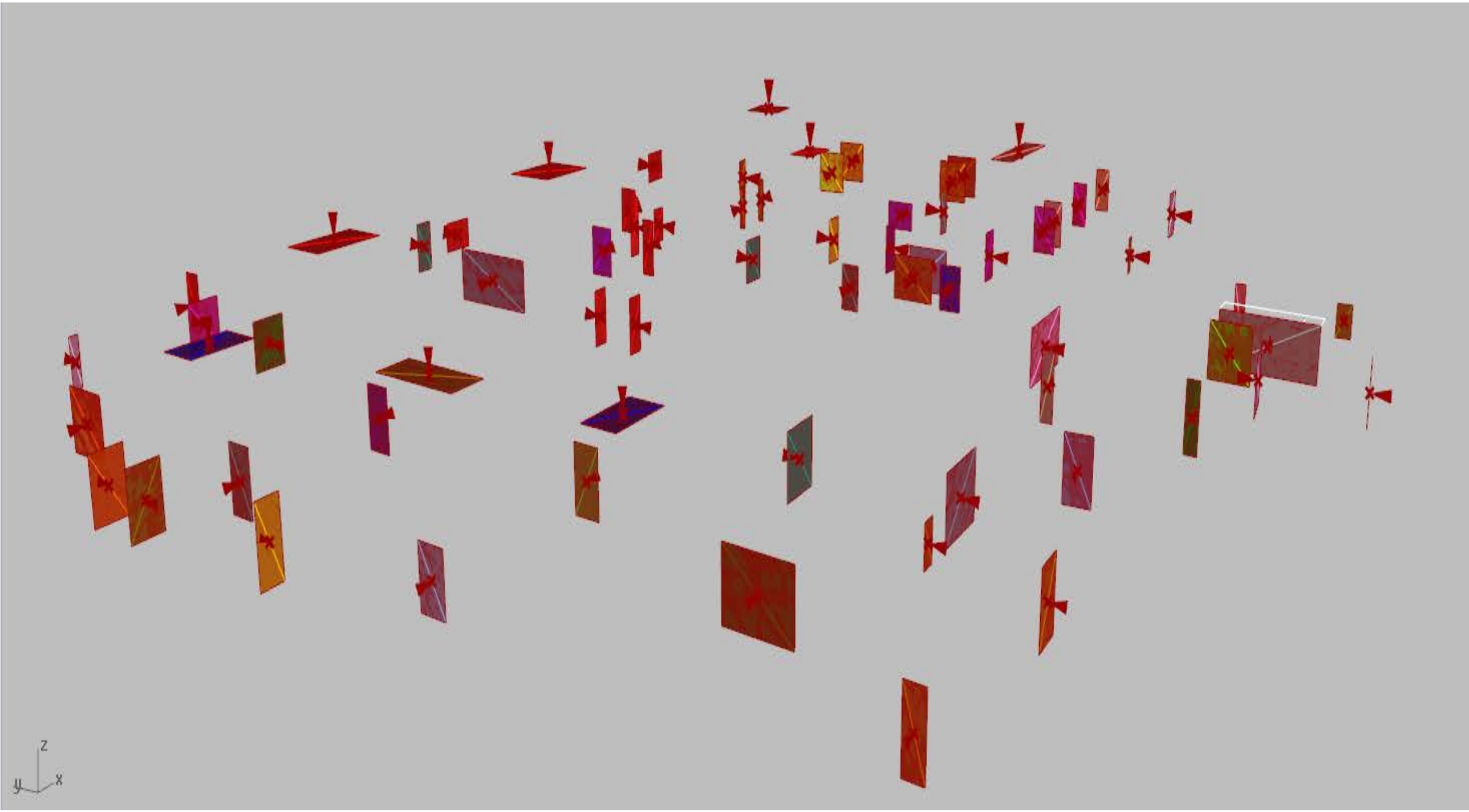


Dome Shading Impact





Dome Shading Impact - View Setup w/ Rhino + Grasshopper



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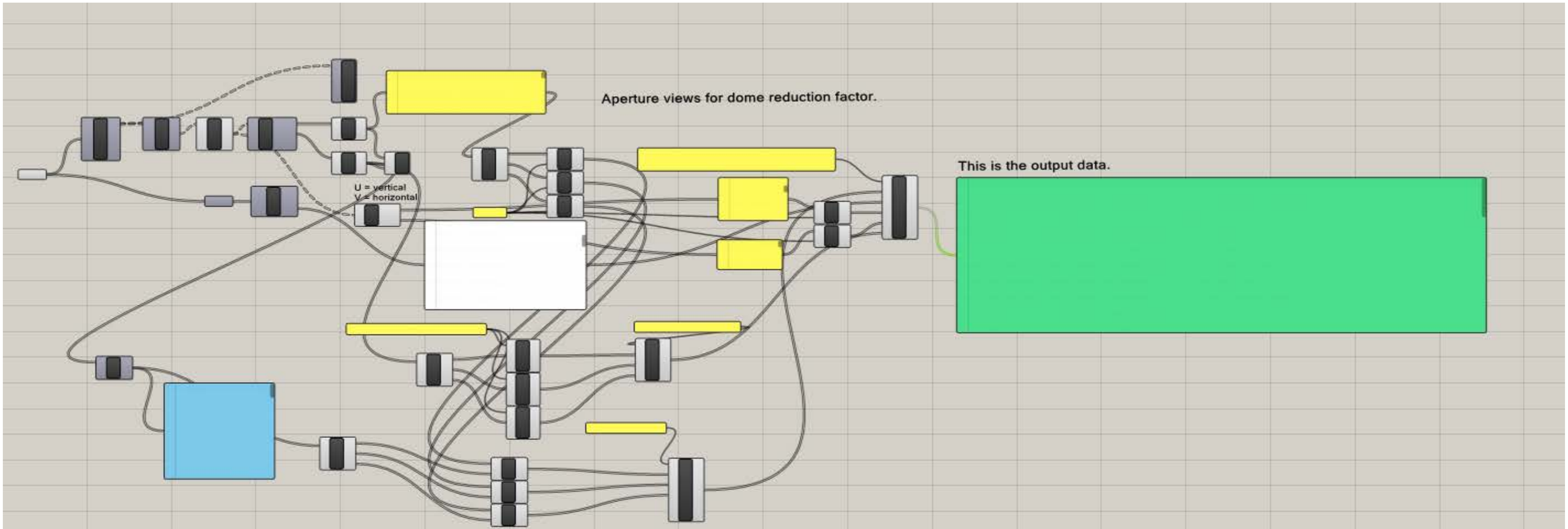
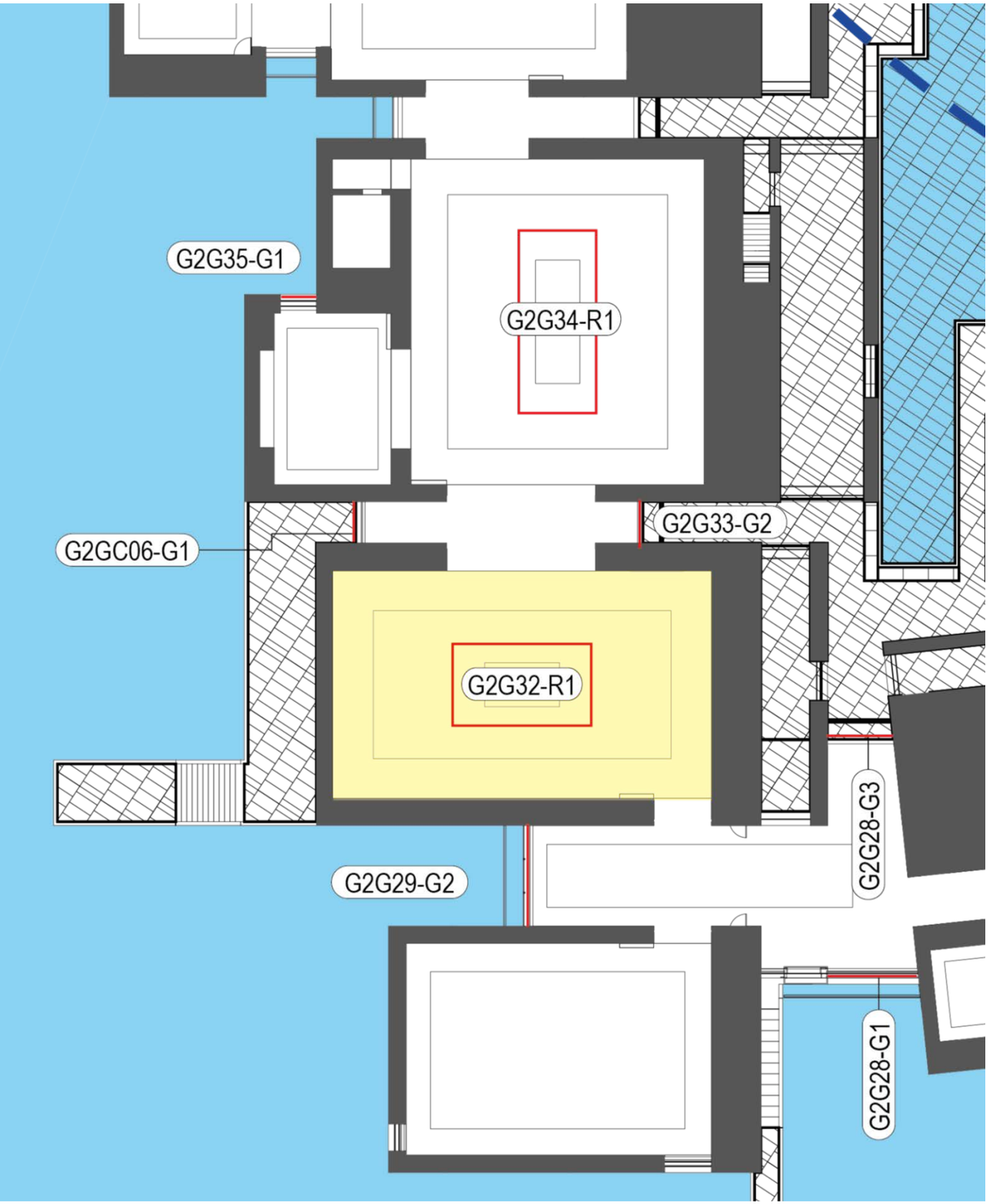


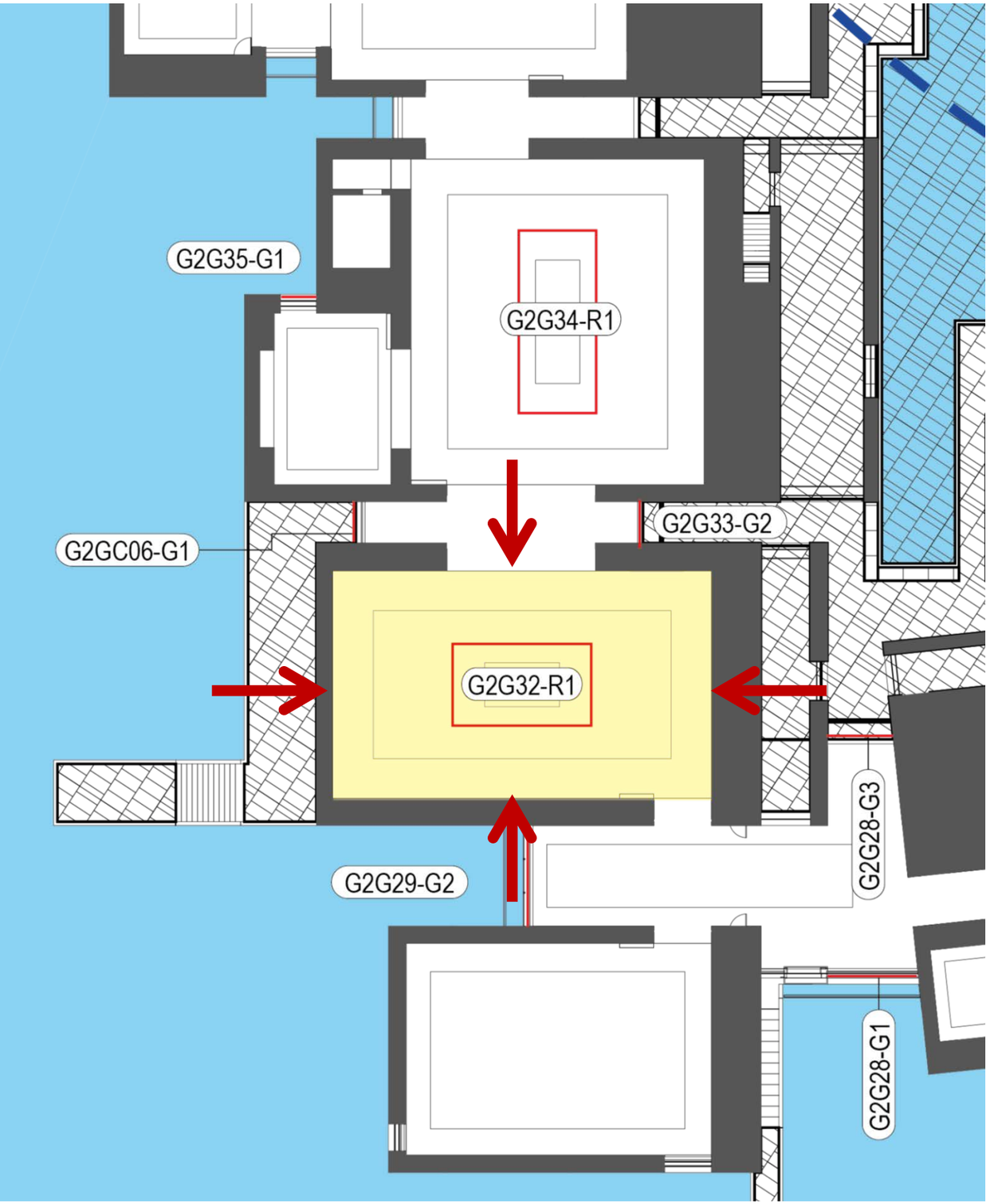

```
 0 bldg_3-2_G2G06-R1 -vp 155.82653125   242.551070313    7.2  -vv  12.88425  -vh  3.115234375 -vd 0    0    -1
 1 bldg_3-5_G2G12-R1 -vp 132.634097656   263.250929688    8.5  -vv  5.327898438  -vh  3.102390625 -vd 0    0    -1
 2 bldg_6-5_G2G37-R1 -vp 45.196527344   269.62596875    8  -vv  3.55  -vh  5.9 -vd 0    0    -1
 3 bldg_3-3_G2G07-G2 -vp 166.52653125   233.374890625    2  -vv  1.8  -vh  4 -vd -1    0    0
 4 bldg_3-3_G2G07-G1 -vp 154.62653125   233.374890625    2  -vv  1.8  -vh  4 -vd 1    0    0
 5 bldg_3-3_G2G08-G1 -vp 157.274070313   220.125921875    2  -vv  4  -vh  2.594921875 -vd 0    1    0
 6 bldg_4-0_G2G18-G2 -vp 119.137117188   238.936632813    1.75  -vv  4.678578125  -vh  3.5 -vd -1    0    0
 7 bldg_4-0_G2G18-G1 -vp 113.226367188   238.936632813    1.75  -vv  4.678578125  -vh  3.5 -vd 1    0    0
 8 bldg_3-0_ST2G11-G2 -vp 146.465066190679   300.693677829835    1.5  -vv  3  -vh  4.0000073 -vd 0.1    -0.99    0
 9 bldg_5-5_G2G46-G1 -vp 105.22653125   269.22990625    2.75  -vv  1.5  -vh  4.5 -vd -1    0    0
10 bldg_5-4_G2G45-G1 -vp 86.5312934933137   278.623882224999    2  -vv  9.300004876  -vh  4 -vd 1    0    0
11 bldg_5-4_G2G45-G3 -vp 104.03190625   275.37490625    2  -vv  2.8  -vh  4 -vd -1    0    0
12 bldg_5-1_G2G50-G1 -vp 101.976402344   299.5313125    1.25  -vv  2.500000188  -vh  3.799257813 -vd 0    -1    0
13 bldg_5-4_G2G45-G2 -vp 93.141527344   296.32590625    2  -vv  4  -vh  2.070007813 -vd 0    -1    0
14 bldg_4-2_G2G22-G2 -vp 128.157979221742   194.950713152939    1.25  -vv  1.500155063  -vh  2.5 -vd -0.99    -0.1    0
15 bldg_4-1_G2G21-G4 -vp 112.883390625   199.5625    2  -vv  9.42684375  -vh  4 -vd -1    0    0
16 bldg_4-1_G2G21-G2 -vp 102.296531440767   199.444474747518    2  -vv  4  -vh  4.0000073 -vd 0.1    -0.99    0
17 bldg_4-5_G2G27-G1 -vp 100.52653125   217.075921875    2  -vv  4  -vh  7.8 -vd 0    1    0
```

Calculation Process



Apertures that potentially contribute to a Gallery's annual illuminance were identified.

Calculation Process



Apertures that potentially contribute to a Gallery's annual illuminance were identified.

Daylight coefficients for each aperture were calculated for each surface under study (4 walls + floor).

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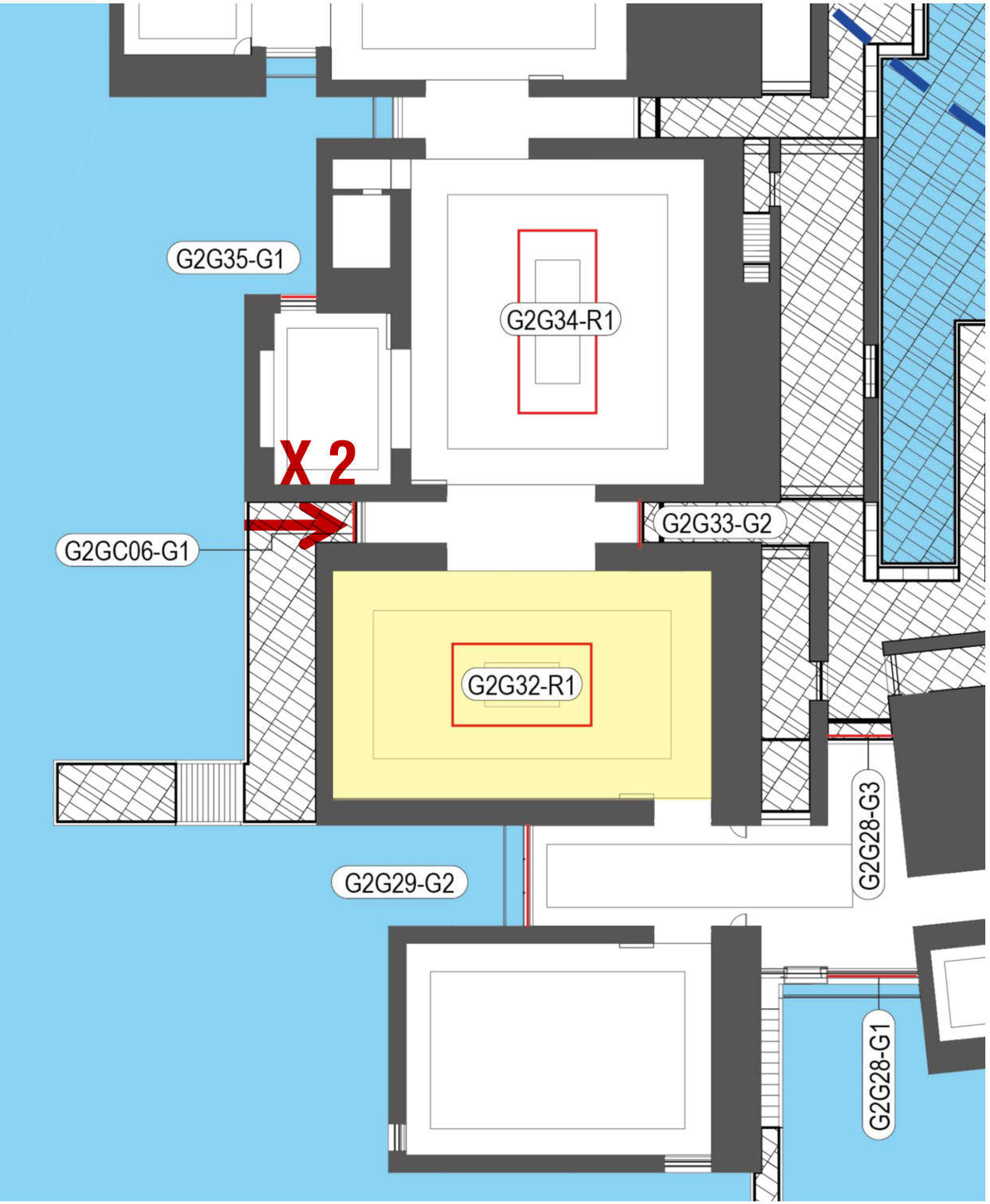

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For each aperture, two sets of daylight coefficients were calculated:

- **Unshaded condition, clear glazing (radiance glass material)**
- **Sun blocking shade, diffuse transmission (radiance trans material)**

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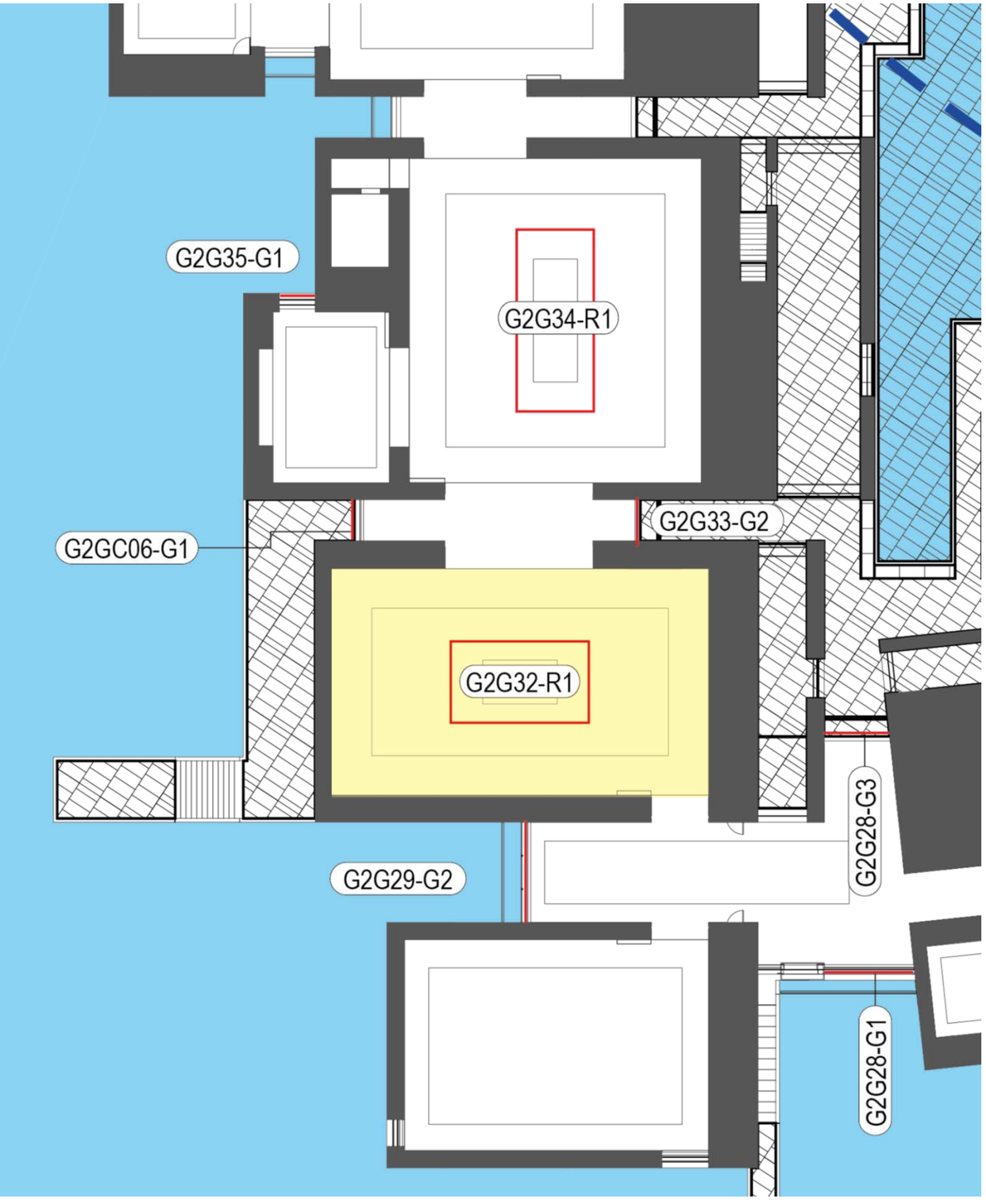

Apertures that potentially contribute to a Gallery's annual illuminance were identified.

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For each aperture, two sets of daylight coefficients were calculated:
- **Unshaded condition, clear glazing (radiance glass material)**
- **Sun blocking shade, diffuse transmission (radiance trans material)**

For example, Gallery 13:
- **8 studied apertures**
- **2 glazing conditions**
- **5 surfaces**

- **80 simulations per Gallery!!**

Gallery Groupings

Typical DC Script

```
#!/bin/ksh
ncpu=7
gal=g13
DIMS=300

for window in  62_G2G32R1 62_G2G33G2 60_G2G29G2 63_G2G34R1 60_G2G28G1 60_G2G28G3 64_G2G35G1 62_G2GC06G1
do
for ver in  clr trans
do

oconv compiled_${gal}_b${window}_${ver}.rad skies/whitesky.rad > oct/annuals/${gal}_b${window}_${ver}_whitesky.oct

#for view in g62_floorfish
#do
#       echo
#       date
#       echo Start ${window} ${view}
#       time vwrays -ff -x $DIMS -y $DIMS -vf views/${view}.vf |rcontrib -i -fo @rtc.opt -n 7 -ab 3 -ffc $(vwrays -d -x $DIMS -y $DIMS -vf views/${view}.vf) -e MF:2 -f reinhart.cal -b rbin -bn 578 -o pic/patches/${gal}_b${window}_${ver}_${view}_p%03d.hdr -m sky_glow -w oct/annuals/${gal}_b${window}_${ver}_whitesky.oct
#done

for wall in north south east west floor
do
        date
        echo Start ${window} ${wall} ${ver}
        time cat data/${gal}_${wall}.pts | rcontrib -h -I -fo @rtc.opt -n $ncpu -e MF:2 -f reinhart.cal -b rbin -bn 578 -o data/patches/${gal}_b${window}_${ver}_${wall}_p%03d.dat -m sky_glow -w oct/annuals/${gal}_b${window}_${ver}_whitesky.oct
done
done
done
```

Edit Aperture ID

Aperture Specs Referenced from Master File

2R1_east	Gallery #	g13	Set Up Sheet	G2G32R1	60.0%	VLT of glass		8.0%	VLT of diffusing shade			100.0%	Mashrabiya RF	
	Aperture ID	62_G2G32R1			98.0%	Dome RF		15.0%	VLT of screening shade			100.0%	MicroLouver RF	
SP54	Wall	east												
			shade-date	shade-val	0	0	0	0	0	0	0	0	0	
1	1	0.5	1221-0100	0	0	0	0	0	0	0	0	0	0	
1	1	1.5	1221-0200	0	0	0	0	0	0	0	0	0	0	
1	1	2.5	1221-0300	0	0	0	0	0	0	0	0	0	0	
1	1	3.5	1221-0400	0	0	0	0	0	0	0	0	0	0	
1	1	4.5	1221-0500	0	0	0	0	0	0	0	0	0	0	
1	1	5.5	1221-0600	0	0	0	0	0	0	0	0	0	0	
1	1	6.5	1221-0700	0	0	0	0	0	0	0	0	0	0	
1	1	7.5	1221-0800	0	0	0	0	0	0	0	0	0	0	
1	1	8.5	1221-0900	0	0	0	0	0	0	0	0	0	0	
1	1	9.5	1221-1000	0	0	0	0	0	0	0	0	0	0	
1	1	10.5	1221-1100	0	0	0	0	0	0	0	0	0	0	
1	1	11.5	1221-1200	0	0	0	0	0	0	0	0	0	0	
1	1	12.5	1221-1300	0	0	0	0	0	0	0	0	0	0	
1	1	13.5	1221-1400	0	0	0	0	0	0	0	0	0	0	
1	1	14.5	1221-1500	0	0	0	0	0	0	0	0	0	0	
1	1	15.5	1221-1600	0	0	0	0	0	0	0	0	0	0	
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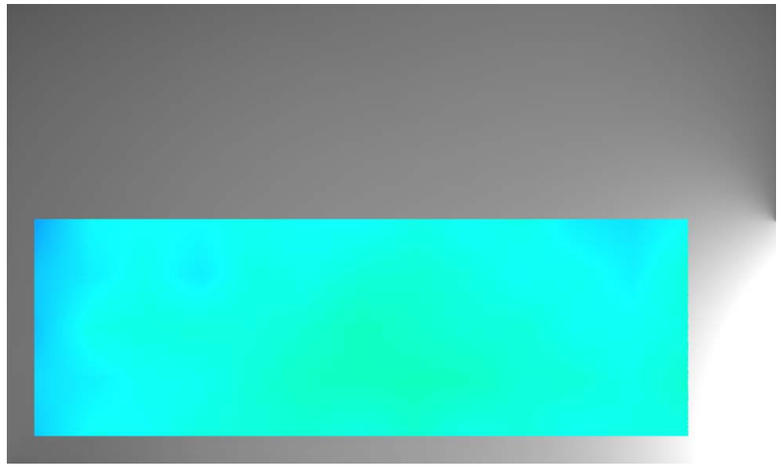
1	1	17.5	1221-1800	0	0	0	0	0	0	0	0	0	0	
1	1	18.5	1221-1900	0	0	0	0	0	0	0	0	0	0	
1	1	19.5	1221-2000	0	0	0	0	0	0	0	0	0	0	
1	1	20.5	1221-2100	0	0	0	0	0	0	0	0	0	0	
1	1	21.5	1221-2200	0	0	0	0	0	0	0	0	0	0	
1	1	22.5	1221-2300	0	0	0	0	0	0	0	0	0	0	
1	1	23.5	1221-2400	0	0	0	0	0	0	0	0	0	0	
1	2	0.5	1221-0100	0	0	0	0	0	0	0	0	0	0	
1	2	1.5	1221-0200	0	0	0	0	0	0	0	0	0	0	
1	2	2.5	1221-0300	0	0	0	0	0	0	0	0	0	0	
1	2	3.5	1221-0400	0	0	0	0	0	0	0	0	0	0	
1	2	4.5	1221-0500	0	0	0	0	0	0	0	0	0	0	
1	2	5.5	1221-0600	0	0	0	0	0	0	0	0	0	0	

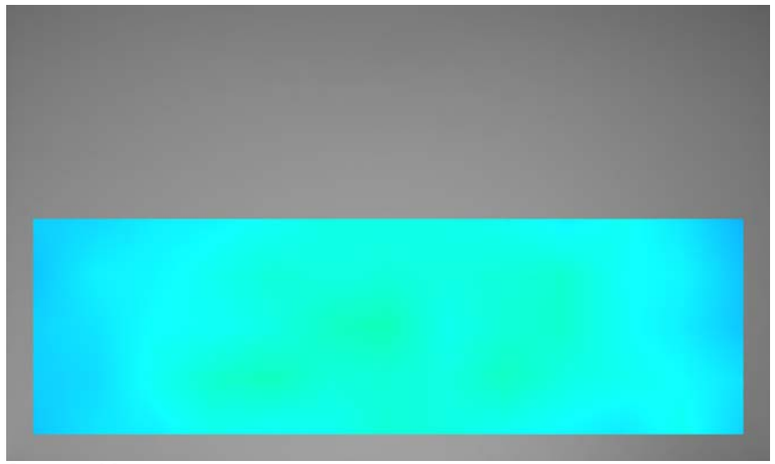
Aperture Schade Schedule Loaded

Annual Average Illuminance Analysis – 'MAX' Lux Scene

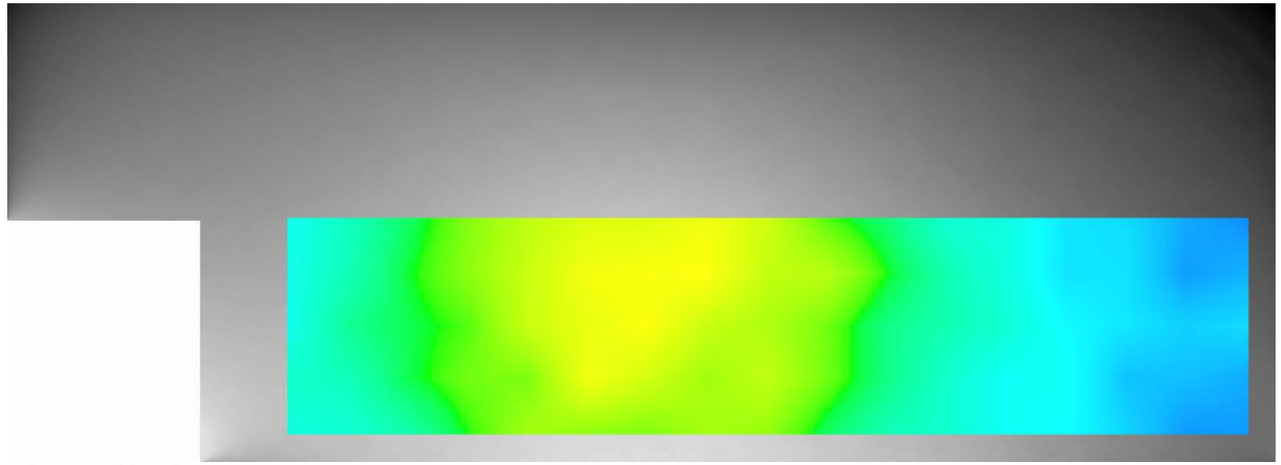


Gallery 13 – East Wall

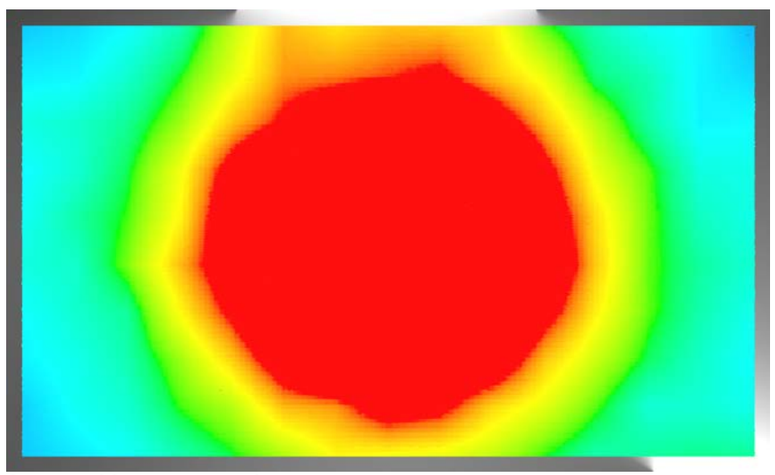
Gallery 13 – North Wall



Gallery 13 – West Wall

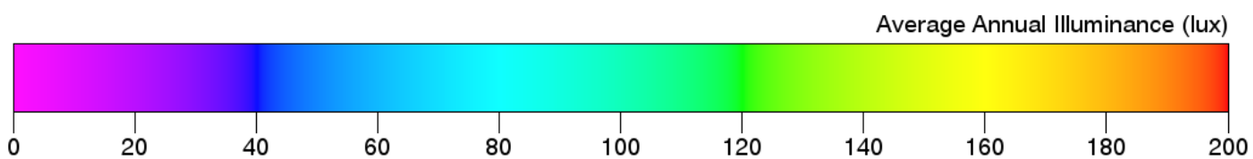


Gallery 13 – South Wall

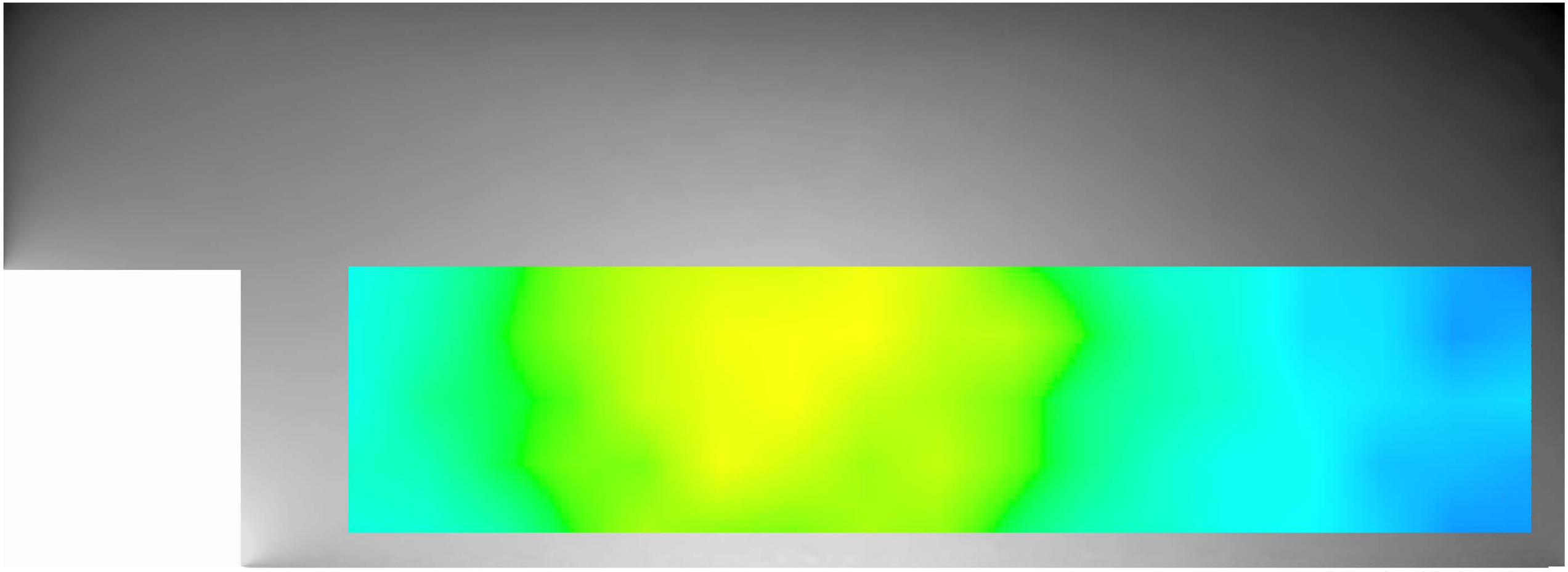


Gallery 13 – Floor (+1 m)

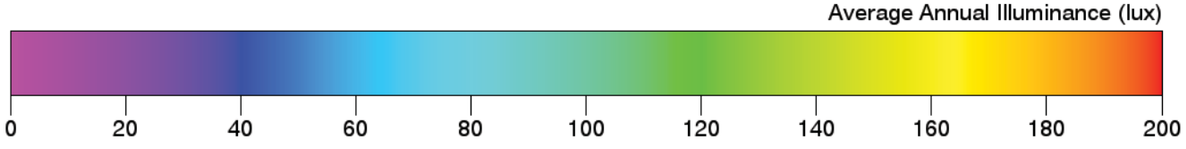
	Average Annual Lux: Average of Surface	Average Annual Lux: Max Point on Surface	Average Monthly Lux: Max Point on Surface											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East	85	99	53	86	96	106	122	160	127	111	133	99	54	42
North	71	92	49	71	93	105	130	140	137	122	114	69	45	34
West	81	100	47	85	86	106	131	148	143	131	116	102	65	42
South	108	159	75	121	135	194	211	228	213	228	191	157	88	70
Floor	163	385	181	285	338	453	555	580	524	547	434	358	204	157



Annual Average Illuminance Analysis – 'MAX' Lux Scene

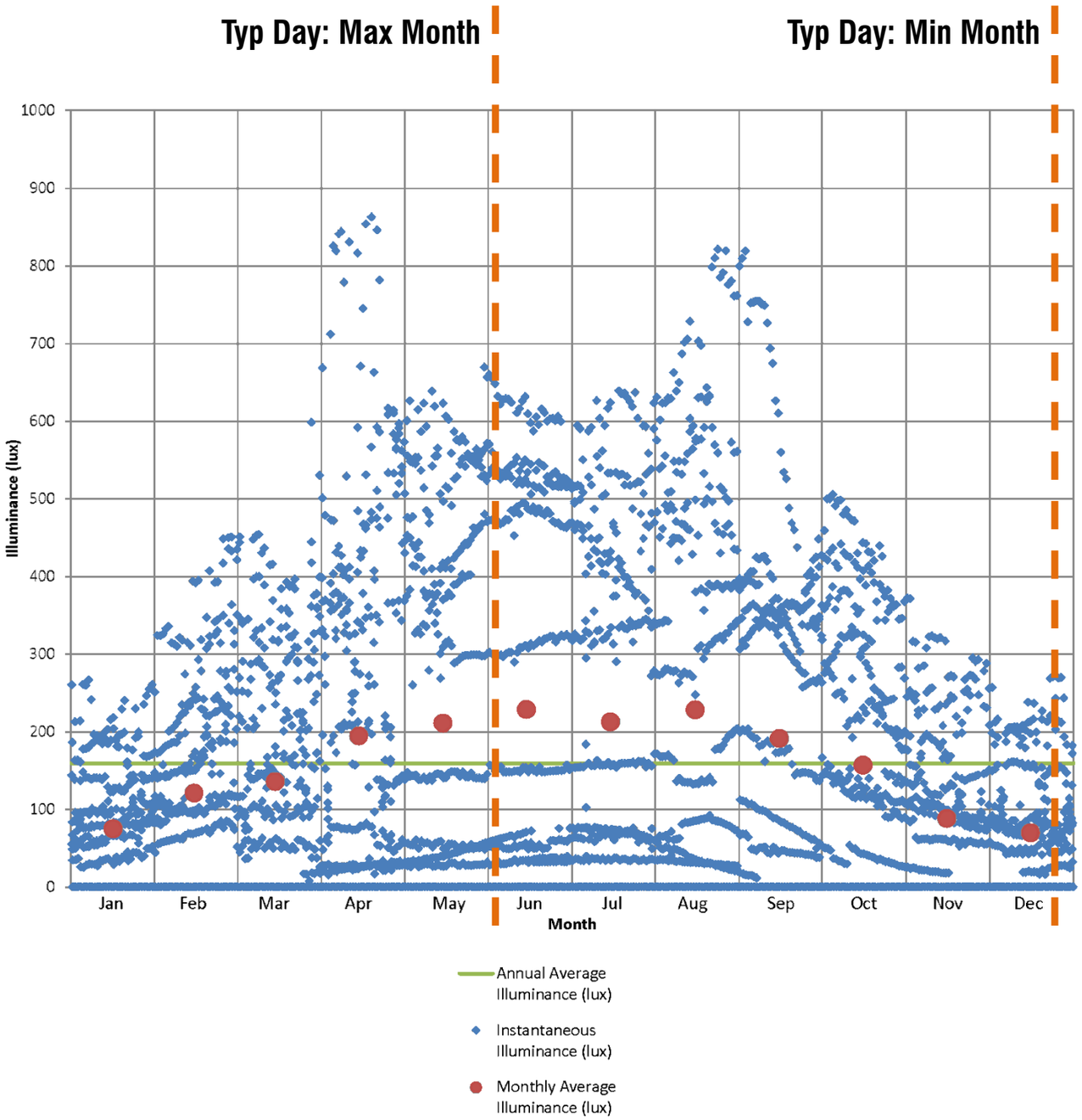


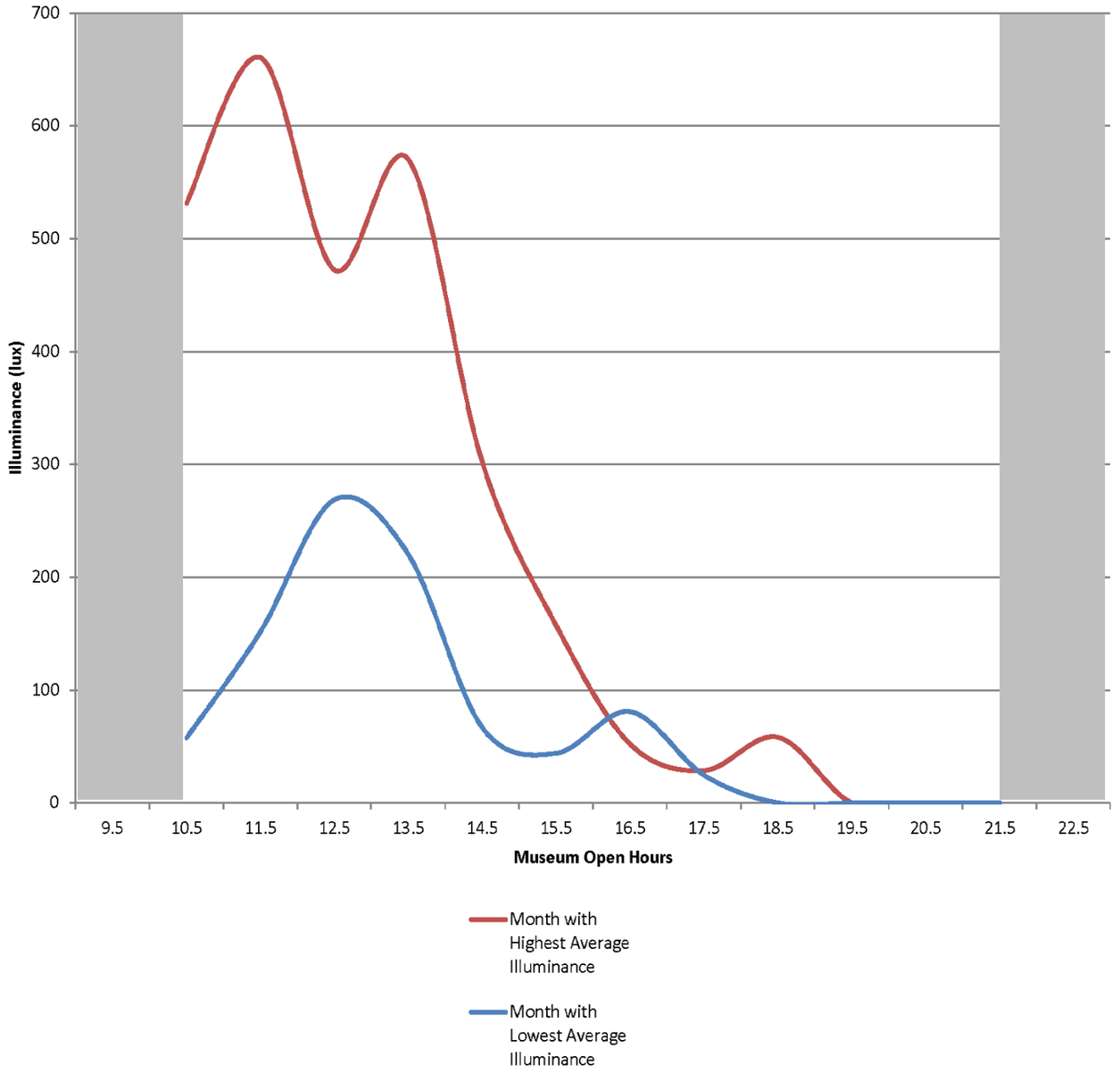
Gallery 13 - South Wall



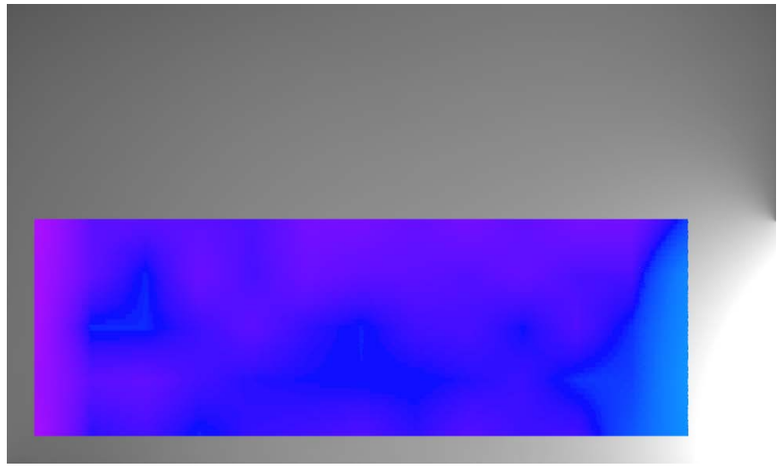
	Average Annual Lux: Average of Surface	Average Annual Lux: Max Point on Surface	Average Monthly Lux: Max Point on Surface											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East	85	99	53	86	96	106	122	160	127	111	133	99	54	42
North	71	92	49	71	93	105	130	140	137	122	114	69	45	34
West	81	100	47	85	86	106	131	148	143	131	116	102	65	42
South	108	159	75	121	135	194	211	228	213	228	191	157	88	70
Floor	163	385	181	285	338	453	555	580	524	547	434	358	204	157

Instantaneous Illuminance Analysis



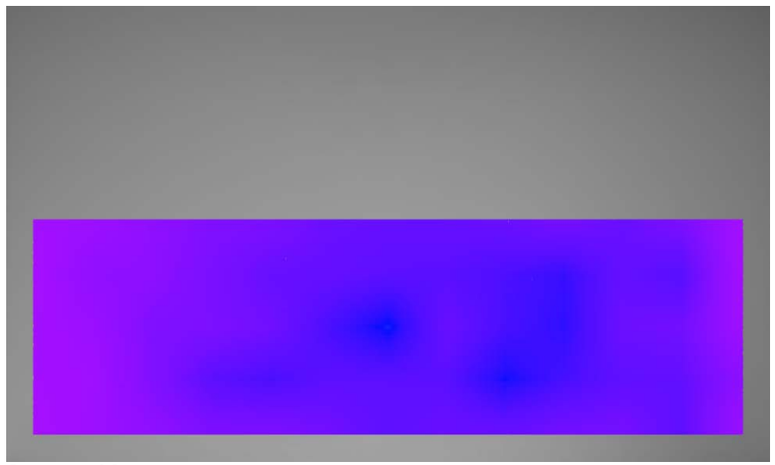


Annual Average Illuminance Analysis – 'MID' Lux Scene

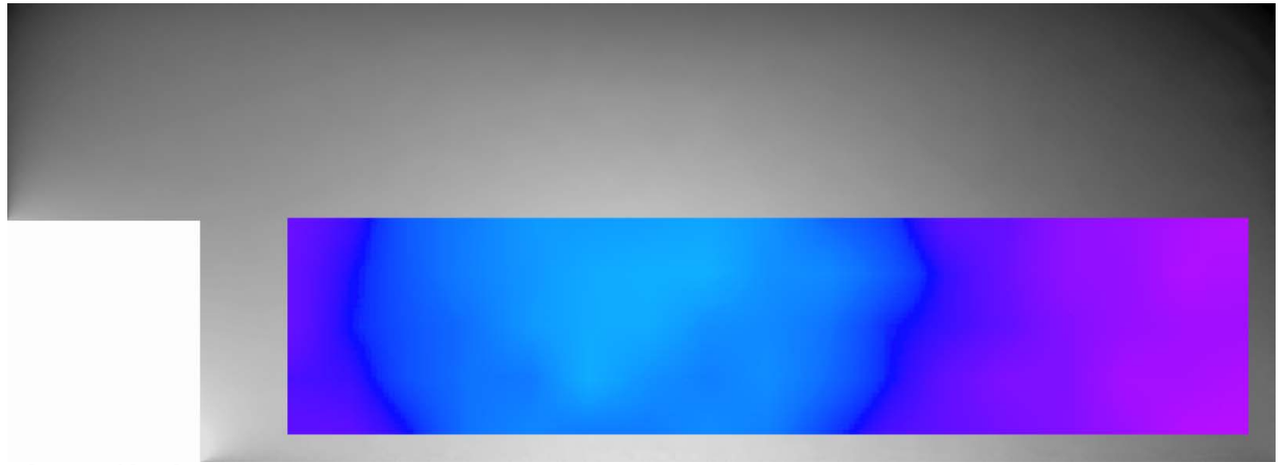


Gallery 13 – East Wall

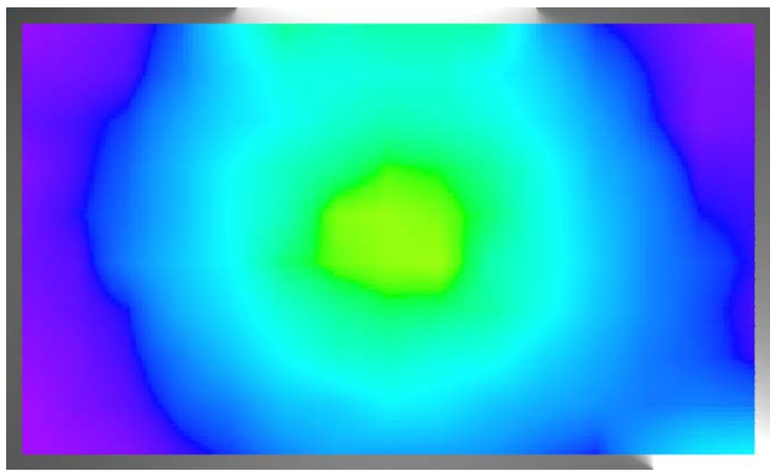
Gallery 13 – North Wall



Gallery 13 – West Wall

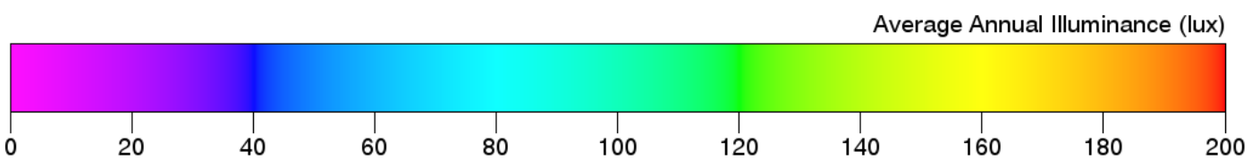


Gallery 13 – South Wall

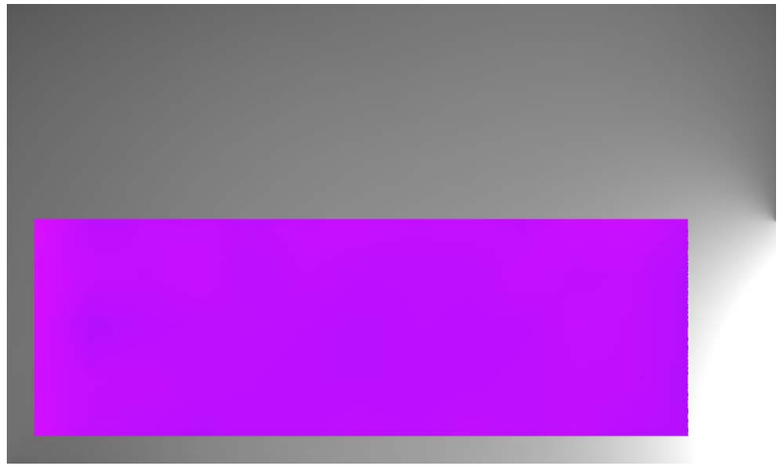


Gallery 13 – Floor (+1 m)

	Average Annual Lux: Average of Surface	Average Annual Lux: Max Point on Surface	Average Monthly Lux: Max Point on Surface											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East	37	52	45	58	50	54	57	56	56	58	56	50	46	41
North	29	36	27	36	35	38	44	41	44	44	44	32	20	24
West	32	41	24	46	34	37	50	58	56	45	43	45	27	21
South	40	58	35	52	51	64	70	76	73	74	68	61	36	30
Floor	64	134	82	124	126	134	183	189	182	165	146	131	78	66

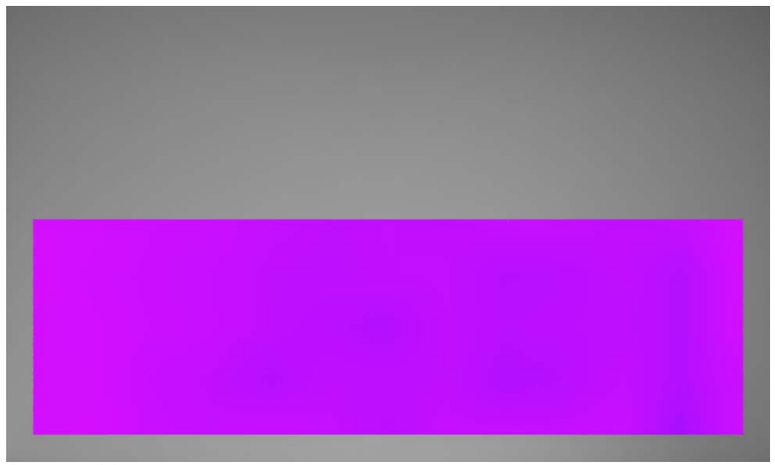


Annual Average Illuminance Analysis – 'MIN' Lux Scene

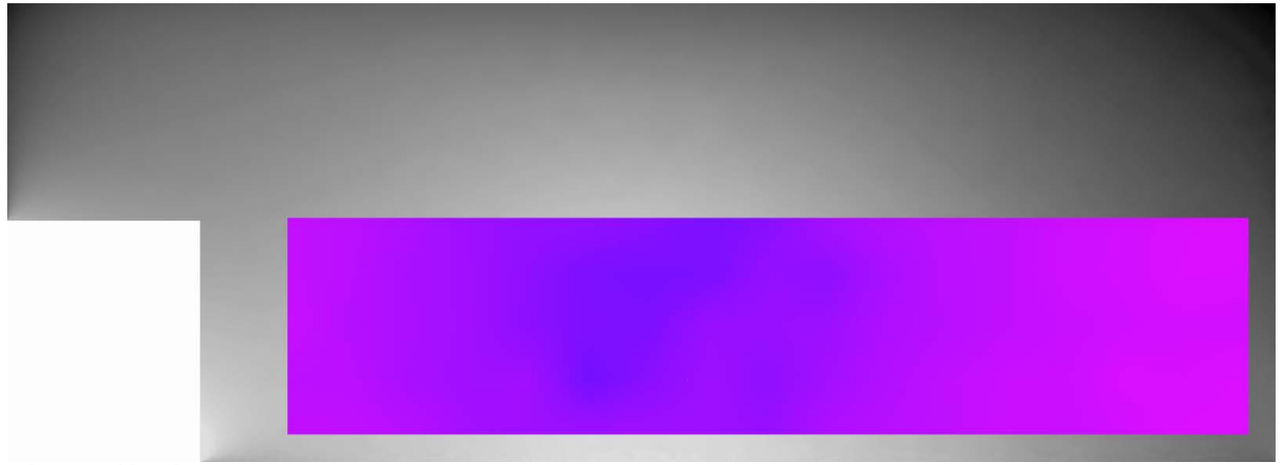


Gallery 13 – East Wall

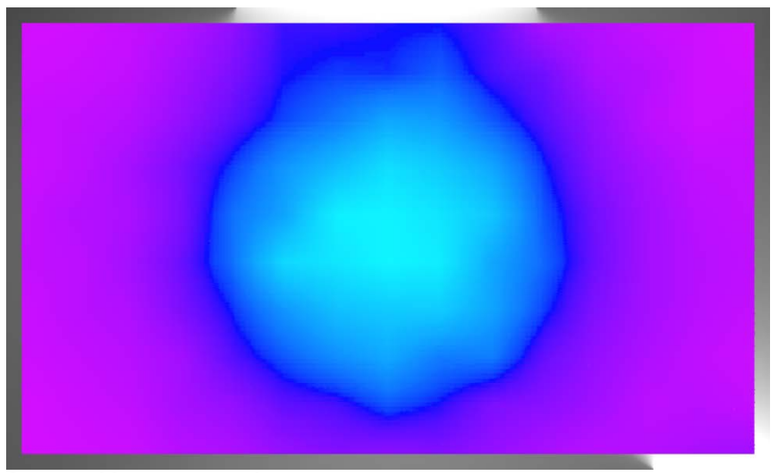
Gallery 13 – North Wall



Gallery 13 – West Wall

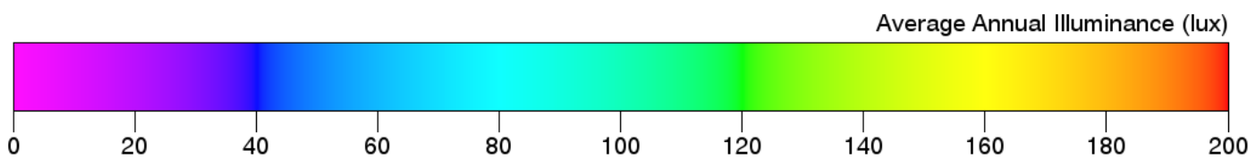


Gallery 13 – South Wall



Gallery 13 – Floor (+1 m)

	Average Annual Lux: Average of Surface	Average Annual Lux: Max Point on Surface	Average Monthly Lux: Max Point on Surface											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East	18	21	13	18	18	22	25	26	26	25	22	30	20	12
North	15	19	13	18	18	21	24	28	28	24	23	15	10	8
West	17	24	14	21	22	25	31	31	28	30	34	25	16	10
South	22	33	16	27	28	37	49	46	48	46	40	33	15	11
Floor	33	76	43	72	70	91	100	107	97	108	81	70	40	34



Lessons Learned

3-Phase method would have reduced calculation time.

Finer sky patch subdivision likely reduces error at shade transitions

Scripts are your friend (and sometimes enemy)

Excel macros streamline repeatable tasks and reduce user error

Need a better database tool, Excel has limitations for large data sets.

Grasshopper to parse model information for views/calc points


Thank You, Questions?