Validation of DVIZ simulations with BSDFs against Radiance

(and hints why the dew point temperature and patch sizes can be important in gendaymtx)

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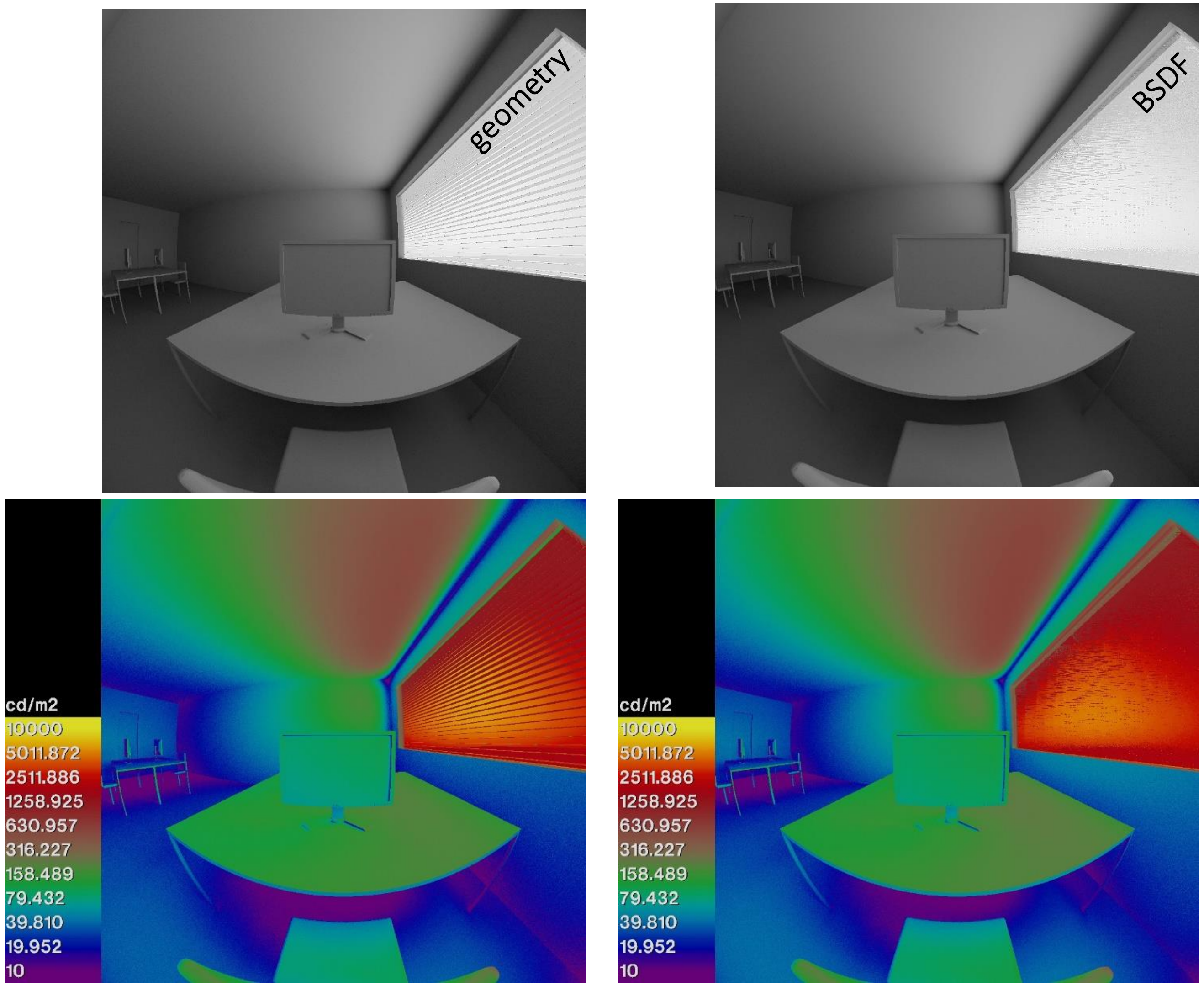
It‘s all about BSDFs

“Photometry of façade systems”
(Complex Fenestration Systems – CFS)

- Basis for including daylighting and shading systems in simulations
  - Lighting simulations (sun & skylight)
  - Energy simulations (angular dependent solar gains)
- Analogon to luminous intensity distributions for daylighting systems
  - BSDF: scattering
  - BRDF: reflection
  - BTDF: transmission
  - BSDF = BRDF + BTDF
- Distribution on the interior side as function of the exterior situation
- Already implemented in various tools



A bit of BSDF history

(without any claim to completeness)

1999: IEA SHC Task 21: Measurement of BTDFs

IEA SHC Task 21 experts

2007: BTDFs in mkillum

Greg Ward

2009: Three-phase method

Greg Ward

2011: BSDF Material Primitive & Variable-resolution BSDFs

Greg Ward & Andy McNeil

2014: Five-phase method

Andy McNeil

2021: Peak extraction

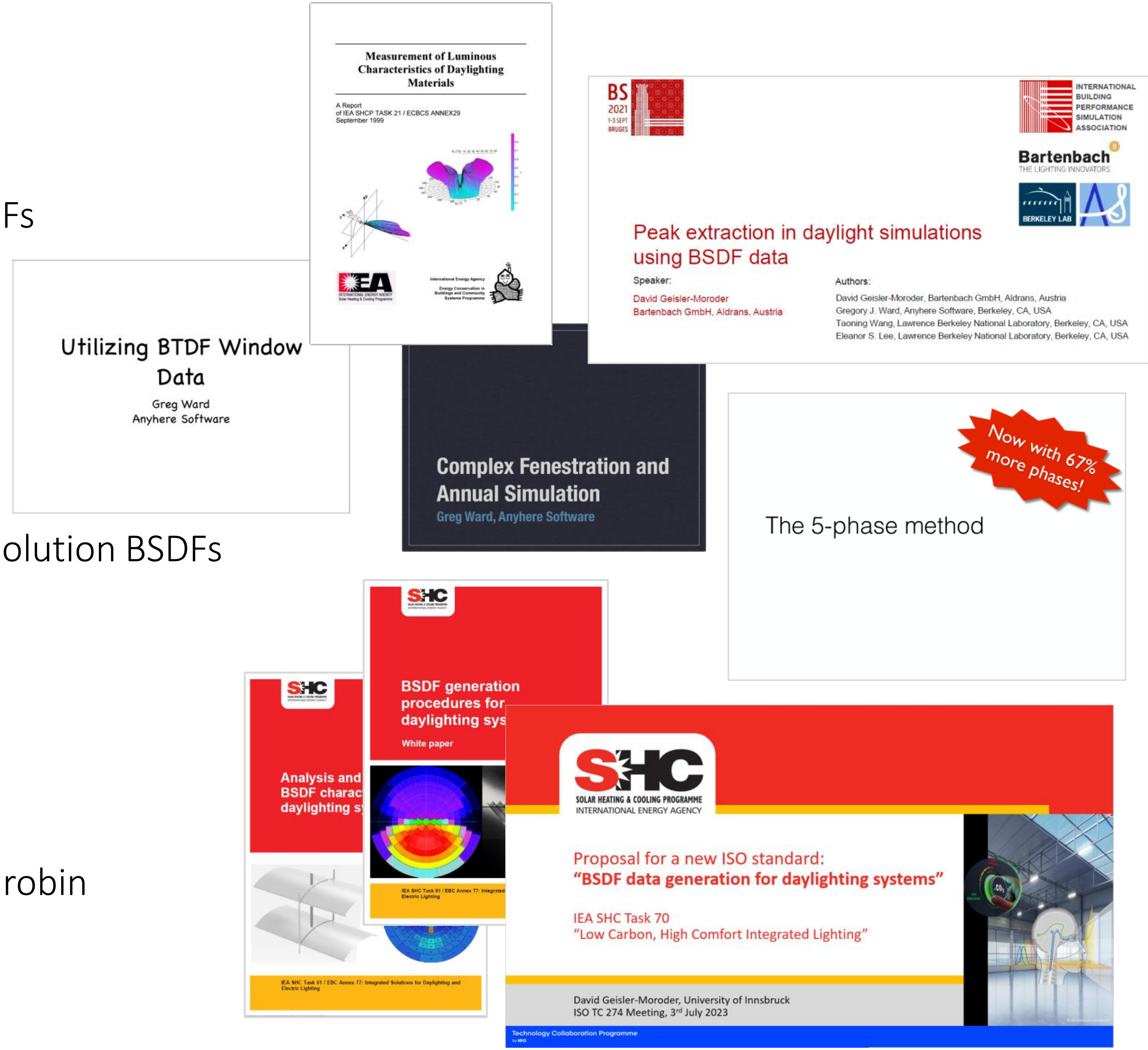
D. Geisler-Moroder, G. Ward, T. Wang, E. Lee

2021: IEA SHC Task 61: white paper & round robin

IEA SHC Task 61 experts

2023: Proposal for ISO standard

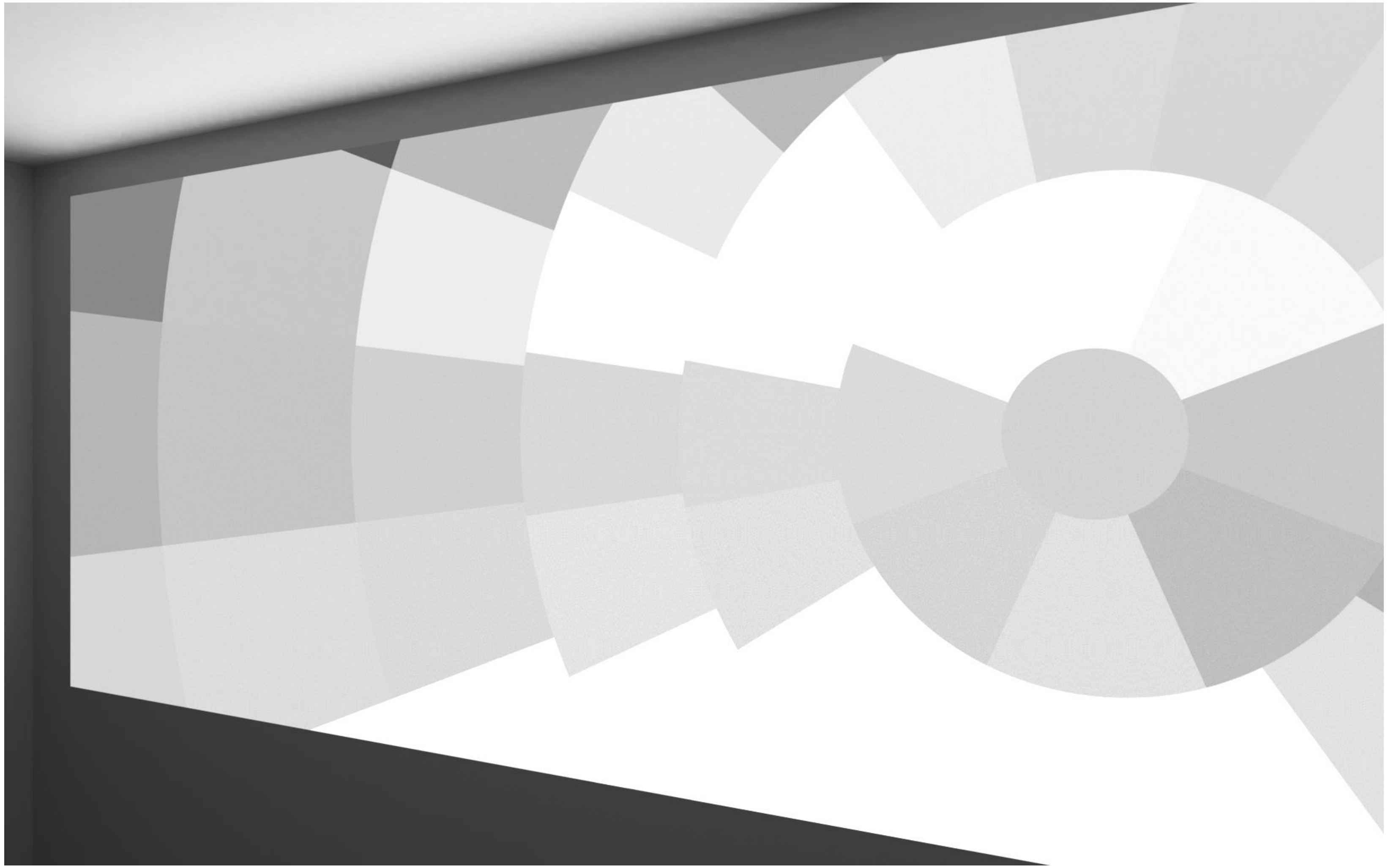
David Geisler-Moroder / IEA SHC Task 70



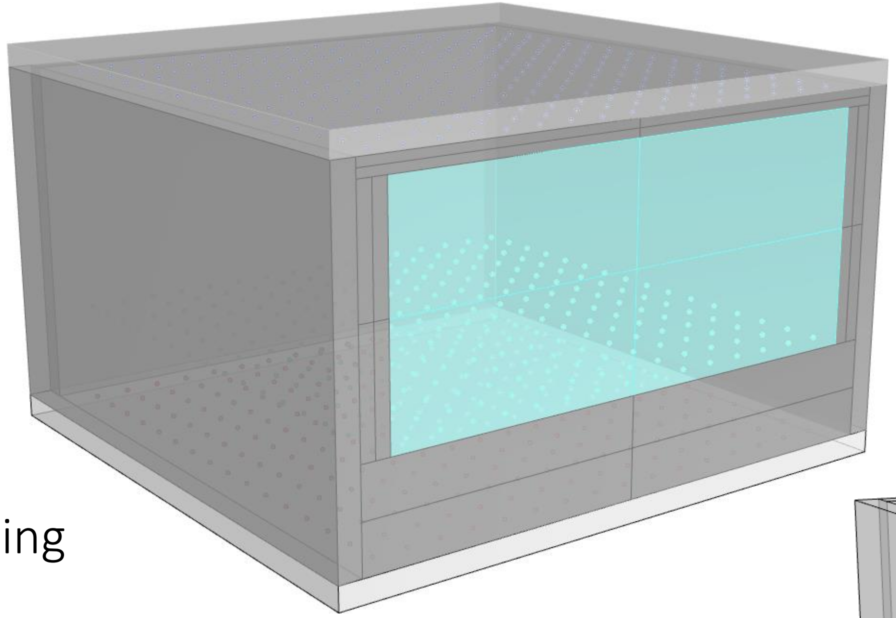
BSDFs in DViz

Loading and sampling:

Radiance: bsdf.h and bsdf.c



Scenes

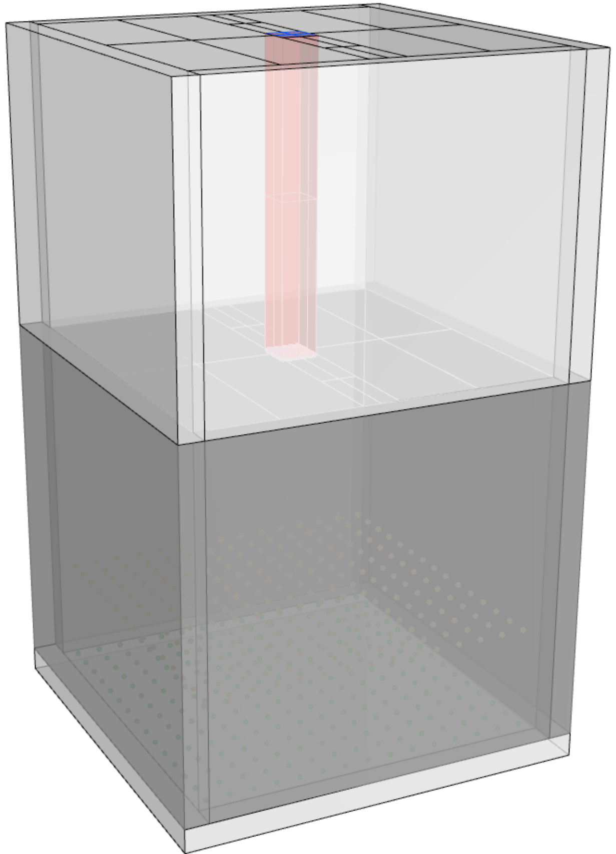


Facade Room

- Simple shoebox model
- Window on one side
- Systems (BSDF): clear glass, redirecting lamella system
- Sensor grids on floor, workplane, and ceiling
- 3-PM simulation

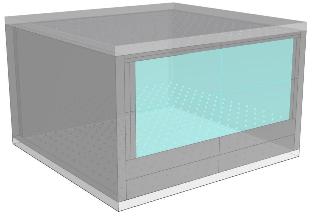
Sun Tunnel Room

- Simple shoebox model
- Rectangular light pipe
- Systems: clear glass, (diffuser BSDFs to come)
- Sensor grids on floor, workplane, and sun tunnel outlet
- x-PM simulation

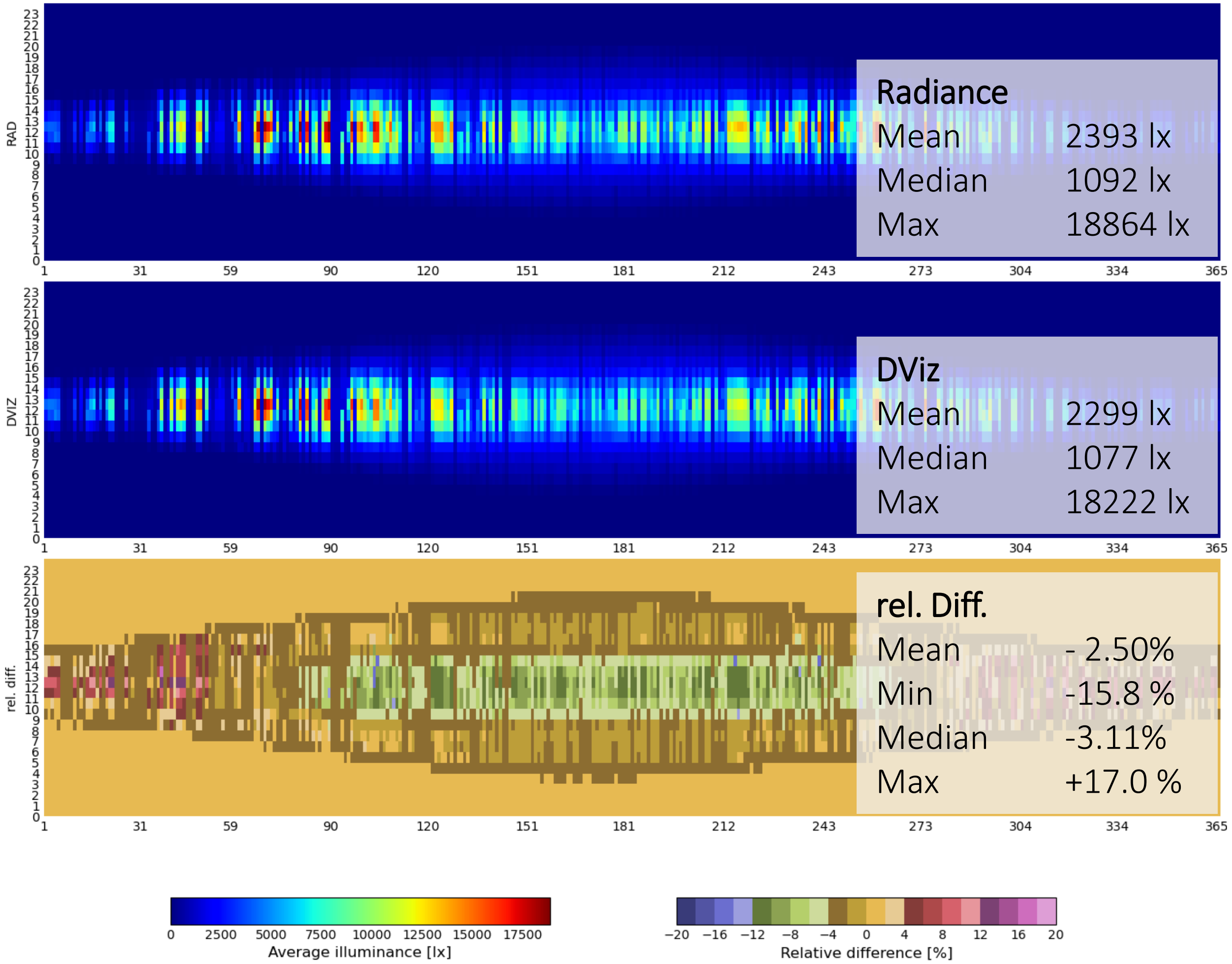


Results

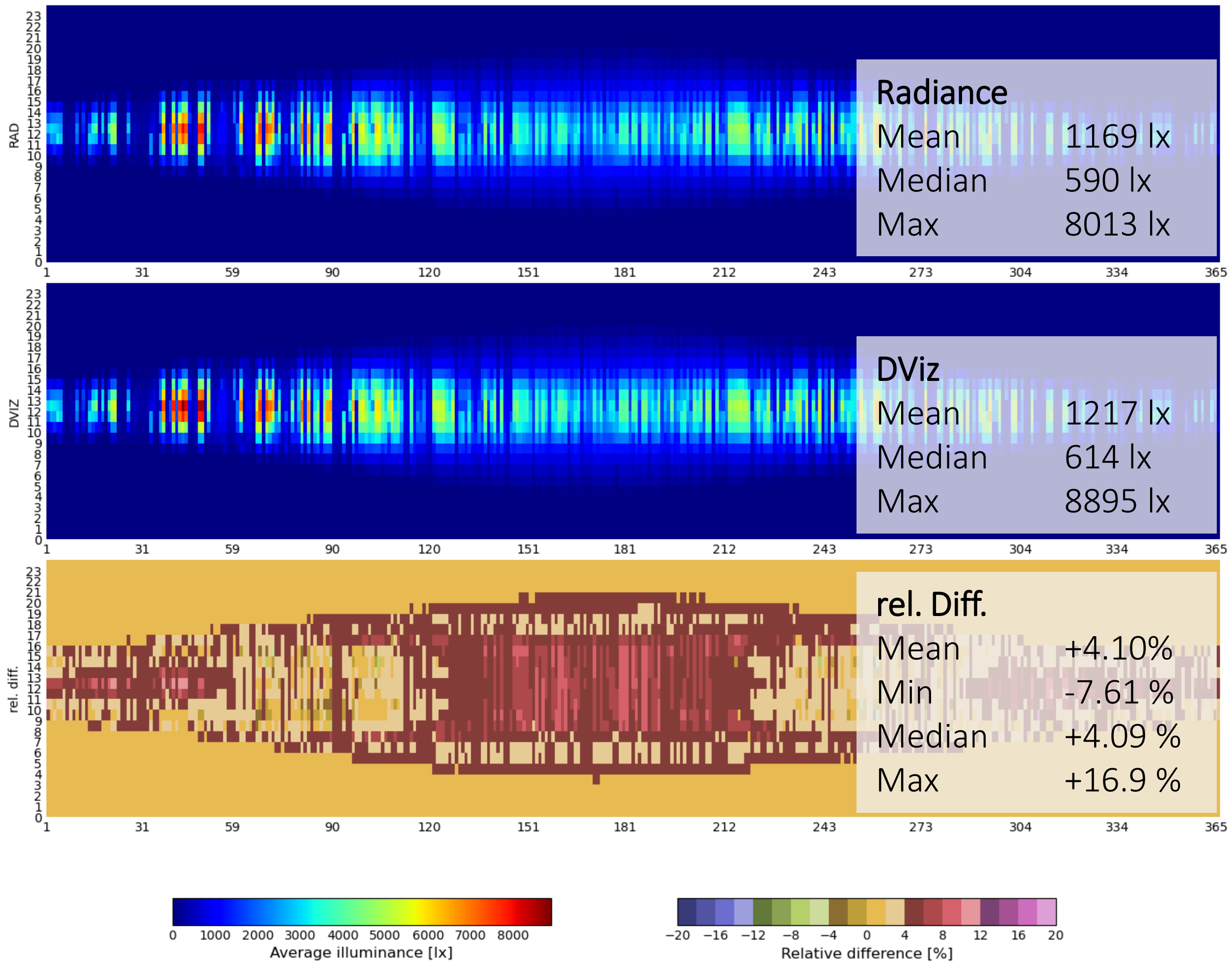
Average illuminance on floor grid



BSDF: Clear glass



BSDF: Redirecting blinds



DViz

Scene

Geometry

- Imported
- Modelled in DViz

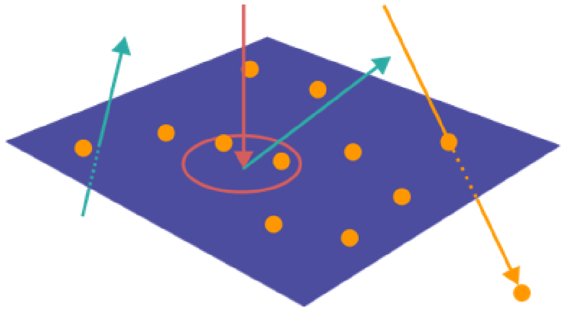
Light Sources

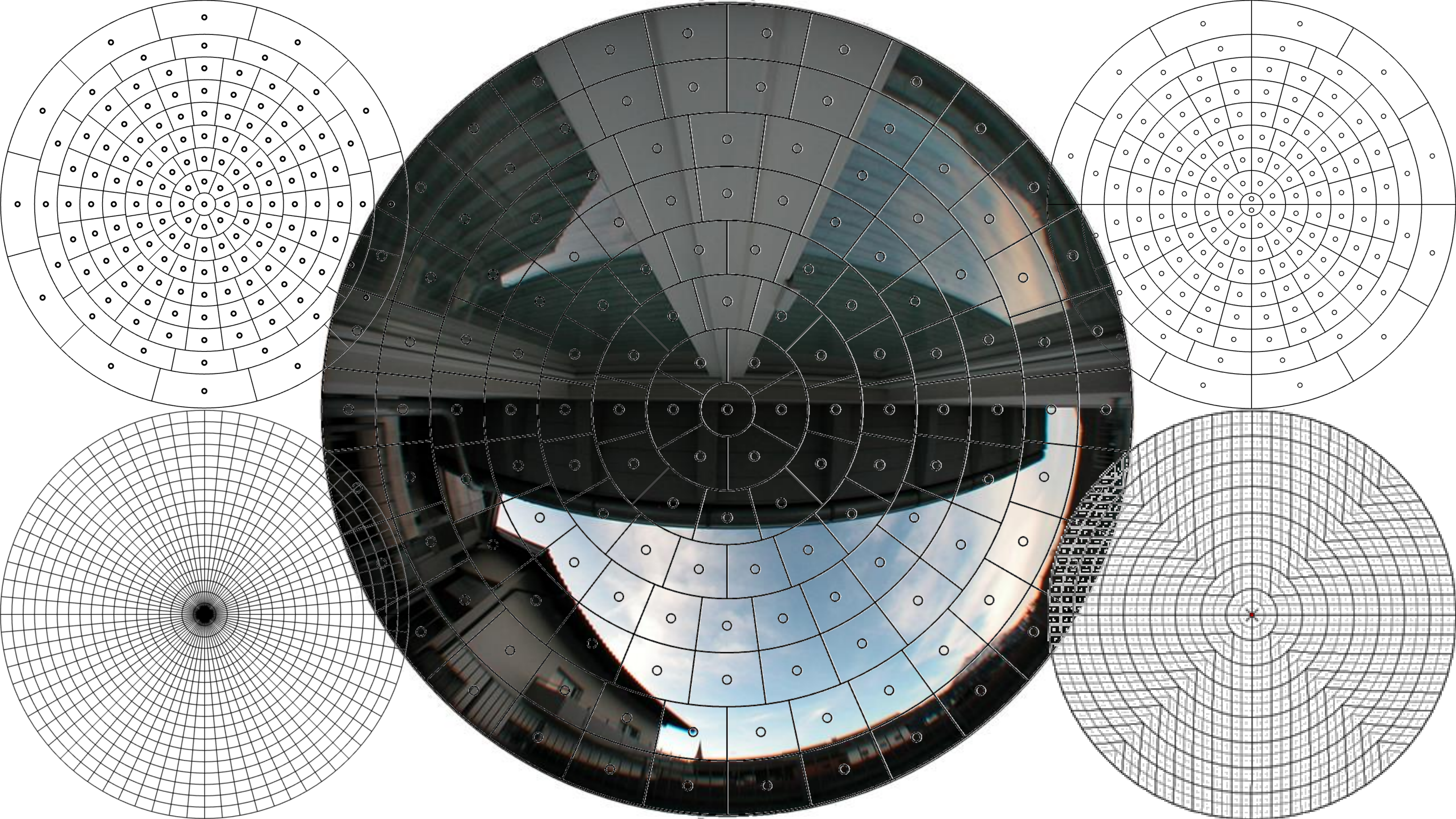
Sky
Environment Light – 360x180

Sun
“Directional” Light
0.5° or 11° opening angle

Sensor Point

- Plane 4x4 cm
- “Intercepts” photons
- Interacts with primary rays
- “Invisible” to other rays

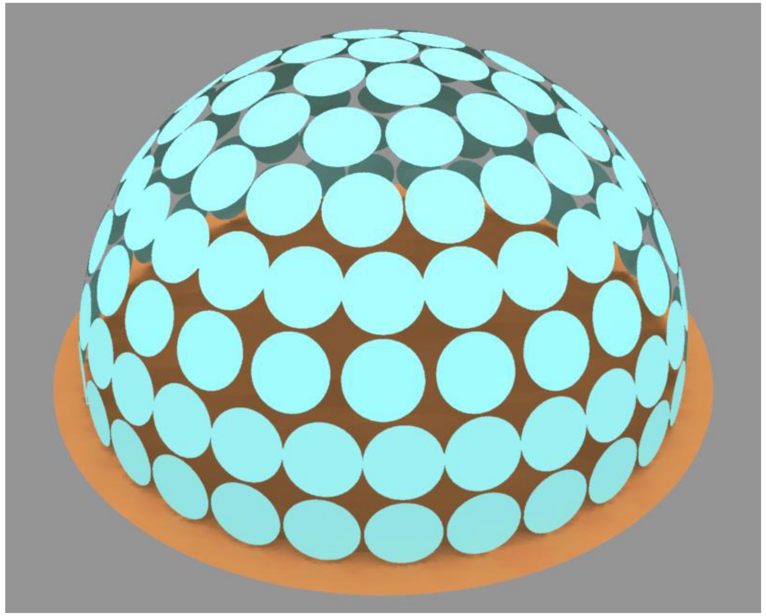


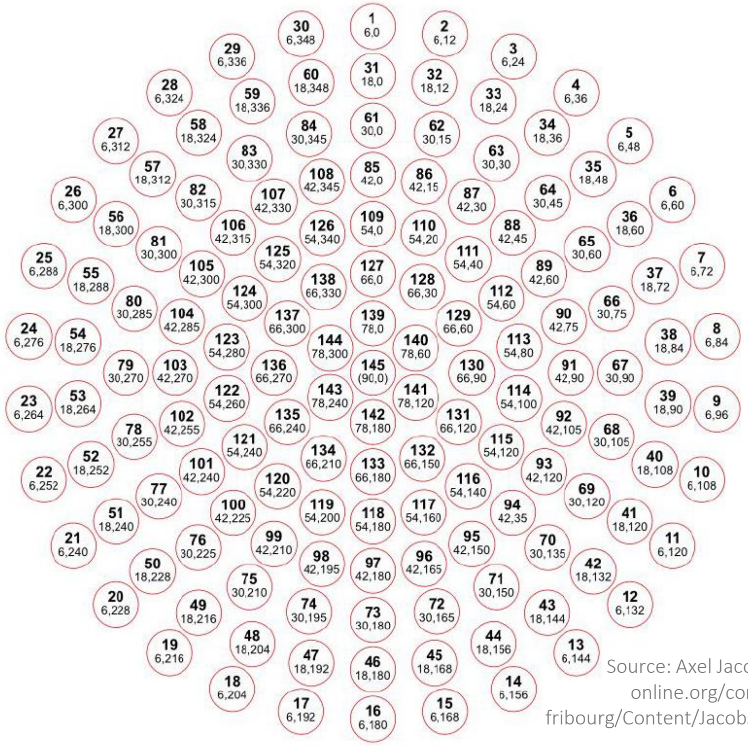


Tregenza Sky Patches

<u>Tregenza patches (CIE 108-1994)</u>

- subdivision of hemisphere into 145 patches
- approx. equal solid angles for each patch
- 8 θ ranges (from zenith):
  {0° - 12° - 24° - 36° - 48° - 60° - 72° - 84°} +/- 6°
- ϕ subdivisions per θ range: {1, 6, 12, 18, 24, 24, 30, 30}
- average solid angle 2π/145 = 0.0433 sr (~2 x 6.73°)





Source: Axel Jacobs: https://www.radiance-online.org/community/workshops/2008-fribourg/Content/Jacobs/jacobs-fribourg2008d.pdf

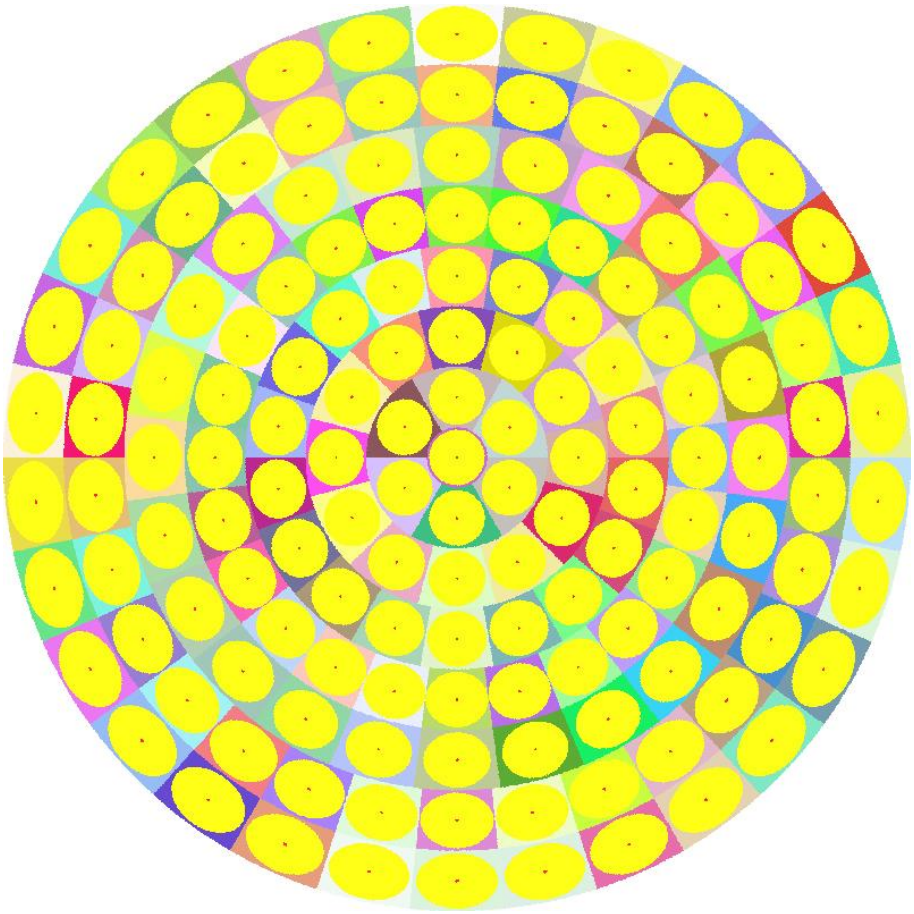
Tregenza Sky Patches

<u>Implementation options</u>

- Full patches
  (backward raytracing)

- 11° aperture angle
  (measurement device)

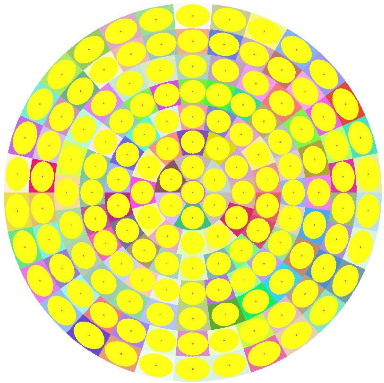
- Center positions mimicking the sun (0.5° aperture)
  (forward raytracing)



Tregenza Sky Patches

<u>Radiance implementation</u>

- Full patches – *Radiance default* (backward raytracing)
- 11° aperture angle – *adapted 5PM option* (measurement device)
- Center positions mimicking the sun (0.5° aperture) – *adapted 5PM option* (forward raytracing)



gendaymtx.c (v 2.39, adapted)

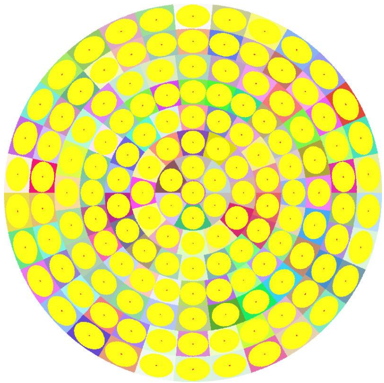
```
	case '5':		/* 5-phase calculation */
		nsuns = 1;
		fixed_sun_sa = PI/360.*atof(argv[++i]);
		if (fixed_sun_sa <= 0) {
			fprintf(stderr, "%s: missing solar disk size argument for '-5' option\n",
					progname);
			exit(1);
		}
		fixed_sun_sa *= fixed_sun_sa*PI;
		break;
	case 'x':		/* hack for sky patch solid angle -- DGM 01.05.2023*/
		fixed_sky_sa = atof(argv[++i]);
		if (fixed_sky_sa <= 0) {
			fprintf(stderr, "%s: missing patch size argument for '-x' option\n",
					progname);
			exit(1);
		}
		fixed_sky_sa = 2.*PI*(1. - cos(PI/360.*fixed_sky_sa));
		break;
```

```
rh_pazi[nskypatch-1] = 0.;
if (fixed_sky_sa > 0) /* hack for fixed sky patch size -- DGM 01.05.2023 */
	rh_dom[nskypatch-1] = fixed_sky_sa;
else
	rh_dom[nskypatch-1] = 2.*PI*(1. - cos(alpha*.5));
p = 1;			/* "normal" patches */
for (i = 0; i < NROW*rhsubdiv; i++) {
	const float ralt = alpha*(i + .5);
	const int   ninrow = tnaz[i/rhsubdiv]*rhsubdiv;
	const float dom = 2.*PI*(sin(alpha*(i+1)) - sin(alpha*i)) /
				(double)ninrow;
	for (j = 0; j < ninrow; j++) {
		rh_palt[p] = ralt;
		rh_pazi[p] = 2.*PI * j / (double)ninrow;
		if (fixed_sky_sa > 0) /* hack for fixed sky patch size -- DGM 01.05.2023 */
			rh_dom[p++] = fixed_sky_sa;
		else
			rh_dom[p++] = dom;
	}
}
return nskypatch;
```

Tregenza Sky Patches

Radiance implementation

- Full patches – *Radiance default* (backward raytracing)
- 11° aperture angle – *adapted 5PM option* (measurement device)
- Center positions mimicking the sun (0.5° aperture) – *adapted 5PM option* (forward raytracing)



```
#@rfluxmtx h=u u=Y
void glow ground_glow
0
0
4 1 1 1 0

ground_glow source ground
0
0
4 0 0 -1 180

#@rfluxmtx h=r1 u=Y
void glow sky_glow
0
0
4 1 1 1 0

sky_glow source sky
0
0
4 0 0 1 180
```

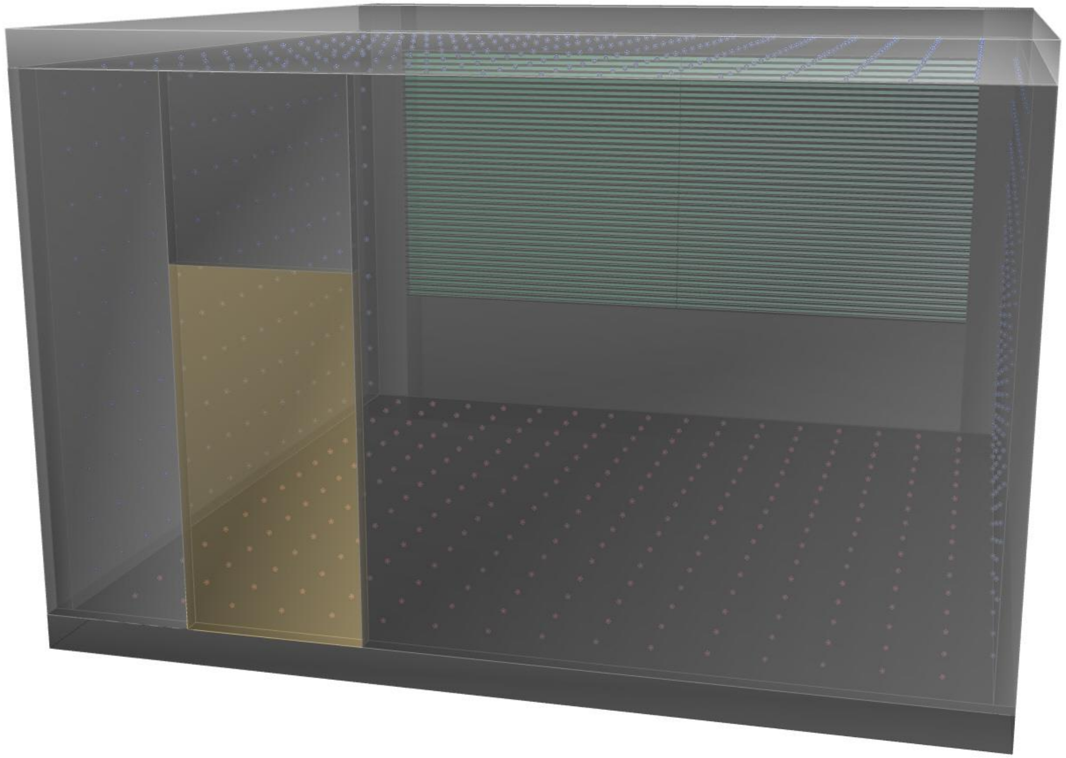
```
#@rfluxmtx h=u u=Y
void glow ground_glow
0
0
4 1 1 1 0

ground_glow source ground
0
0
4 0 0 -1 180


###
### generation done with
### cnt 145 | rcalc -e MF:1 -f reinsrc.cal -e Rbin=recno -o '#@rfluxmtx h=u u=Y
### void glow patch_${Rbin} 0 0 4 1 1 1 0
### patch_${Rbin} source thisPatch 0 0 4 ${Dx} ${Dy} ${Dz} 11.0'
###

#@rfluxmtx h=u u=Y
void glow patch_1       0 0 4 1 1 1 0
patch_1        source thisPatch 0 0 4     0 0.994522 0.104528 11.0
#@rfluxmtx h=u u=Y
void glow patch_2       0 0 4 1 1 1 0
patch_2        source thisPatch 0 0 4 0.206773 0.972789 0.104528 11.0
#@rfluxmtx h=u u=Y
void glow patch_3       0 0 4 1 1 1 0
patch_3        source thisPatch 0 0 4 0.404508 0.908541 0.104528 11.0
#@rfluxmtx h=u u=Y
void glow patch_4       0 0 4 1 1 1 0
patch_4        source thisPatch 0 0 4 0.584565 0.804585 0.104528 11.0
#@rfluxmtx h=u u=Y
void glow patch_5       0 0 4 1 1 1 0
patch_5        source thisPatch 0 0 4 0.739074 0.665465 0.104528 11.0
```

Scene



Test room for BSDF validation: „Facade Empty“

Renderings without facade system for direct view to the sky

Variants

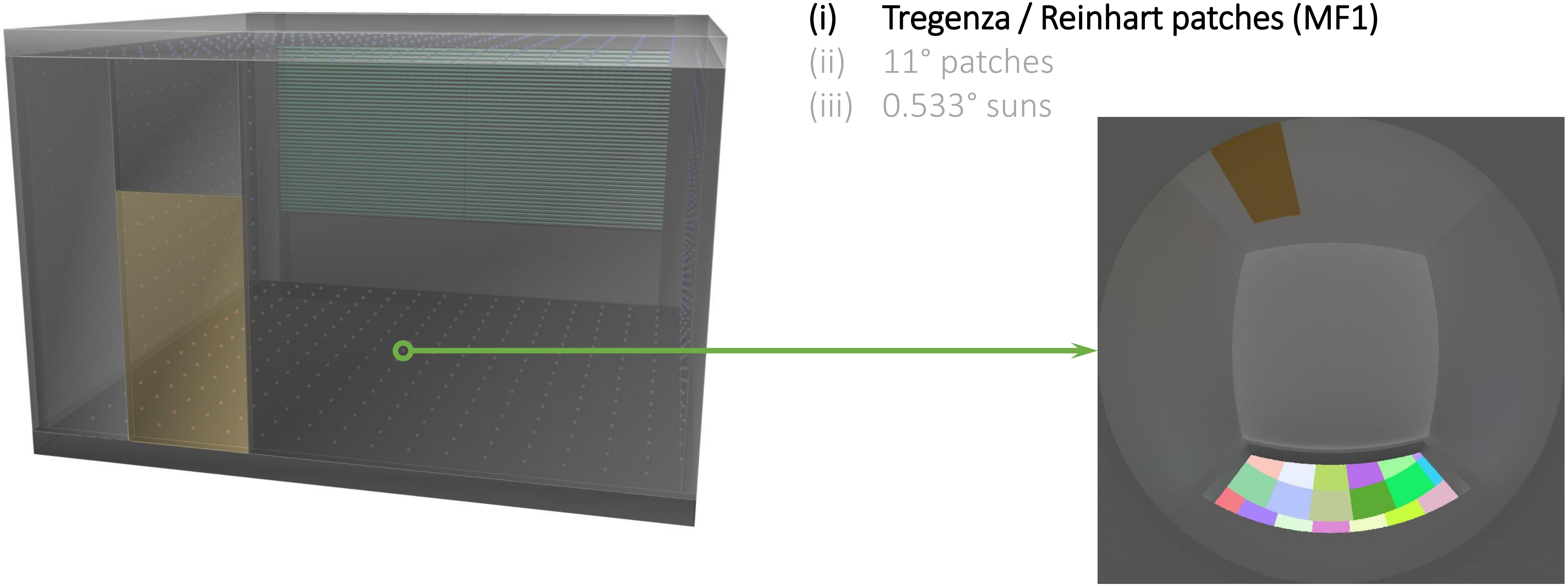
Test room for BSDF validation: „Facade Empty“

Renderings without facade system for direct view to the sky

(i) Tregenza / Reinhart patches (MF1)

(ii) 11° patches

(iii) 0.533° suns



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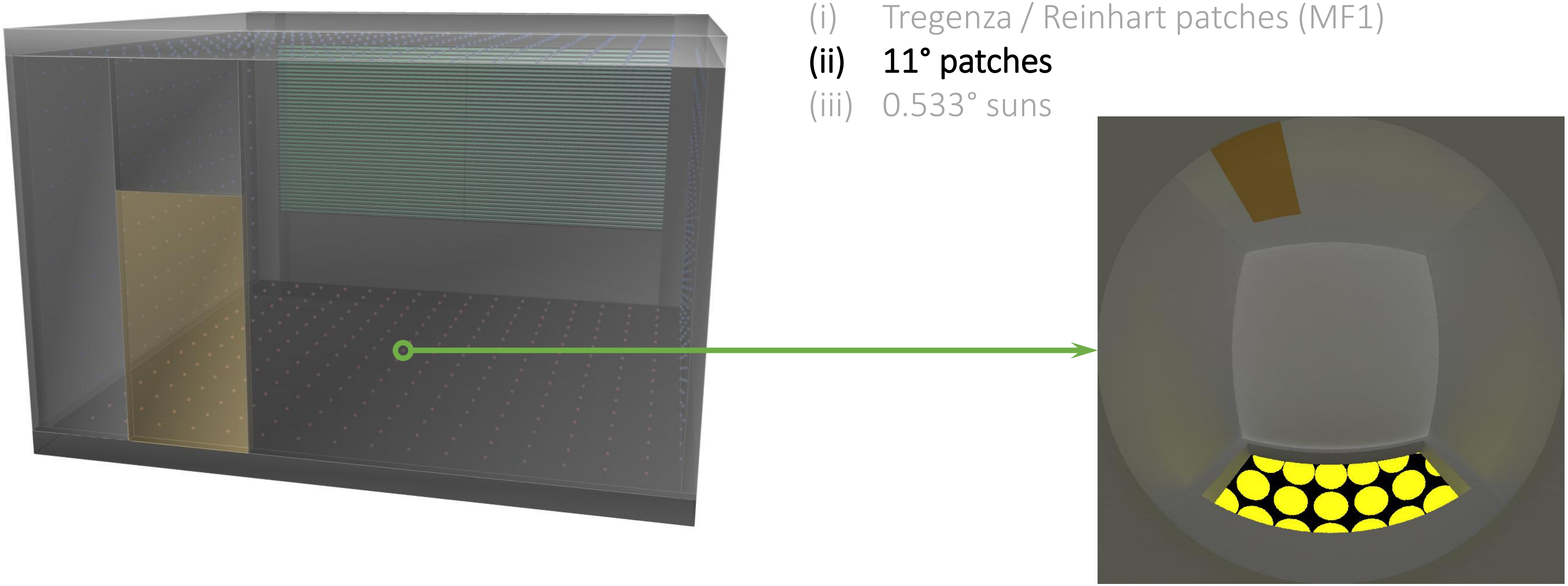

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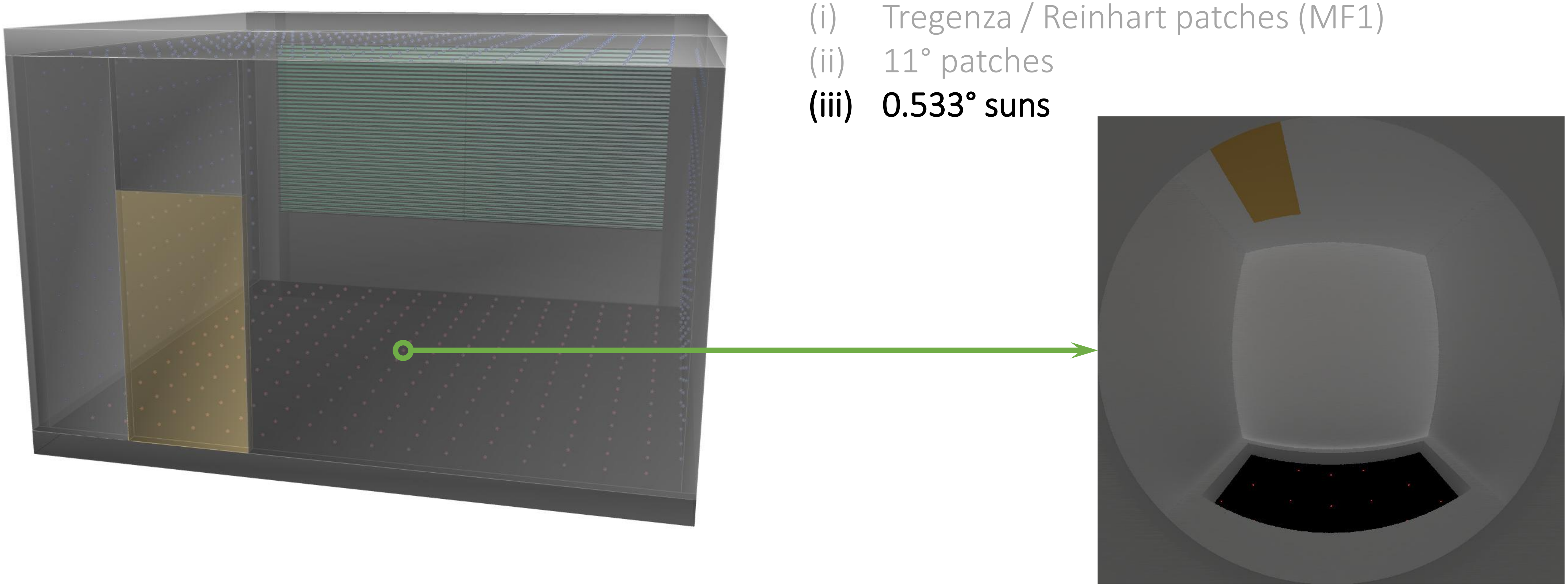

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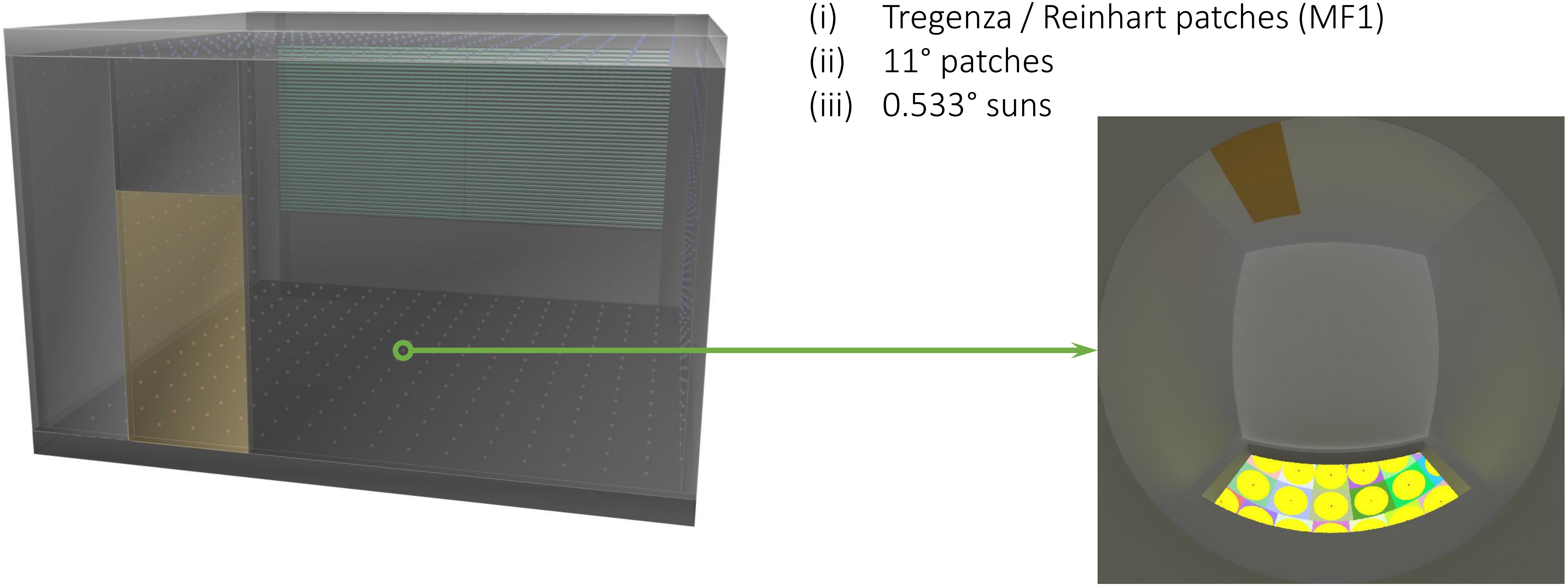
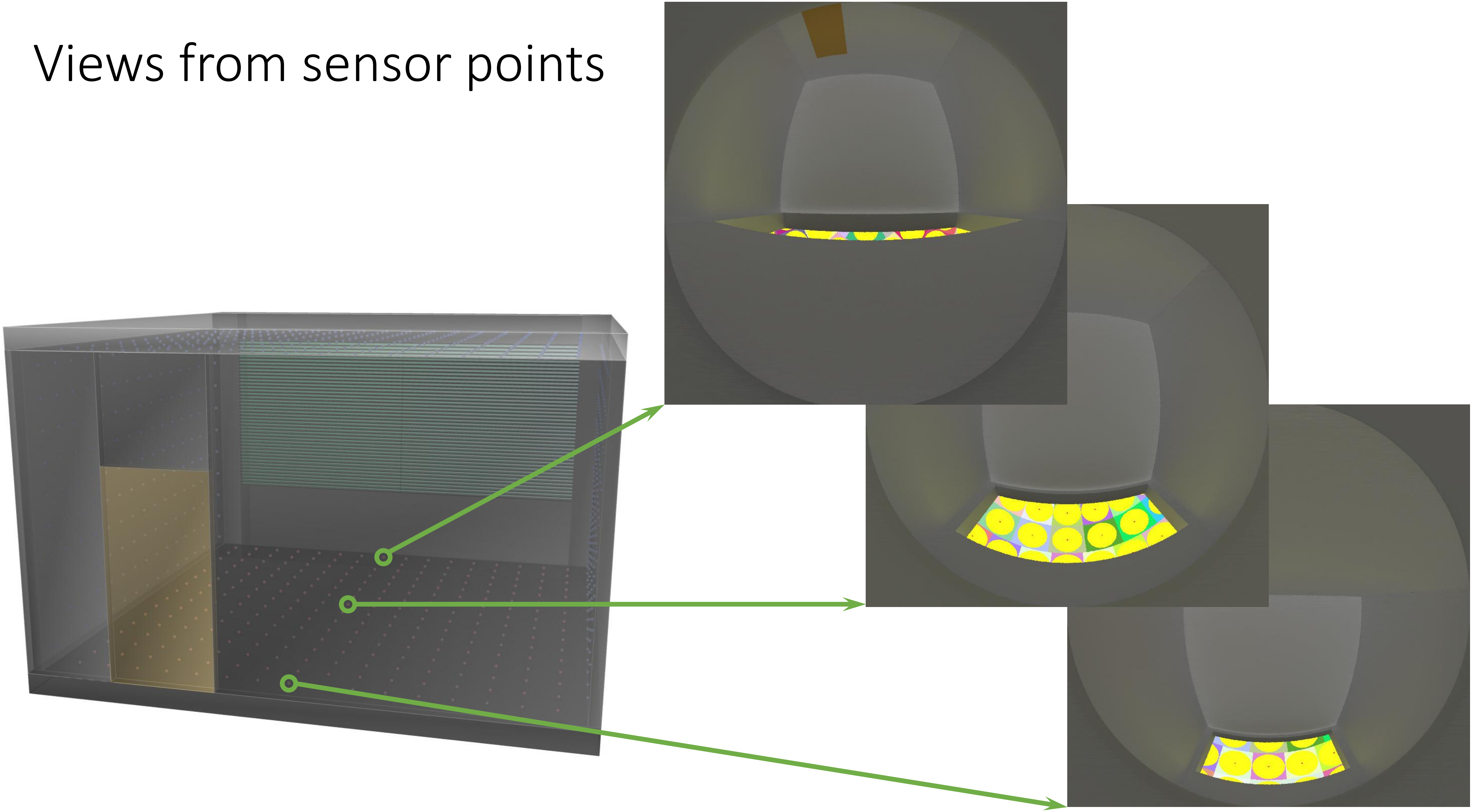
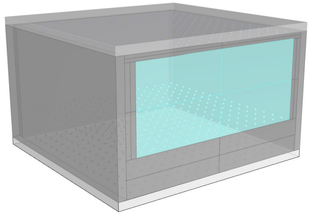


Views from sensor points



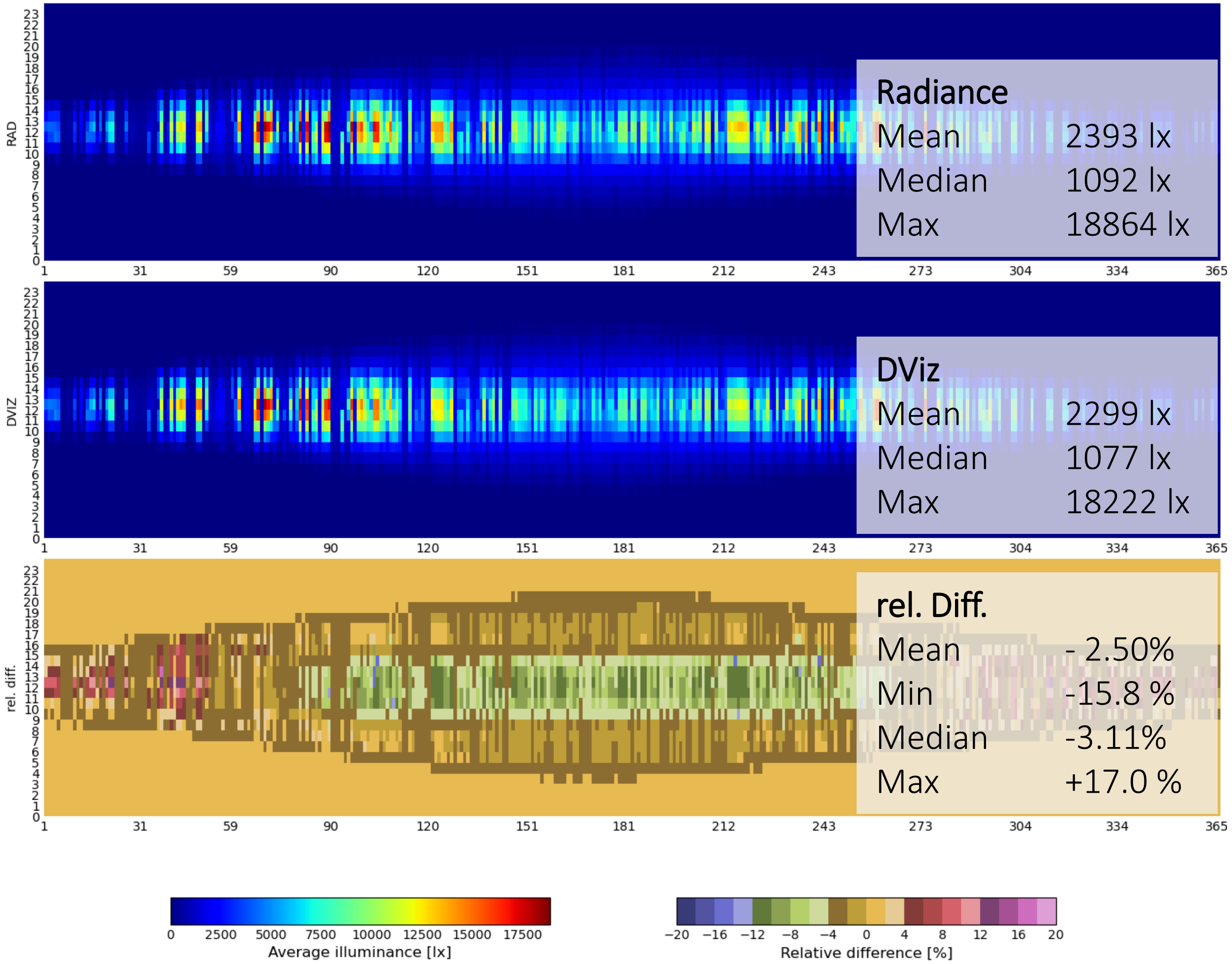
Results

Average illuminance on floor grid

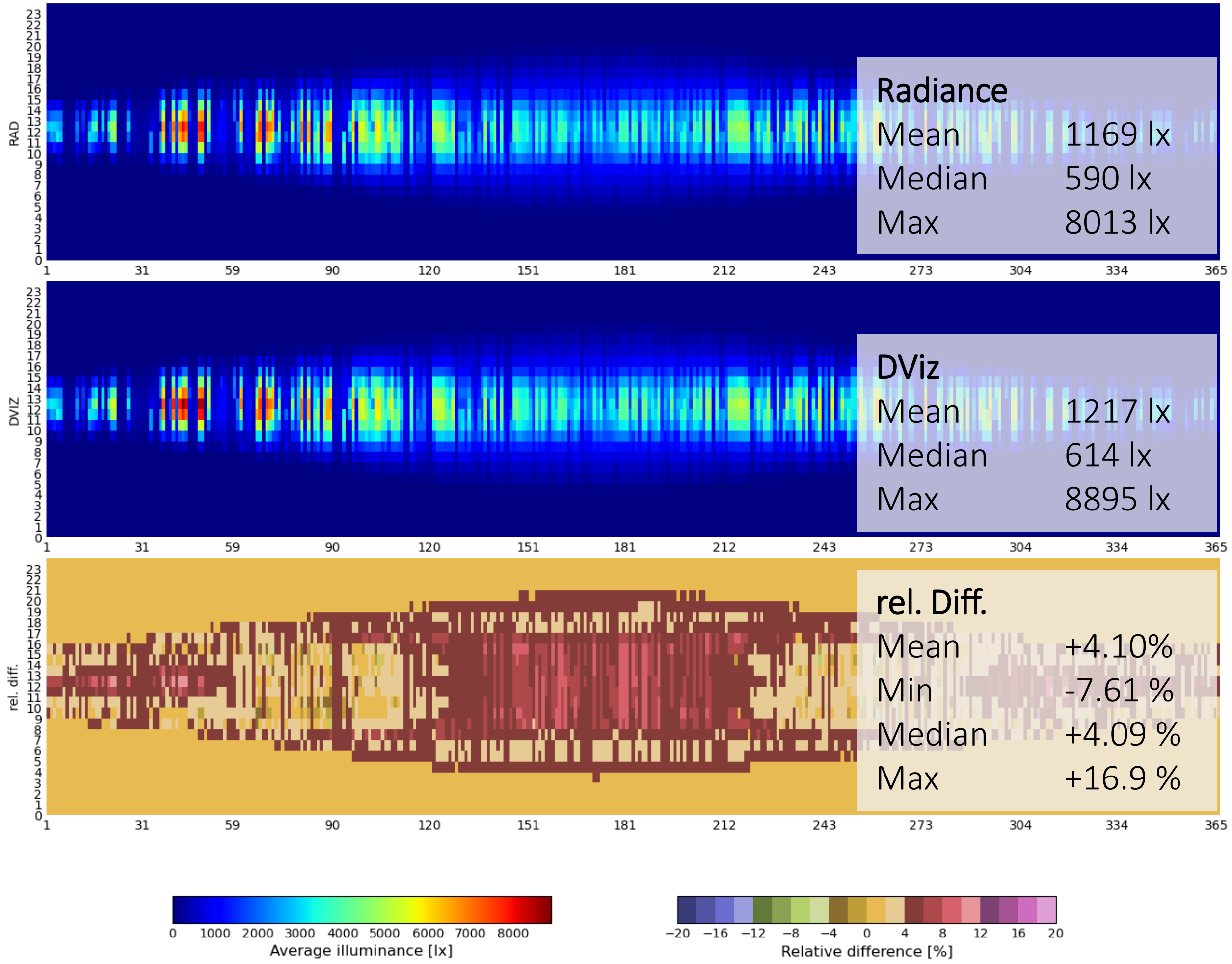


Radiance:	Reinhart MF:1
DVIZ:	11° patches

BSDF: Clear glass

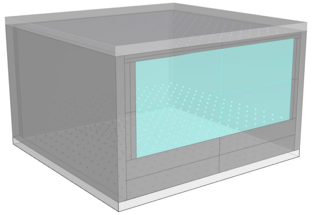


BSDF: Redirecting blinds



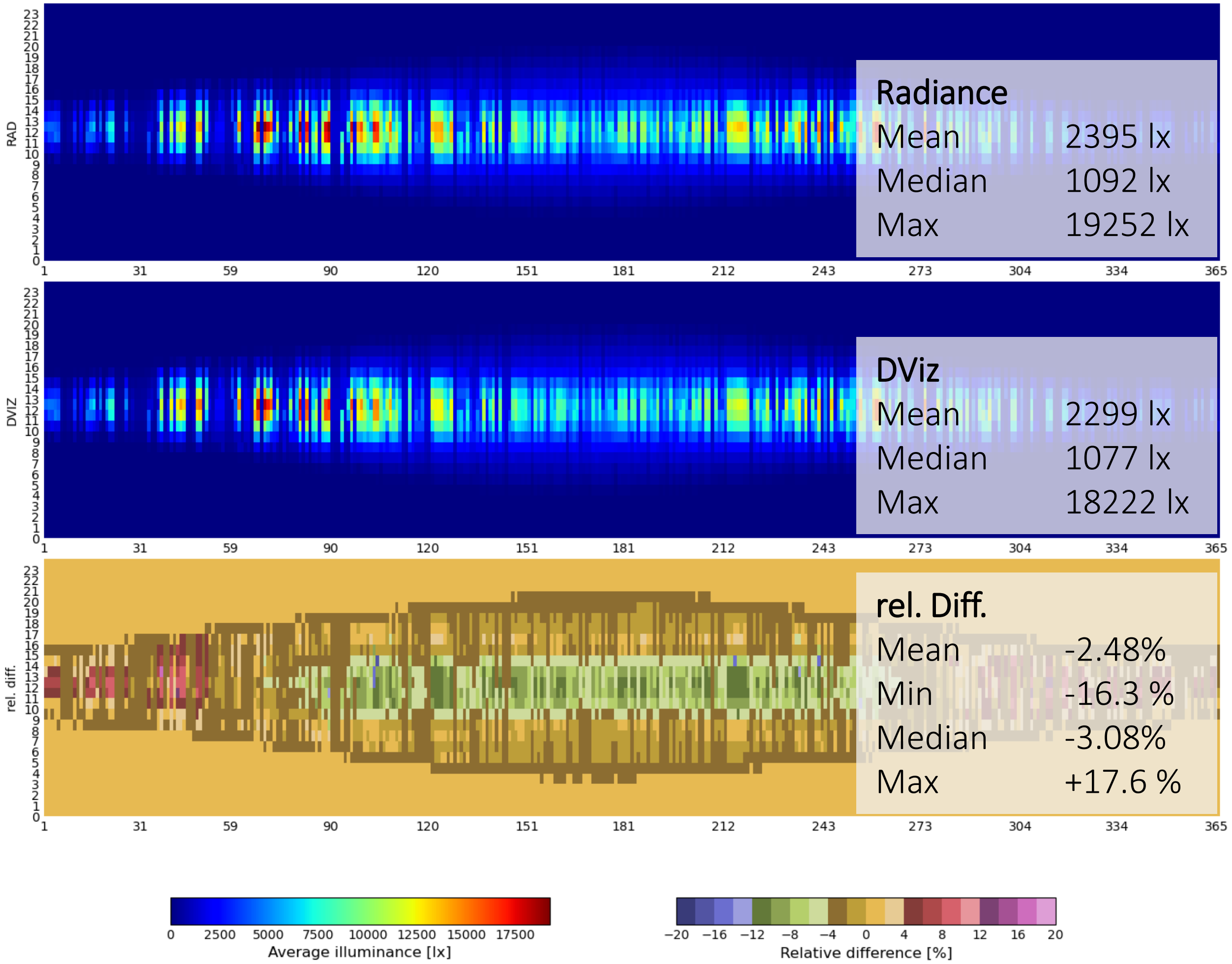
Results

Average illuminance on floor grid

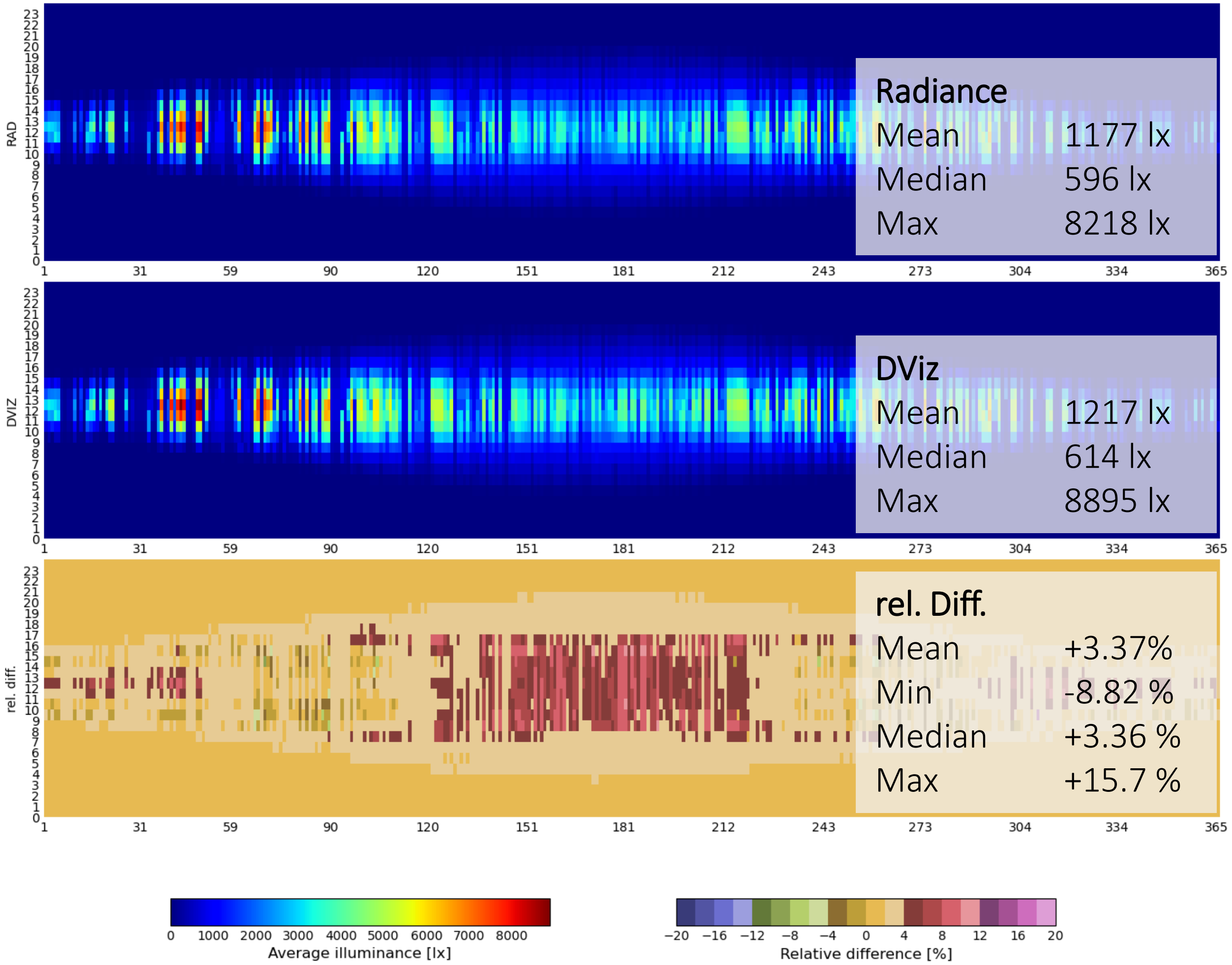


Radiance: 11° patches
DVIZ: 11° patches

BSDF: Clear glass

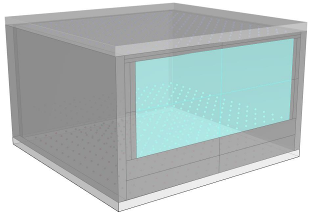


BSDF: Redirecting blinds



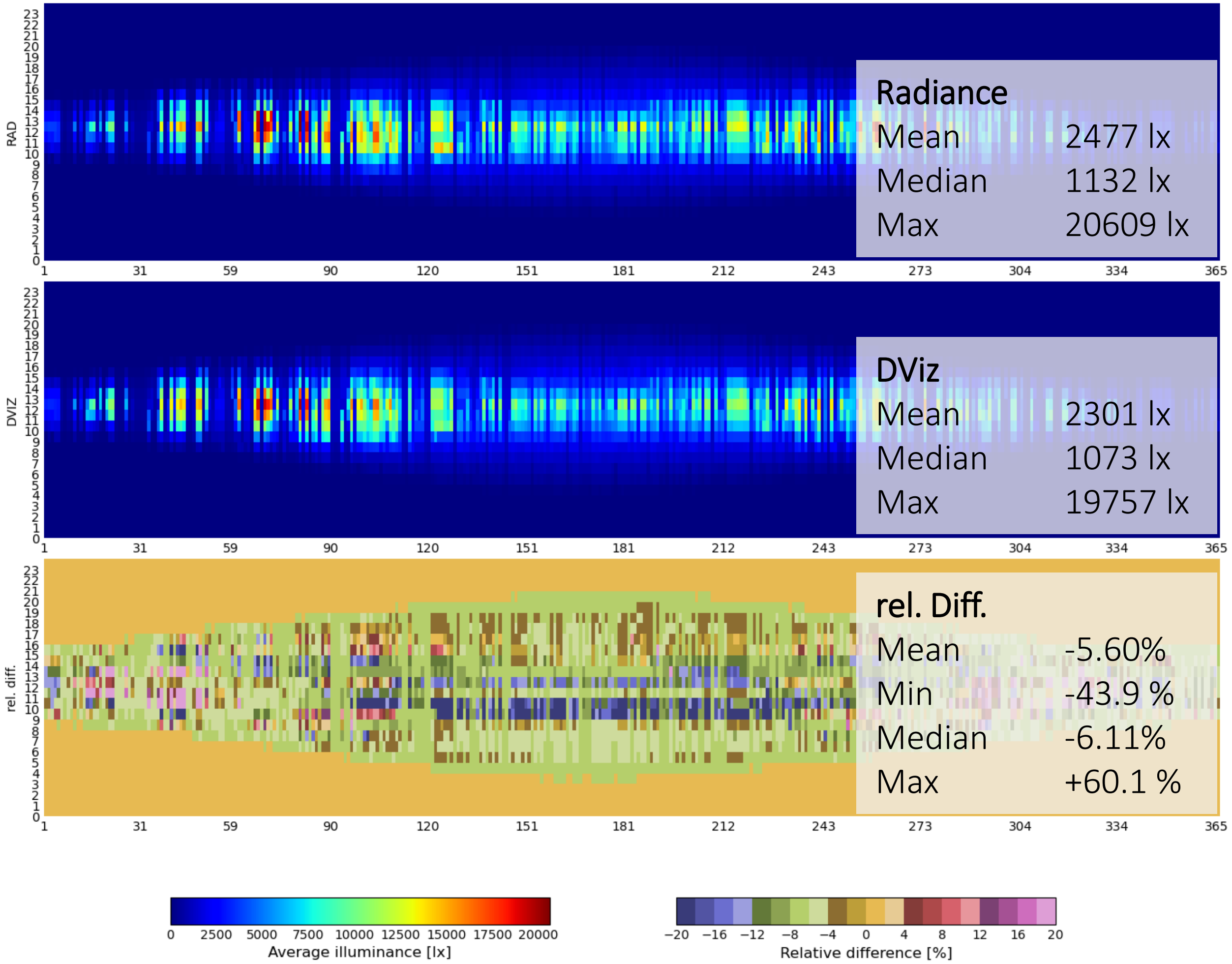
Results

Average illuminance on floor grid

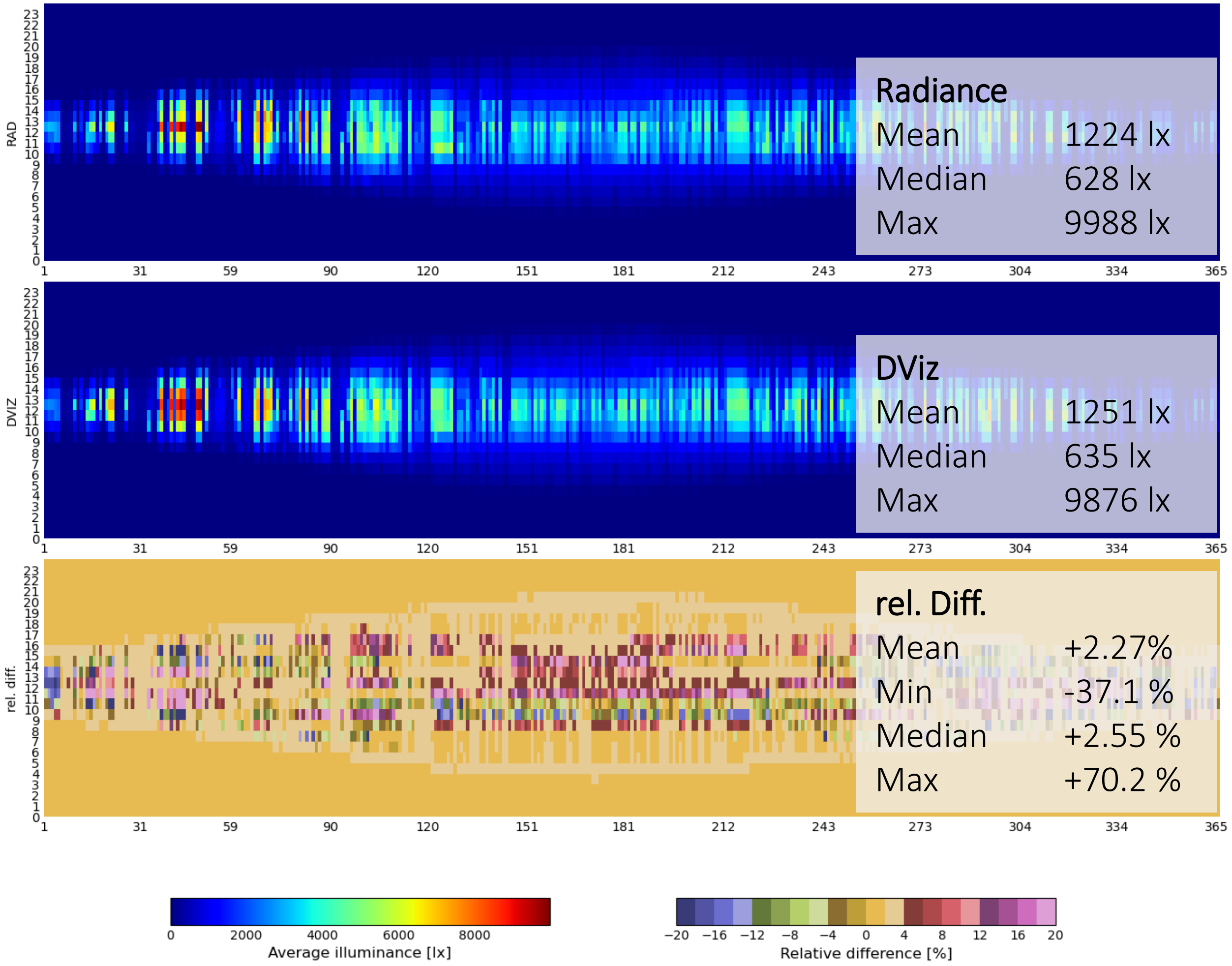


Radiance: 0.5° patches
DVIZ: 0.5° patches

BSDF: Clear glass



BSDF: Redirecting blinds



DViz

Methodology

4 Component Method

Daylight Coefficients

Direct Sky Shadow rays	**Direct Sun** Shadow rays	**Indirect Sky** Photon Mapping	**Indirect Sun** Photon Mapping

Luminance

Sky Luminance gendaymtx	**Sun Normal Illuminance** Perez LE [1] with 3h sma DPT

[1] Perez, Richard, et al. "Modeling daylight availability and irradiance components from direct and global irradiance." *Solar energy* 44.5 (1990): 271-289.

Perez Sky

Luminous efficacy model:

- R. Perez, P. Ineichen, R. Seals, J. Michalsky and R. Stewart. Modeling Daylight Availability and Irradiance Components from Direct and Global Irradiance. Solar Energy, Vol. 44, pp. 271-289, 1990.

Luminance distribution model:

- R. Perez, R. Seals and J. Michalsky. All-weather model for sky luminance distribution – Preliminary configuration and validation. Solar Energy, Vol. 50, Issue 3, pp. 235-245, 1993.

and

- R. Perez, R. Seals and J. Michalsky. Erratum to All-Weather Model for Sky Luminance Distribution. Solar Energy, Vol. 51, Issue 5, p. 423, 1993.

Perez Sky

<u>Luminous efficacy model:</u>

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2.2.2 *Models structure.* All the models presented here have a common structure represented by the following equation:

$$Y = X * F(\text{insolation condition}, \text{receptor/sun geometry}) \quad (4)$$

$$F(\epsilon, \Delta, Z, W) = a_i(\epsilon) + b_i(\epsilon) f(W) + c_i(\epsilon) g(Z) + d_i(\epsilon) h(\Delta) \quad (5)$$

Y … modeled quantity

X … quantity depending on three basic inputs

- direct irradiance
- global irradiance
- three-hourly dew point temperature

F … transfer function

Perez Sky

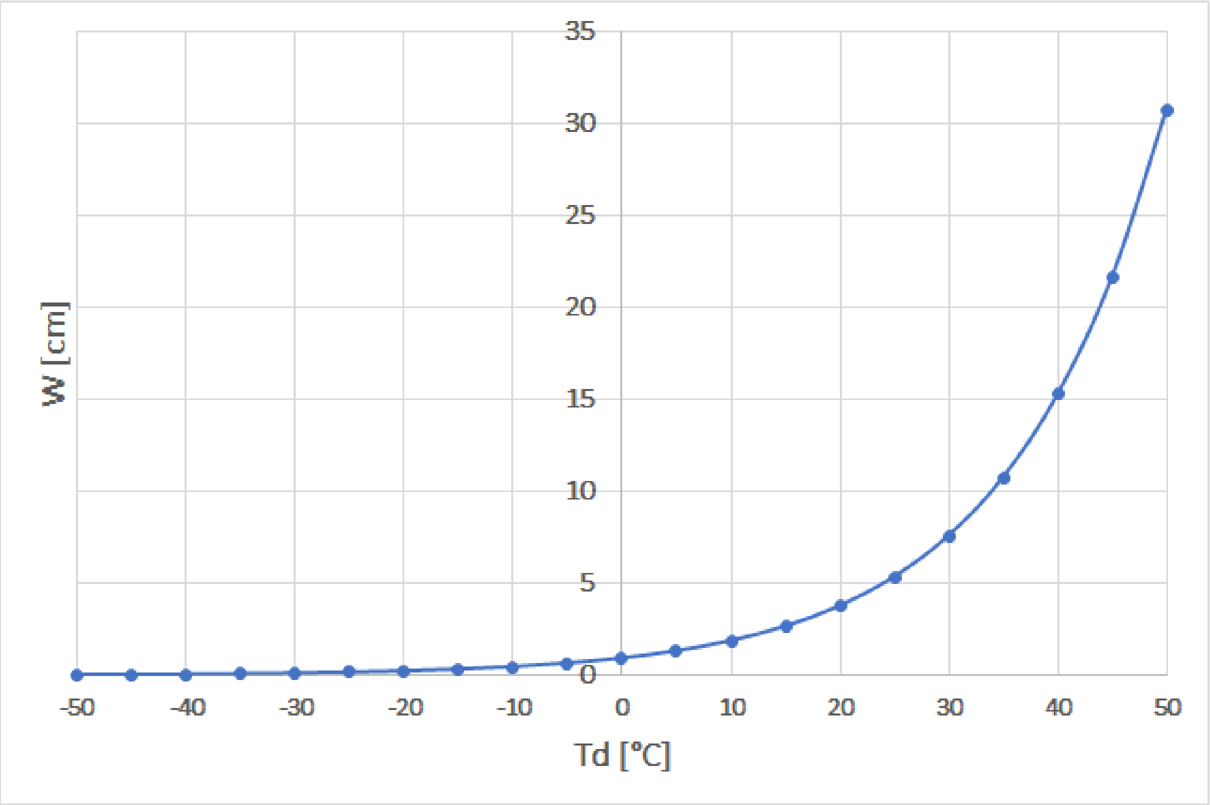
<u>Luminous efficacy model:</u>

- R. Perez, P. Ineichen, R. Seals, J. Michalsky and R. Stewart. Modeling Daylight Availability and Irradiance Components from Direct and Global Irradiance. Solar Energy, Vol. 44, pp. 271-289, 1990.

(4) The atmospheric precipitable water content, denoted W (cm), and given by

$$W = \exp(0.07 * Td - 0.075) \qquad (3)$$

where Td (°C) is the three-hourly surface dew point temperature.



gendaymtx & gendaylit

gendaymtx.c (v 2.39)

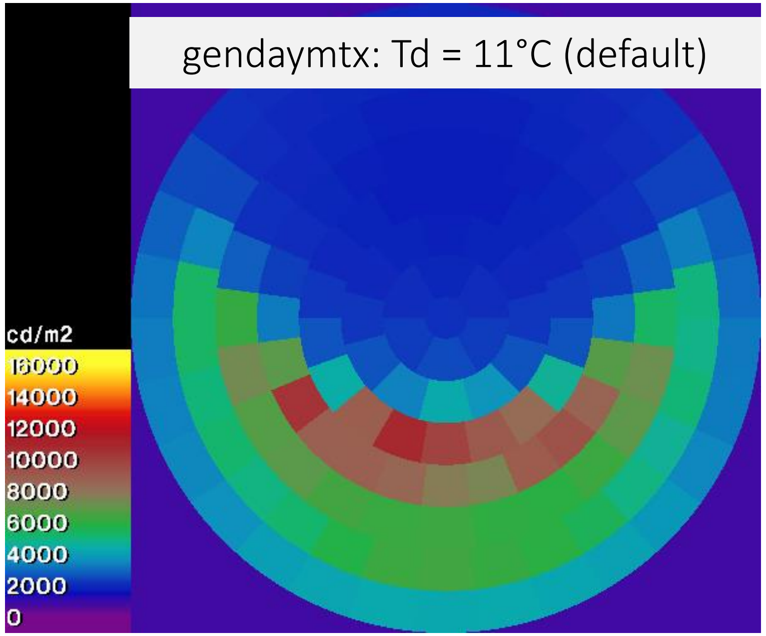
```
double dew_point = 11.0;        /* Surface dew point temperature (deg. C) */

/* Calculate atmospheric precipitable water content */
apwc = CalcPrecipWater(dew_point);
```

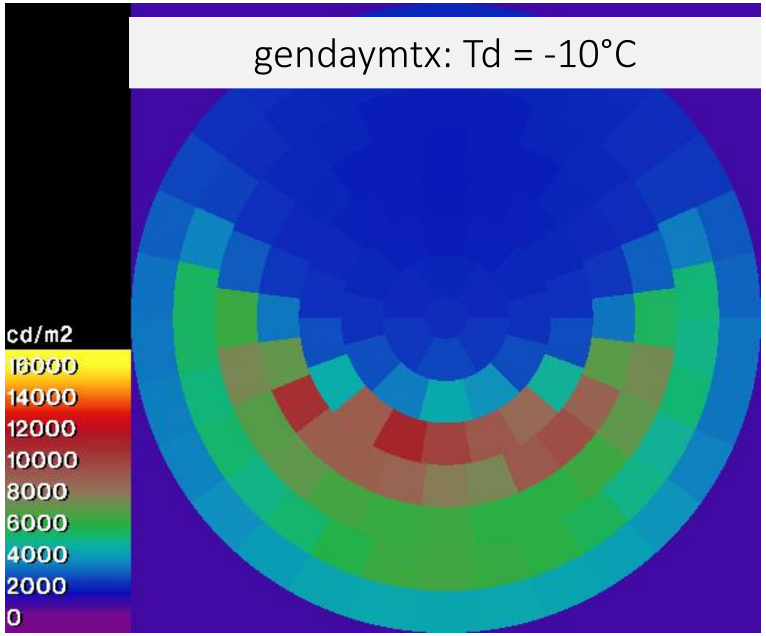
gendaylit (v 2.21)

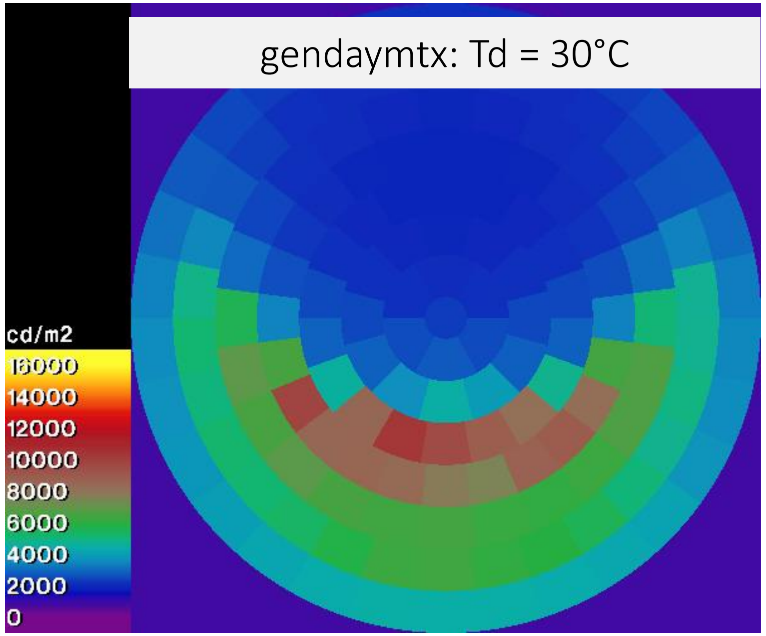
```
*  version 2.6 (2021/01/29): dew point dependency added according to Perez publication 1990

/* definition of the sky conditions through the Perez parametrization */
double  skyclearness = 0;
double  skybrightness = 0;
double  solarradiance;
double  diffuseilluminance, directilluminance, diffuseirradiance, directirradiance, globalirradiance;
double  sunzenith, daynumber, atm_preci_water, Td=10.97353115;

for (i = 4; i < argc; i++)
    if (argv[i][0] == '-' || argv[i][0] == '+')
        switch (argv[i][1]) {
        case 'd':
            Td = atof(argv[++i]);
            if (Td < -40 || Td > 40) {
                Td=10.97353115; }
            break;
```

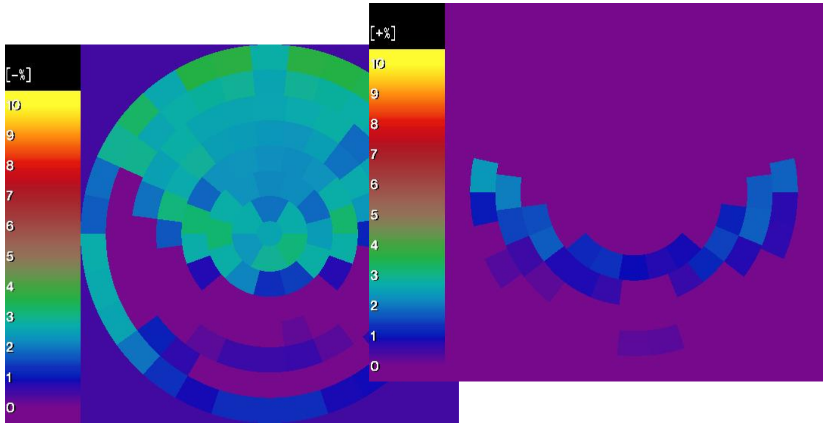
Perez Sky: Dew Point Temperature Effect

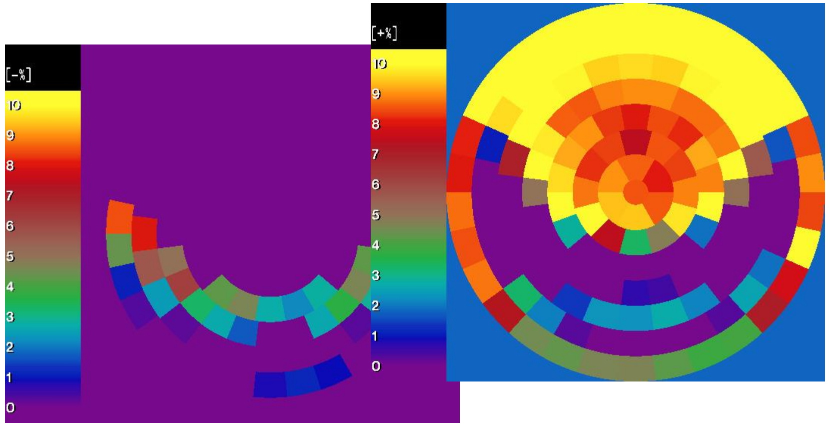
Climate data: DNK_Copenhagen.061800_IWEC.epw
gendaymtx -A -m 1



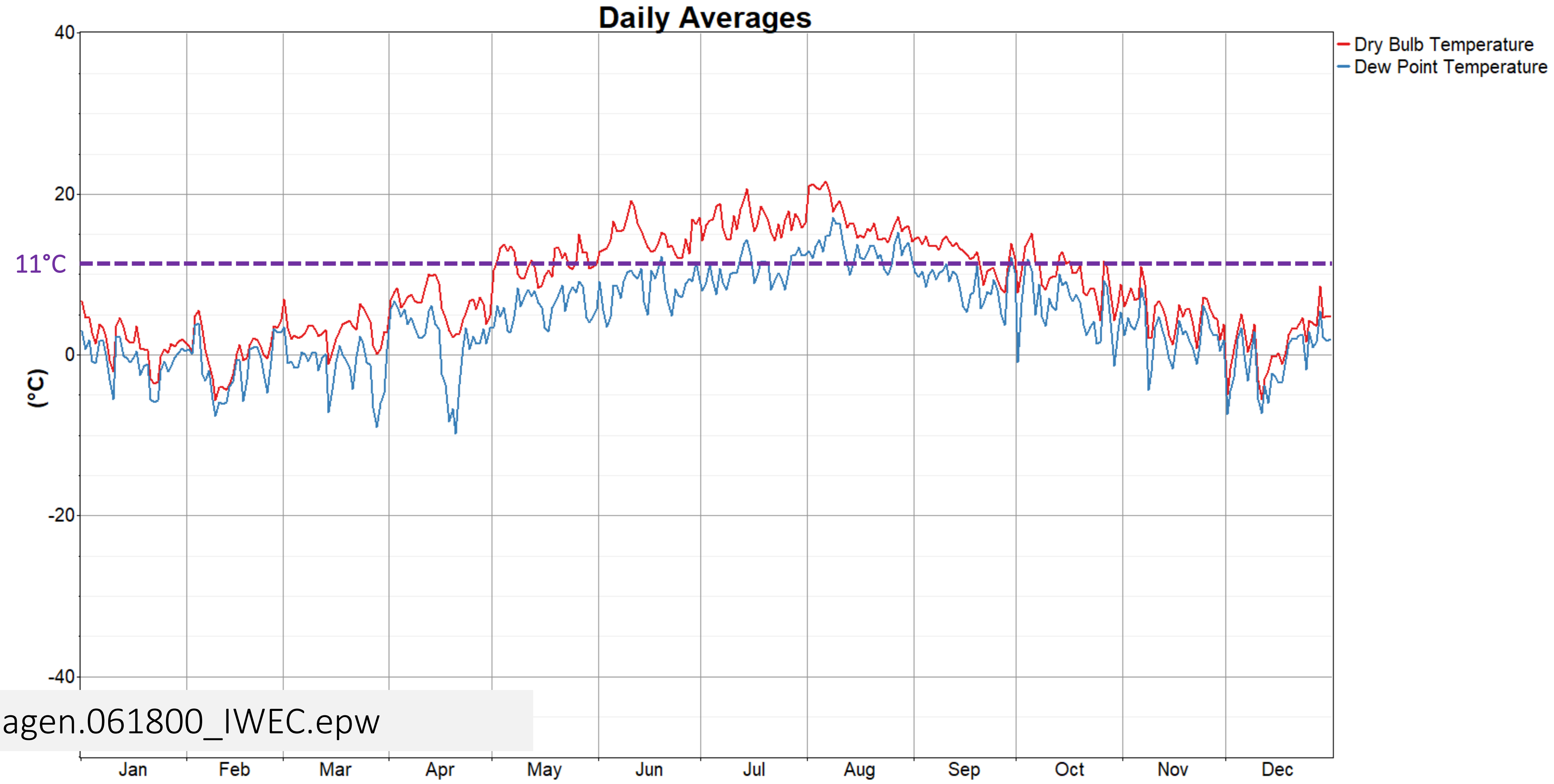








Dew Point Temperature



DNK_Copenhagen.061800_IWEC.epw

gendaymtx & epw2wea

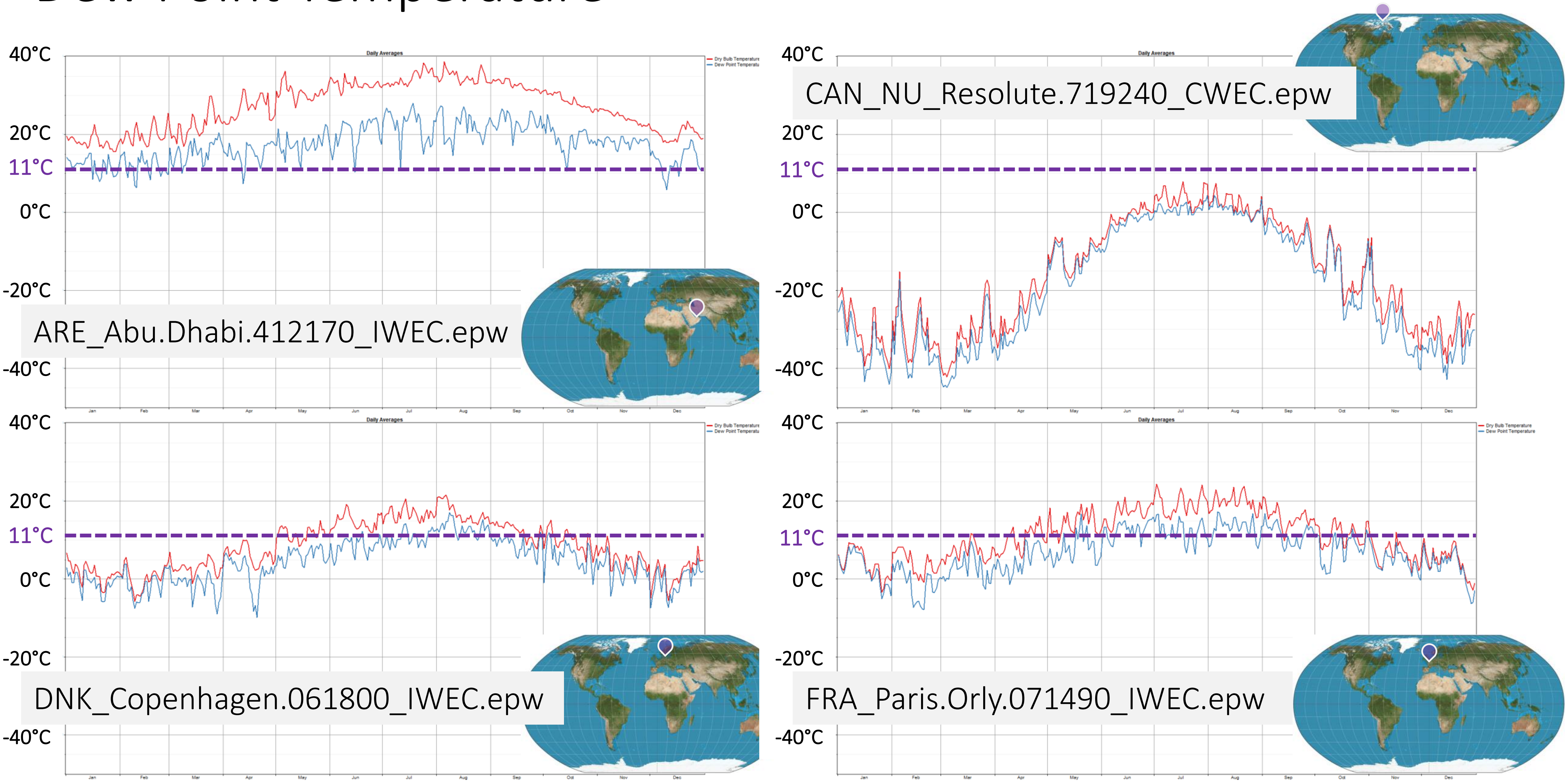
gendaymtx.c (v 2.39, adapted)

```
                /* process each time step in tape */
while (scanf("%d %d %lf %lf %lf %lf\n", &mo, &da, &hr, &dir, &dif, &dew) == 6) {

    dew_point = dew; /* assign dew point from wea file instead of fixed value */
```

epw2wea.c (v 2.3, adapted)

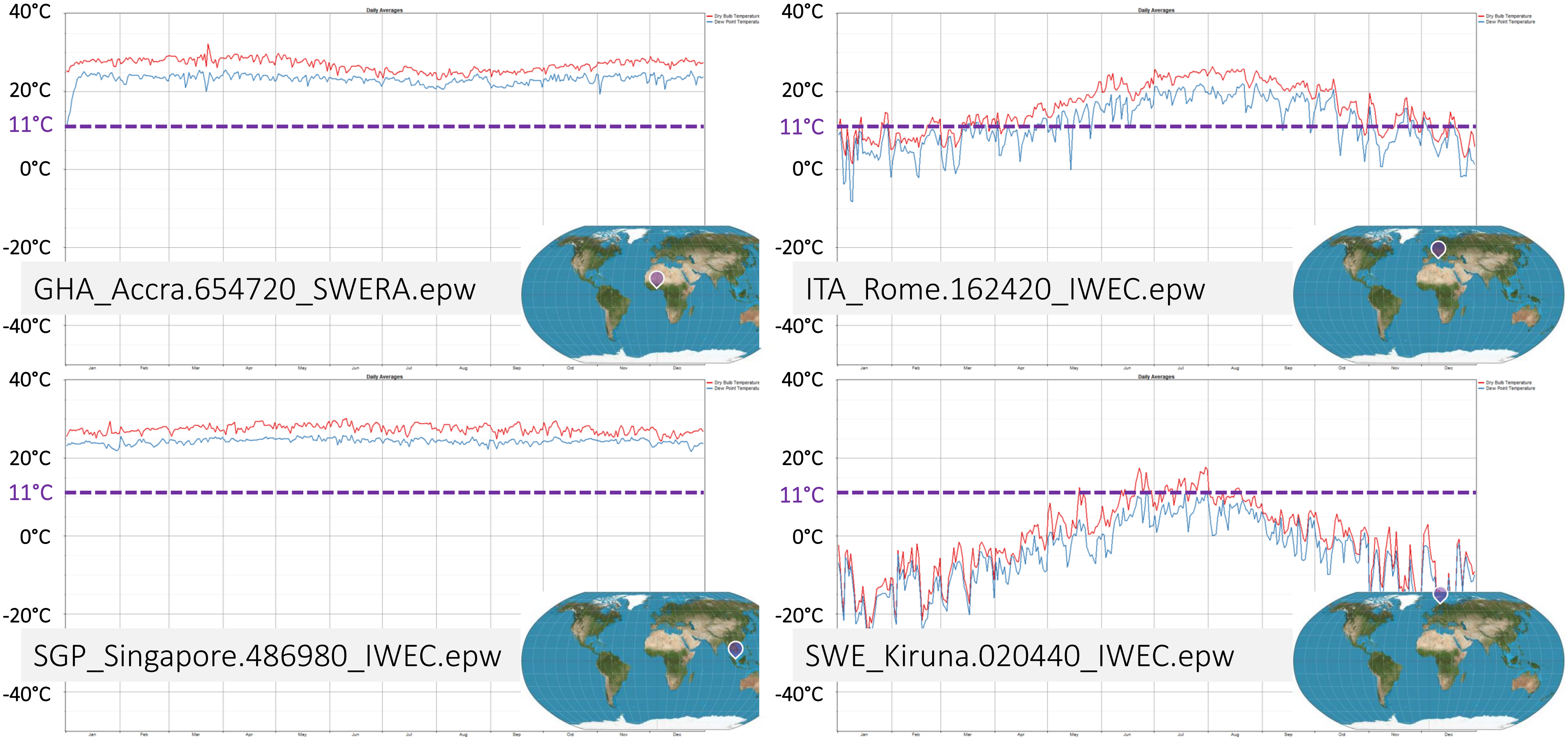
```
while( EOF != fscanf(EPW_FILE,"%d,%d,%d,%d",&year,&month,&day, &hour_in)){

    fprintf(WEA_FILE,"%d %d %.3f ",month,day,hour_in*1.0-minute*(0.5/60));

    /* fscanf(EPW_FILE,",%f",&dummy_float); */
    fscanf(EPW_FILE,",%f",&dew_pt);
    dew_pt_avg3 = (dew_pt + dew_pt_m1 + dew_pt_m2) / 3.0;
    dew_pt_m2 = dew_pt_m1;
    dew_pt_m1 = dew_pt;


    fscanf(EPW_FILE,",%f,%f",&dir_norm_rad, &dif_or_rad);
    fprintf(WEA_FILE,"%.0f %.0f %.1f", dir_norm_rad, dif_or_rad, dew_pt_avg3);
```

Dew Point Temperature



World map: https://en.wikipedia.org/wiki/File:Robinson_projection_SW.jpg

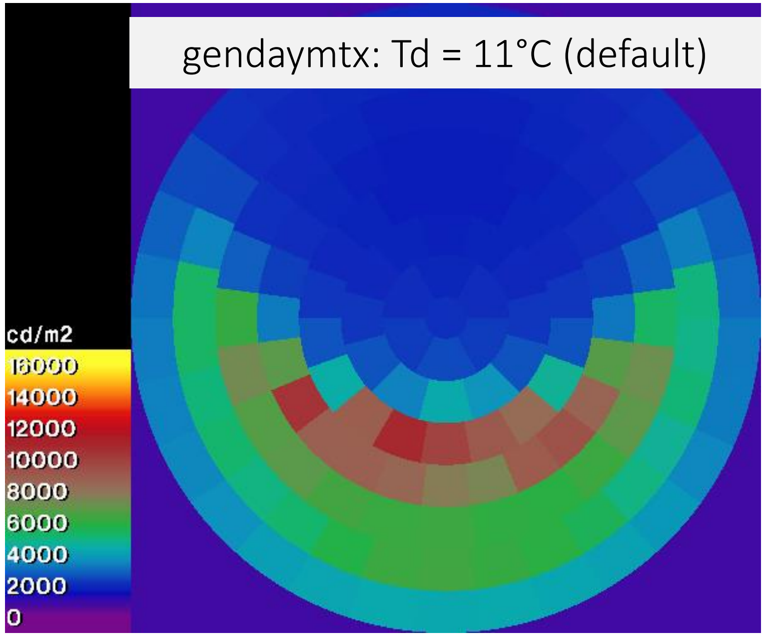
Dew Point Temperature

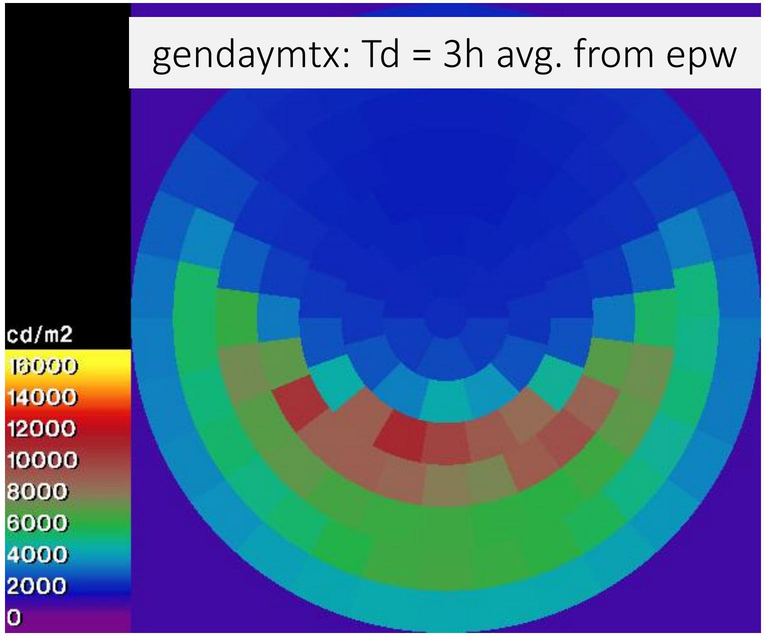


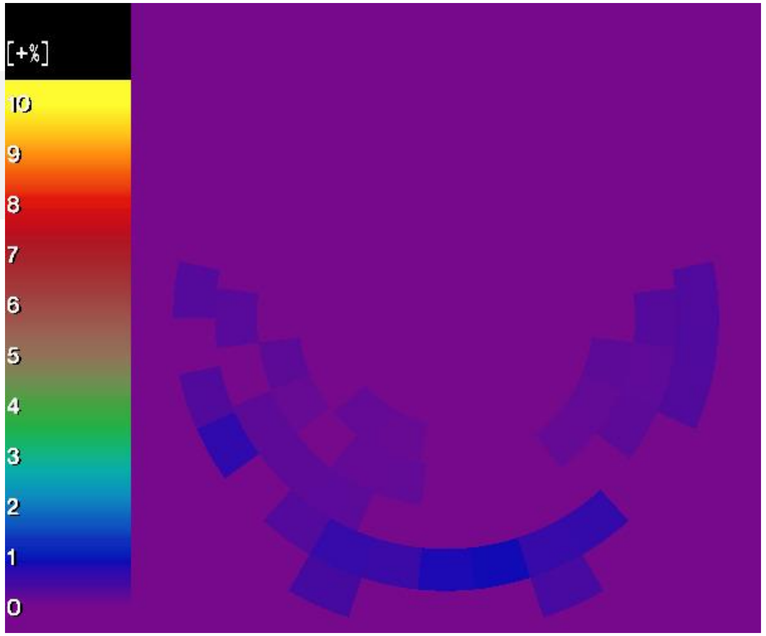
World map: https://en.wikipedia.org/wiki/File:Robinson_projection_SW.jpg

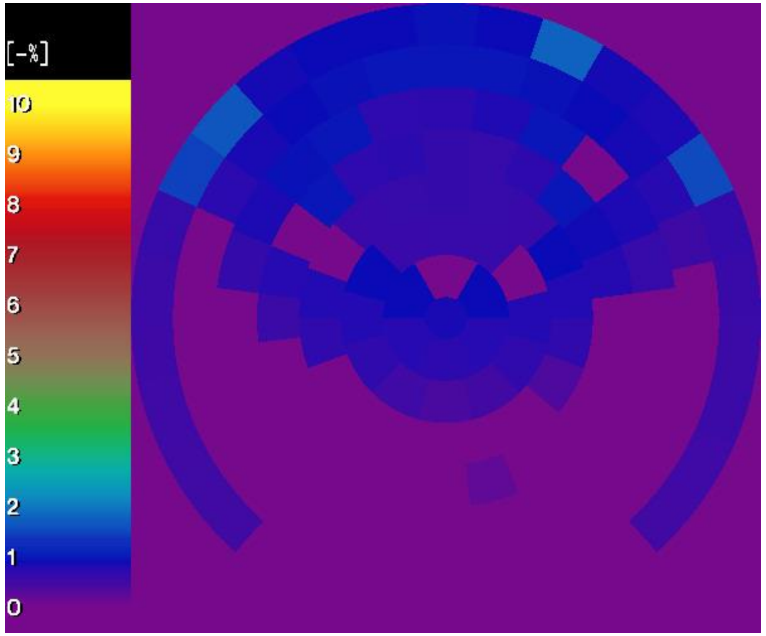
Perez Sky: Dew Point Temperature Effect

Climate data: DNK_Copenhagen.061800_IWEC.epw
Average sky: gendaymtx -A -m 1





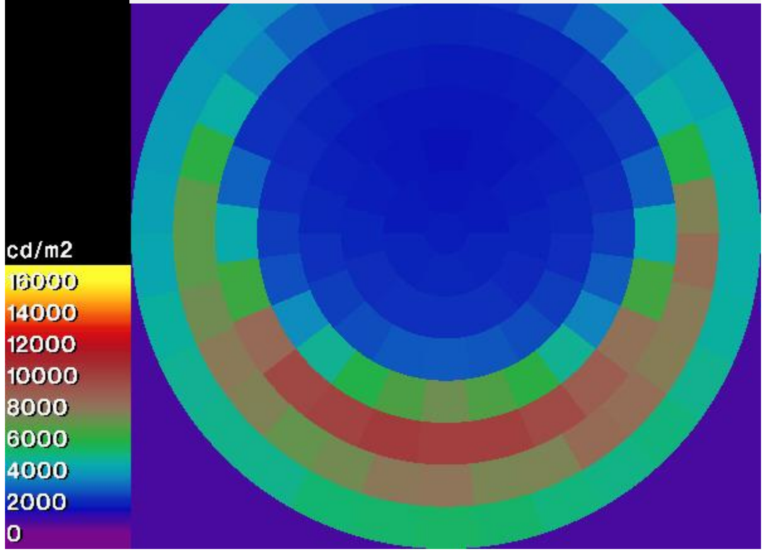




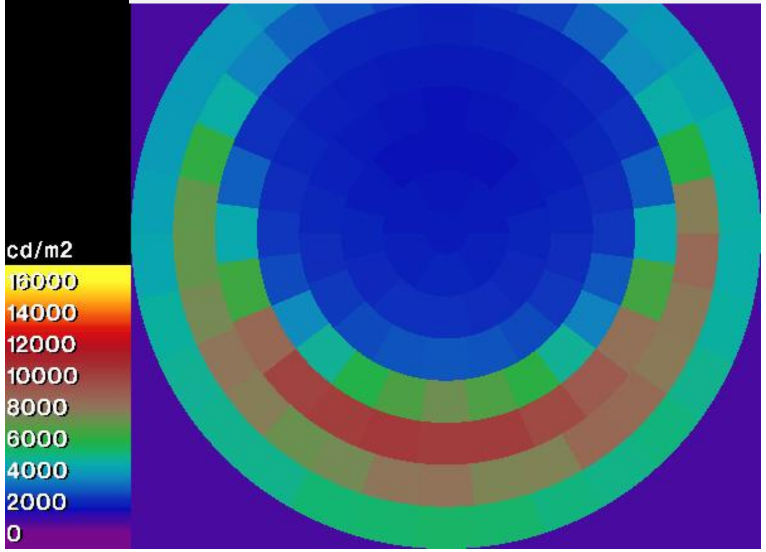
Perez Sky: Dew Point Temperature Effect

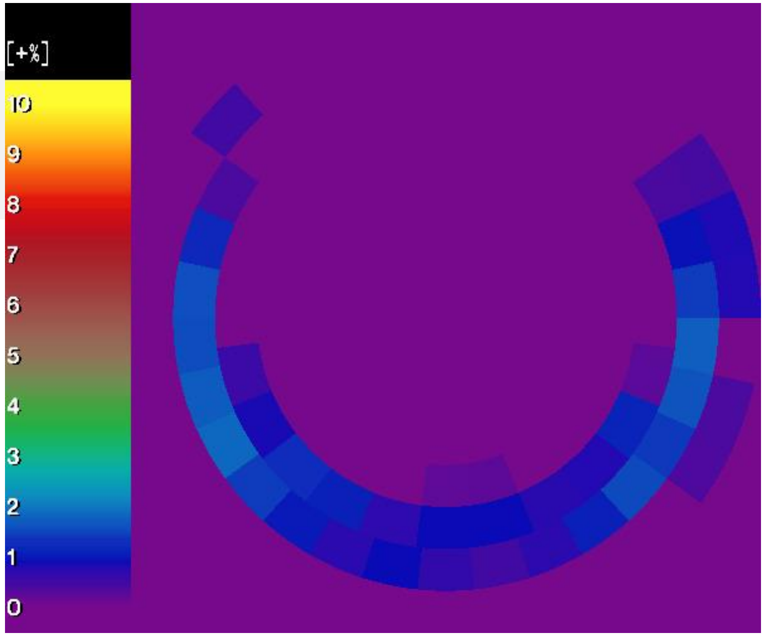
Climate data: CAN_NU_Resolute.719240_CWEC.epw
Average sky: gendaymtx -A -m 1

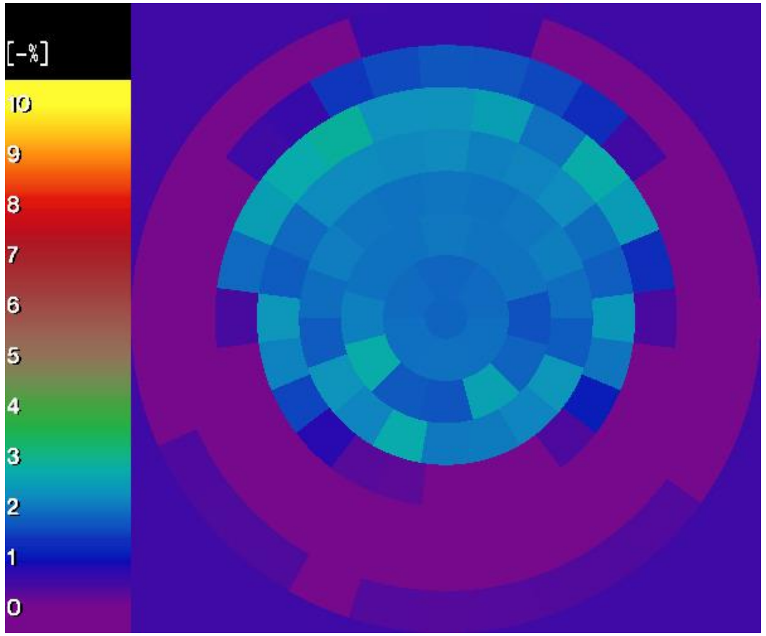
gendaymtx: Td = 11°C (default)

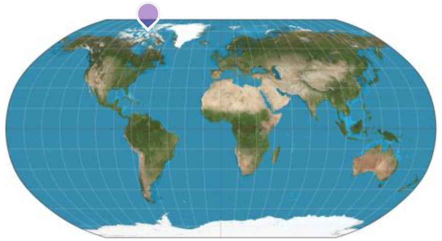


gendaymtx: Td = 3h avg. from epw



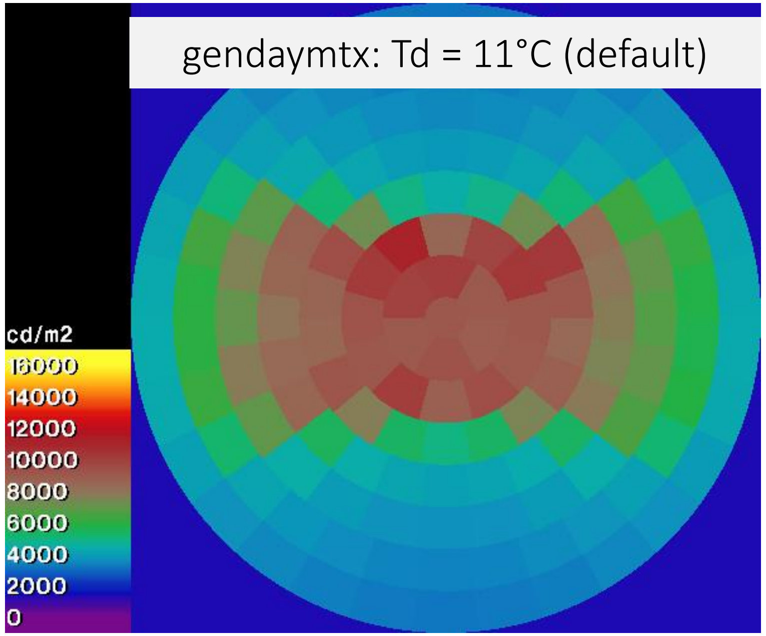


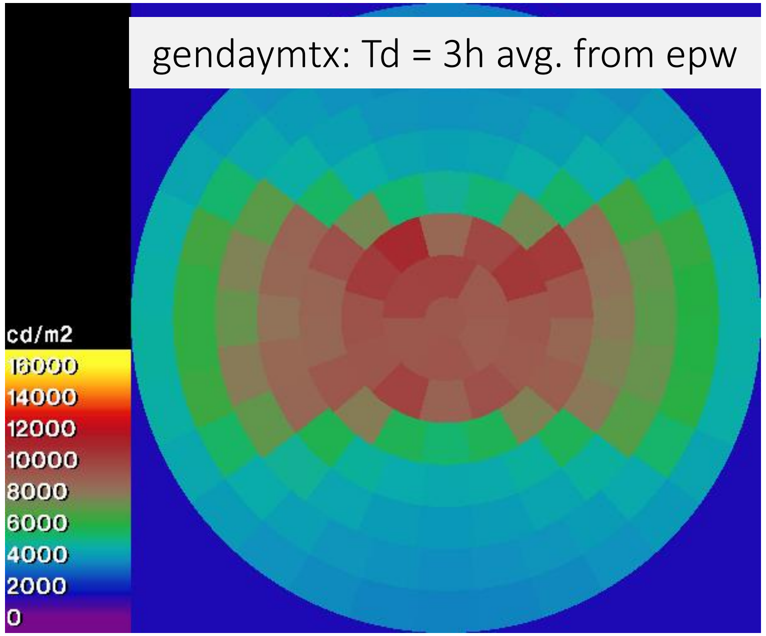


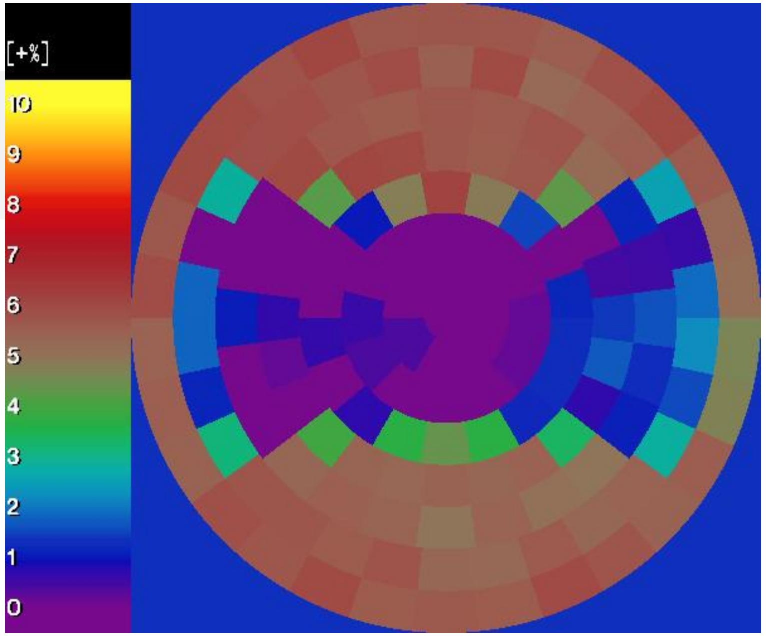


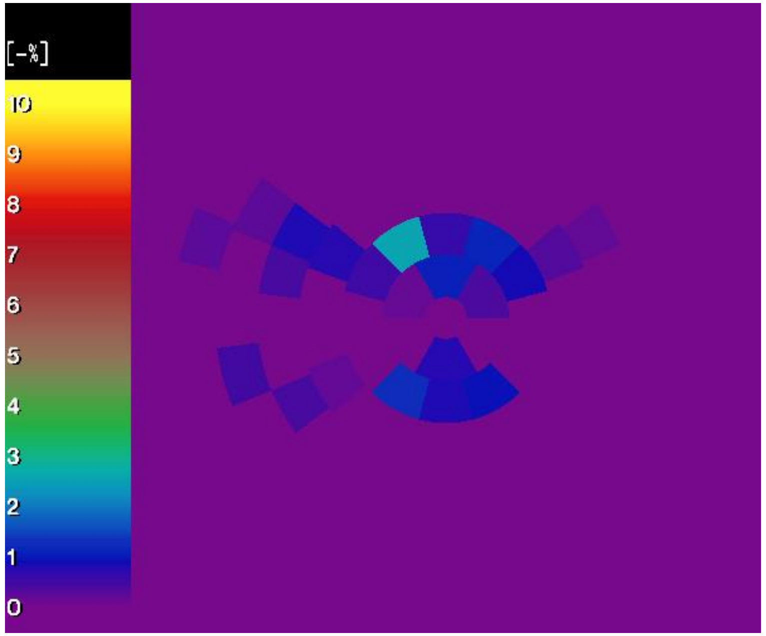
Perez Sky: Dew Point Temperature Effect

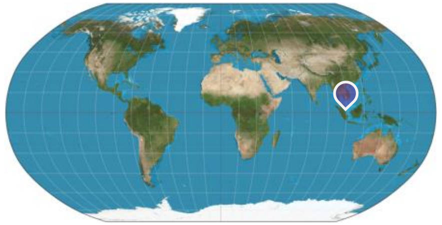
Climate data: SGP_Singapore.486980_IWEC.epw
Average sky: gendaymtx -A -m 1





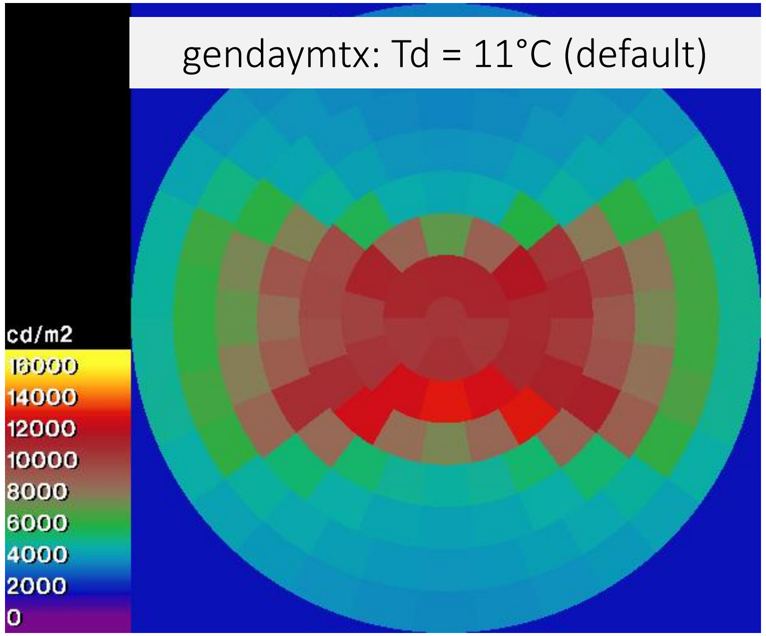


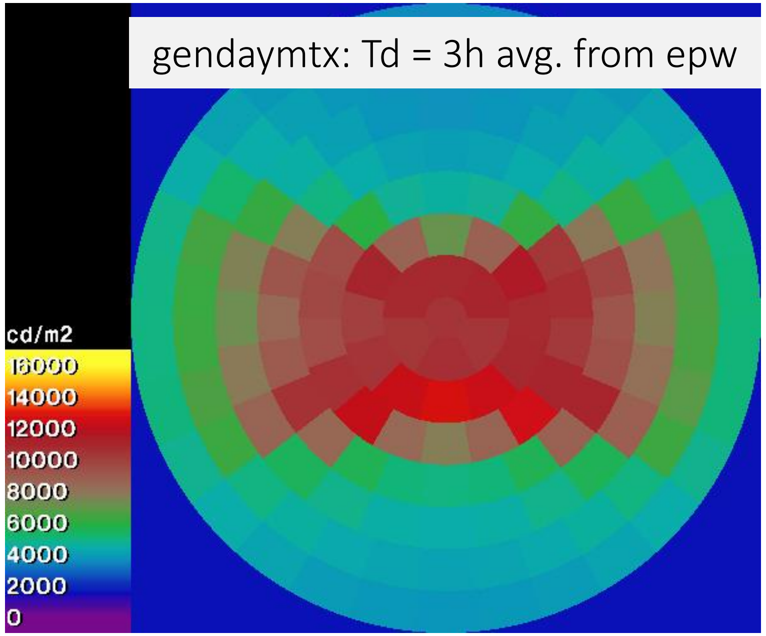


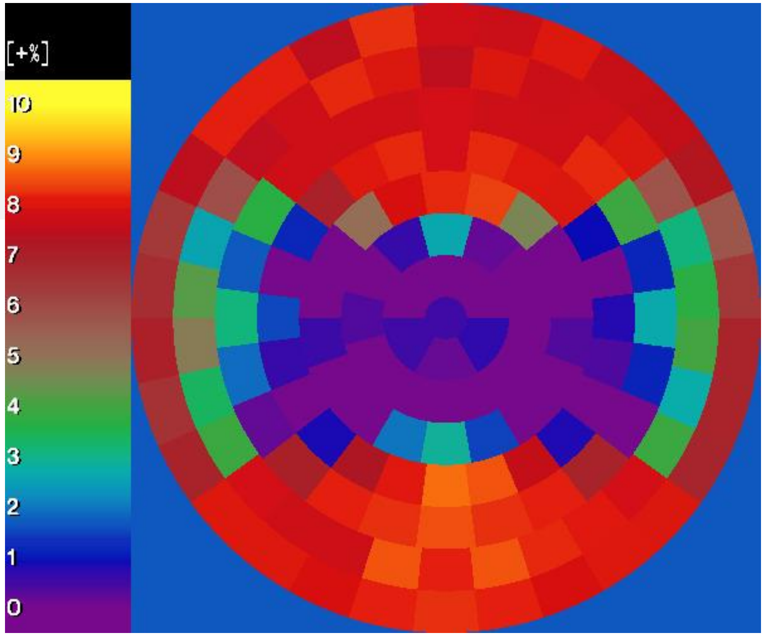


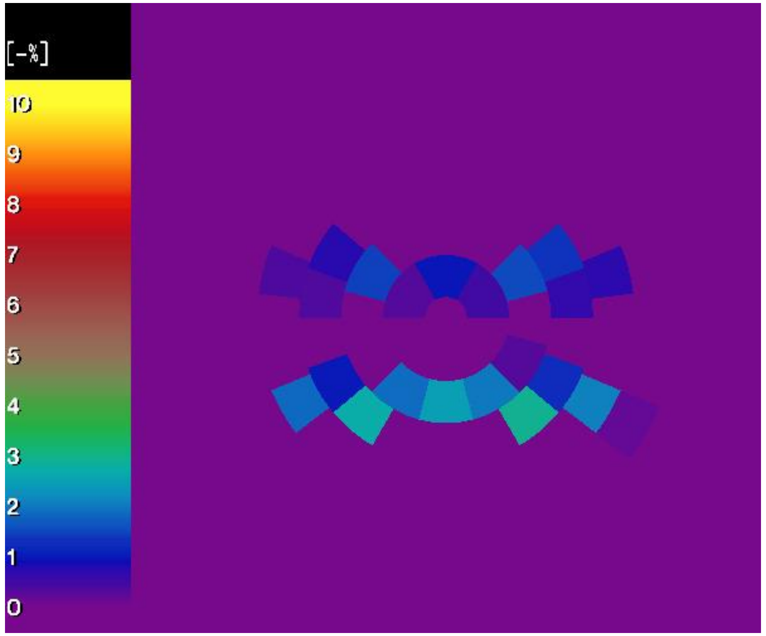
Perez Sky: Dew Point Temperature Effect

Climate data: GHA_Accra.654720_SWERA.epw
Average sky: gendaymtx -A -m 1

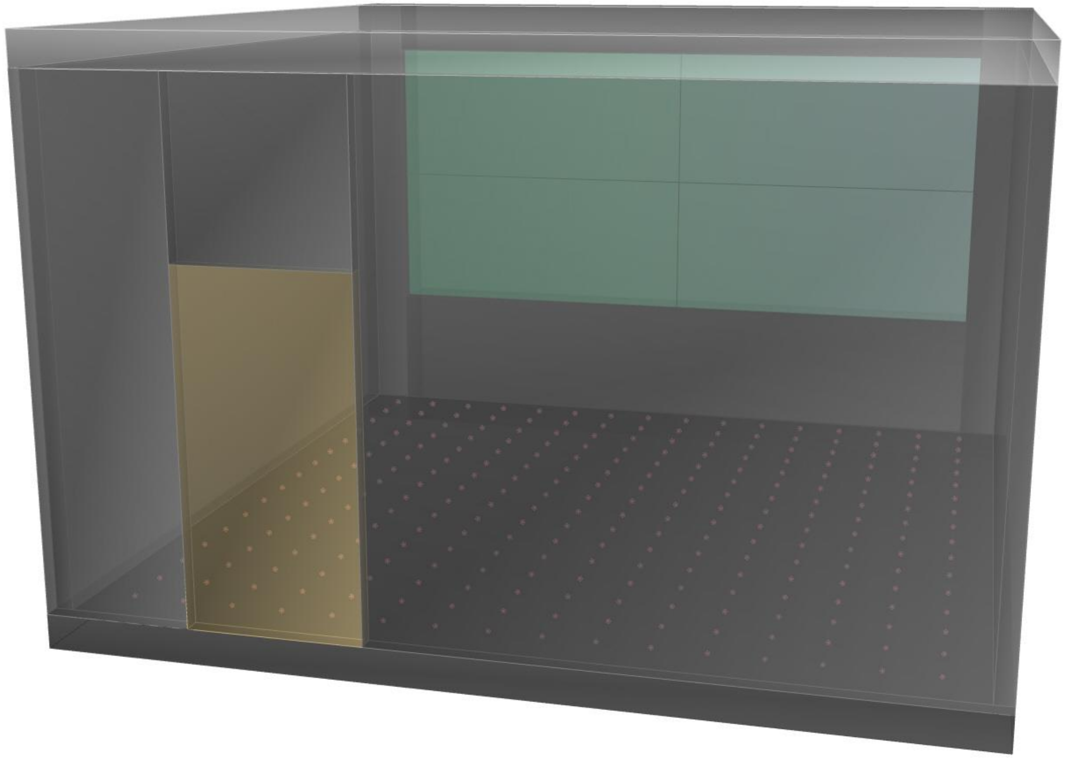








Impact on simulation

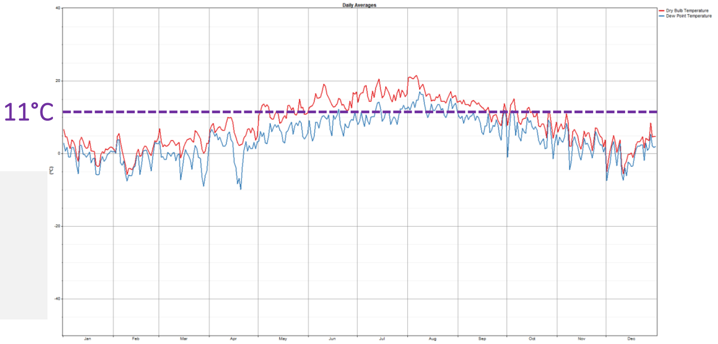


Test room

Simple shoebox model
South-facing façade
Window with clear glass (Klems BSDF)
Sensor grid on floor level
3-PM simulation

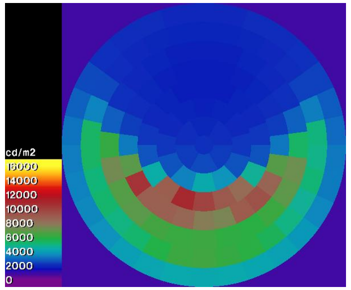
Evaluation of average illuminance on sensor grid over the course of the year

Perez Sky: Dew Point Temperature Effect

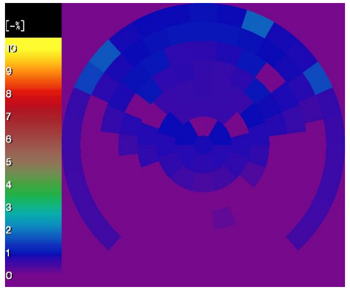


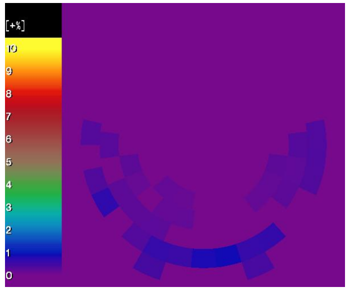
Climate data: DNK_Copenhagen.061800_IWEC.epw
Sky matrix: gendaymtx -m 1 -c 1 1 1

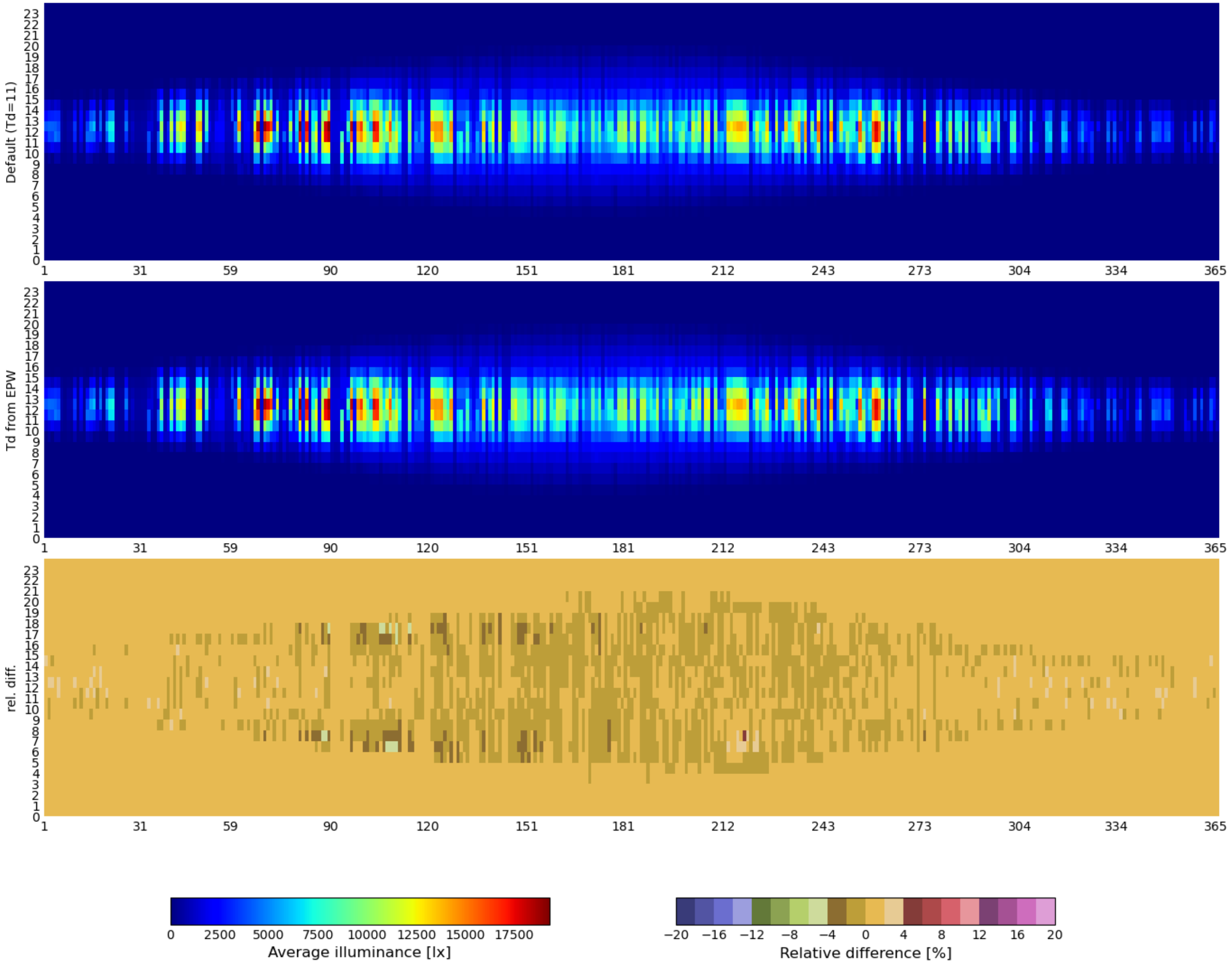
Td = 11°C (default)



Td = 3h avg. from EPW [-/+ %]



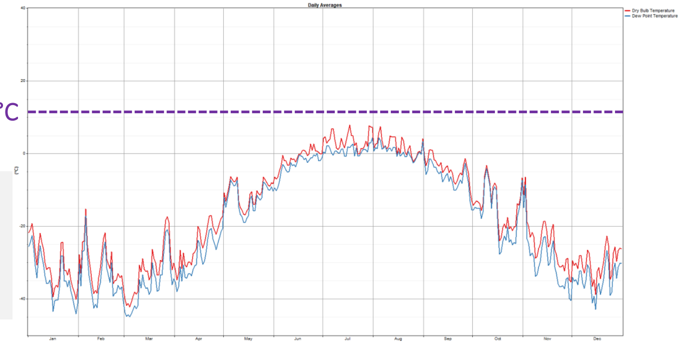




Average illuminance on sensor grid "floor"
Td 11°C: mean = 2561 lx
Td from EPW: mean = 2564 lx

Relative difference
Min = -5.8%
Max = +4.0%
Median = +0.1%

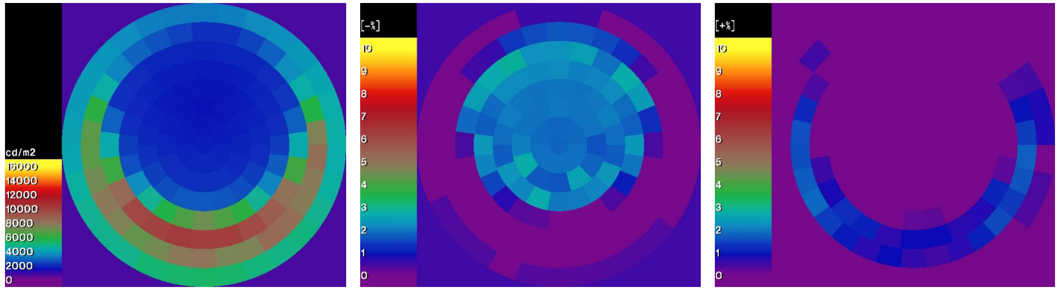
Perez Sky: Dew Point Temperature Effect

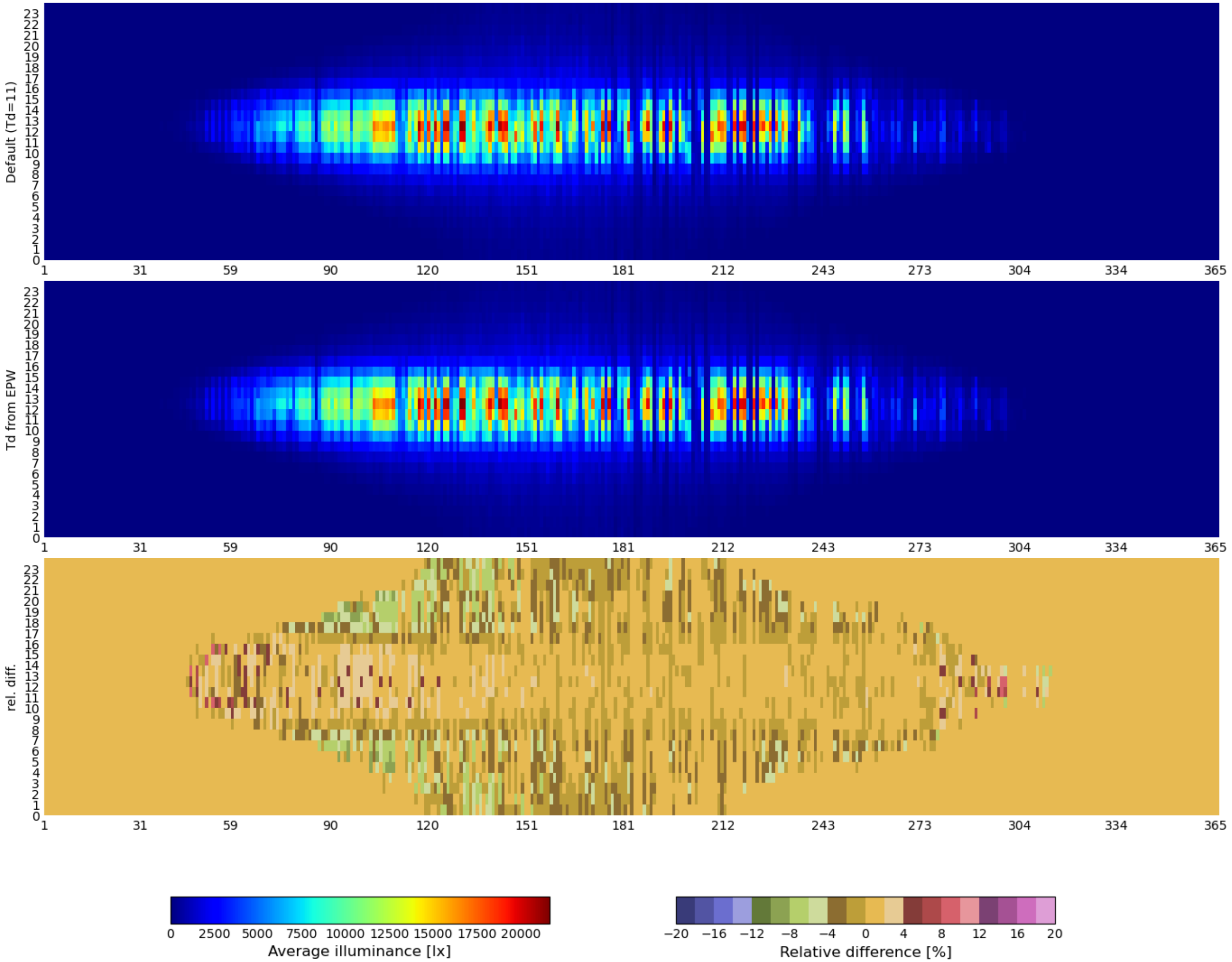


Climate data: CAN_NU_Resolute.719240_CWEC.epw
Sky matrix: gendaymtx -m 1 -c 1 1 1

Td = 11°C (default)

Td = 3h avg. from EPW [-/+ %]





Average illuminance on sensor grid "floor"

Td 11°C: mean = 2491 lx

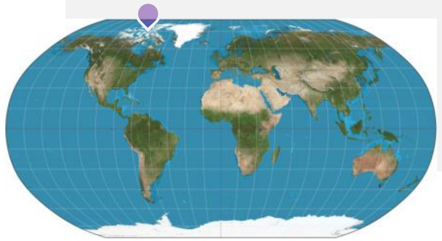
Td from EPW: mean = 2501 lx

Relative difference

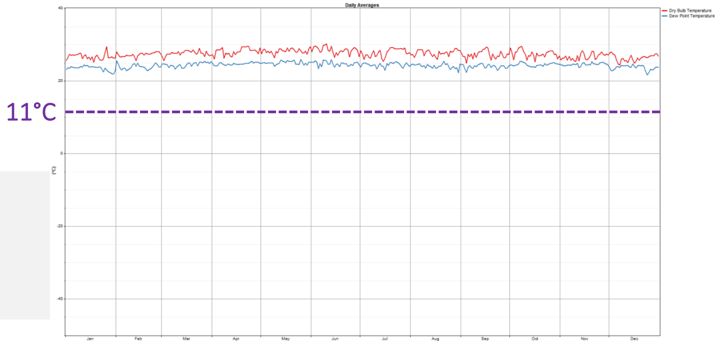
Min = -9.2%

Max = +9.4%

Median = +0.4%

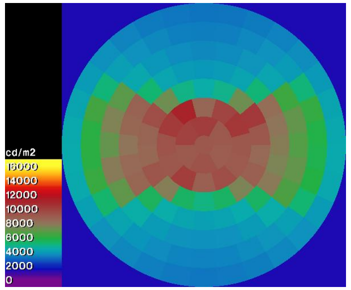


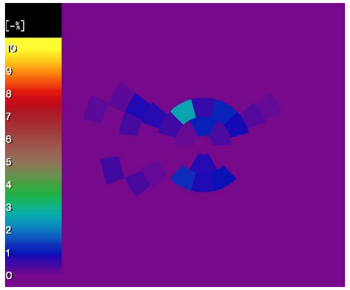
Perez Sky: Dew Point Temperature Effect

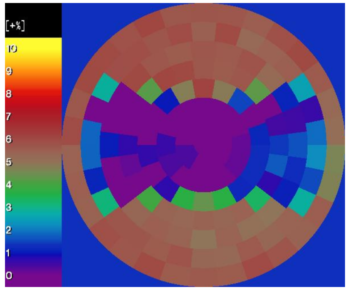


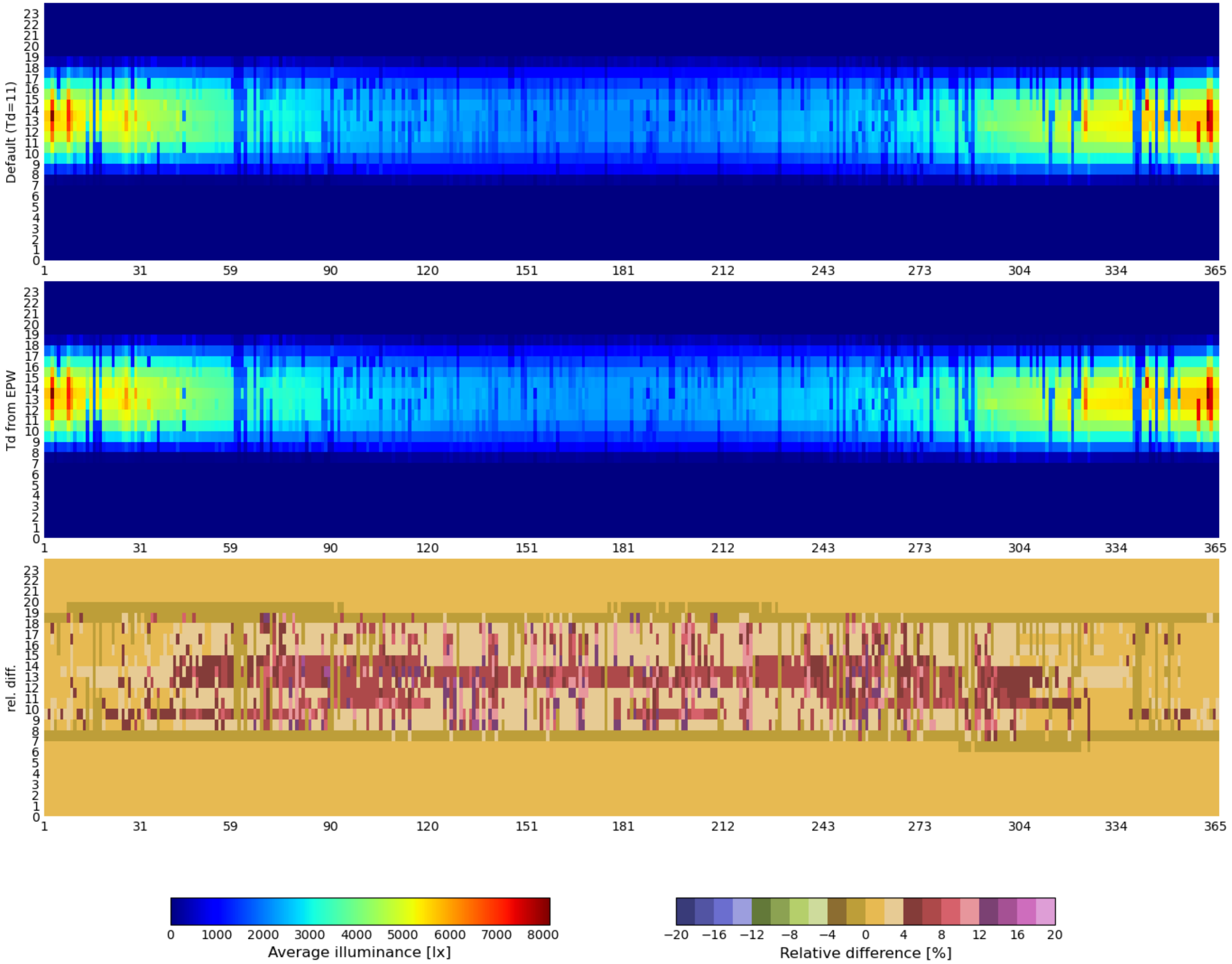
Climate data: SGP_Singapore.486980_IWEC.epw
Sky matrix: gendaymtx -m 1 -c 1 1 1

Td = 11°C (default)	Td = 3h avg. from EPW [-/+ %]



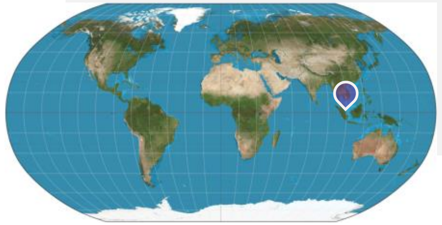




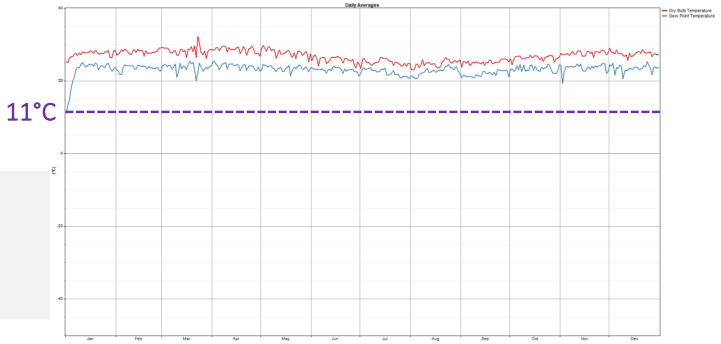


Average illuminance on sensor grid "floor"
Td 11°C: mean = 19661 lx
Td from EPW: mean = 2038 lx

Relative difference
Min = -2.0%
Max = +15.0%
Median = +2.6%

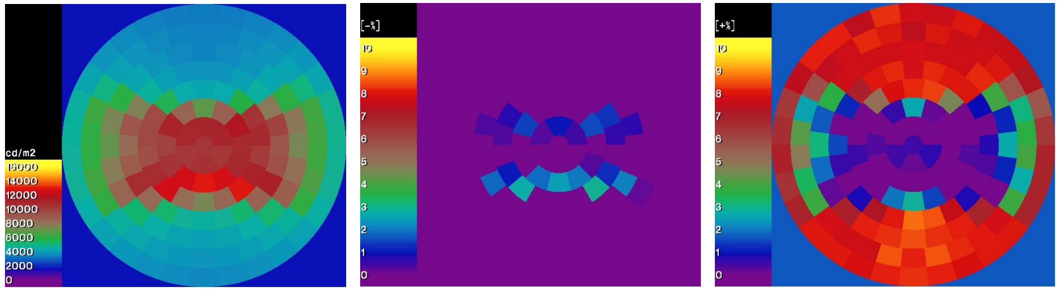


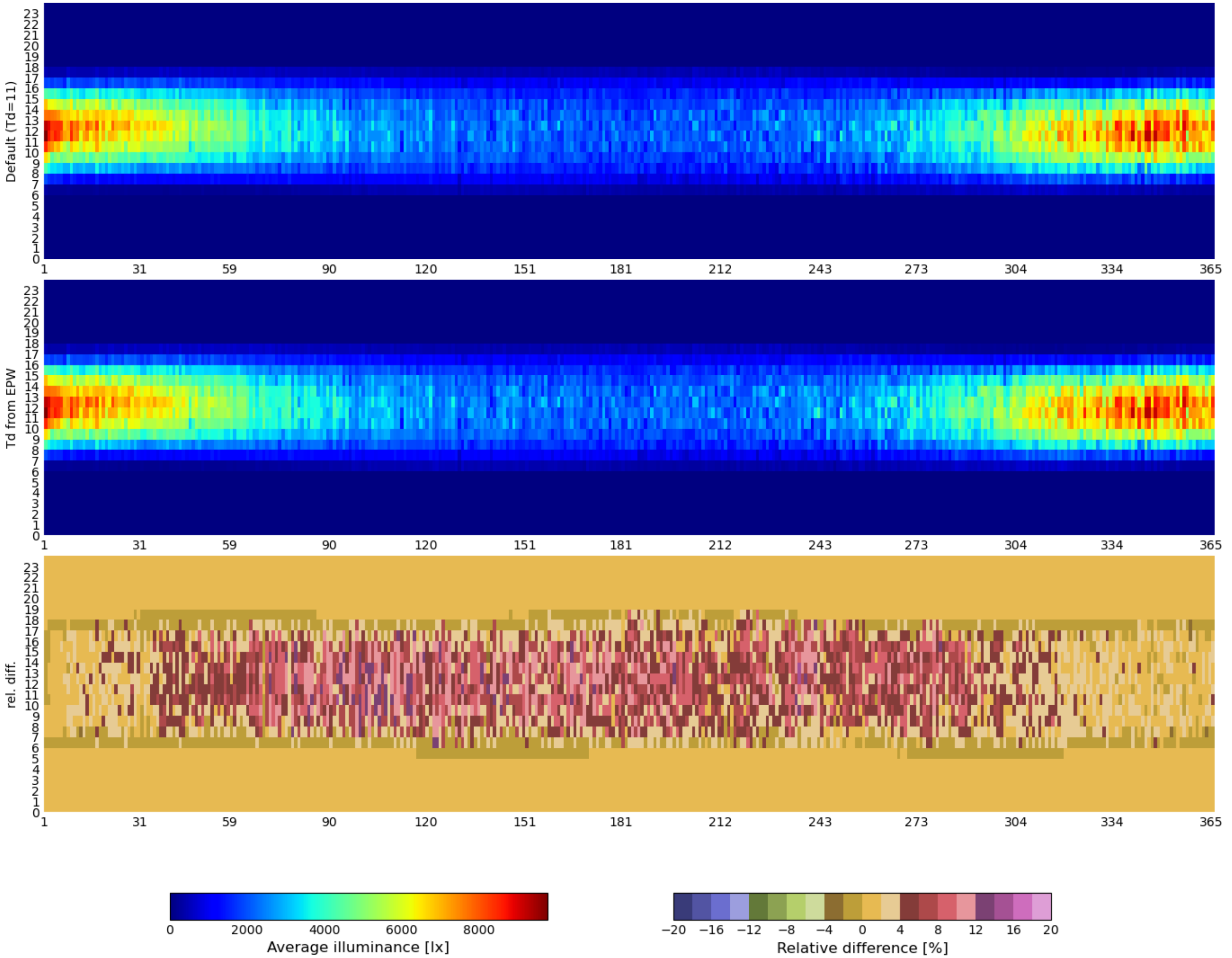
Perez Sky: Dew Point Temperature Effect



Climate data: GHA_Accra.654720_SWERA.epw
Sky matrix: gendaymtx -m 1 -c 1 1 1

Td = 11°C (default) | Td = 3h avg. from EPW [-/+ %]





Average illuminance on sensor grid "floor"

Td 11°C: mean = 2351 lx

Td from EPW: mean = 2451 lx

Relative difference

Min = -2.7%

Max = +15.1%

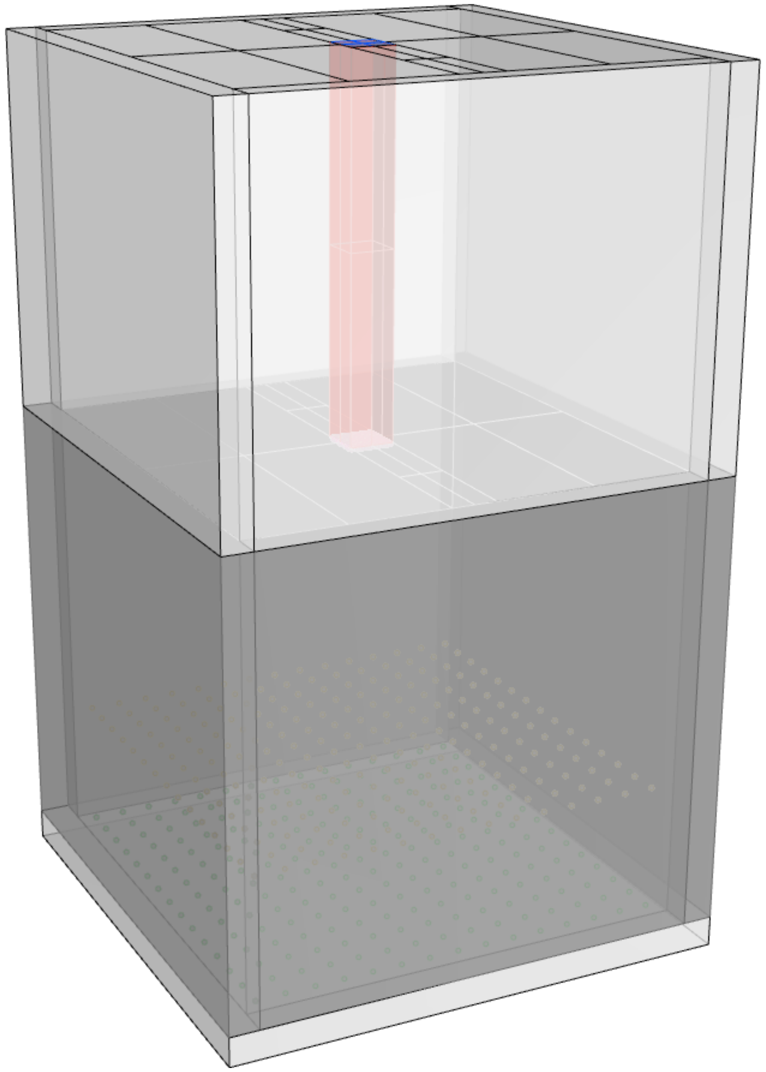
Median = +3.0%

Sun tunnel results

Average illuminance on floor grid

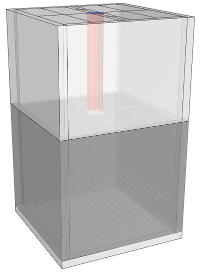
Sun Tunnel Room

- Simple shoebox model
- Rectangular light pipe
- Systems: clear glass, (diffuser BSDFs to come)
- Sensor grids on floor, workplane, and sun tunnel outlet
- x-PM simulation



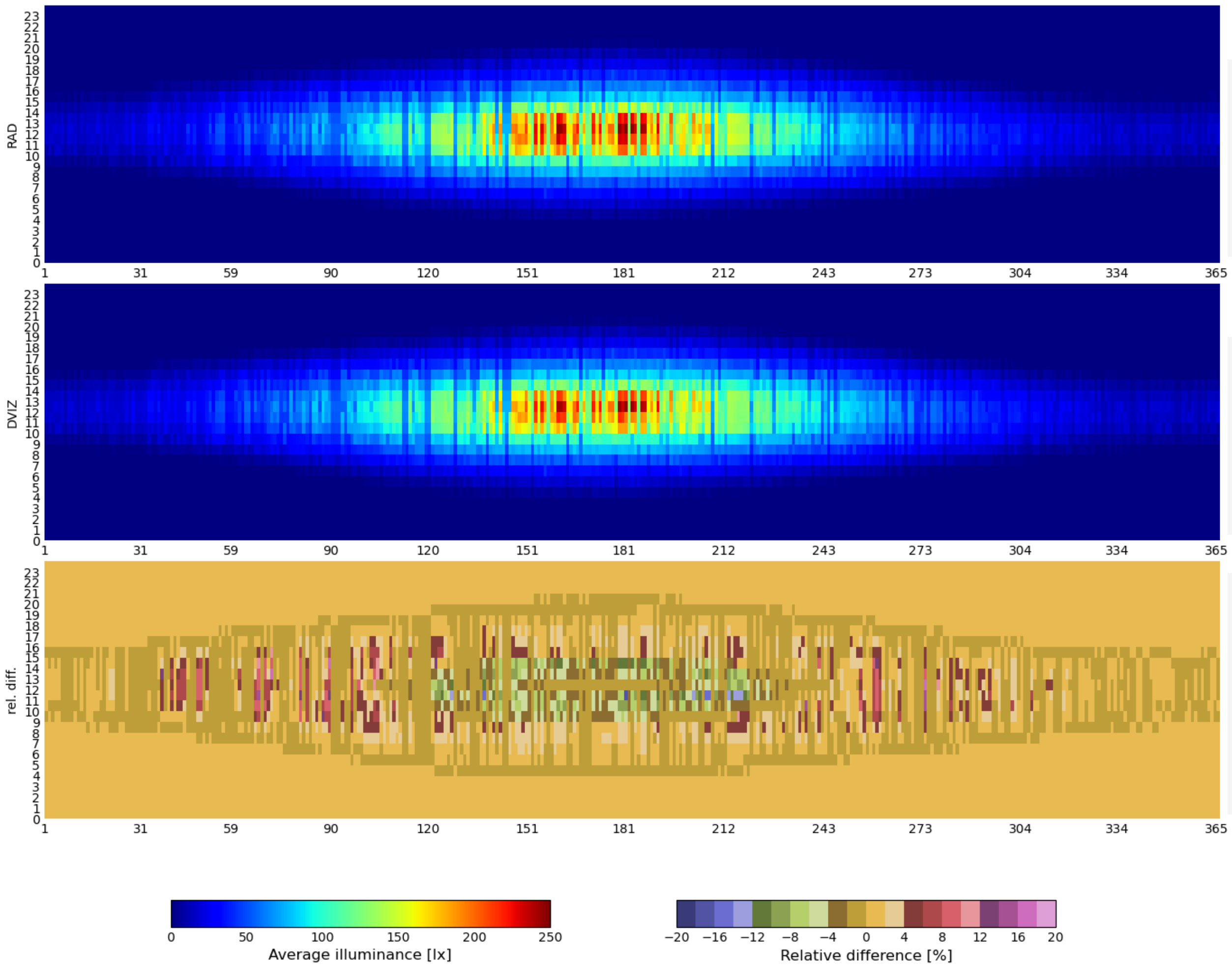
Sun tunnel results

Average illuminance on floor grid



Radiance: Reinhart MF:1
DVIZ: 11° patches
Dew point settings as in DViz

Sun tunnel, clear glass



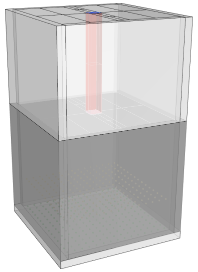
Radiance	
Mean	42.9 lx
Median	27.1 lx
Max	247.8 lx

DViz	
Mean	42.4 lx
Median	27.3 lx
Max	245.1 lx

rel. Diff.	
Mean	-0.09%
Min	-16.1 %
Median	-0.8 %
Max	+17.5 %

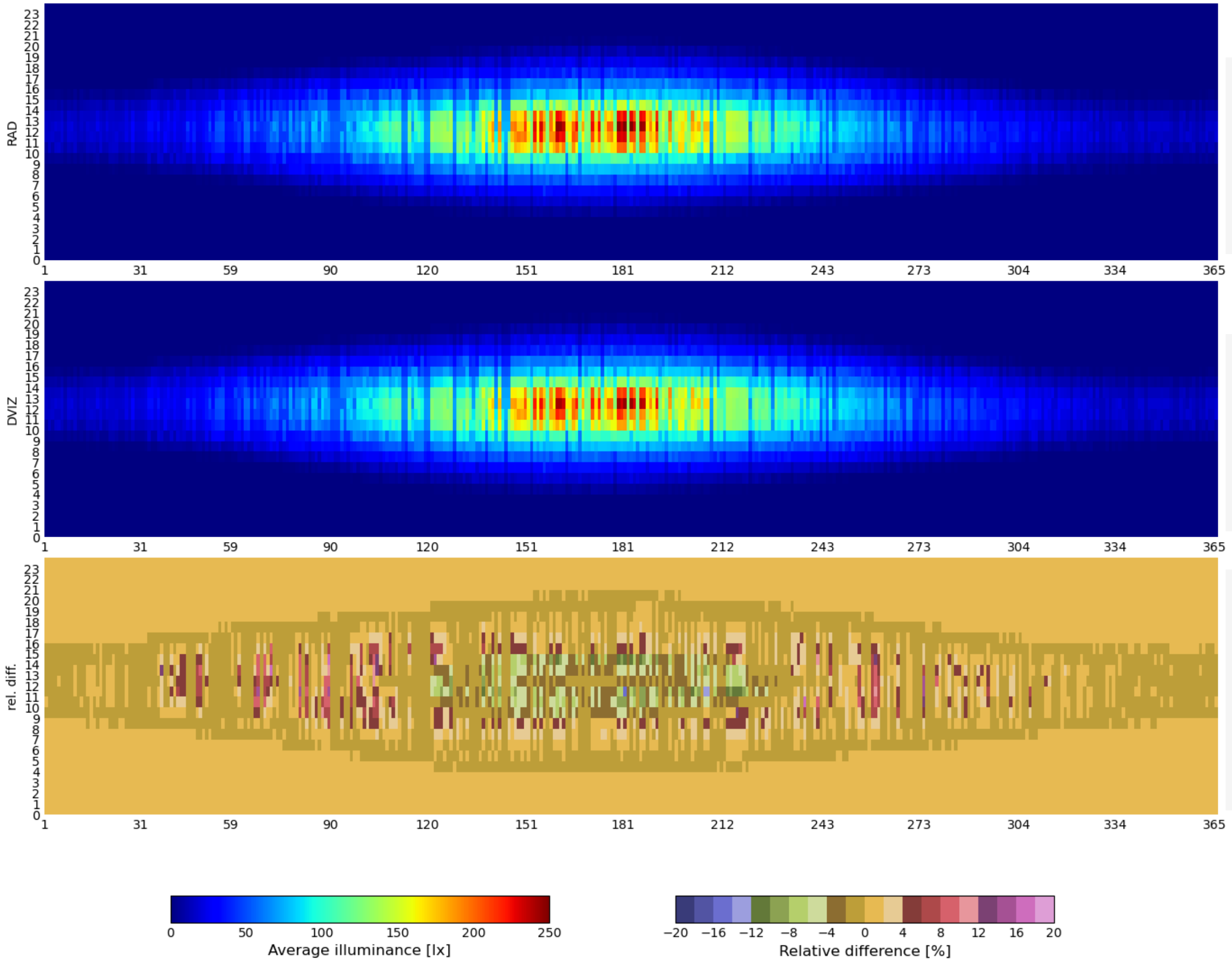
Sun tunnel results

Average illuminance on floor grid



Radiance: 11° patches
DVIZ: 11° patches
Dew point settings as in DViz

Sun tunnel, clear glass



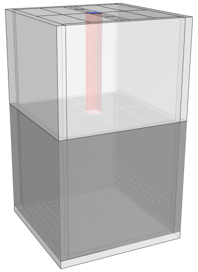
Radiance	
Mean	42.9 lx
Median	27.3 lx
Max	250.7 lx

DViz	
Mean	42.4 lx
Median	27.3 lx
Max	245.1 lx

rel. Diff.	
Mean	-0.4%
Min	-15.9 %
Median	-1.3 %
Max	+17.0 %

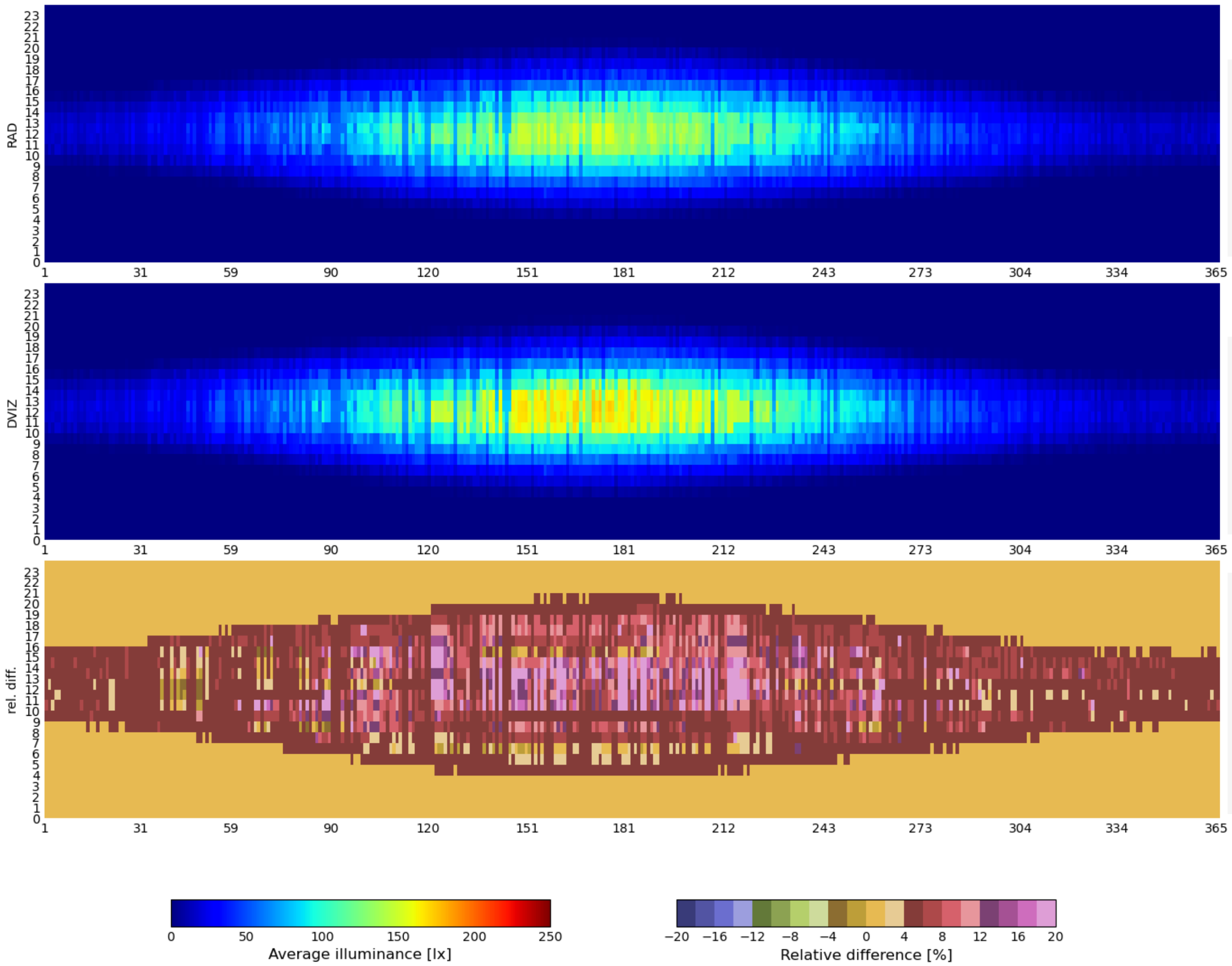
Sun tunnel results

Average illuminance on floor grid



Radiance: 0.5° patches
DVIZ: 0.5° patches
Dew point settings as in DViz

Sun tunnel, clear glass



Radiance

Mean	40.5 lx
Median	27.9 lx
Max	157.2 lx

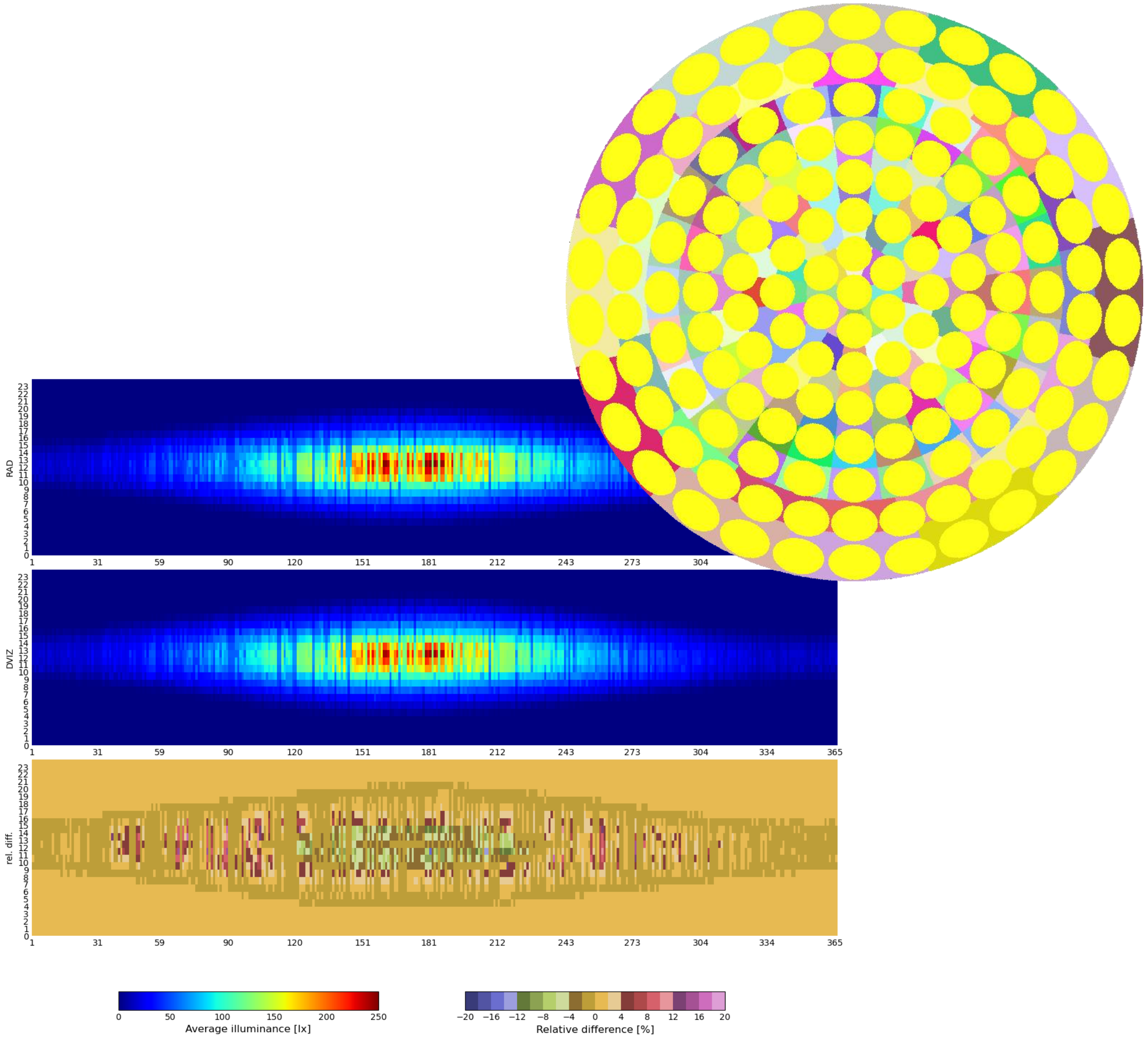
DViz

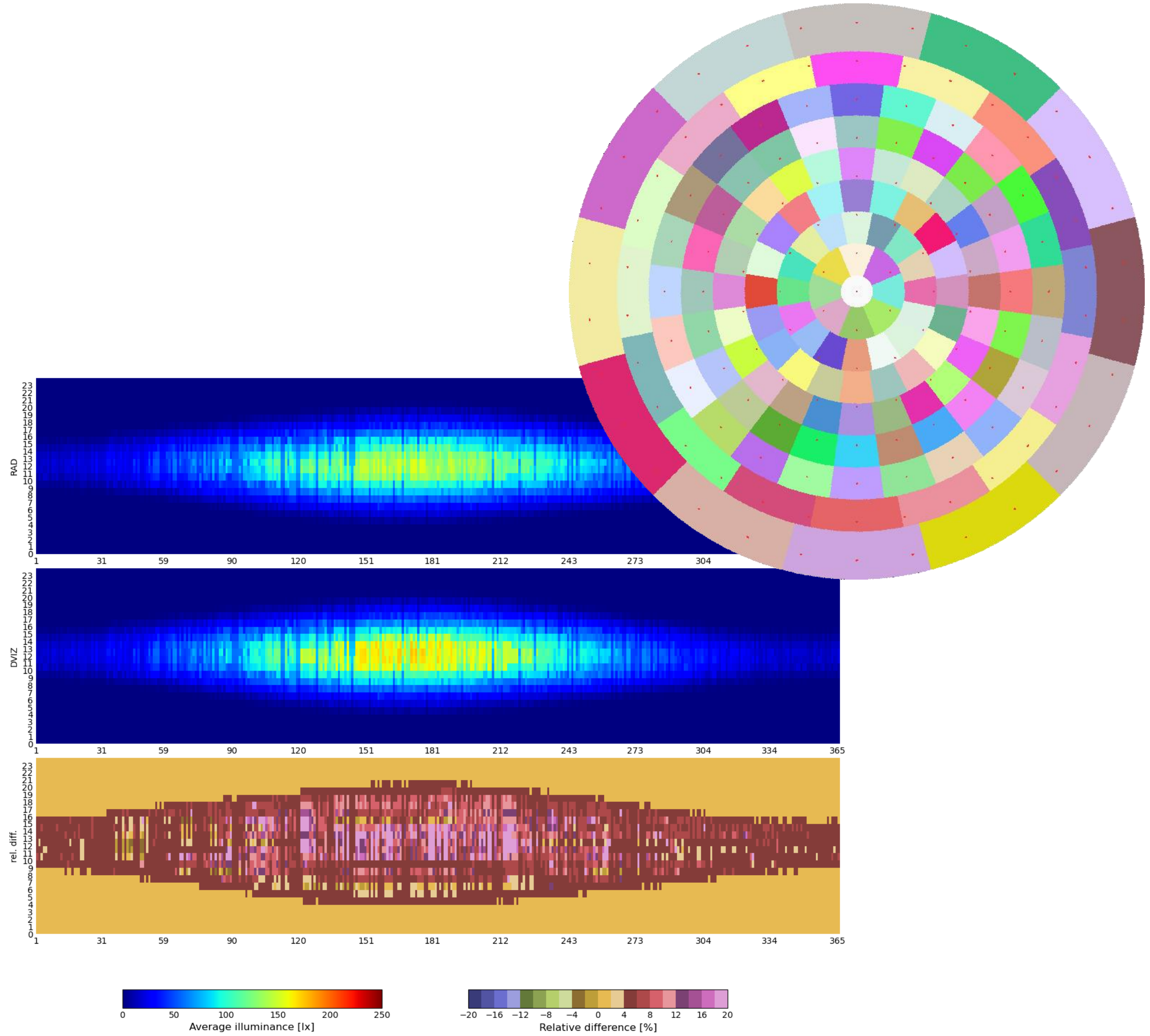
Mean	44.2 lx
Median	29.3 lx
Max	176.8 lx

rel. Diff.

Mean	+7.1%
Min	-3.9 %
Median	+5.4 %
Max	+78.3 %

Klems‘ view to the sky

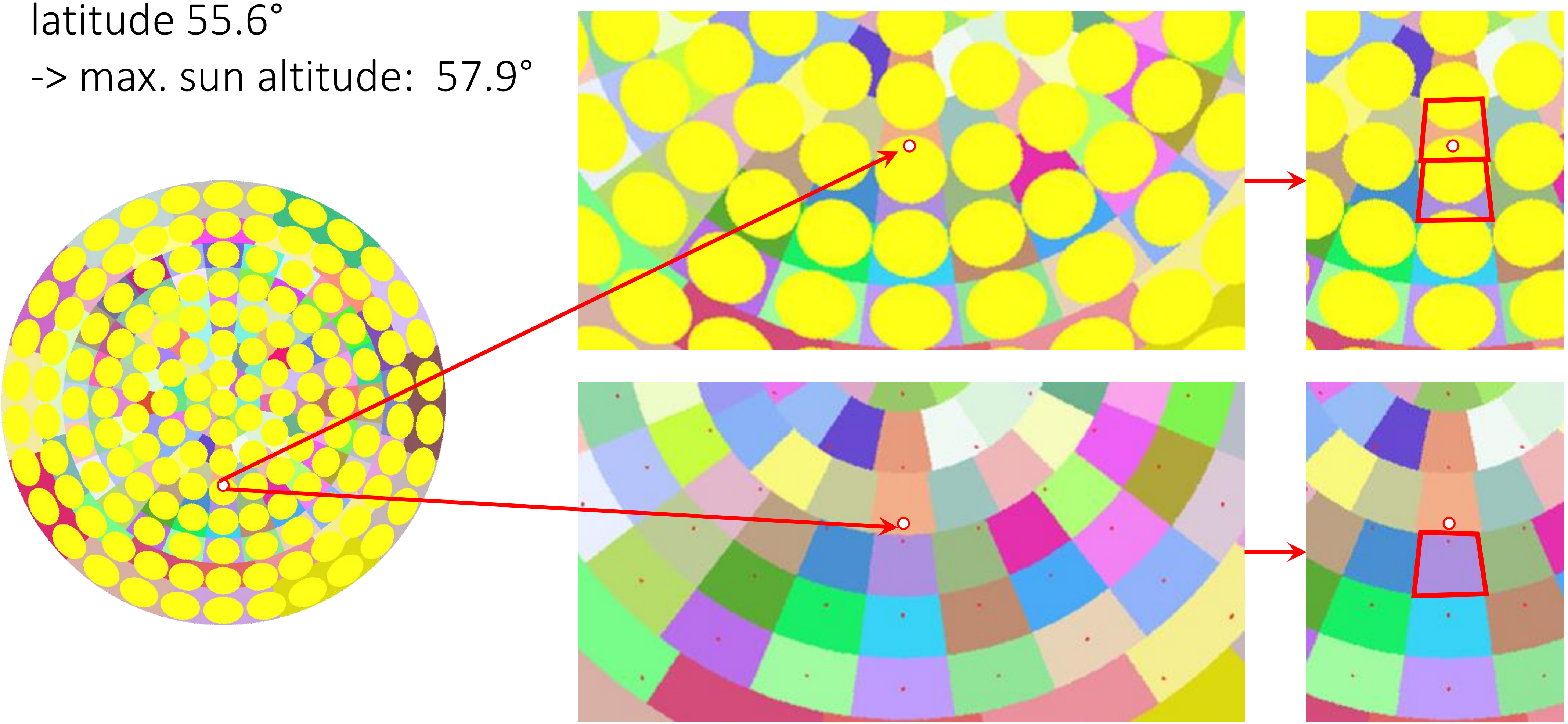




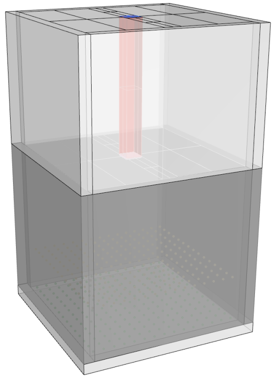
Klems‘ view to the sky

<u>Summer solstice in Copenhagen</u>

- latitude 55.6°
- -> max. sun altitude: 57.9°

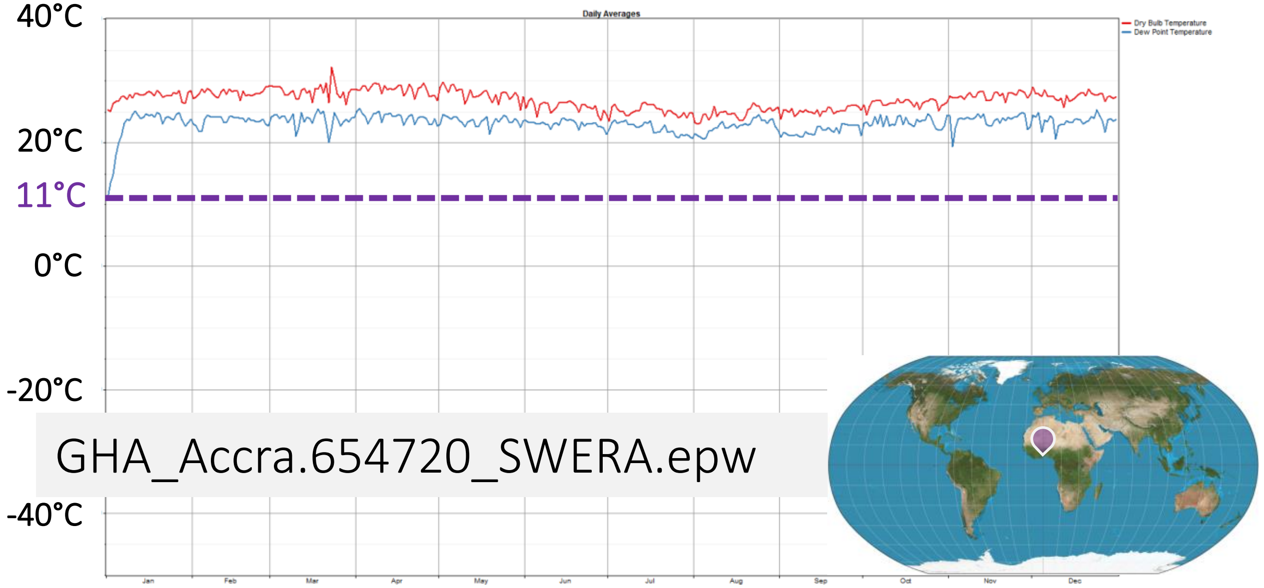


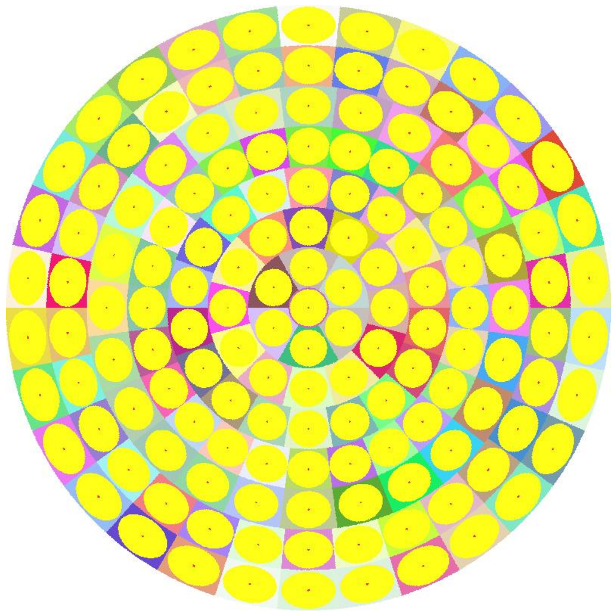
Next steps



- Resolve issue with underestimation of transmission in some cases
- Test sun tunnel with BSDF materials at entrance and / or outlet
- Documentation

- Implementation of dew point temperature in epw2wea & gendaymtx?





Thank you for listening!

Questions?

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