Dynamic Visualization of Annual Building Simulation Data

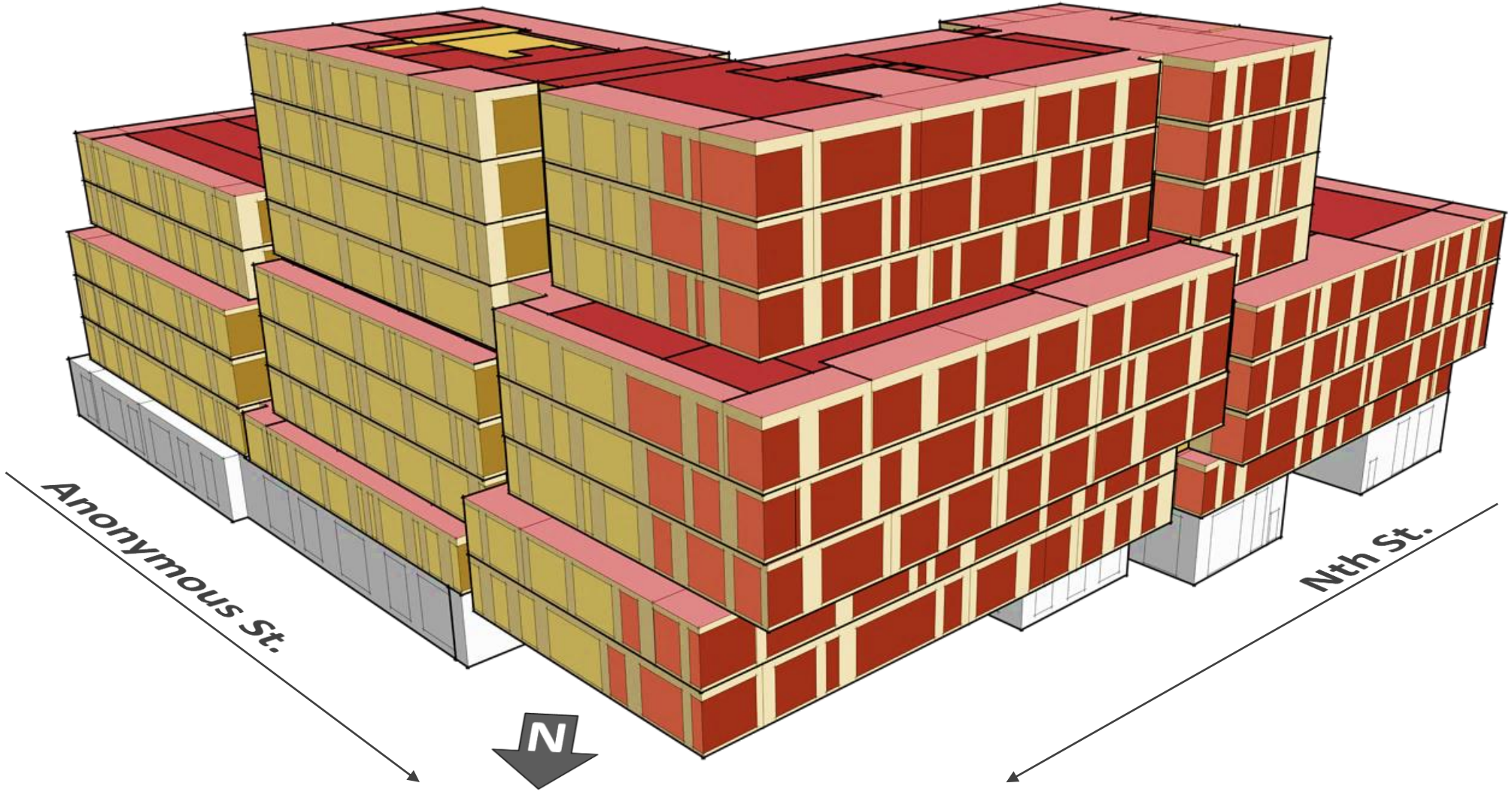
15th Annual Radiance Workshop – Padua, Italy

Alen Mahić, Energy Studies in Buildings Laboratory
University of Oregon

month	day	time	zn_ne_01_e	zn_ne_01_n	zn_ne_01_w	zn_ne_02_e	zn_ne_02_n	zn_ne_02_w	zn_ne_03a_e	zn_ne_03b_e	zn_ne_03_n	zn_ne_04_e	zn_ne_04_n	zn_ne_05a_e	zn_ne_05b_e	zn_ne_05_n	zn_ne_06_n	zn_ne_07_n	zn_ne_08_n	zn_ne_
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.
1	1	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0
1	1	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0
1	1	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0
1	1	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0
1	1	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	1	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.
1	2	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	0.5	0.0	0.0	0.0	0
1	2	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0
1	2	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0
1	2	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0
1	2	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0
1	2	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0
1	2	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0
1	2	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0
1	2	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

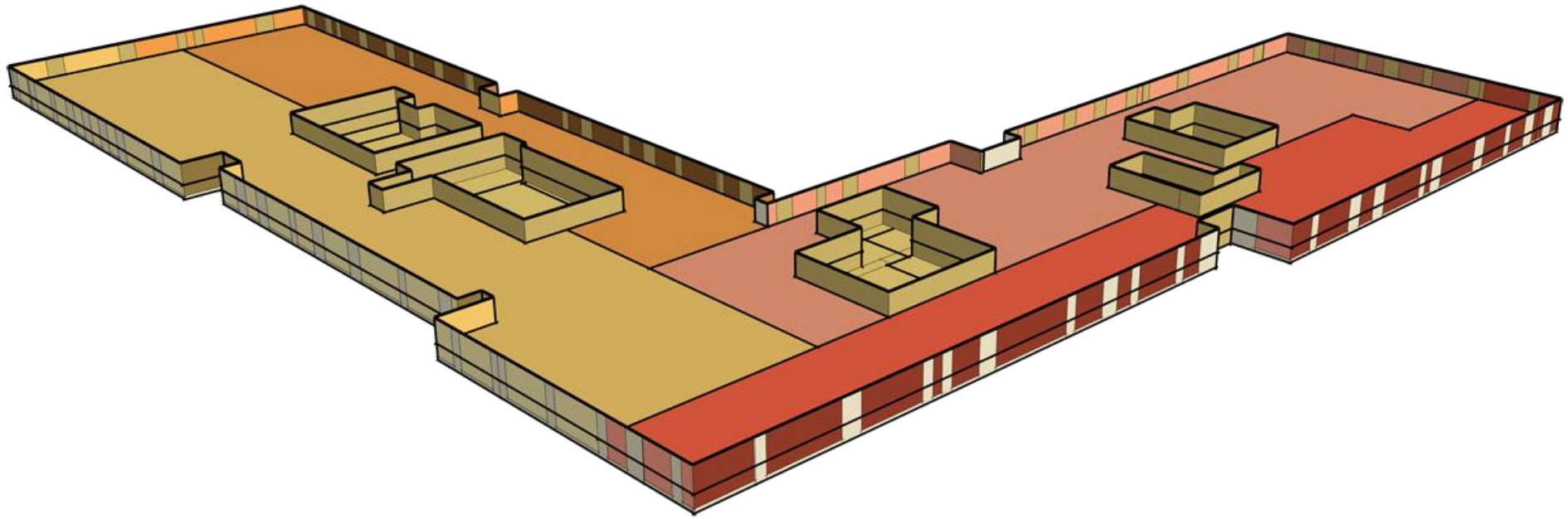
Purpose and scope

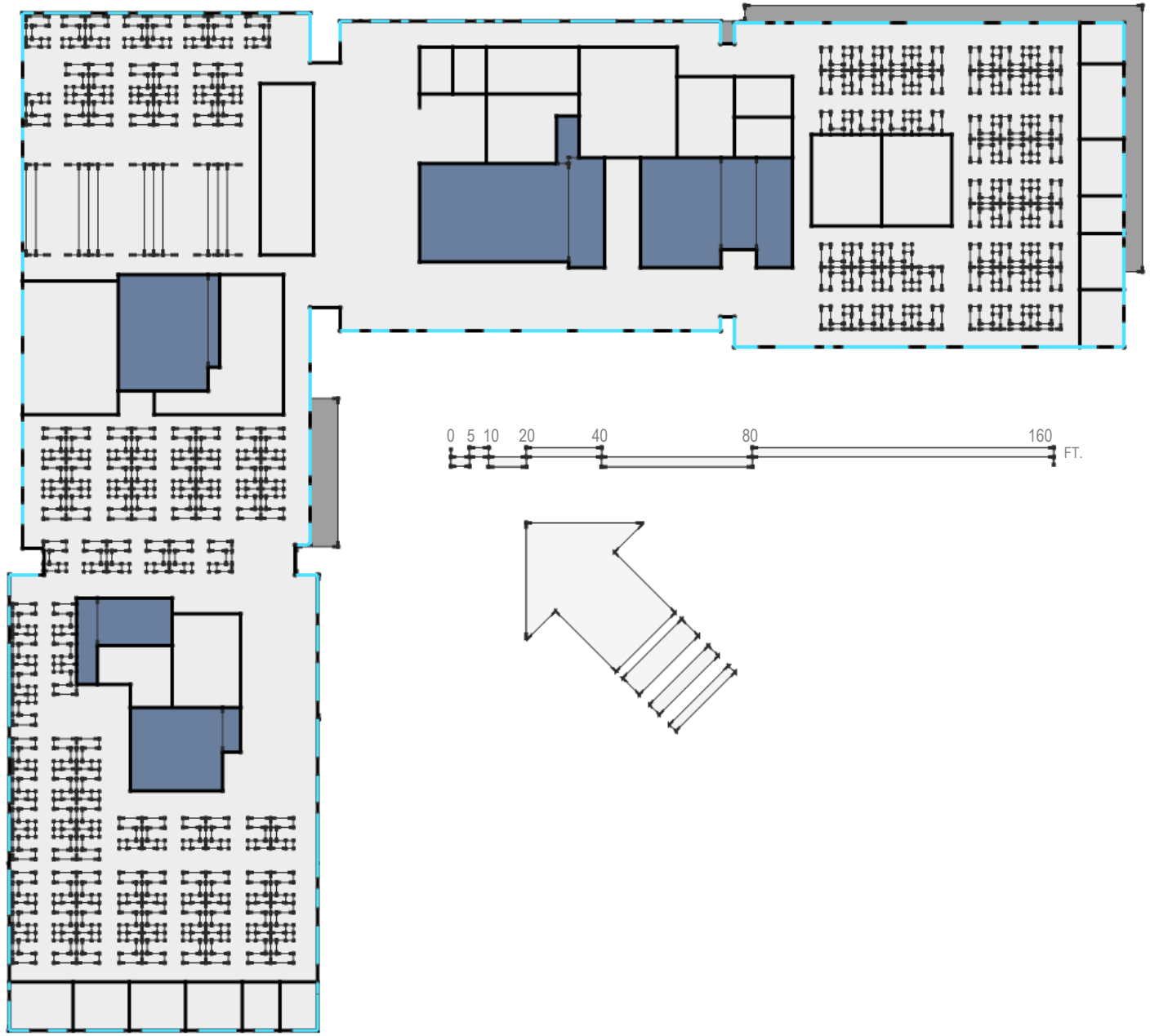
- Quantification of energy savings attributed to blinds system.
- Annual daylight and energy modeling of 9-storey office building with roughly 325,000 square feet of floor area.
- Both models to include Lutron motorized shades (MechoShade) and automated controls.


Anonymous St.
N
Nth St.

Daylight zoning

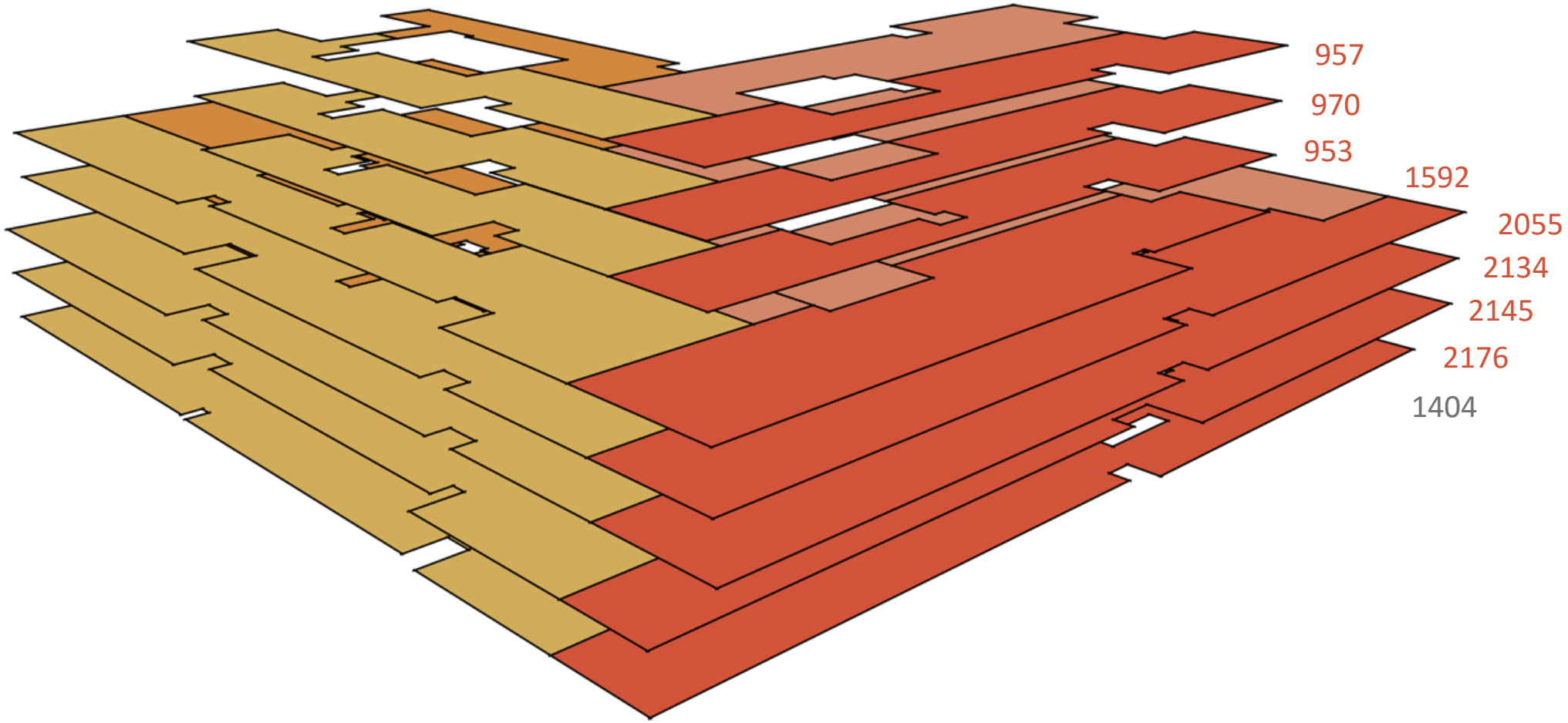
- Blinds operation based on zoning of spaces and window groups.
- Four spatial zones per floor.
- Windows grouped as designed and operated as part of each spatial zone.
- 4’x4’ analysis grid spacing.
- Cores excluded.




0 5 10 20 40 80 160
FT.

Daylight zoning

14,386 analysis points. (4'x4' grids)



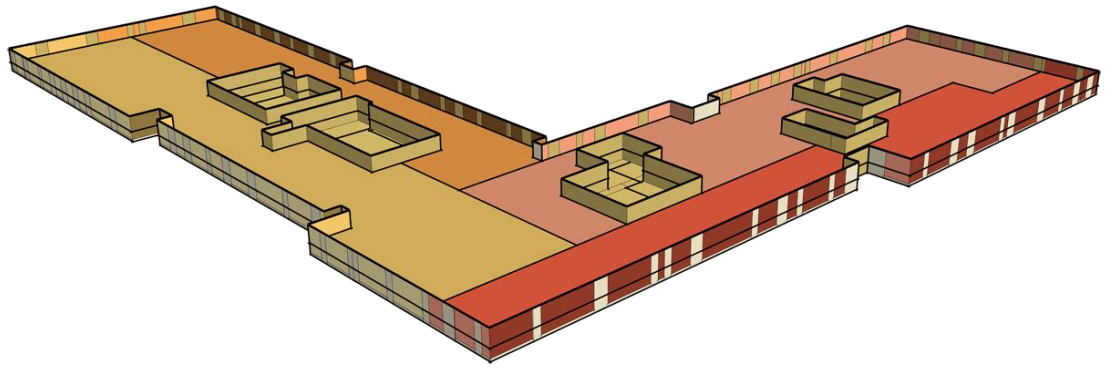
Model organization

- Radiance model structure
  - Generation of blinds operation schedules per spatial zone:
    - North-East Zone
    - North-West Zone
    - South-East Zone
    - South-West Zone

    } 691 window groups } Direct solar simulations (1)
  - Application of blinds schedule to entire floor plate:
    - Whole floor

    } 691 window groups } Ambient simulations per blind condition (2)

} **Blinds operated result**



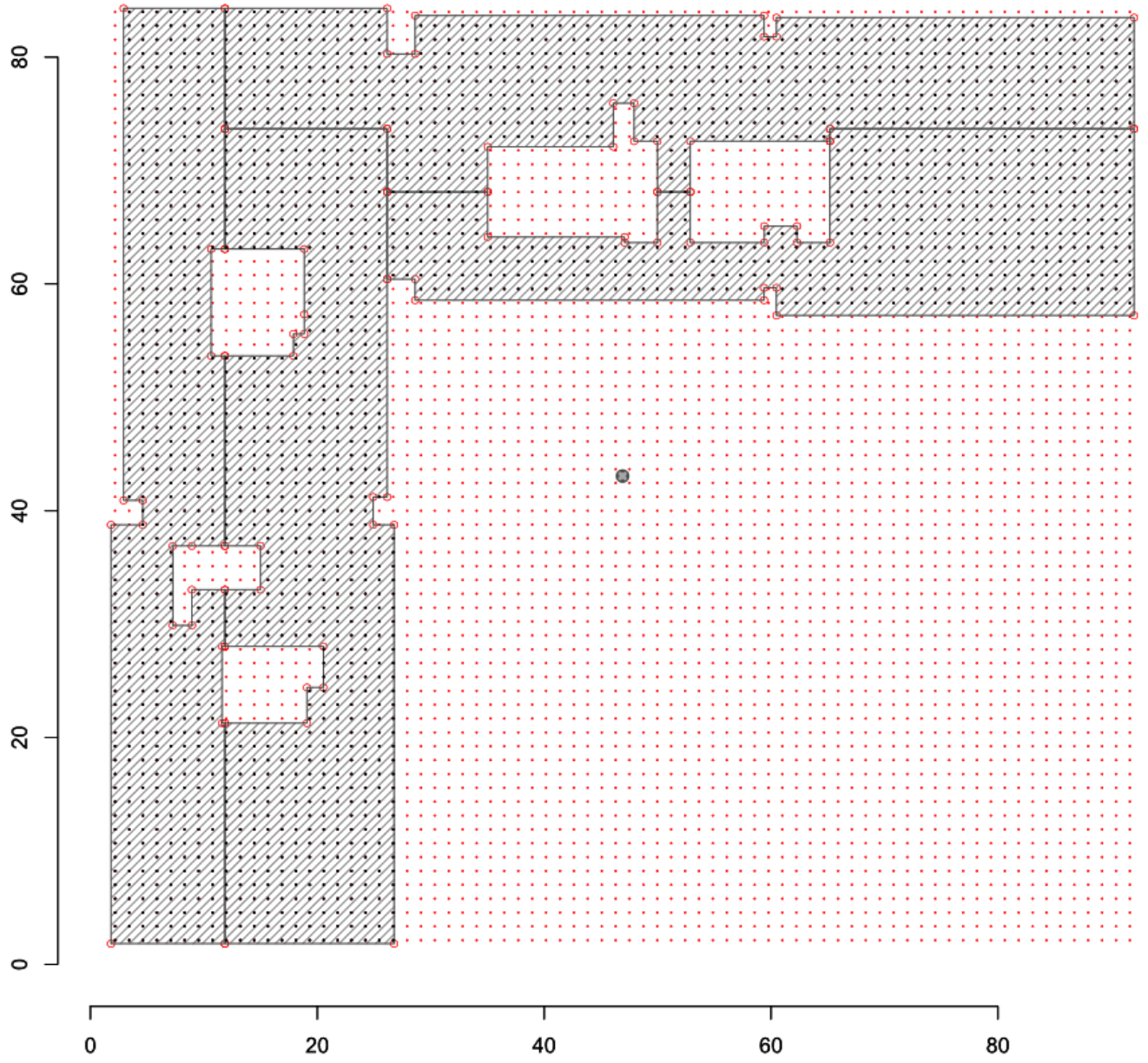
Using RAD and OBJ geometry as processing tools

- Generating additional simulation elements using available geometry.
  - Wavefront .OBJ
  - Native .RAD

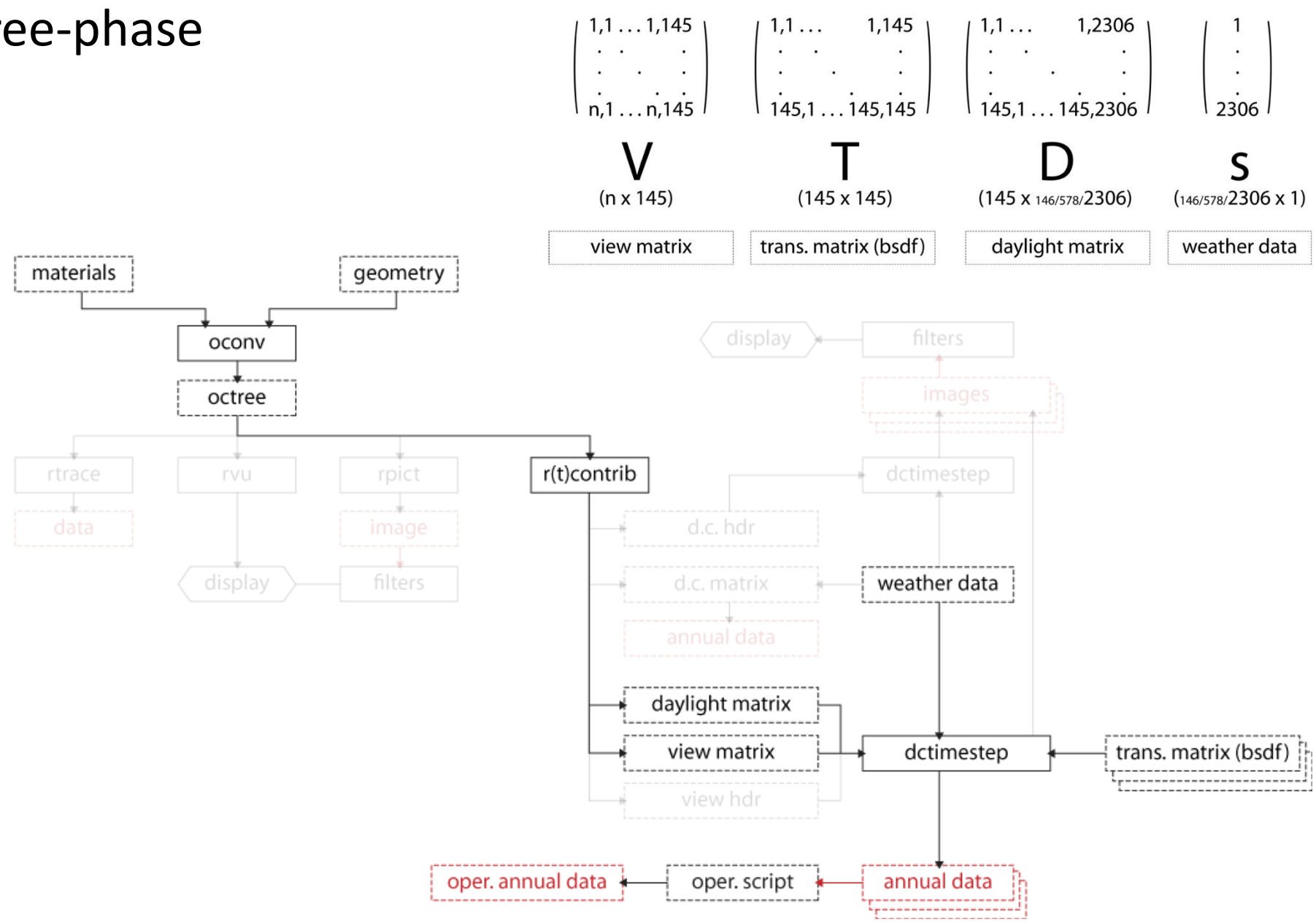
```
# obj2rad -f usb.obj
# Alias OBJ Model File
# Exported from SketchUp, (c) 2000-2012 Trimble Navigation Limited
# File units = meters

OpenStudio_Floor_Ext polygon Mesh1.Group1.Model.1
0
0
18
        7.04808         64.0353         0.0381
        32.7513         64.0353         0.0381
        32.7513         50.2002         0.0381
        -1.5283         50.2002         0.0381
        -1.5283         56.7708         0.0381
       0.375115          57.2217          0.0381

# Done processing file: usb.obj
# 24 lines, 20 statements, 1 unrecognized
```

```
# Alias OBJ Model File
# Exported from SketchUp, (c) 2000-2012 Trimble Navigation Limited
# File units = meters

mtllib EDITED_US Bank Sketchup 6th floor.mtl

g Mesh1 Group1 Model

usemtl OpenStudio_Floor_Ext
v 7.04808 64.0353 0.0381
vt -262.715 499.317
vn 0 0 -1
v 32.7513 64.0353 0.0381
vt -1274.65 499.317
v 32.7513 50.2002 0.0381
vt -1274.65 -45.375
v -1.5283 50.2002 0.0381
vt 74.9375 -45.375
v -1.5283 56.7708 0.0381
vt 74.9375 213.313
v 0.375115 57.2217 0.0381
vt 0 231.063
f 1/1/1 2/2/1 3/3/1 4/4/1 5/5/1 6/6/1
```

Leverage the R statistical analysis software to generate assets for Radiance simulation.



Radiance three-phase

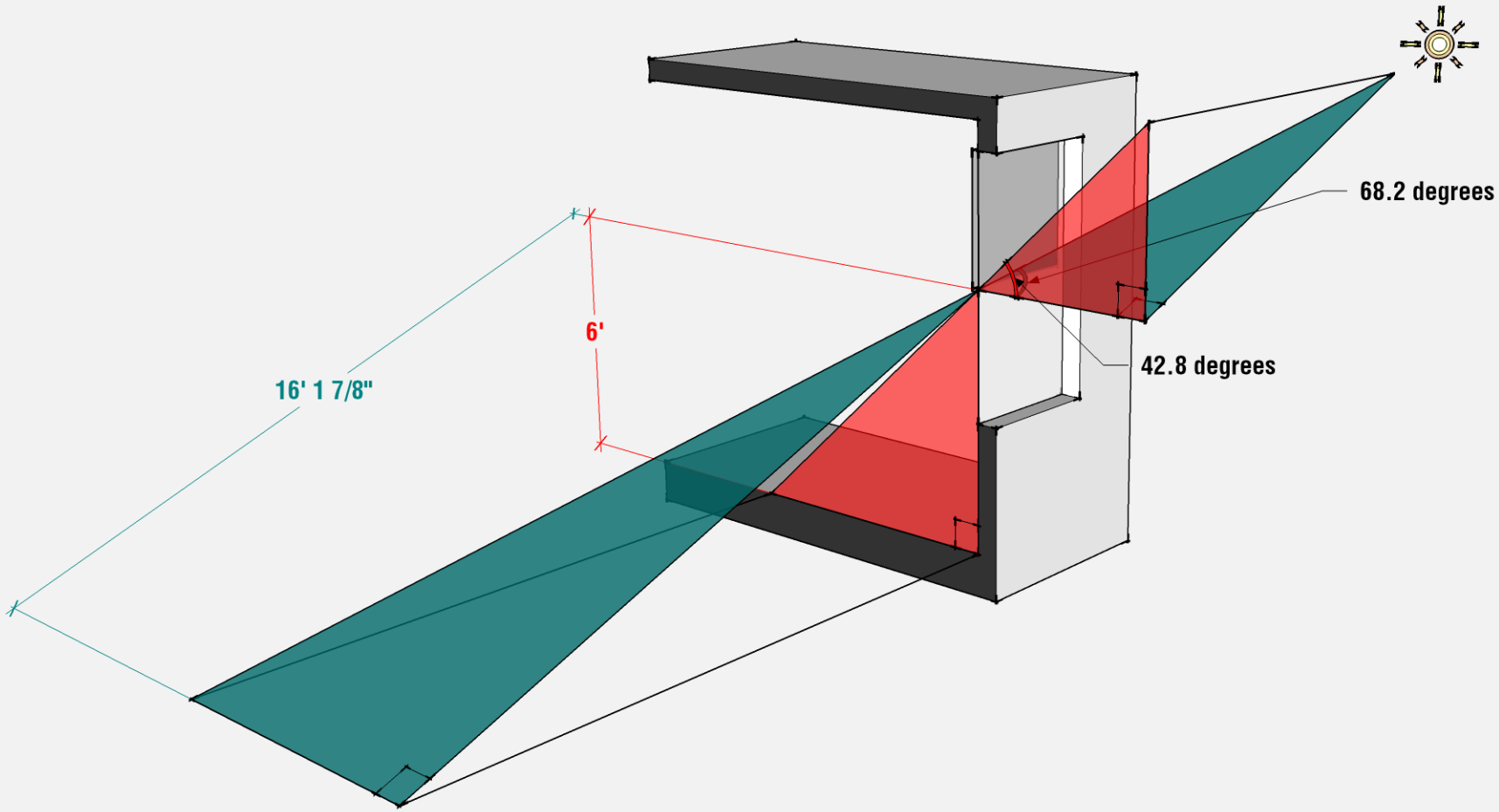


Adapting Lutron's automated Quantum operation logic.

- Operates under three primary conditions, with an optional fourth.
- Photosensor-based control
  - Single 60-degree FOV vertical illuminance sensor centered horizontally, 25% from the window head.
  - Two 30-degree FOV vertical illuminance to be placed on opposite sides of a vertical mullion piece, effectively giving a 60-degree FOV.
- Condition 1
  - "Darkness Threshold" – If the sensor sees less than this level, shades attached to it are fully open/retracted.
- Condition 2
  - "Brightness Threshold" – If the sensor sees more than this level, shades attached to it are fully closed/deployed.
- Condition 3
  - If conditions 1 and 2 are not triggered, the penetration depth is calculated based on the sun's position and if it should exceed the maximum allowed setting then the shades are systematically lowered until below the maximum allowed depth.
- Condition 4 (optional)
  - "Visor" – This sets the fully retracted shade height to a minimum level to help mitigate sky brightness.

Horizontal Profile Angle

- Using horizontal and parallel profile angles to calculate solar penetration depth.



Horizontal profile angle
Incidence angle

Photo-sensor representation

- Sensor-based operation
- Captured field of view

```
#
# Angle/view cut-off cones...
#
# Cone height/length: 0.1524 meters (6 inches)
# Base/opening radius: 0.0889 meters (3.5 inches)
# Apex radius: 0 meters (0 inches)
# Resulting view angle: 62.28 degrees
#
# Generated for input: “2nd_sensors.pts"
#

void plastic black                    0 0 5                0 0 0 0 0

black cone cutoff.1
0
0
8
  26.133921 75.817913 29.2481
  26.286575 75.817913 29.2481
  0 0.0889
```

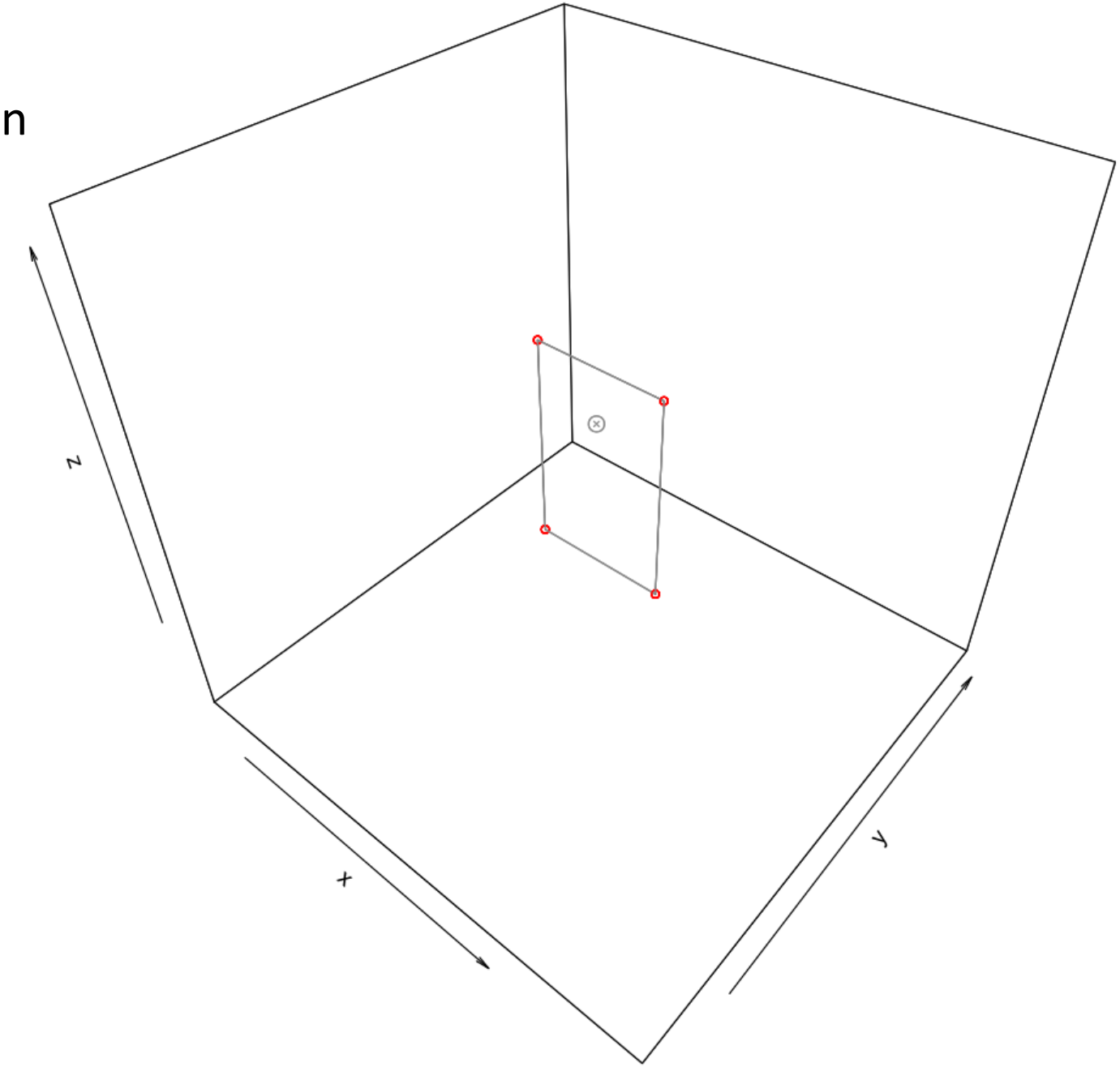


Photo-sensor representation

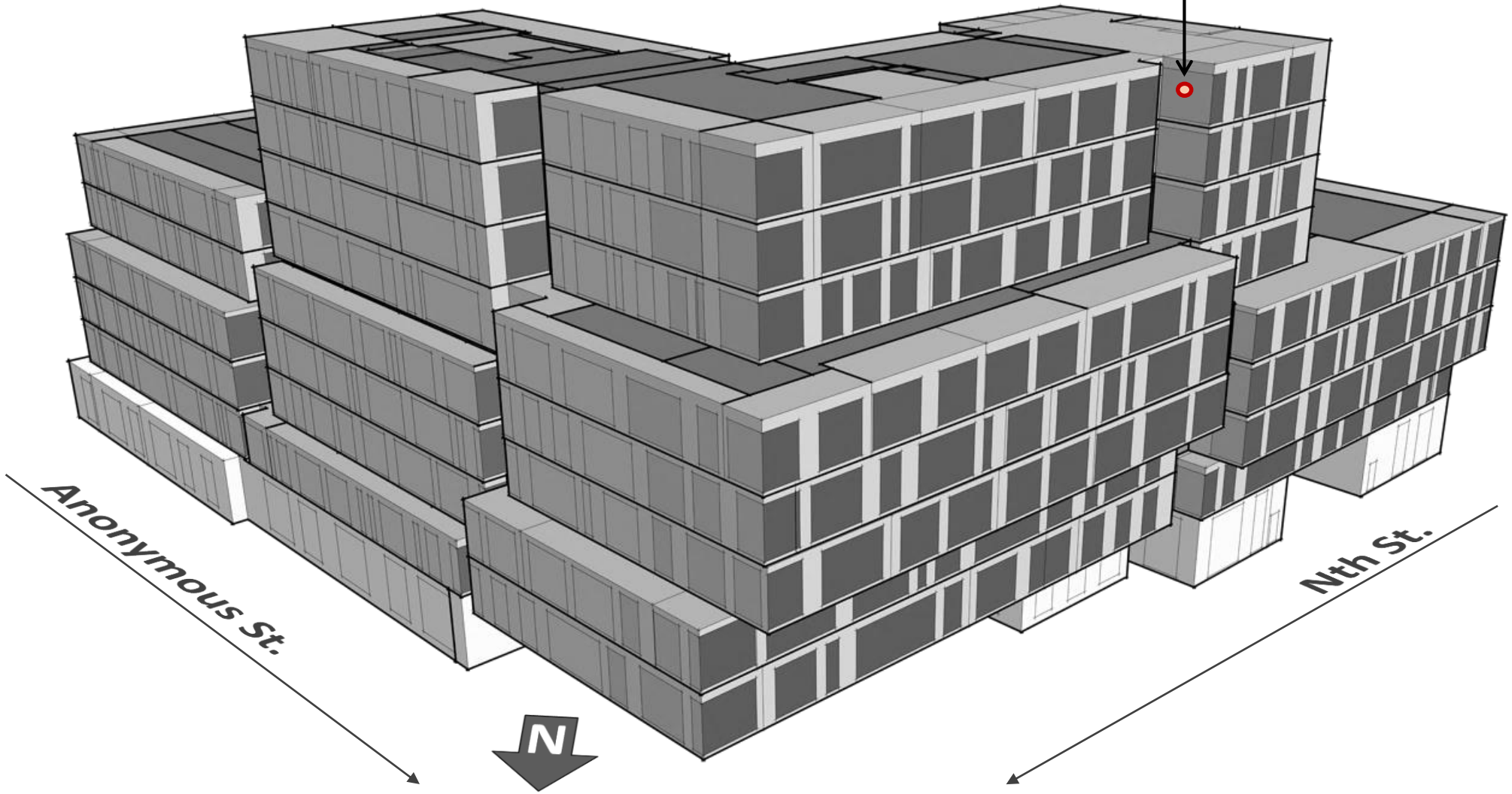
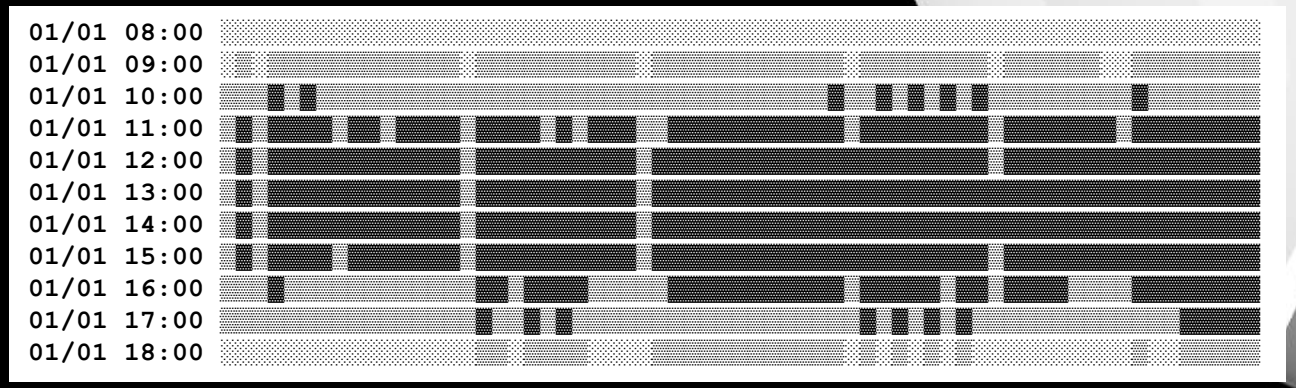


Photo-sensor representation

- 180 degree FOV
- 400 Lux Darkness Threshold
- 5000 Lux Brightness Threshold
- 2.5 meter (8 ft.) penetration depth allowed
- 3+ shade/blind conditions
  - open (100%)
  - intermittent (interval)
  - closed (0%)



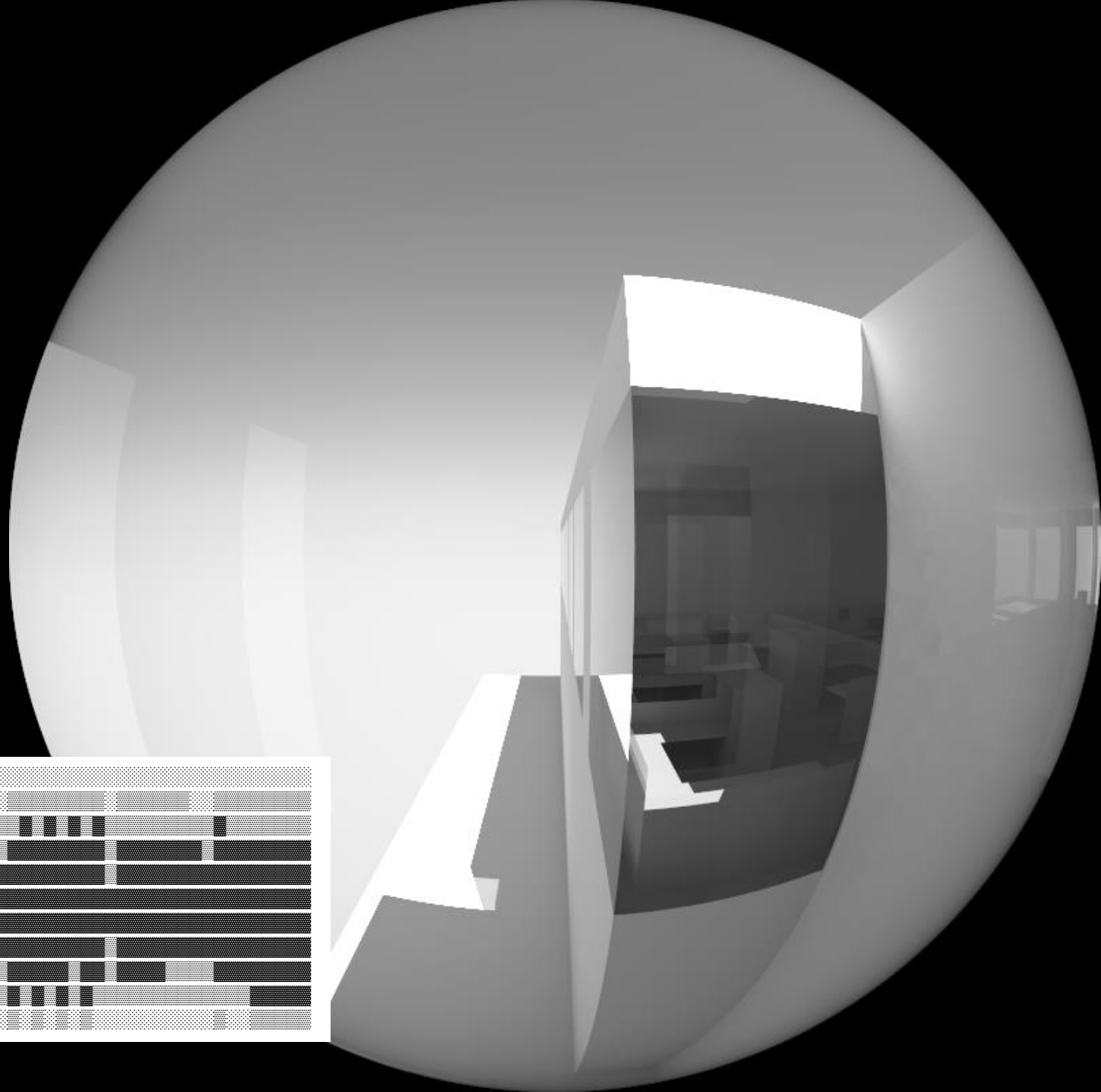
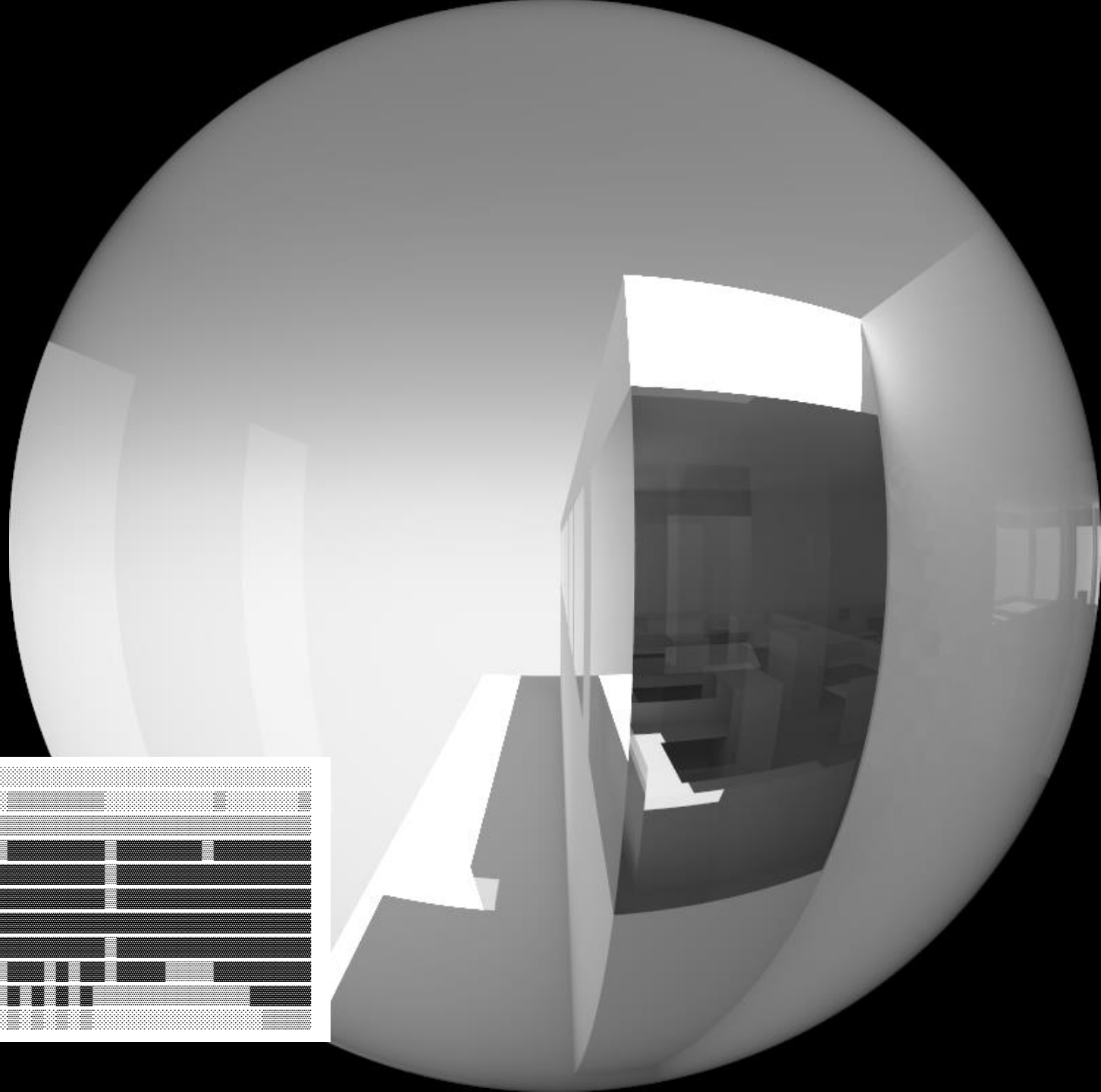


Photo-sensor representation

- 180 degree FOV
- 500 Lux Darkness Threshold
- 6000 Lux Brightness Threshold
- 2.5 meter (8 ft.) penetration depth allowed
- 3+ shade/blind conditions
  - open (100%)
  - intermittent (interval)
  - closed (0%)



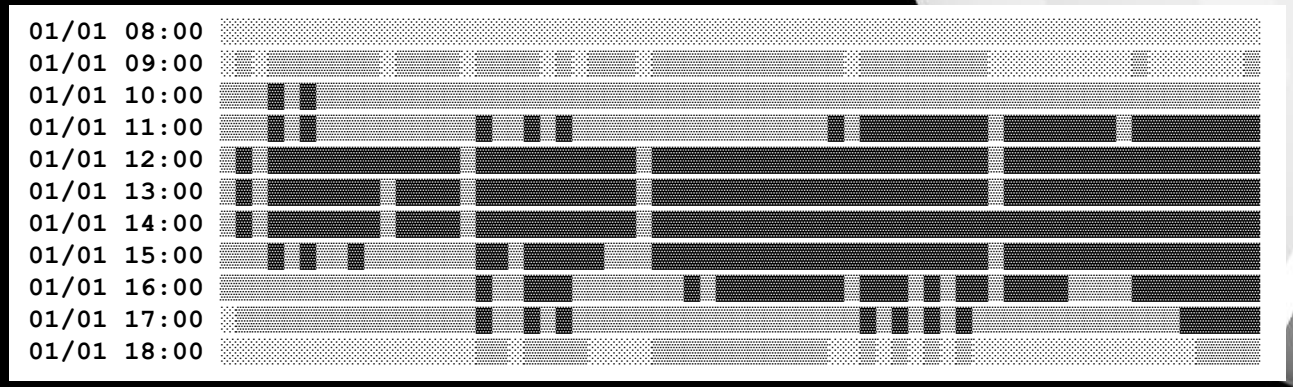
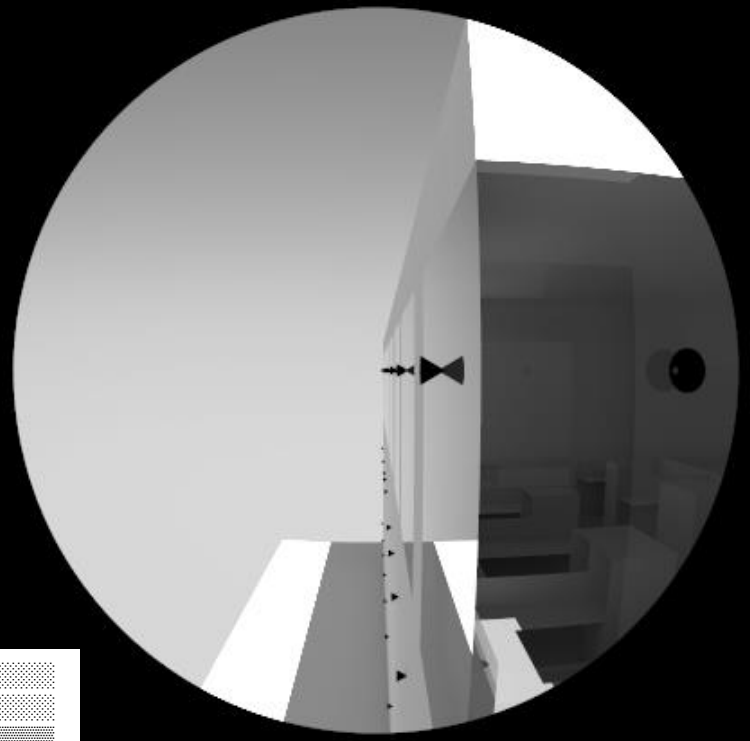
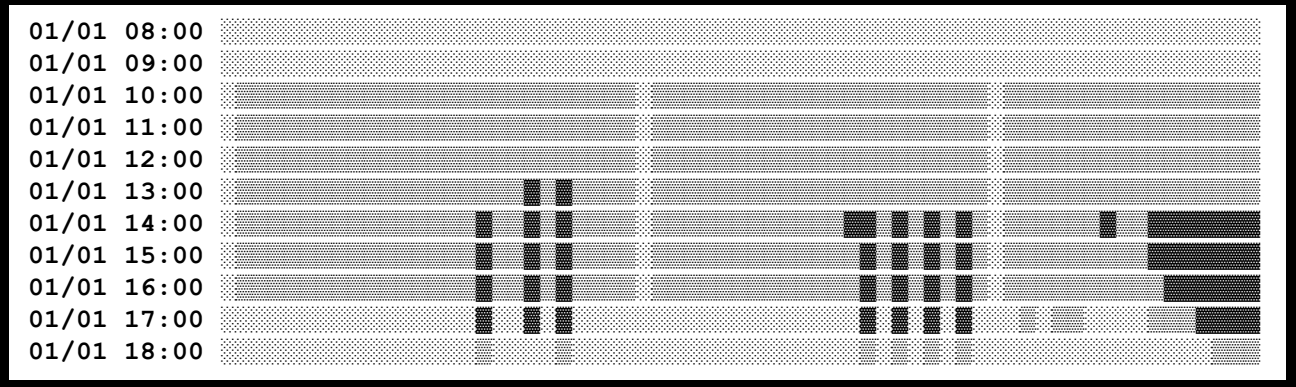


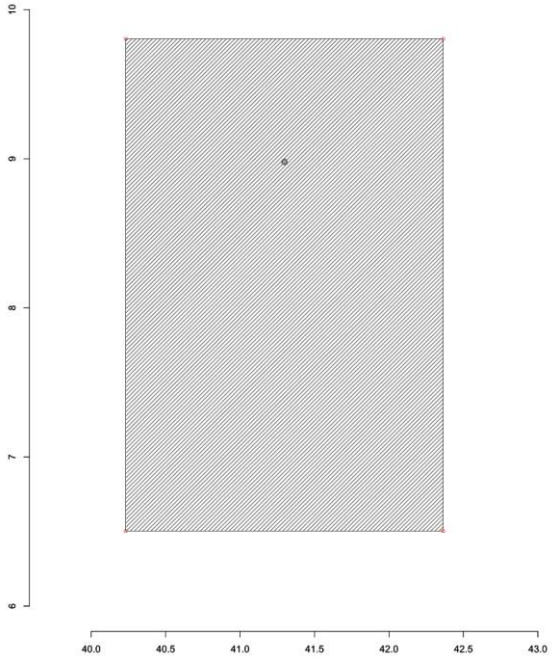
Photo-sensor representation

- 60 degree FOV
- 500 Lux Darkness Threshold
- 6000 Lux Brightness Threshold
- 2.5 meter (8 ft.) penetration depth allowed
- 3+ shade/blind conditions
  - open (100%)
  - intermittent (interval)
  - closed (0%)

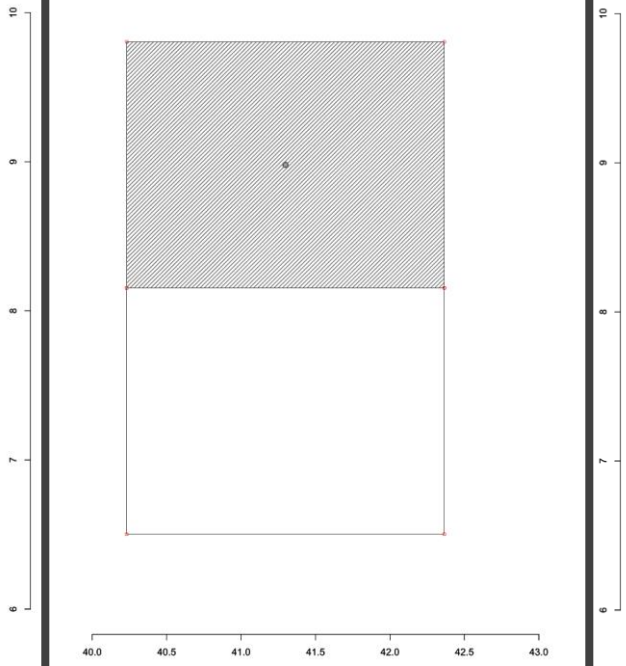




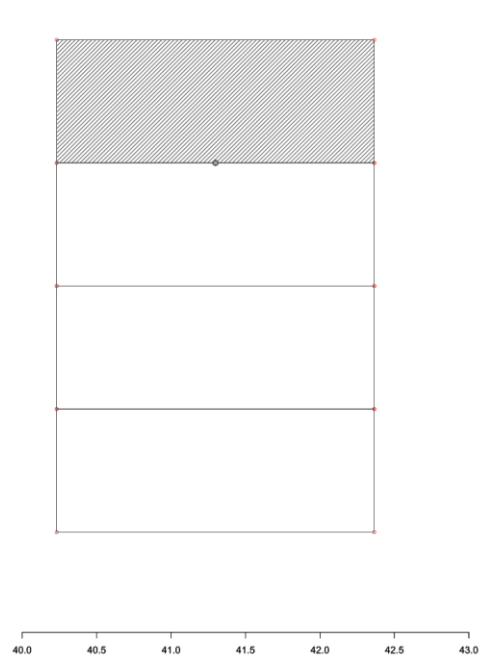
Accounting for blind/shade height



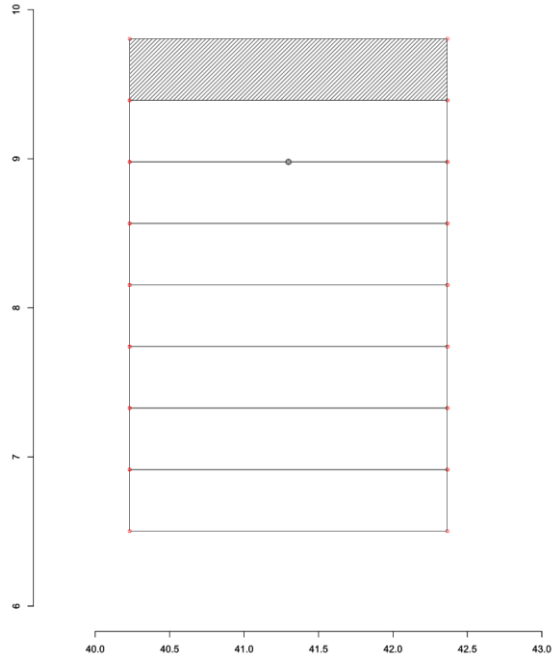
Single-core runtime
6 hours



Single-core runtime
12 hours

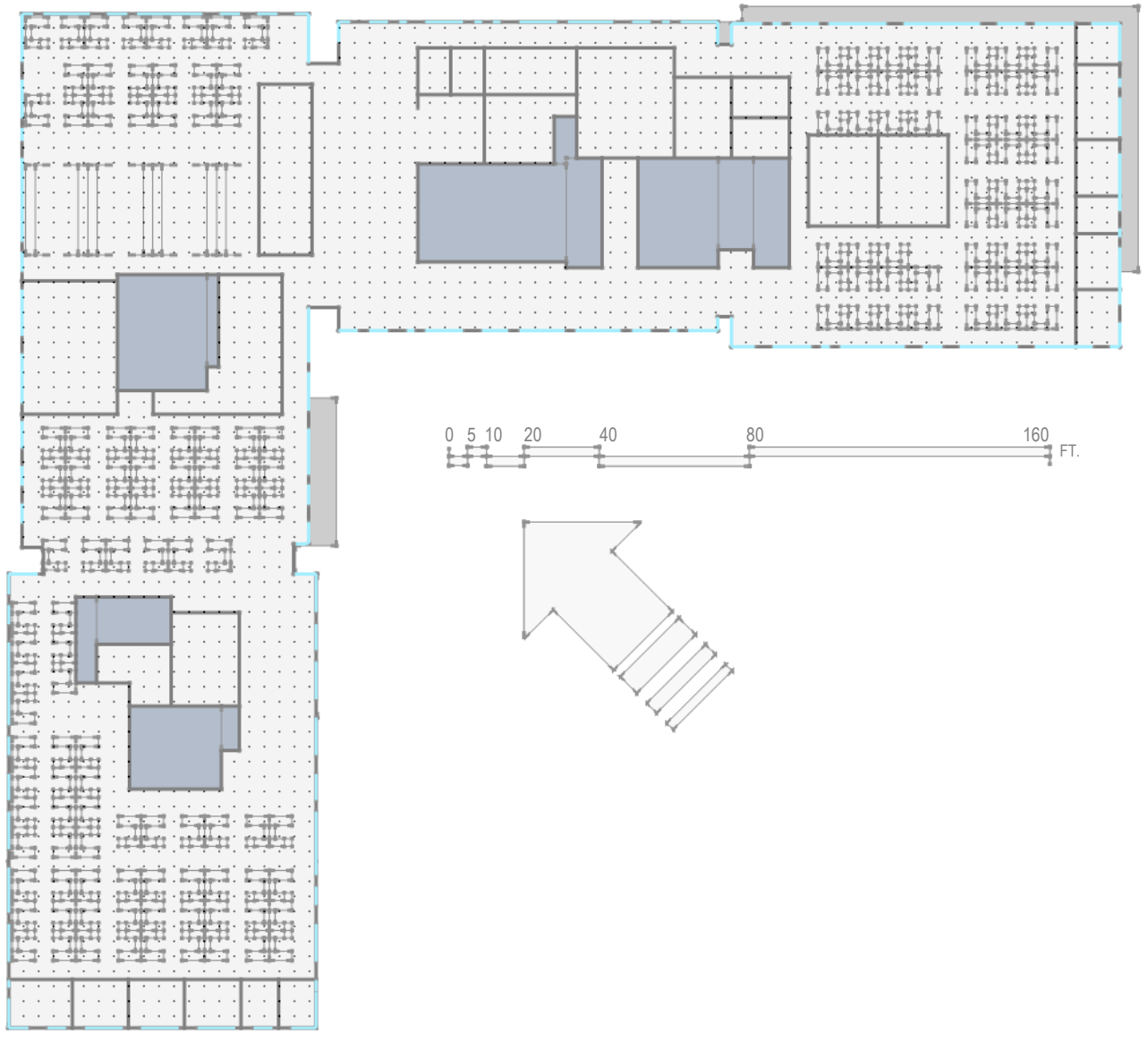


Single-core runtime
24 hours



Single-core runtime
48 hours

Blinds operated results

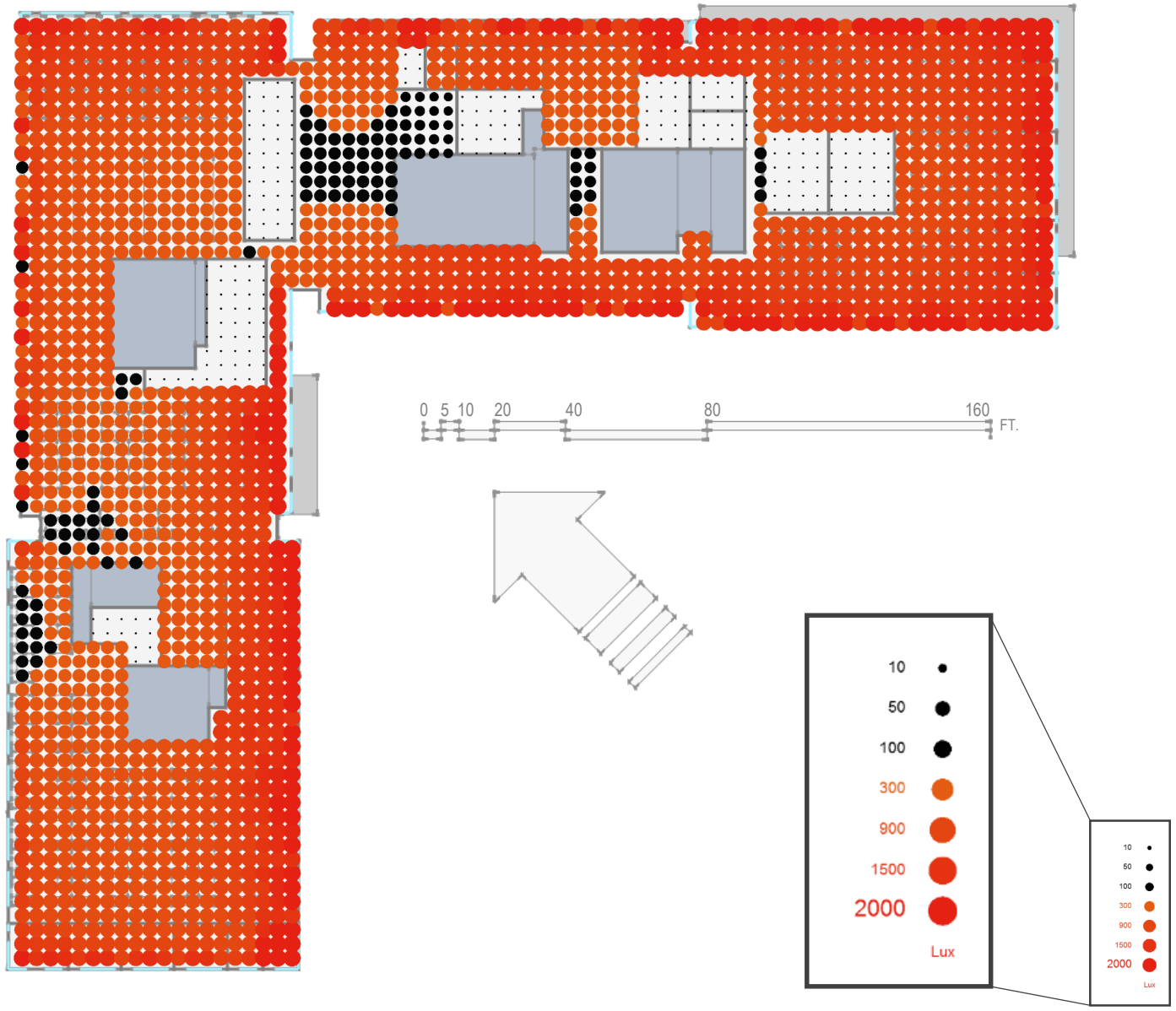


Blinds operated results
June 24th, 9:00

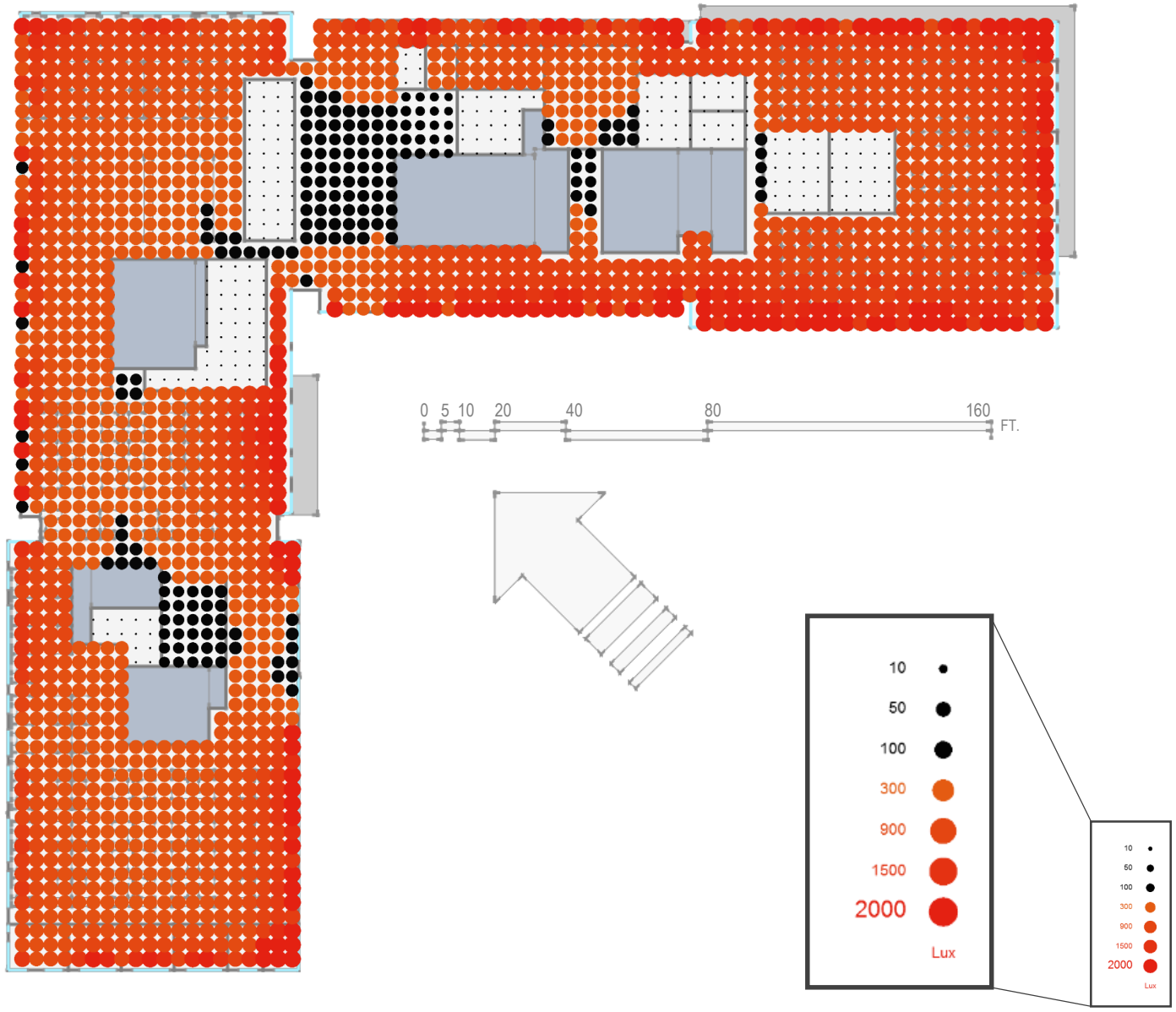
Blinds operated results
June 24th, 10:00

Blinds operated results
June 24th, 11:00

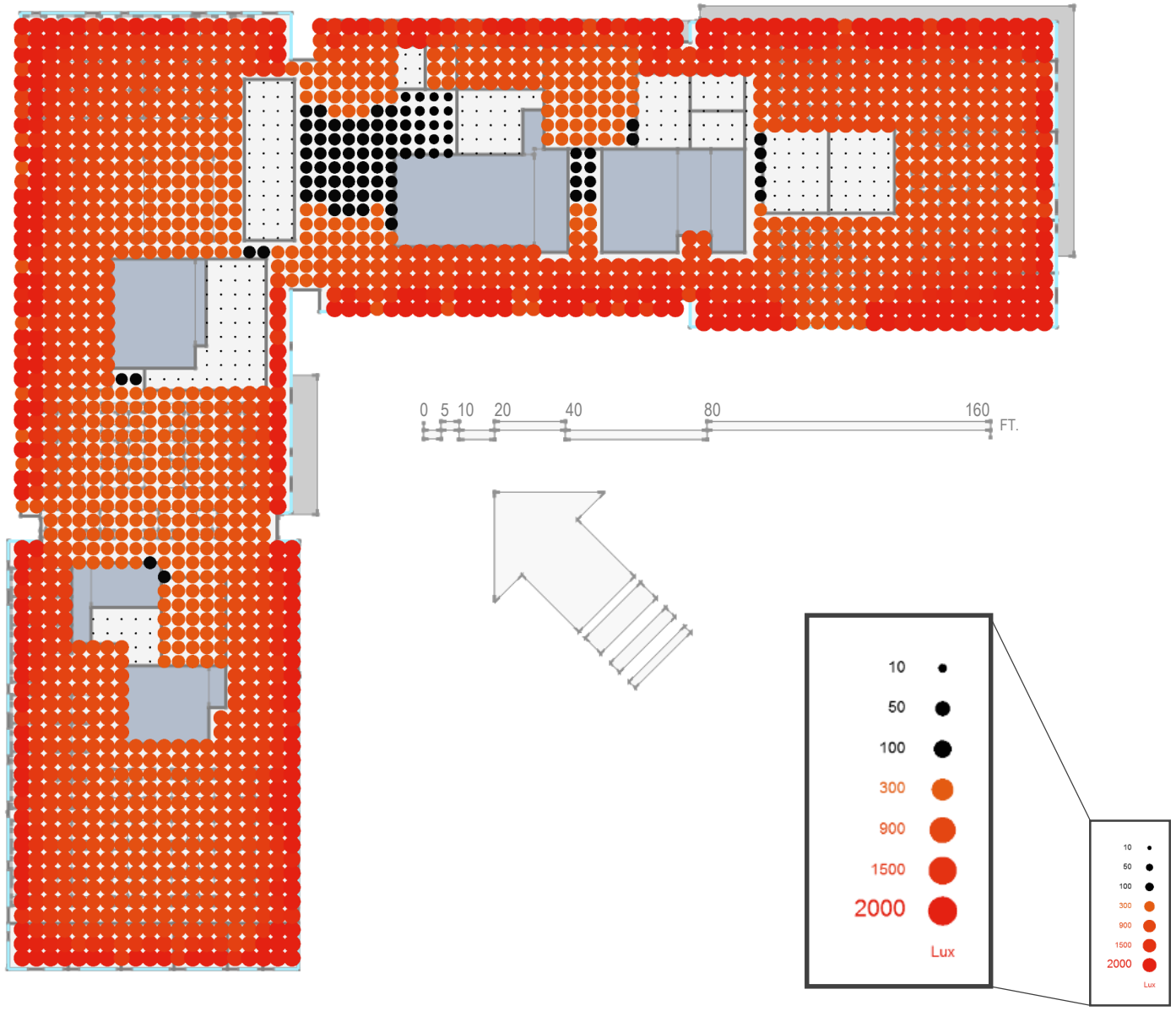
Blinds operated results
June 24th, 12:00



Blinds operated results
June 24th, 13:00

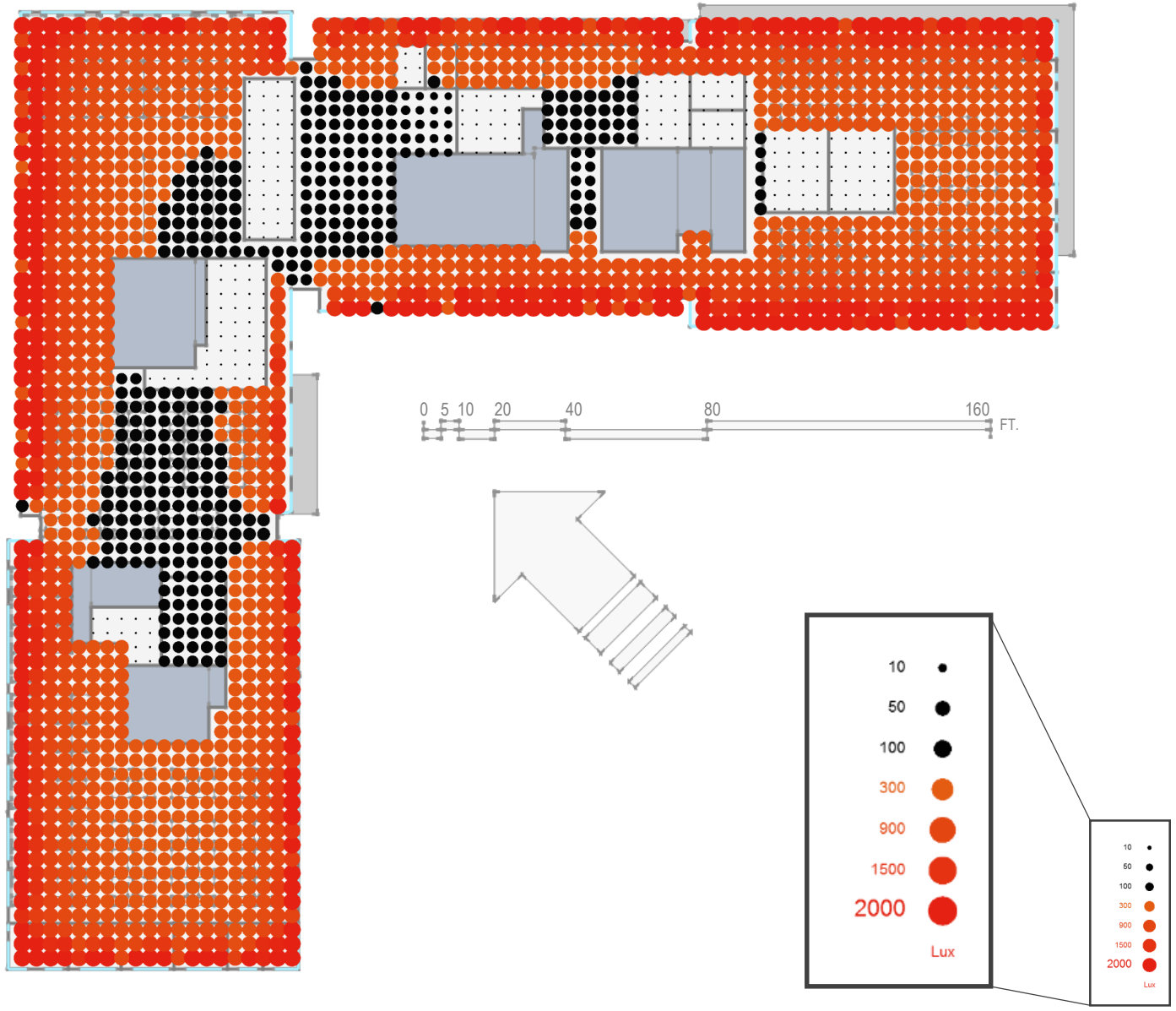


Blinds operated results
June 24th, 14:00

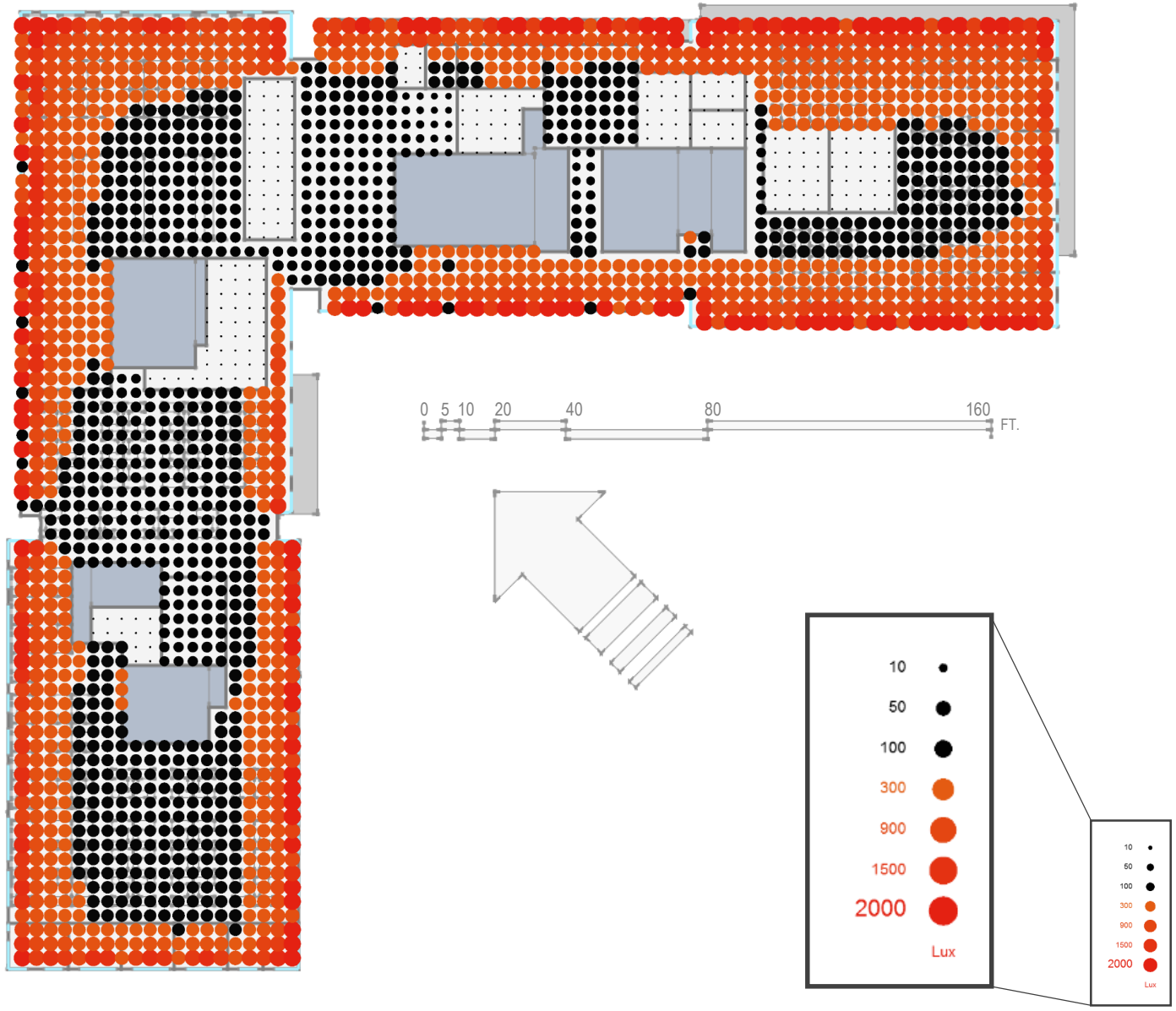


Blinds operated results
June 24th, 15:00

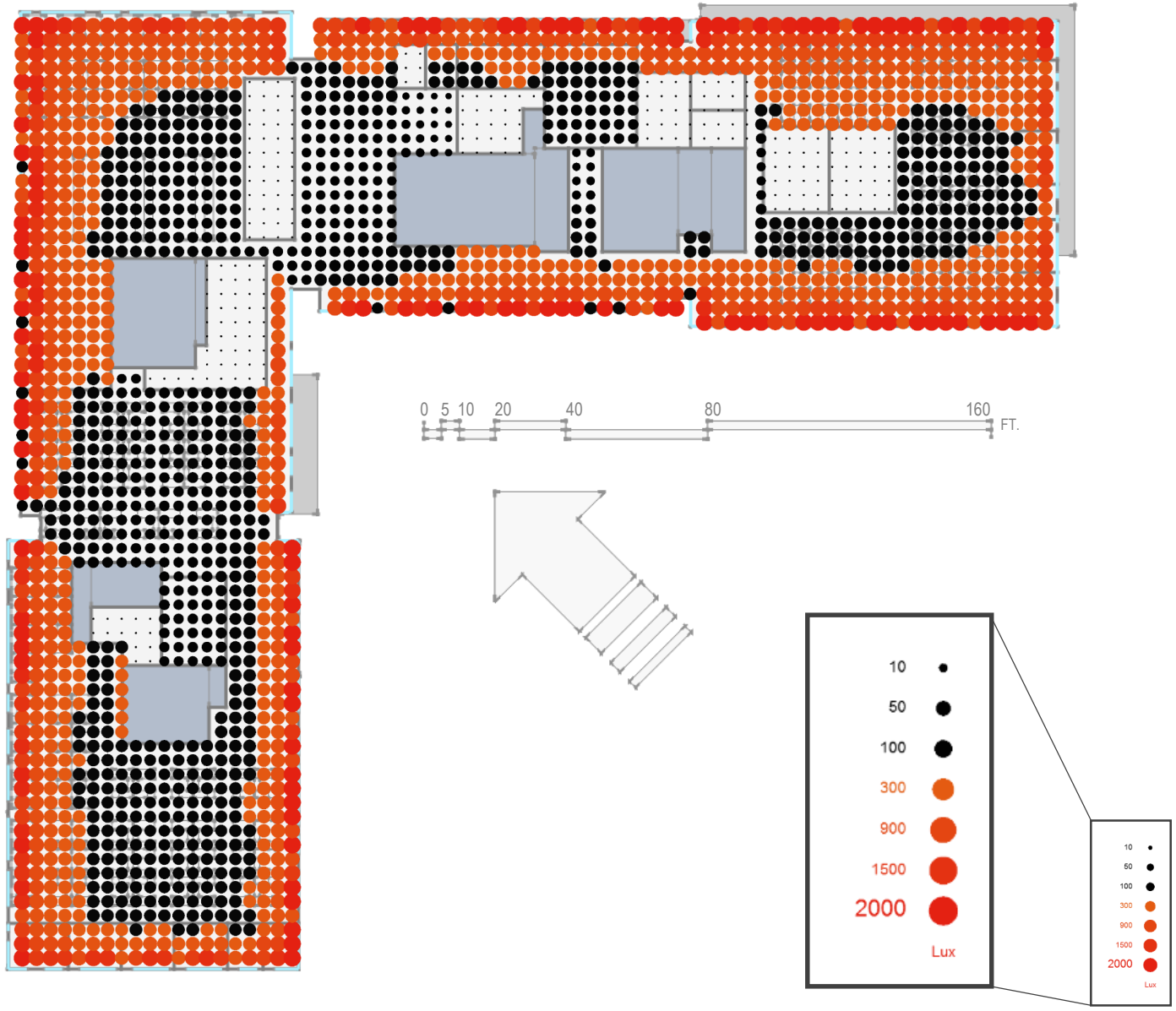
Blinds operated results
June 24th, 16:00



Blinds operated results
June 24th, 17:00



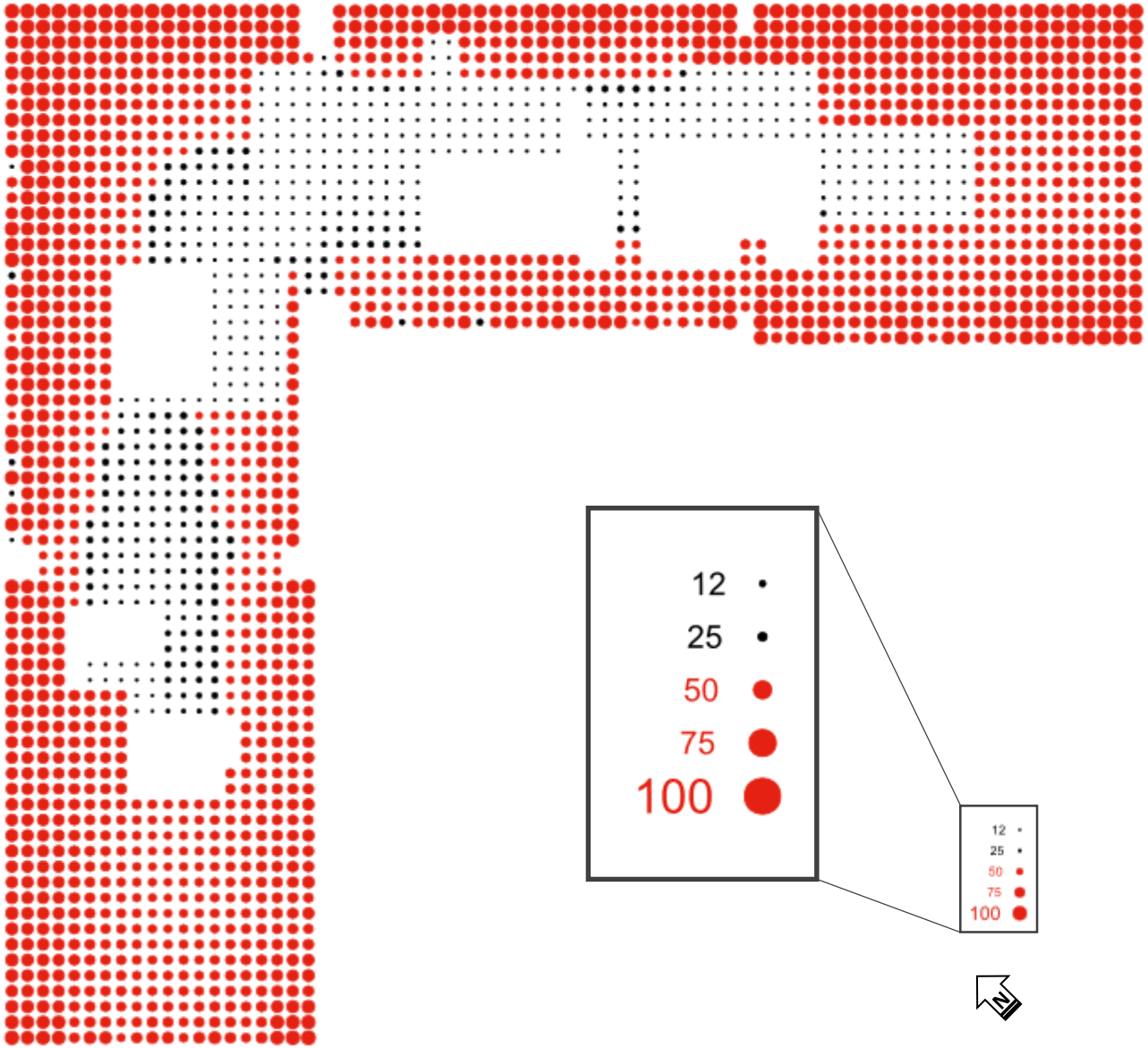
Blinds operated results
June 24th, 18:00



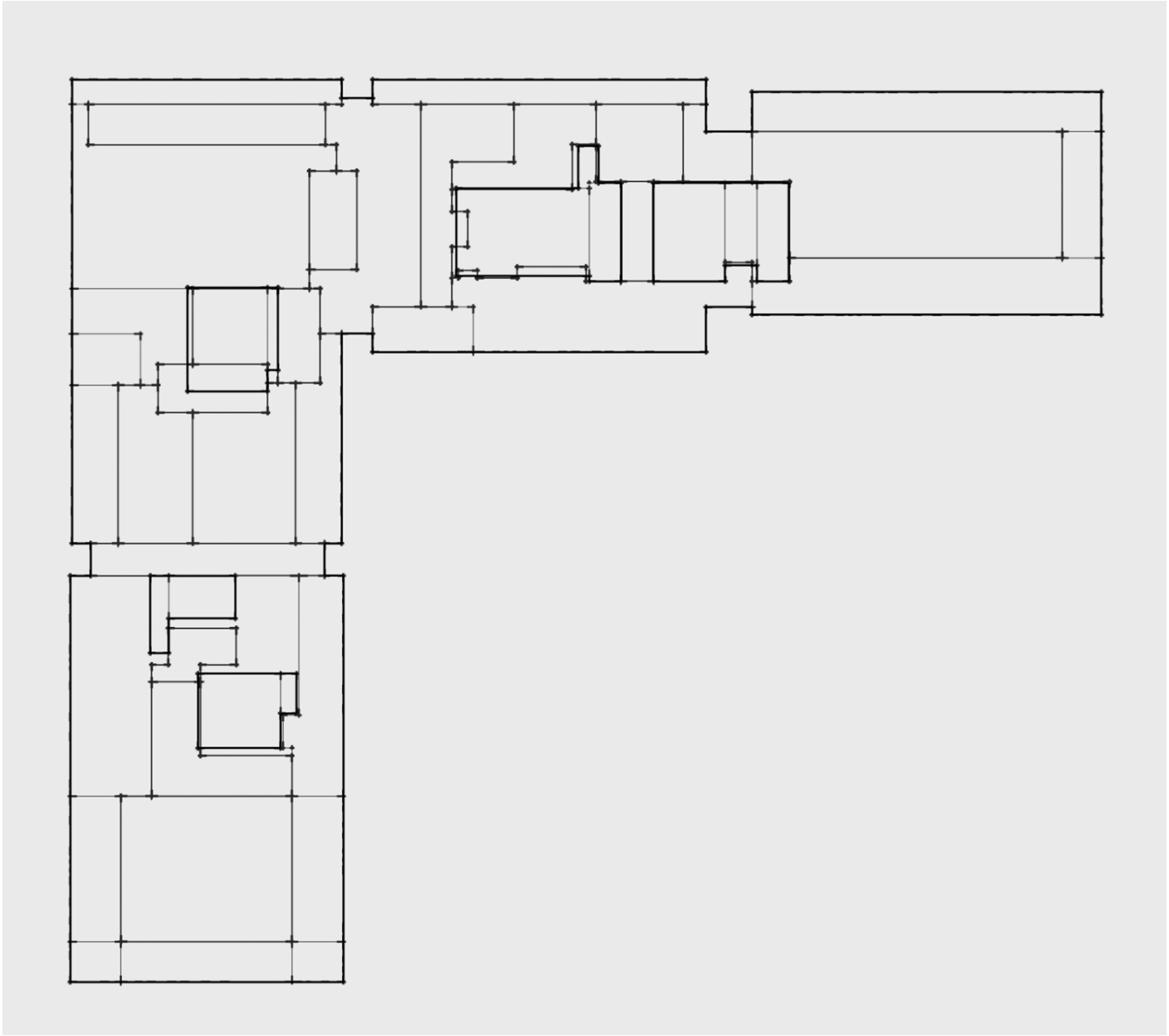
Blinds operated results

- Spatial Daylight Autonomy

Floor		Zone	Time		DA(%)
2nd		all	Annual		73.2
3rd		all	Annual		80.4
4th		all	Annual		80.1
5th		all	Annual		71.3
6th		all	Annual		84.0
7th		all	Annual		72.9
8th		all	Annual		81.6
9th		all	Annual		88.3

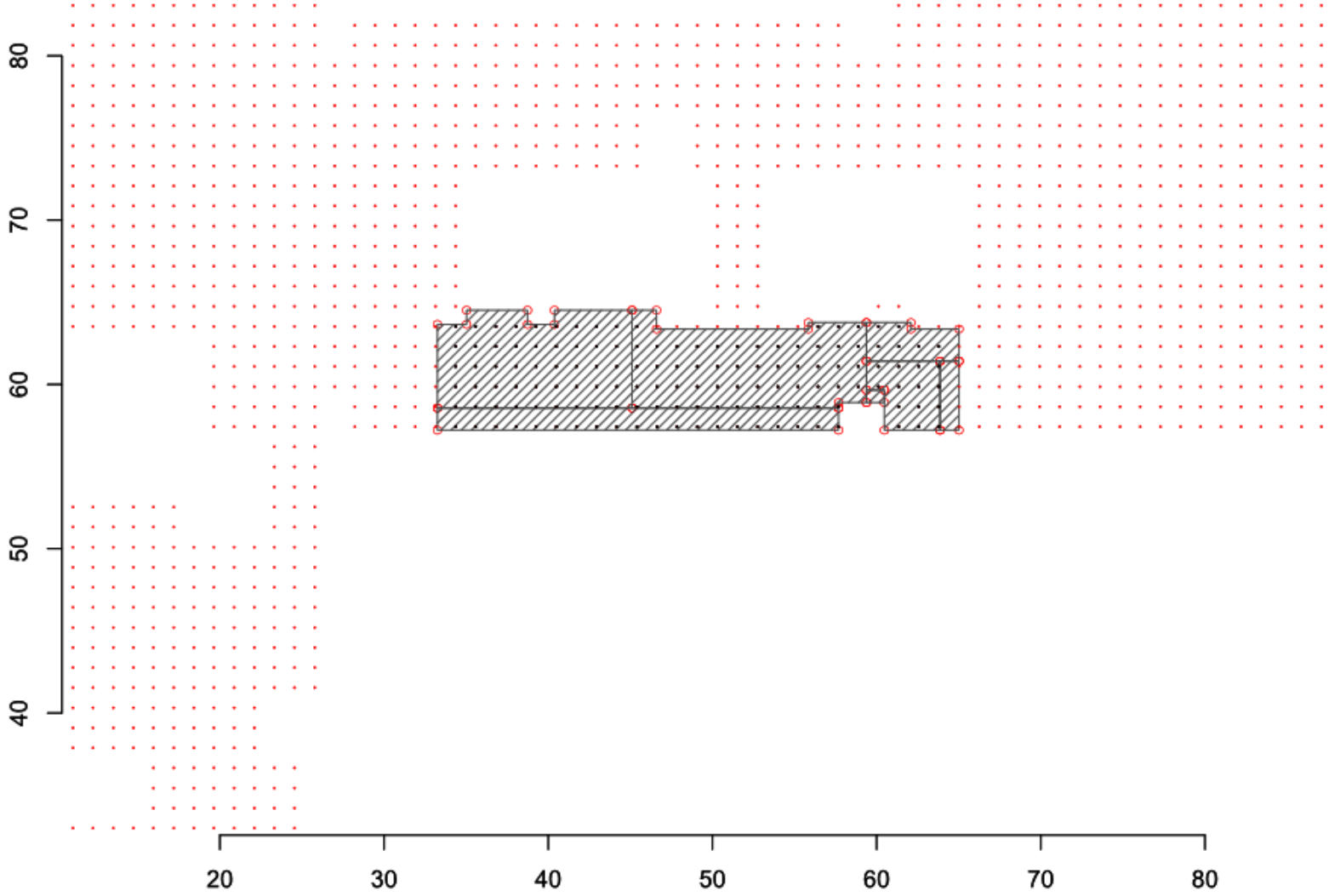


EnergyPlus and Radiance sharing geometry inputs.

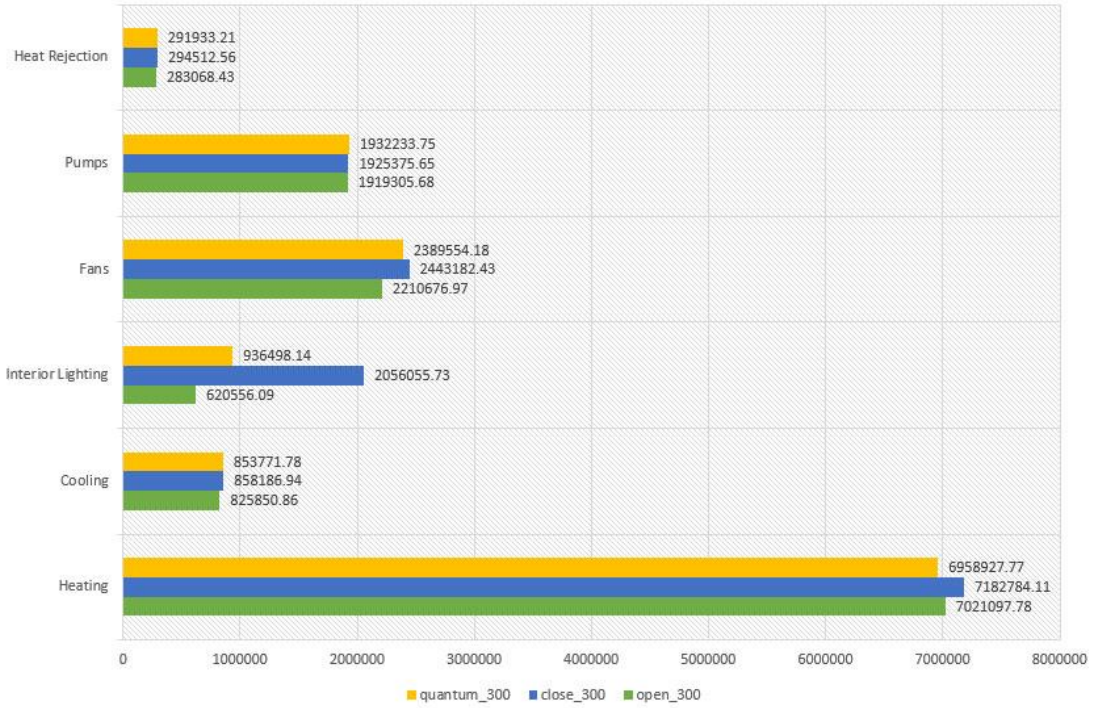


Overlaying of EnergyPlus thermal zones onto the Radiance analysis grid in order to isolate the points that are inside the zone.

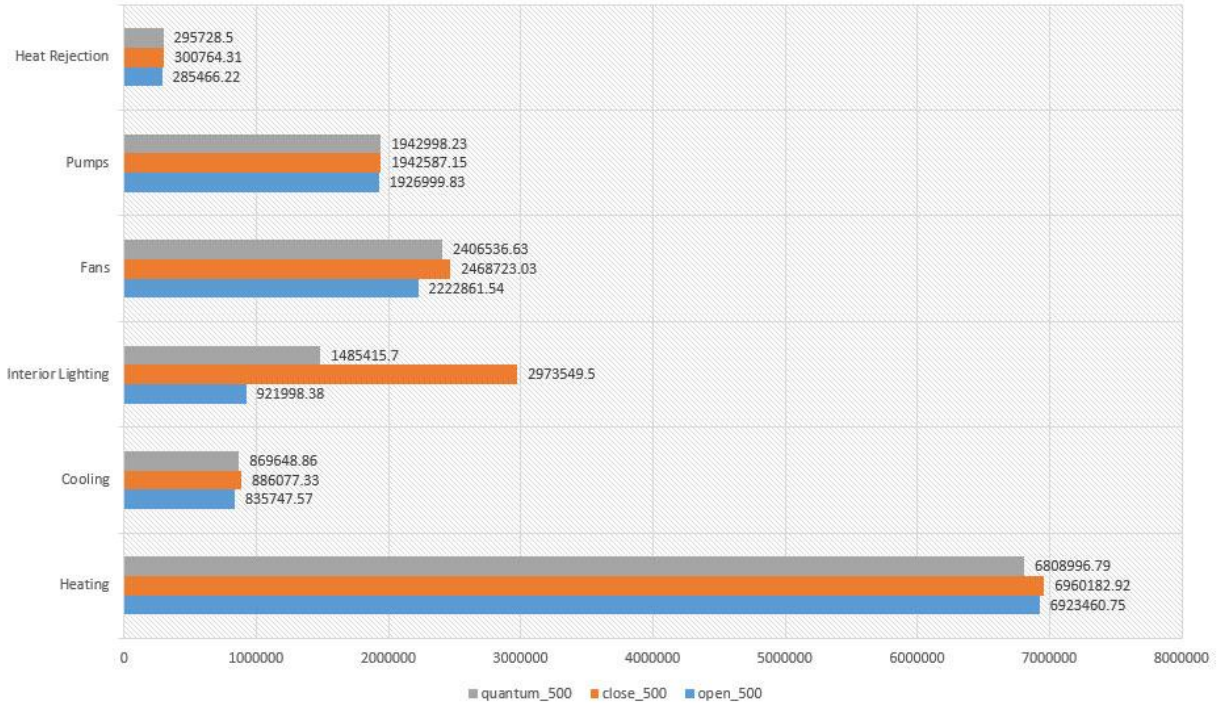
These can be averaged, or a single point specified to generate the fractional lighting schedule.



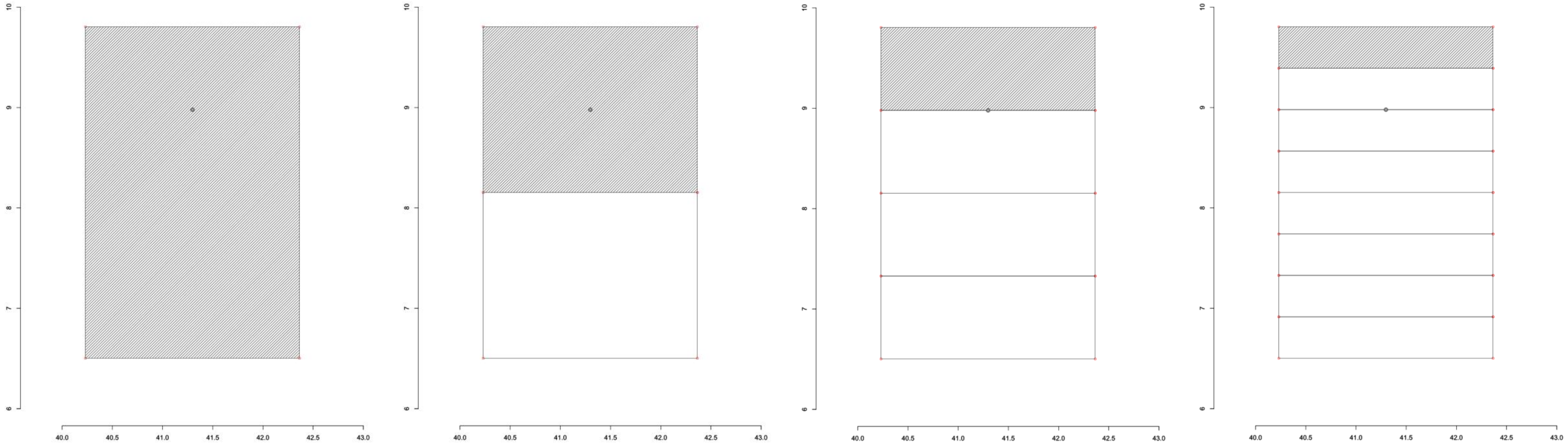
Energy end uses with 300 Lux level @ workplane

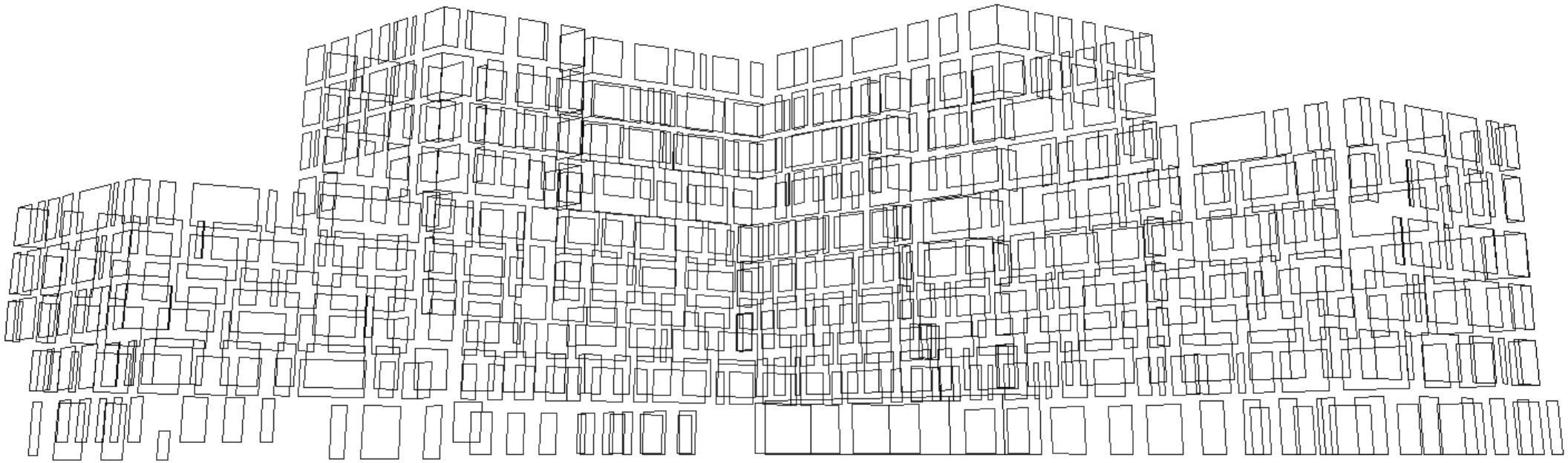


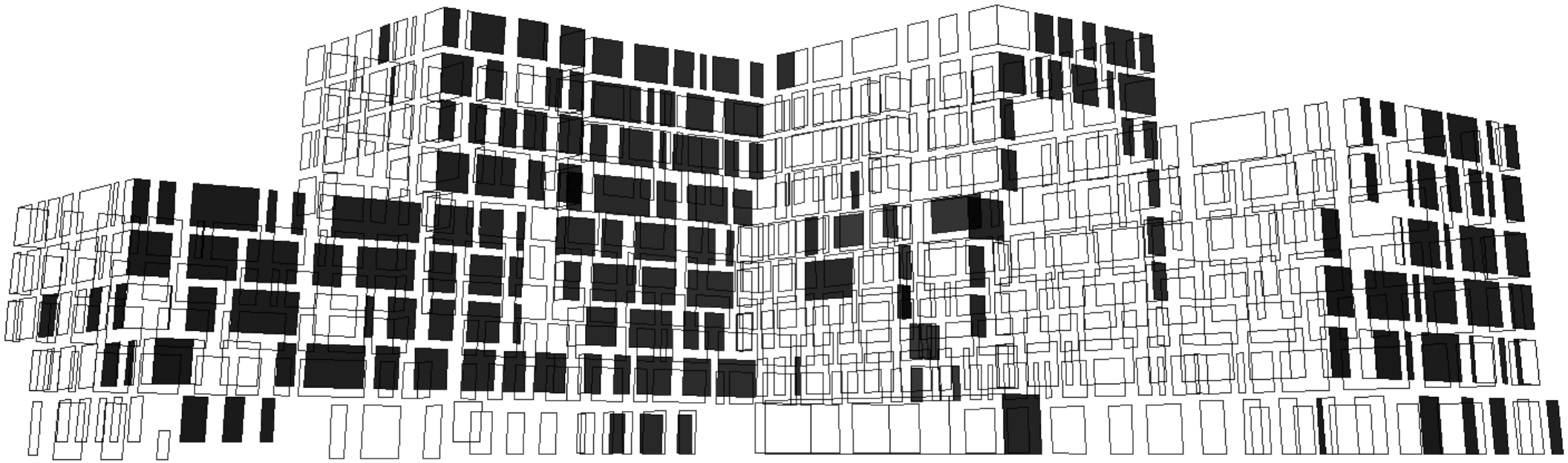
Energy end uses with 500 Lux level @ workplane

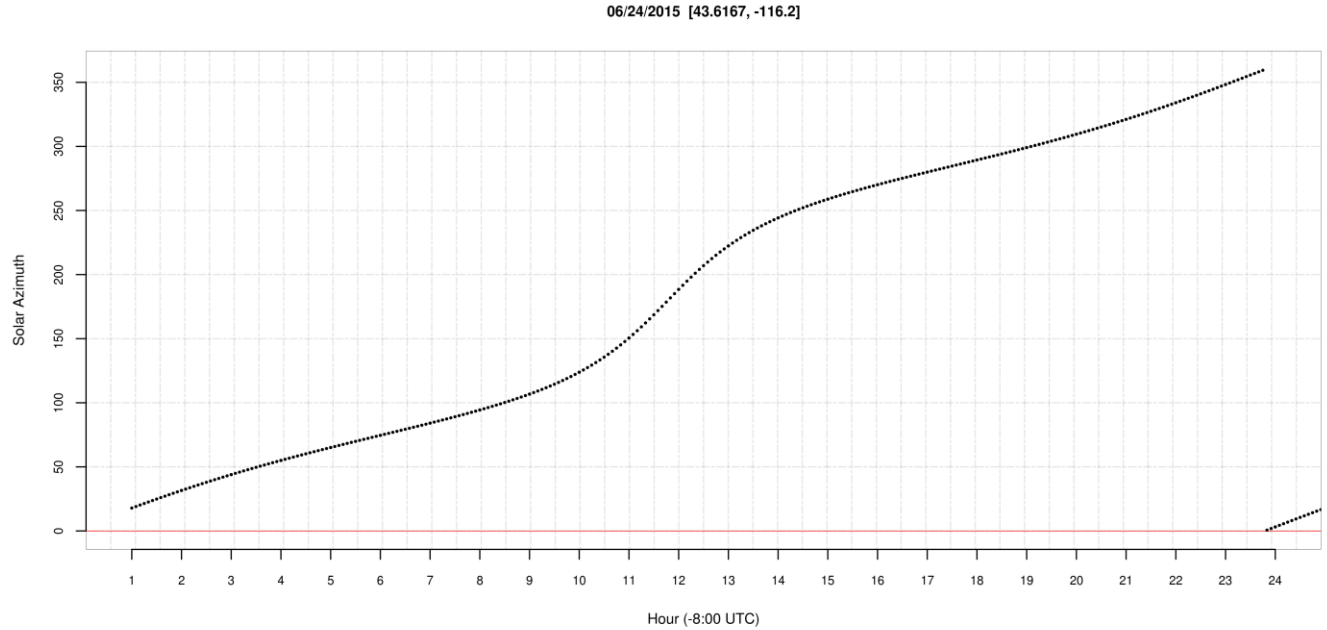


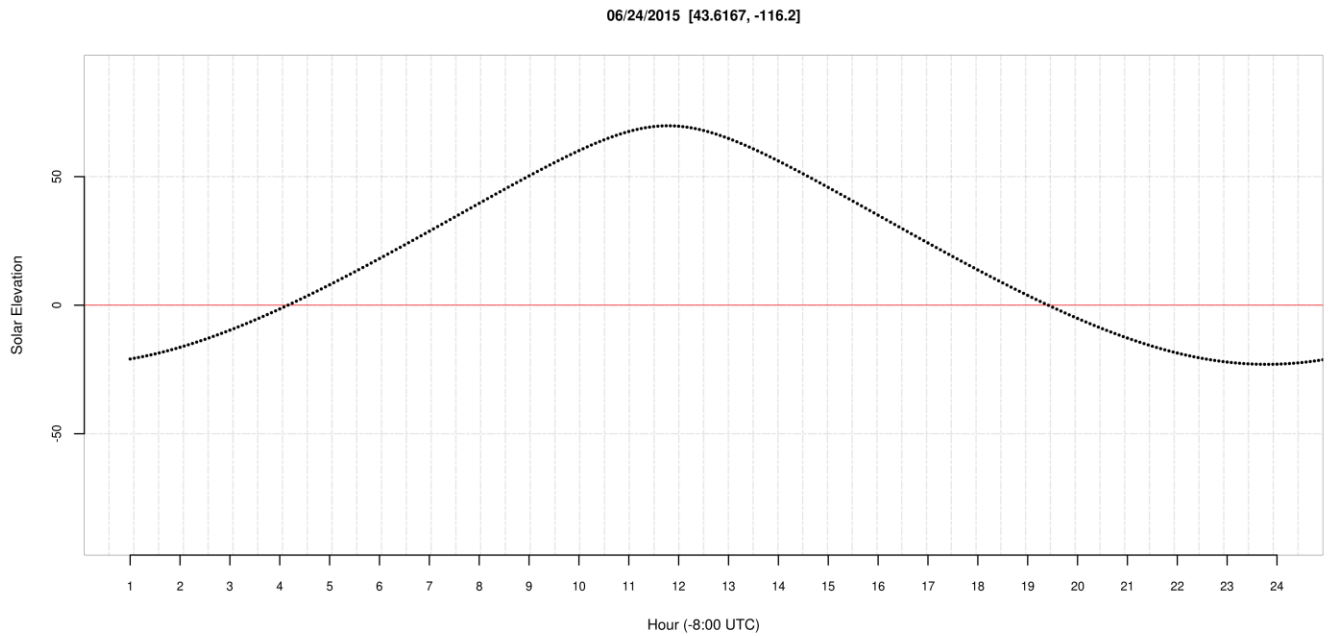
Back to the blinds operation data

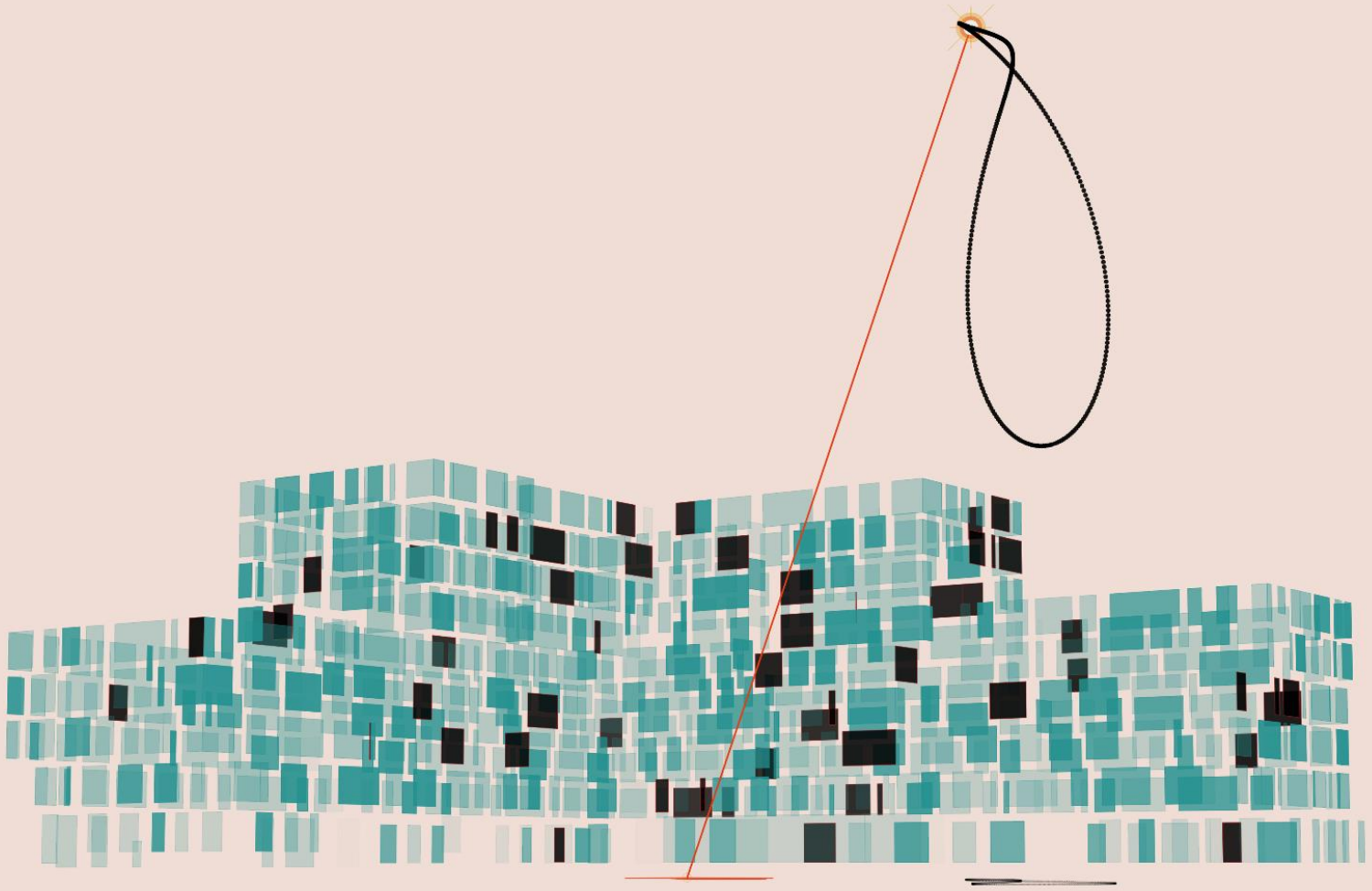


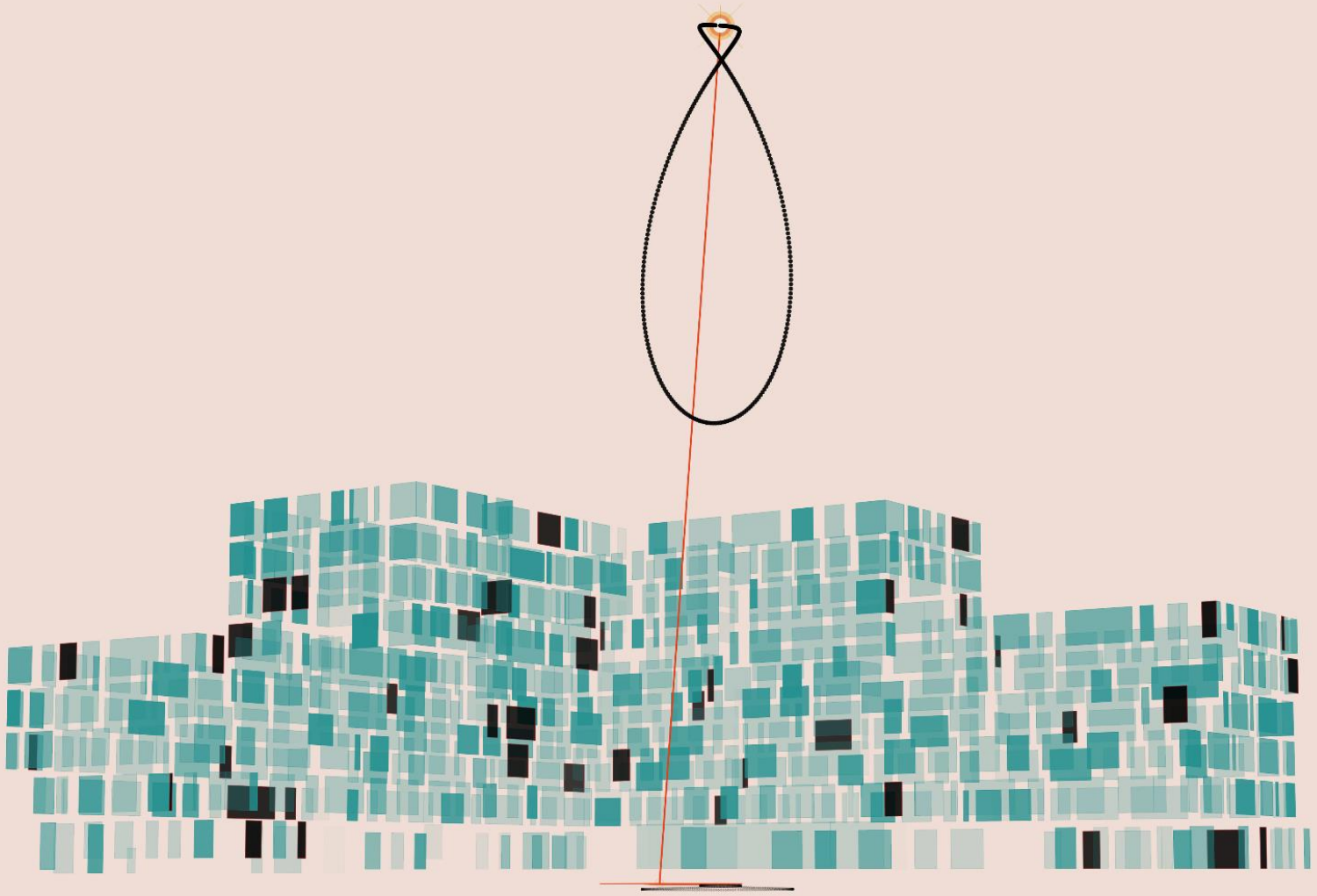


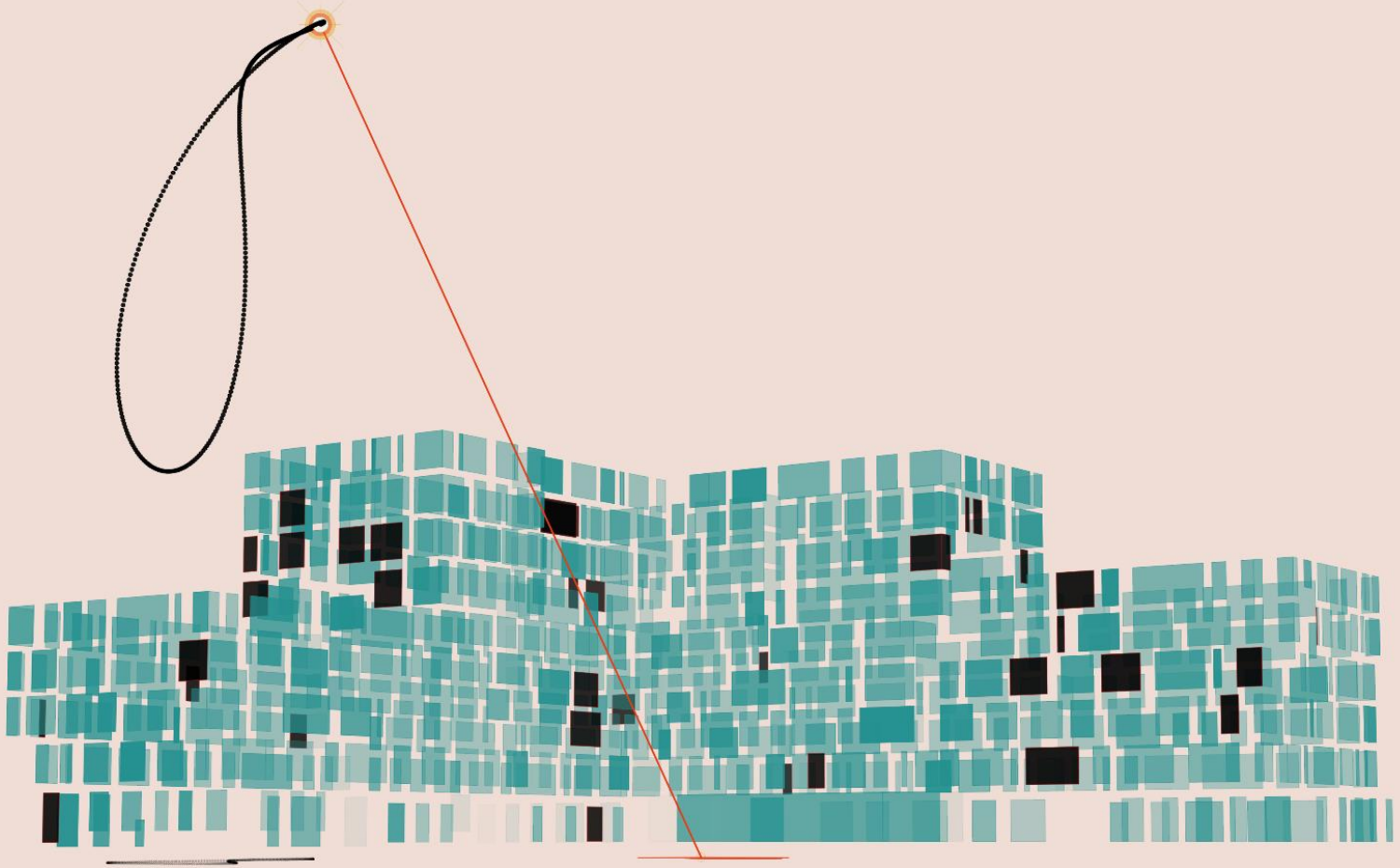


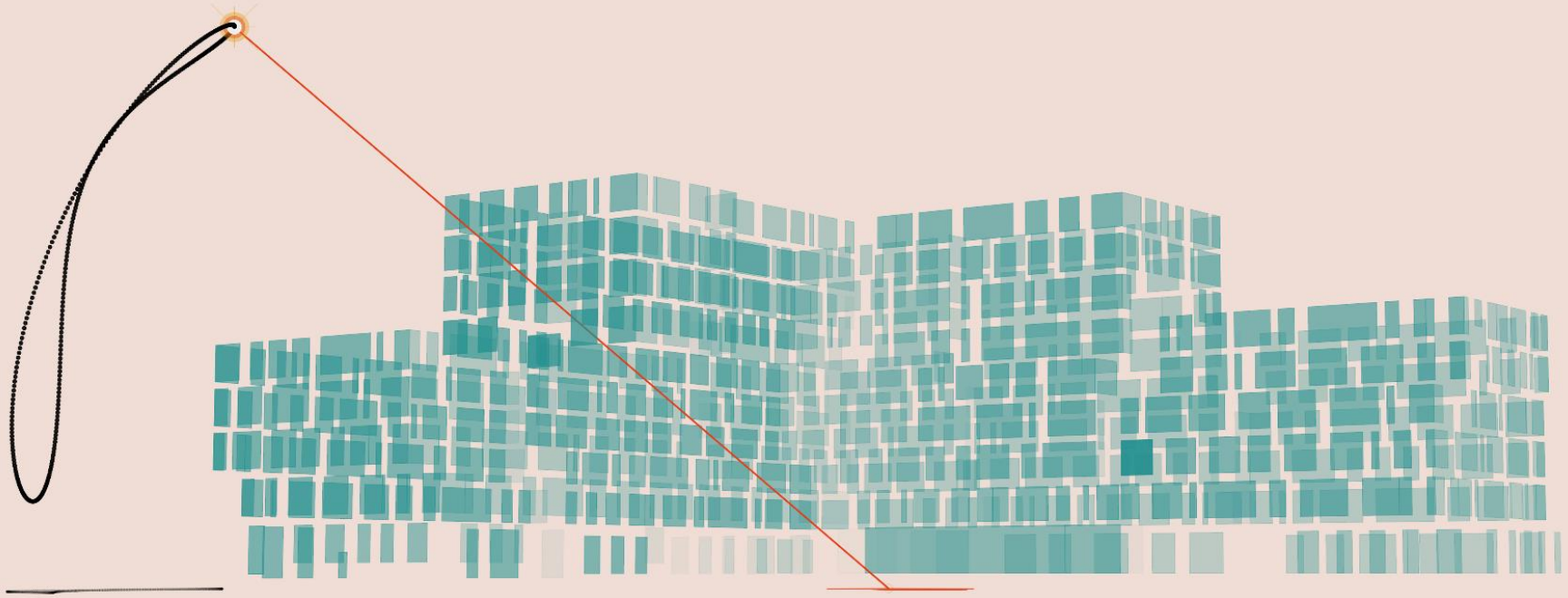

06/24/2015 [43.6167, -116.2]
Solar Azimuth
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour (-8:00 UTC)


06/24/2015 [43.6167, -116.2]
Solar Elevation
-50
0
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour (-8:00 UTC)









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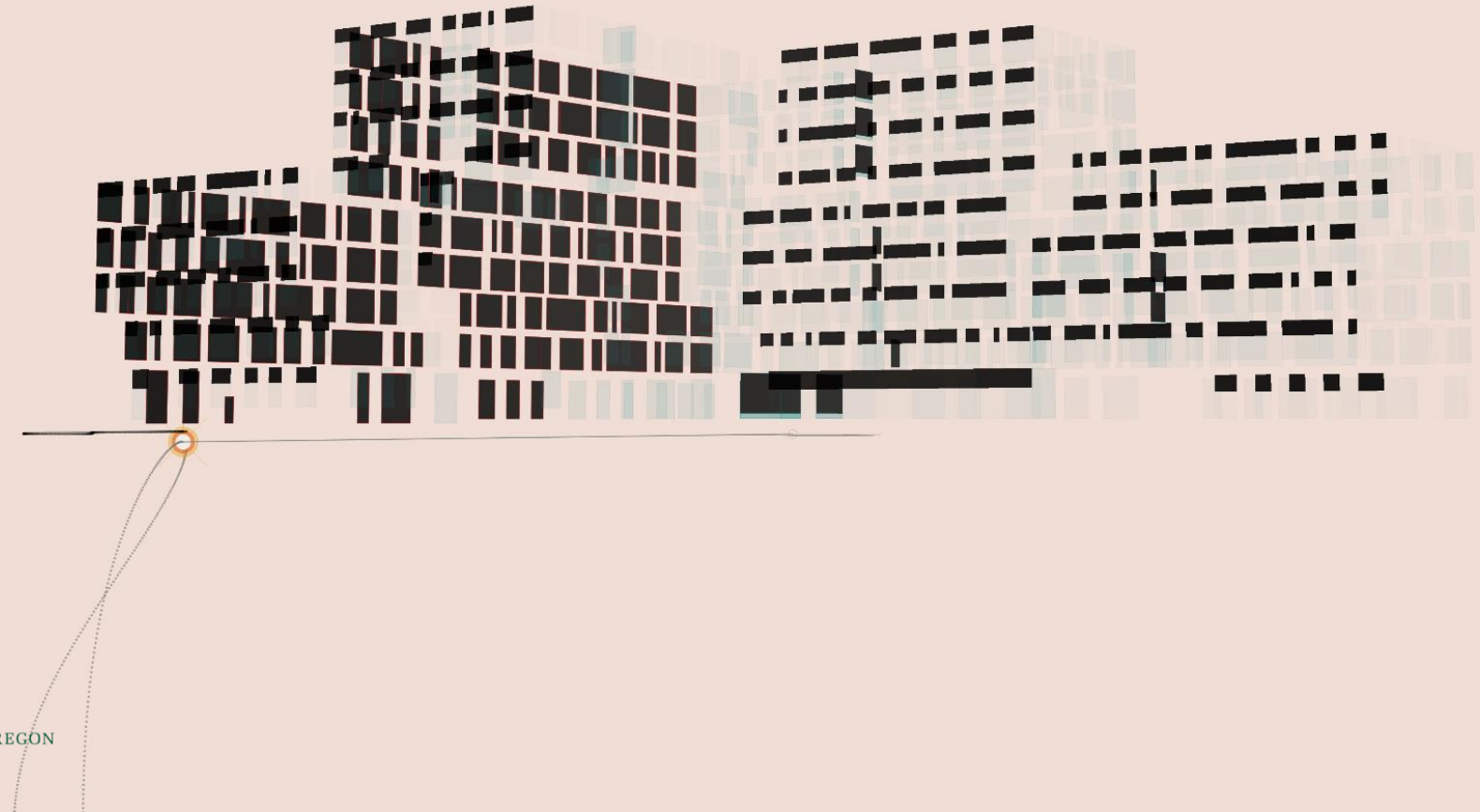

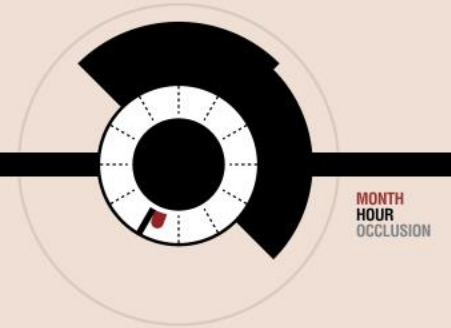

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R building blocks

- Packages
  - sp -- Classes and methods for spatial data
  - plot3D -- Plotting multi-dimensional data
  - plot3Drgl -- Plotting multi-dimensional data in openGL
  - rgl -- 3D visualization using OpenGL
- Functions
  - svg(), png() to set up the file outputs.
  - perspbox() to set up the plot environment, min/max coordinate values.
  - plot(), plot3D(), polygon(), polygon3D() to plot sets of coordinates.
  - RGL-specific:
    - open3d() to initialize RGL.
    - rgl.bg() to set up 3D environment.
    - rgl.points(), rgl.lines(), rgl.spheres(), rgl.triangles(), rgl.quads() to plot and render various geometries.
    - rgl.viewpoint() and rgl.snapshot() to set up a point of view and save as an image file.

Animations available online:

vimeo.com/142585361 *(Full year)*

vimeo.com/130748828 *(RGL June short)*

vimeo.com/130748827 *(RGL January short)*

Thanks to all of our industry partners and great research staff that made this project happen!

And thank all of you for your time!