Annual Simulation for Out-of-Plane Shading Systems

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Problem Statement

- We have a problem.
- More specifically: the original 3-phase method assumes BTDFs sit in rectangular openings
- External out-of-plane shading systems can be modeled, but only as part of “the environment”
- We would like to treat exterior shading systems as a kind of generalized BSDF…

But How?

Limitations of **genBSDF**

- Needs parallel, matched rectangular openings with well-defined border conditions
- Does not generalize to systems with disparate input & output apertures, such as out-of-plane shading or core daylighting

New **rfluxmtx** utility

- Introduced in *Radiance* 4.2
- General flux matrix calculation tool
- Latest version of **genBSDF** uses **rfluxmtx** (and **wrapBSDF**) to simplify script and support color
- Acts as front-end to **rcontrib**
  - Replacement for **genklemsamp** and others

Basic **rfluxmtx** Operation

rfluxmtx [-v][rcontrib options] sender.rad receiver.rad [-i system.oct][system.rad ..]

- Most options are simply passed to **rcontrib**
  - the **-v** option reports on execution
- Sender file contains single sender object
  - special comments identify sampling basis
- Receiver file contains one or more objects
  - similar comments indicate sampling bins
- System files given to **oconv** before receiver.rad

Comparison to **genklemsamp**

```
oconv -w -f material_detailed.rad simple.rad \
        dummysky.rad > dumbsky.oct
genklemsamp -vd -0.415671599 0.909514773 0 -c 20000 \
        material.rad bg4wind.rad \
        | rcontrib -n 2 -c 20000 -faf -e MF:4 -f reinhart.cal \
                -b rbin -bn Nrbins -m skyglow \
                @rtc_dmx.opt dumbsky.oct \
        > bg4.dmx
rm dumbsky.oct
```

```
rfluxmtx -v -n 2 -c 20000 -ff @rtc_dmx.opt bg4wind.rad \
        dummysky.rad -w material.rad simple.rad \
        > bg4.dmx
rfluxmtx: opening pipe to: rcontrib -fo+ -n 2 -w -ab 2 -ad 300 -fdf -c 20000 \
        -f reinhartb.cal -p MF=4,rNx=0,rNy=0,rNz=-1,Ux=0,Uy=1,Uz=0 \
        -bn Nrbins -b rbin -m skyglow -b 0 -m groundglow -y 145 \
        '!oconv -f -w material.rad simple.rad dummysky.rad'
rfluxmtx: sampling 145 directions
```

Sender File

```
rfluxmtx -v -n 2 -c 20000 -ff @rtc_dmx.opt bg4wind.rad \
    dummysky.rad -w material_detailed.rad simple.rad \
    > bg4.dmx
```

```
#@rfluxmtx h=kf u=+Z

Translucent_20 polygon zone02.rad00014b
0
0
12
   -0.733460650921     11.5416867963        0.762
   -0.733460650921     11.5416867963        2.7178
    0.652638345832     12.1751696194        2.7178
    0.652638345832     12.1751696194        0.762
```

No need to define material “Translucent_20”

Receiver File

```
rfluxmtx -v -n 2 -c 20000 -ff @rtc_dmx.opt bg4wind.rad \
    dummysky.rad -w material_detailed.rad simple.rad \
    > bg4.dmx
```

BEFORE

```
void glow skyglow
0
0
4 1 1 1 0

skyglow source sky
0
0
4 0 0 1 360
```

```
#@rfluxmtx h=u

void glow groundglow
0
0
4 1 1 1 0

groundglow source ground
0
0
4 0 0 -1 180
```

```
#@rfluxmtx h=r4 u=+Y

void glow skyglow
0
0
4 1 1 1 0

skyglow source sky
0
0
4 0 0 1 180
```

Separate (uniform) ground source

Advantages of **rfluxmtx**

- Simpler operation
  - –manages **rcontrib** parameters/order
  - –generates source sample rays
- Handles non-planar sources & receivers
- Unifies hemispherical sampling methods
  - –consistent application of Tregenza & Reinhart sky, Klems hemispherical bases, Shirley-Chiu disk
- Sender & receiver need not be parallel
- Receiver may be reused as subsequent sender

Pass-through Mode

- Specify '-' in place of sender file, e.g.:
  sample_generator | rfluxmtx [options] - receiver.rad
- **rfluxmtx** executes **rcontrib**, but does not generate sample rays
  - standard input is sent to **rcontrib** directly
- Same behavior as executing command reported by **-v** option
  - provided primarily as a convenience

Example Pass-through Mode

```
vwrays -ff -vf back.vf -x 600 -y 600 \
    | rfluxmtx -v `vwrays -vf back.vf -x 600 -y 600 -d` -n 4 \
        -ffc -ab 12 -ad 50000 -lw 2e-5 - window.rad testroom.mat testroom.rad
rfluxmtx: running: rcontrib -fo+ -n 4 -ab 12 -ad 50000 -lw 2e-5 -x 600 -y 430 \
    -ld- -ffc -c 1 -o vmx/window_%03d.hdr -f klems_full.cal \
    -bn Nkbins -b 'kbin(0,1,0,0,0,1)' -m windowglow \
    '!oconv -f testroom.mat testroom.rad window.rad'
```

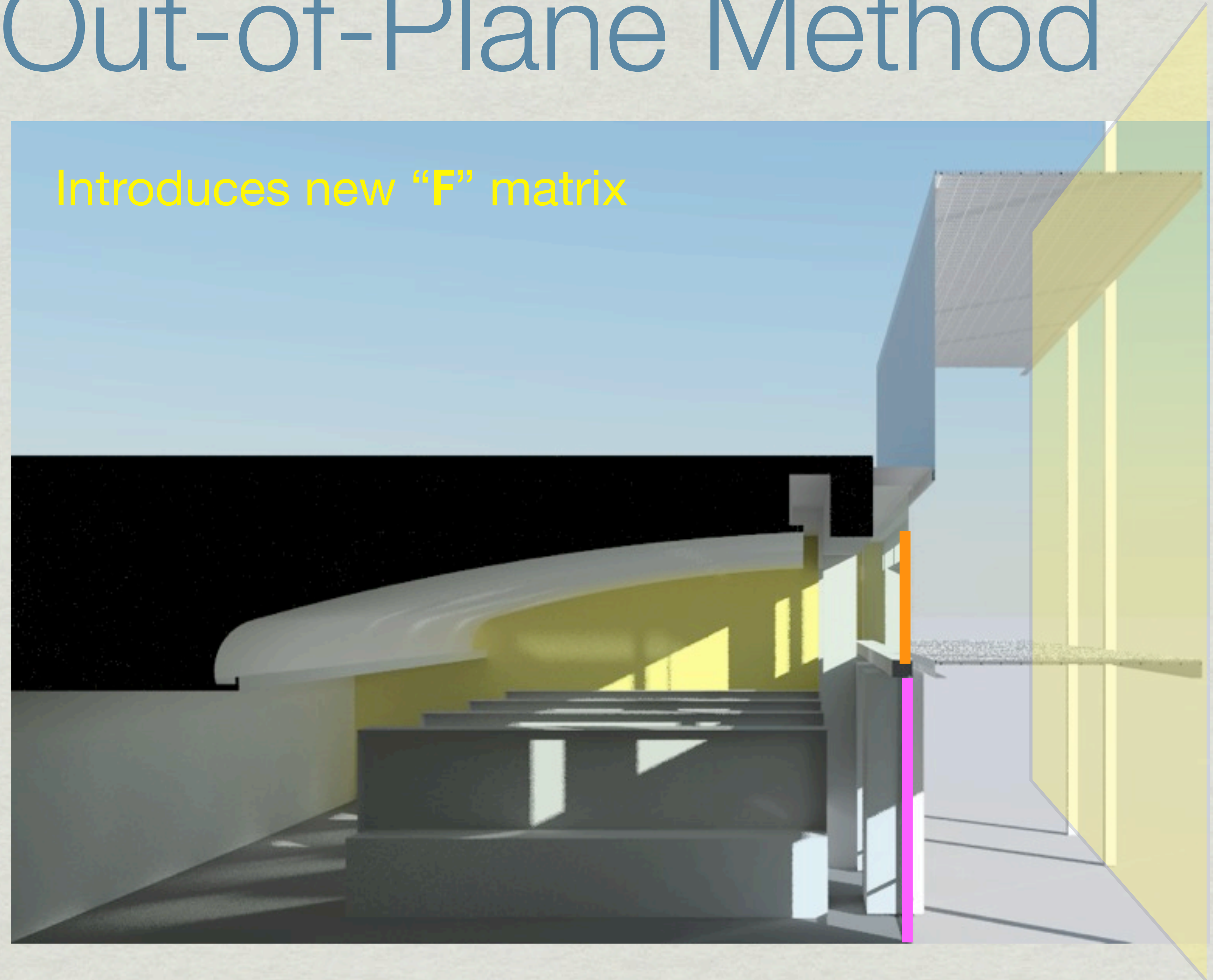
```
#@rfluxmtx h=kf u=Z o=vmx/window_%03d.hdr

void glow windowglow
0
0
4   1   1   1     0

windowglow polygon window
0
0
…
```

Due to Andy McNeil.

Out-of-Plane Method



F Matrix Represents Shading Flux Transfer

i = VTFDs

where:

i	is the desired result vector (radiances, irradiances, etc.)
V	is the "View" matrix defining the lighting connection between results and exiting directions for a window group
T	is the "Transmission" matrix defining the BTDF of the window group
F	is the "Facade" matrix defining the flux transfer of exterior shading
D	is the "Daylight" matrix defining the coefficients between incoming directions for the window group and sky patches
s	is a vector of sky patch luminances for a particular time and date

Similar to **V** matrix, multiple **F** matrices may be used to represent different exit apertures

Original 3-phase

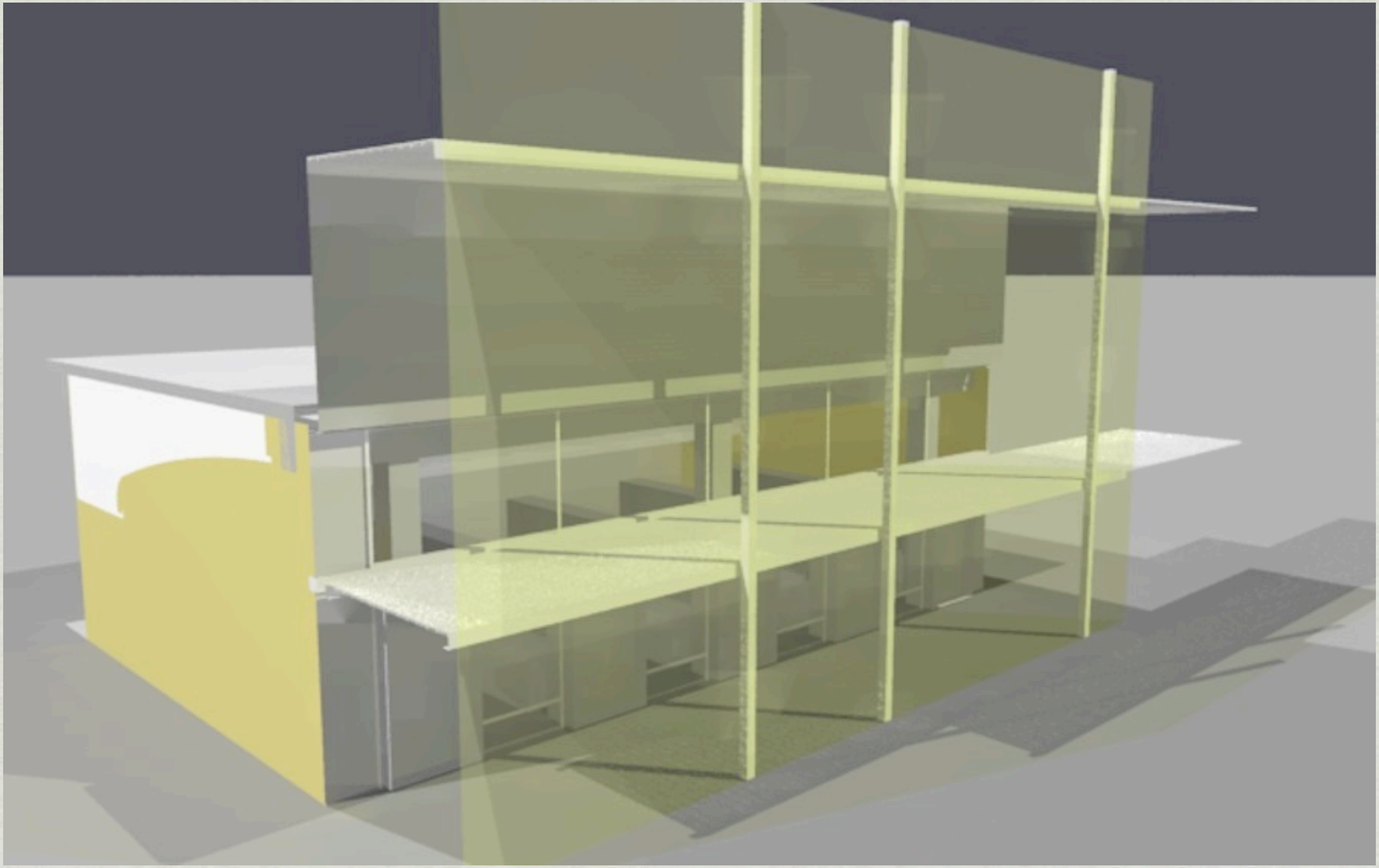
```
# Compute regular D matrix for clerestory glazing
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 glass_clerestory.rad \
skyglow.rad -i octs/model_3ph.oct > matrices/clerestory.dmx
# Compute regular D matrix for vision glazing
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 glass_vision.rad \
skyglow.rad -i octs/model_3ph.oct > matrices/vision.dmx
# Compute V matrix corresponding to illuminance points
rfluxmtx -faf -o matrices/%s.vmx -I+ -ab 7 -ad 50000 -lw 1e-7 \
- glazing.rad -i octs/model_3ph.oct < points.txt
# Followed by dctimestep or similar….
```

rfluxmtx source input

```
#@rfluxmtx h=kf u=Z

clerestory polygon zone22.rad08702
0
0
12
    -4.12477  20.16760  2.94640
    -4.12477  20.16760  4.80060
    -4.12478  5.75628  4.80060
    -4.12478  5.75628  2.94640
```

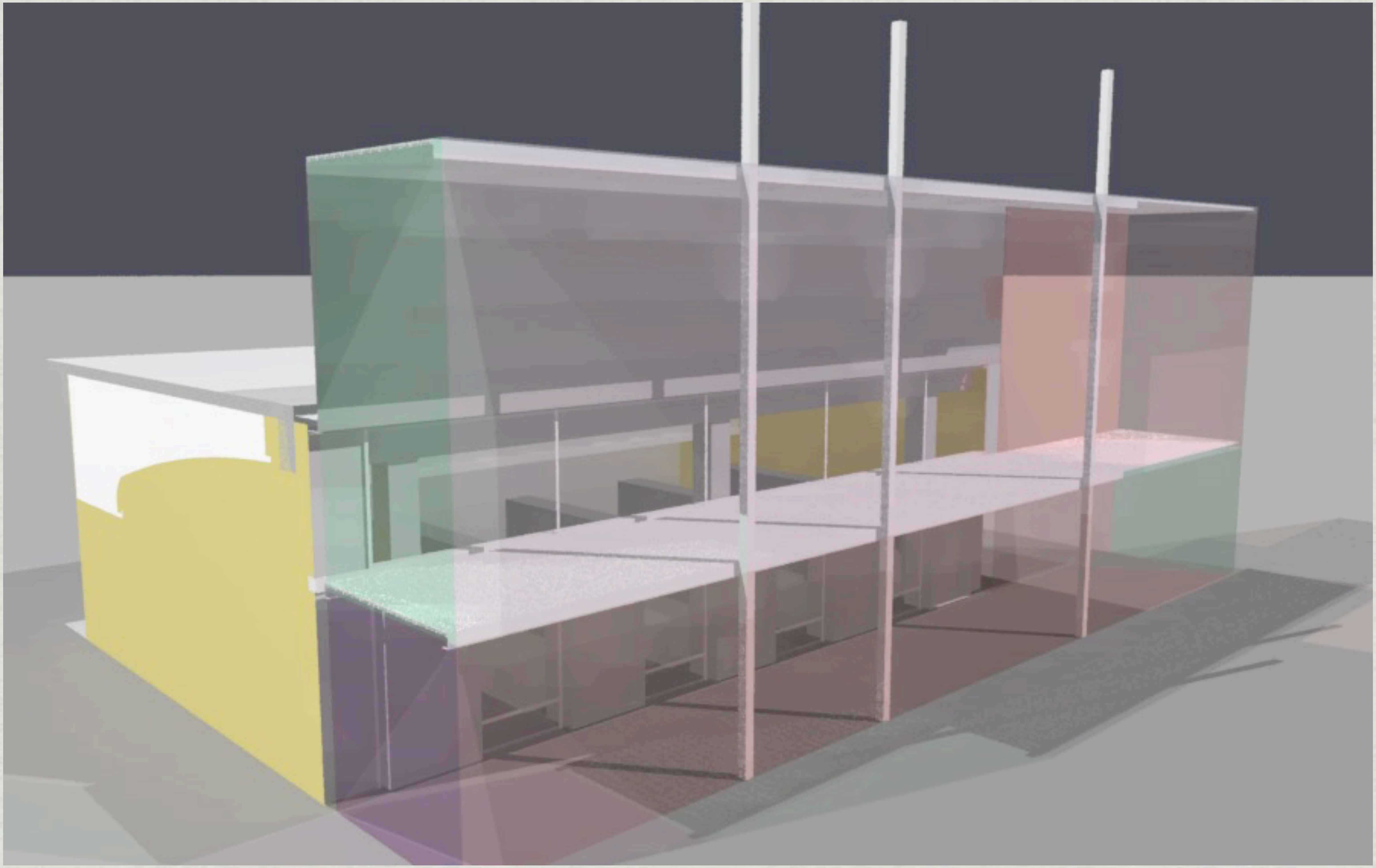
Placement of **F** Aperture



Single **F** Matrix Usage

```
# Compute D matrix from exterior aperture
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 portF1.rad \
skyglow.rad -i octs/model_3ph.oct > matrices/F1/facade.dmx
# Compute F matrix connecting clerestory glazing to exterior aperture
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 glass_clerestory.rad \
portF1.rad -i octs/model_3ph.oct > matrices/F1/clerestory.fmx
# Compute F matrix connecting vision glazing to exterior aperture
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 glass_vision.rad \
portF1.rad -i octs/model_3ph.oct > matrices/F1/vision.fmx
# Compute V matrix corresponding to illuminance points
rfluxmtx -faf -o matrices/%s.vmx -I+ -ab 7 -ad 50000 -lw 1e-7 \
- glazing.rad -i octs/model_3ph.oct < points.txt
# Followed by dctimestep or similar….
```

Multiple (9) **F** Apertures



Decision to divide upper and lower regions may improve accuracy when F apertures have different view of environment, in this case, adjacent building.

Using 9 **F** Matrices

```
# Compute separate D matrix from each exterior aperture
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 portF9a.rad \
skyglow.rad -i octs/model_3ph.oct > matrices/F9/F9a.dmx
...7 similar lines for F9b through F9h...
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 portF9i.rad \
skyglow.rad -i octs/model_3ph.oct > matrices/F9/F9i.dmx
# Compute F matrices connecting clerestory glazing to exterior apertures
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 -o matrices/F9/clerestory%s.fmx \
    glass_clerestory.rad portalsF9.rad -i octs/model_3ph.oct
# Compute F matrices connecting vision glazing to exterior apertures
rfluxmtx -ff -ab 4 -ad 10000 -lw 1e-5 -c 5000 -o matrices/F9/vision%s.fmx \
    glass_vision.rad portalsF9.rad -i octs/model_3ph.oct
# Compute V matrix corresponding to illuminance points
rfluxmtx -faf -o matrices/%s.vmx -I+ -ab 7 -ad 50000 -lw 1e-7 \
- glazing.rad -i octs/model_3ph.oct < points.txt
# Followed by dctimestep or similar….
```

Comments

* In this case, we expect the 9-aperture calculation to be more accurate because it matches the original test condition more closely
* In general, the single aperture might be preferred if the model is a section of a larger façade
* More importantly, the **F** matrix calculation adds a needed 4th phase to fill the gap between 3-phase and 5-phase methods

6-phase, anyone?

Results Comparison

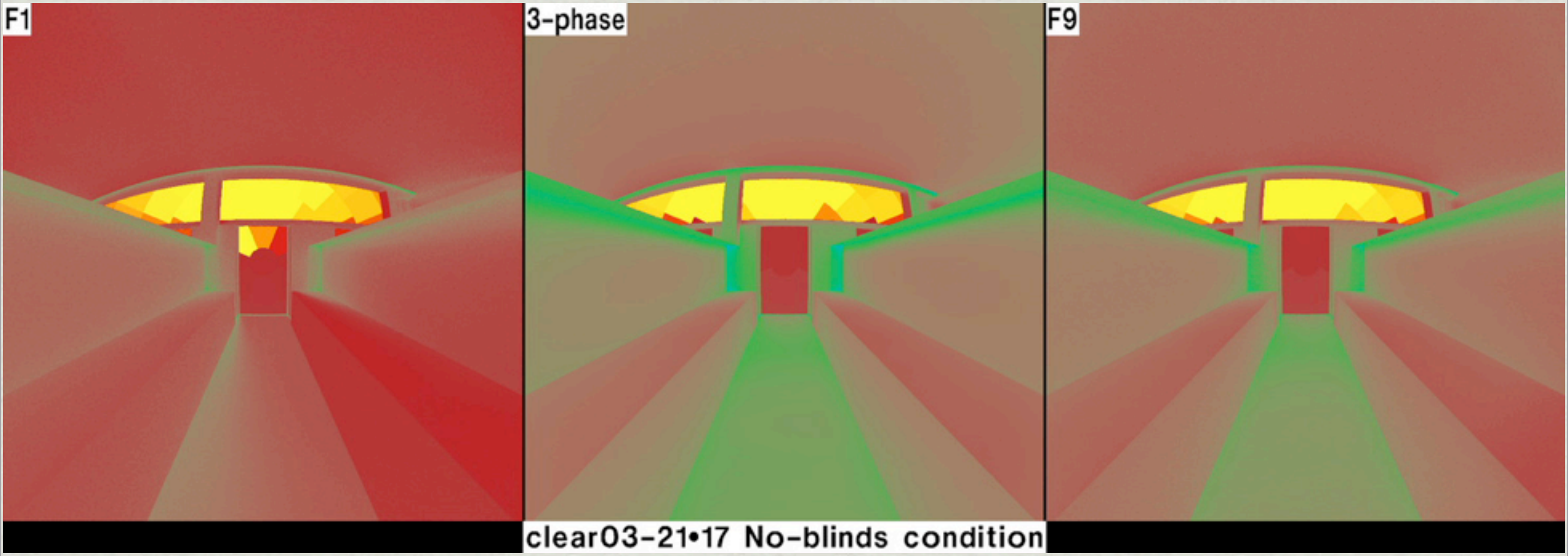
- Compared F-matrix calculations to original 3-phase method in west-facing structure
- 576 workplane illuminance test points
- No blinds and 5 venetian blind angles
- On 21st for each of 7 months, solstice-to-solstice
- One-hour intervals over daylight period

Results Comparison

Relative Error	Avg.	Max.
Single **F** matrix	22%	33%
Nine **F** matrices	6%	10%

Largest errors occurred in direct lighting conditions

No-blinds Comparison



Conclusions

- **F**-matrix method is effective method to account for exterior shading systems and façades
- Provides for operable exterior shades, non-standard apertures
- Efficient comparison of alternative façade designs
- Potential to develop exterior shade library