Evaluating solar irradiance on urban sites by superimposing Radiance pictures

13th International Radiance workshop, September 2014

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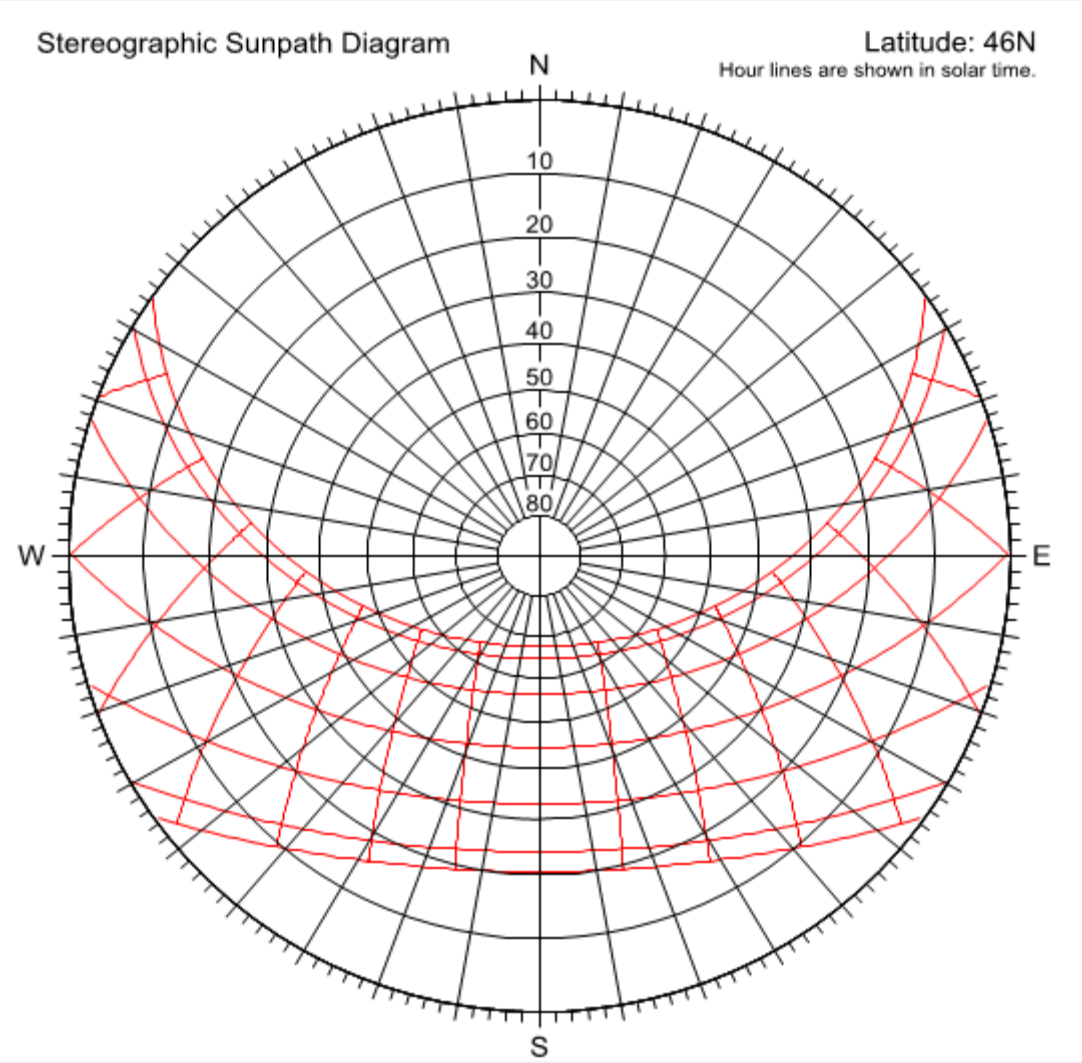
Outline

- Sky models
- Motivations
- Explanation of the method
- Examples

A common tool…



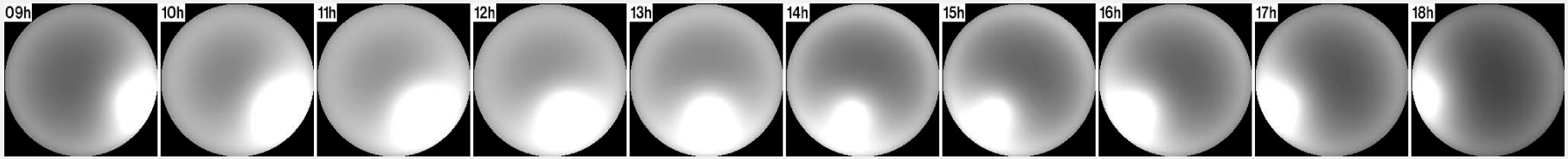
Tip 1 for Radiance geeks:

- How to generate such a stereographical projection using Radiance?

rpict -vts -vh 180 -vv 180 -vp *x y z* -vd 0 0 1 -vu 0 1 0 …
octree > temp.pic

pflip -h temp.pic > final.pic

Sky models



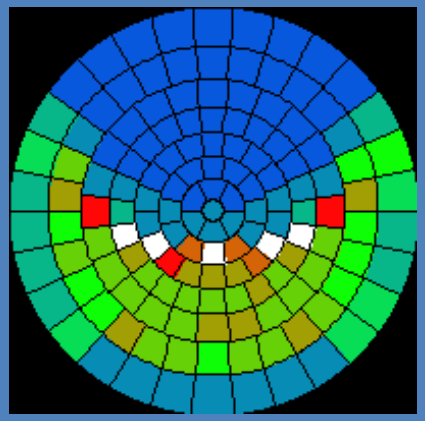
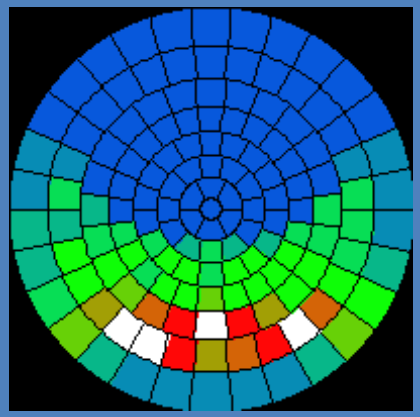
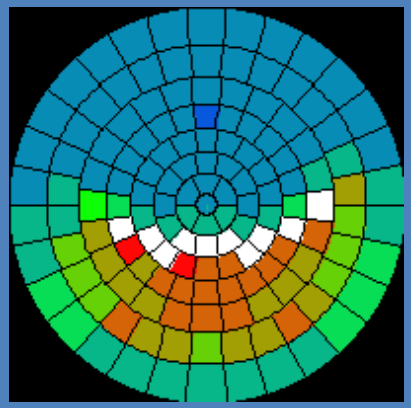
Hourly sky models generated from climatic data provided by METEONORM

Averaging process to obtain «average sky models » for specific applications

Time intervals considered:

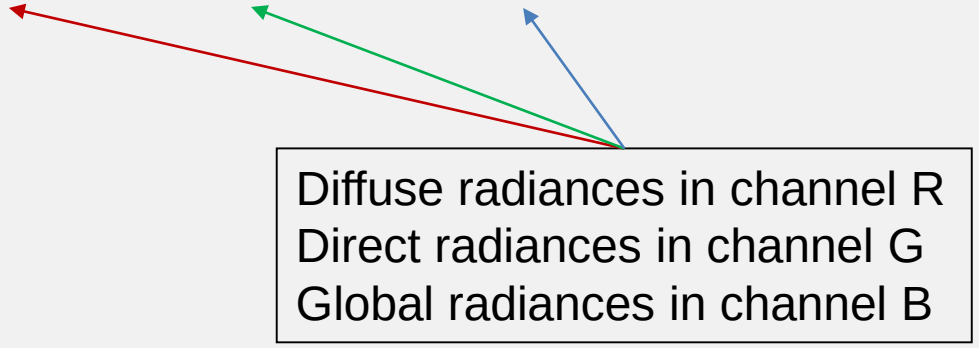
Year	Heating season	Working hours (8h–18h) over a year
radiance values in [W/(m²sr)]	radiance values in [W/(m²sr)]	luminance values in [lm/(m²sr)]
Photovoltaic modules	Passive solar devices	Daylighting systems

Sky models

Year	Heating season	Year 8h–18h
		
Photovoltaic modules	Passive solar devices	Daylighting systems

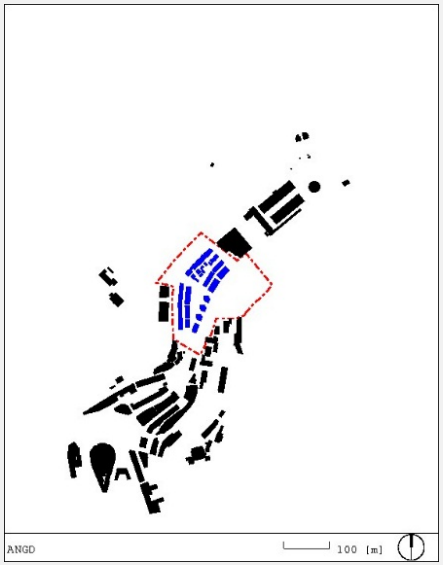
Inside look of a sky model scene file:

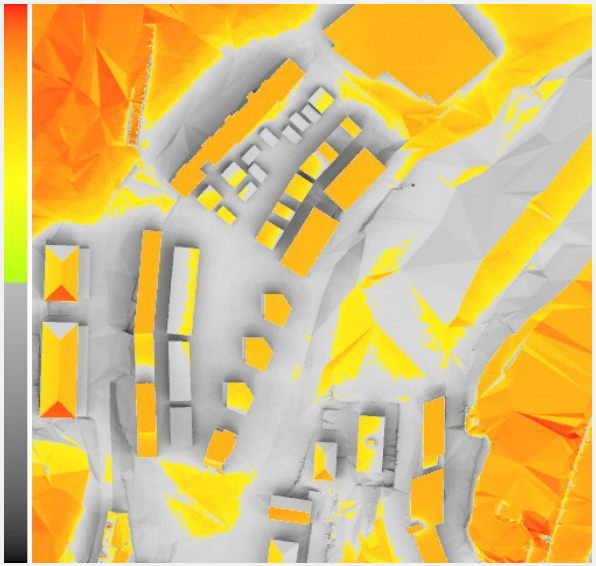
```
# London yearly mean sky
# number of daylight hours: 4317 [h]
# mean diffuse horizontal irradiance: 120 [W/m2]
# mean direct horizontal irradiance: 102 [W/m2]
# mean global horizontal irradiance: 223 [W/m2]

void colordata sky_dist
8 noop noop noop LDN_dif00.dat LDN_dir00.dat LDN_tot00.dat sky_zones.cal zone
0
0

sky_dist glow sky_glow7
0
0
4 1 1 1 0

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

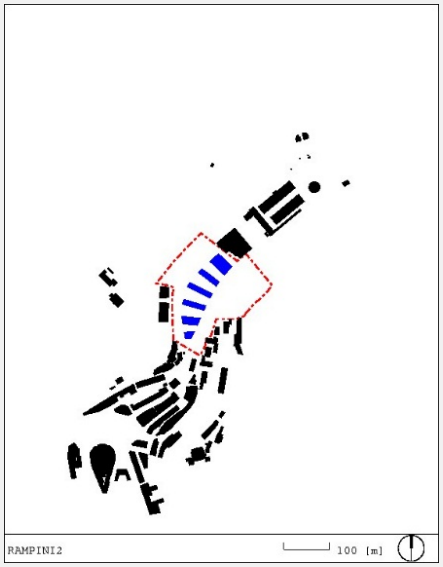


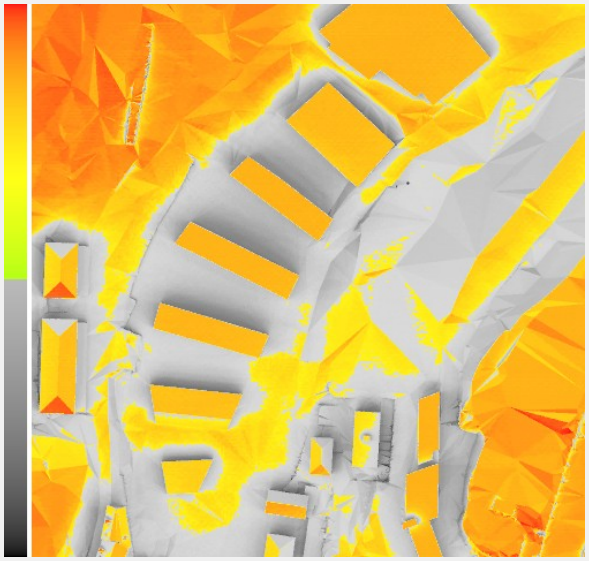
ground omitted here!

Solar irradiation visualisations









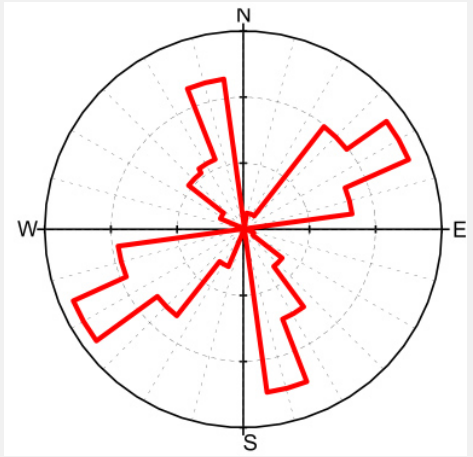
Coloured roof areas
are those where the
yearly irradiation
>1000 [kWh/m^2]
i.e. suitable for PV systems!

Question:
how to easily understand
why one urban layout is
better irradiated than an other?

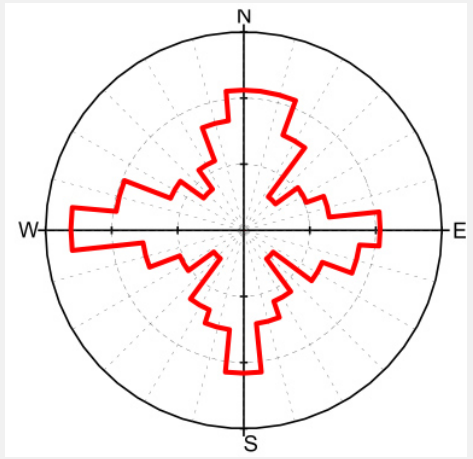
How to define the “orientation” of an urban area ?

- Count SVF-weighted facades areas facing every directions

Perolles area
Fribourg (CH)



Plaka area
Athens (GR)

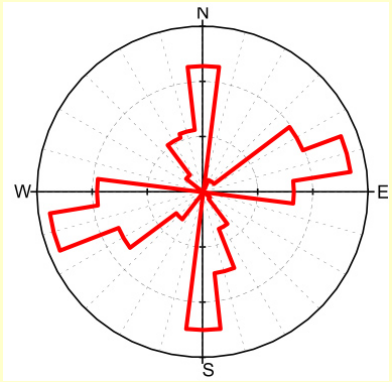


Fractions of façade areas suitable for various solar techniques

See how they change even by a slight rotation of the whole site!

Existing site

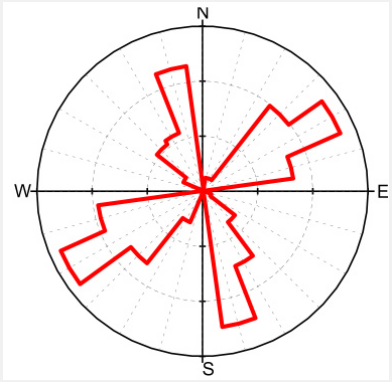
-15° rotation



PV = 5.7 %

pasive solar = 53 %

daylighting = 56 %

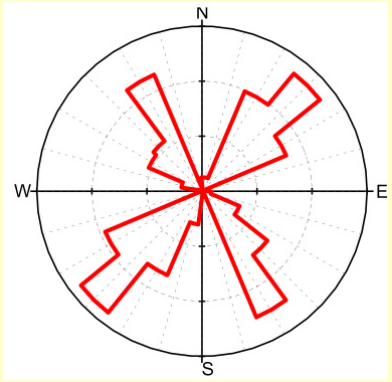


PV = 6.5 %

passive solar = 52 %

daylignting = 54 %

+15° rotation



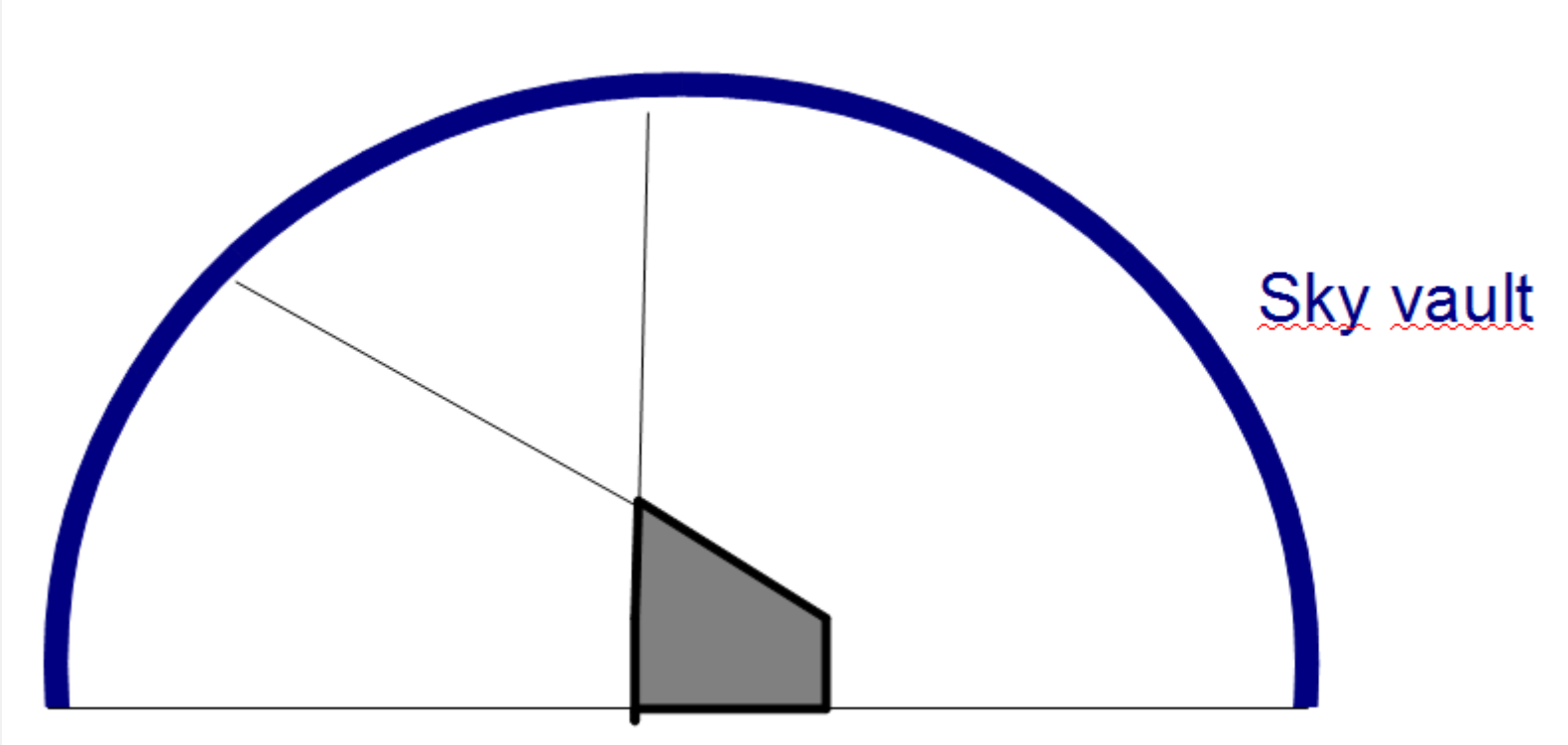
PV = 9.8 %

passive solar = 49 %

daylighting = 53 %

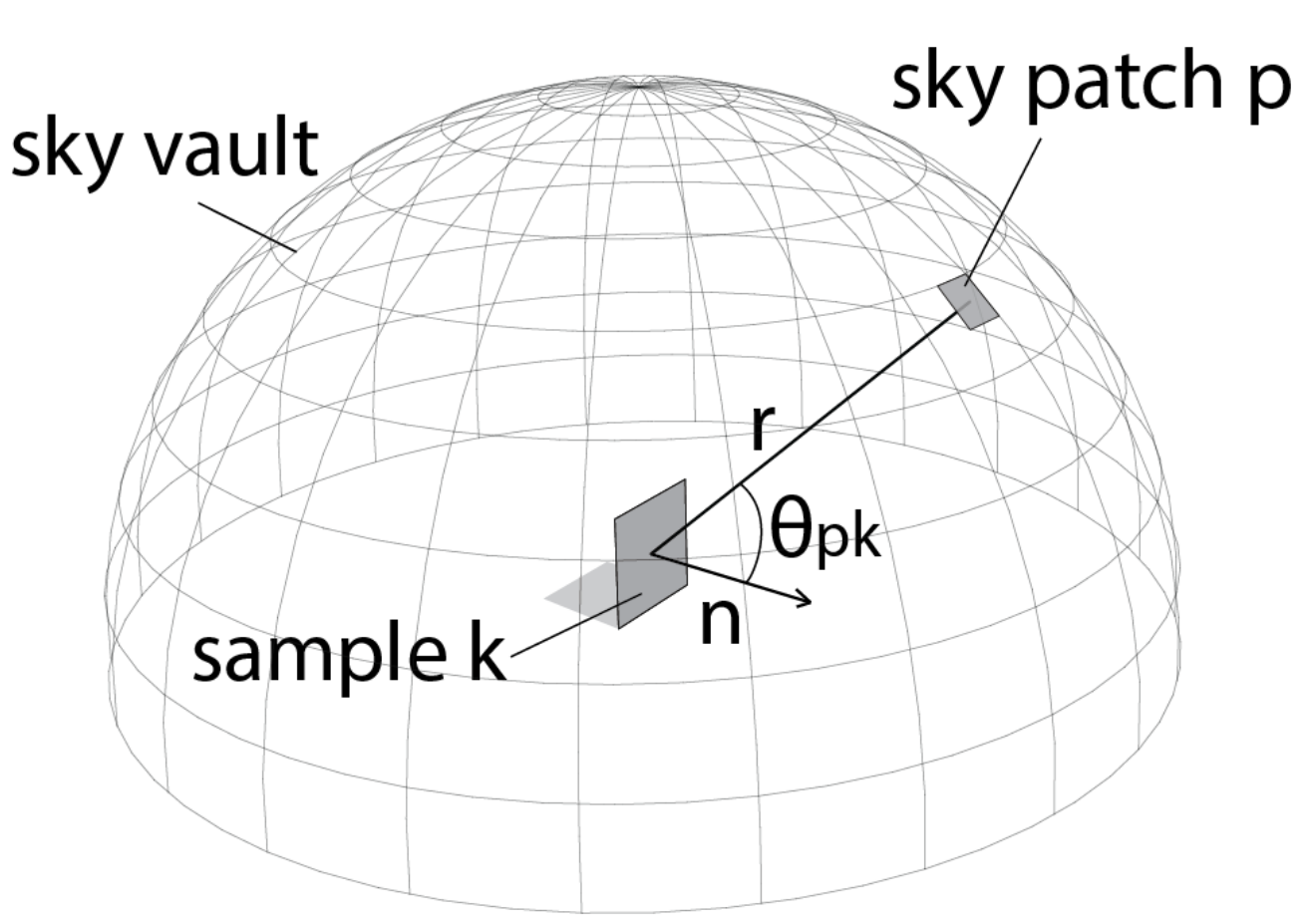
Basic idea

Each part of the sky does not «see» the same amount of building envelope area



The amount of building envelope area seen by each part of the sky can be represented on a stereographic diagram

Solar irradiance received by a building envelope sample k



$$I_{pk} = \text{vis}(p,k) \cdot \cos(\theta_{pk}) \cdot R_p \cdot \Omega_p \quad \text{in [W/m}^2\text{]}$$

with R_p the radiance value of sky patch p in [W/(m^{2}sr)]

Total irradiance from several samples k and several patches p

$$I_{tot} = \sum_p \sum_k \left[A_k \cdot \mathrm{vis}(p,k) \cdot \cos(\theta_{pk}) \right] \cdot R_p \cdot \Omega_p$$

U_p in [m²]
named: «effective envelope area»

$$I_{tot} = \sum_p \left[U_p \cdot R_p \cdot \Omega_p \right]$$

R'_p in [W/m²]

Note that we end up with a sum over all sky vault patches!

Picture processing:

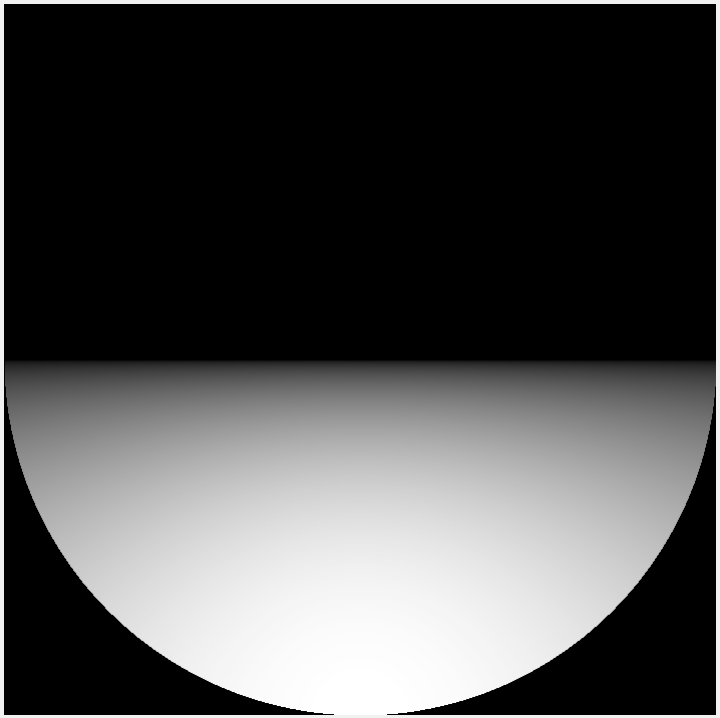
U_p can be visualised as an
«effective envelope area picture» (eea.pic)

R'_p can be visualised as a «sky model picture» (sky.pic)

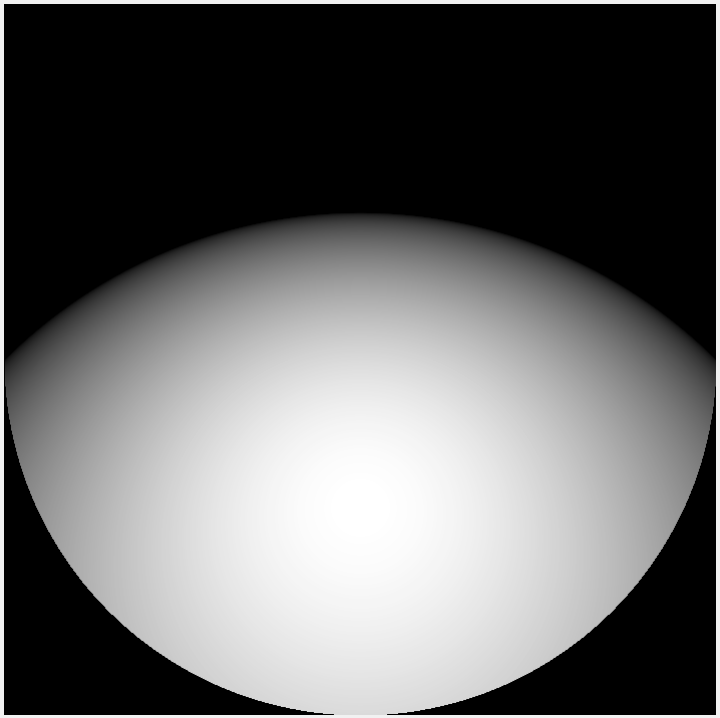
A «product picture» (pp.pic) can be built by mutiplying one by one each pixel of these two pictures!
= superimposing these two pictures!

The total irradiance is then computed by summing up all pixels of the product picture!

Simple effective area pictures

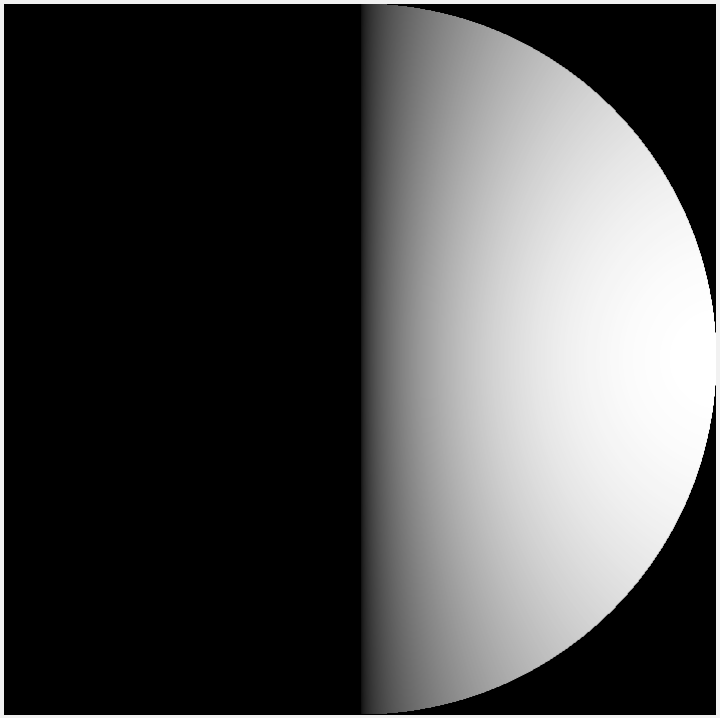


South vertical facade

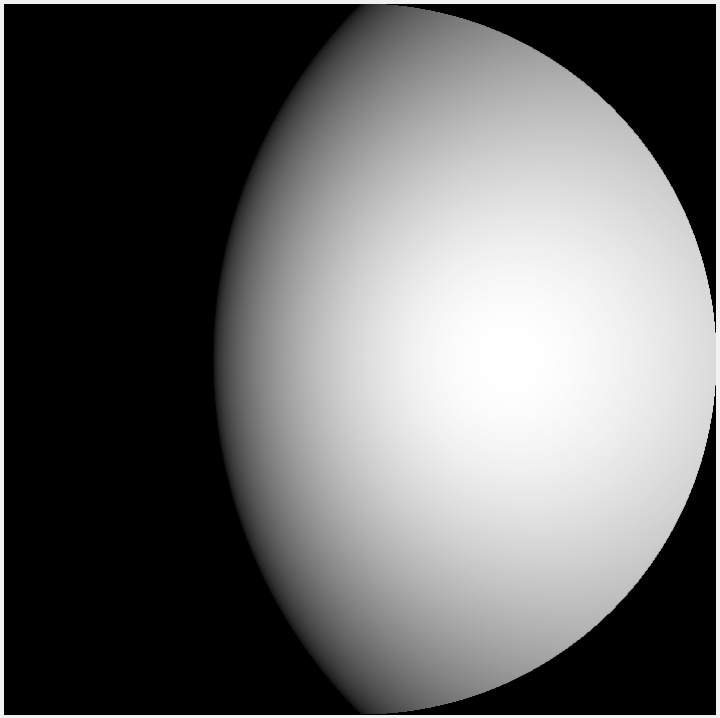


South 45° slanted roof

Simple effective area pictures



East vertical facade



East 45° slanted roof

Tip 2 for Radiance geeks:

- How to generate an «effective envelope area picture»?

  cat samples.xyz | **uppict** octree > eea.pic

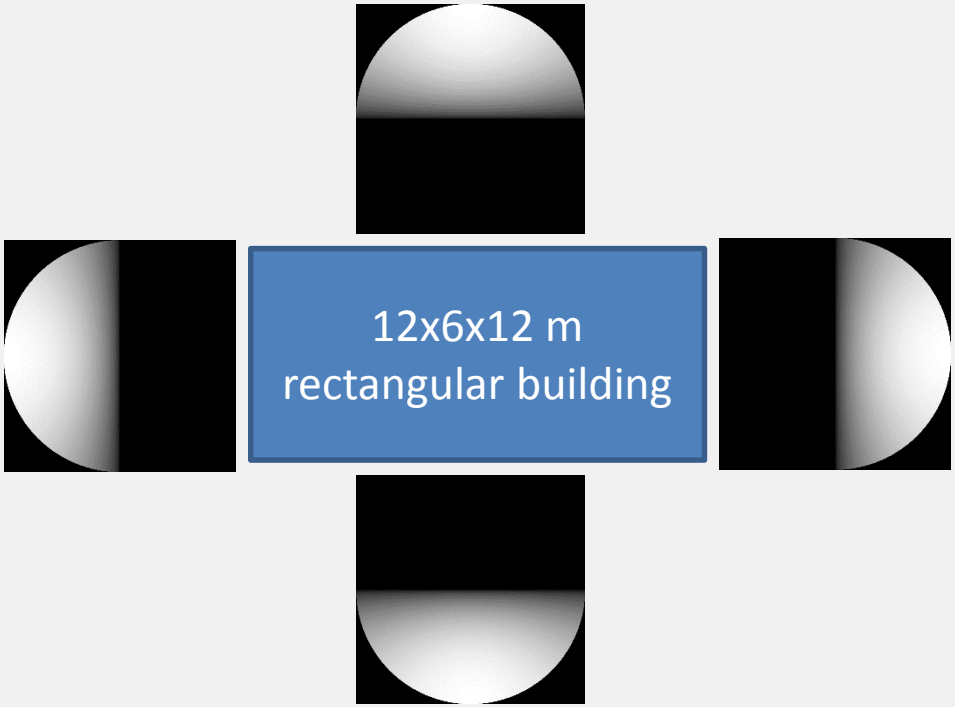
File samples.xyz defines all sample points
(typically located on regular grids just a few cm in front of the building's façade and roof areas):

x y z *xdir ydir zdir* *area* (one line per point)

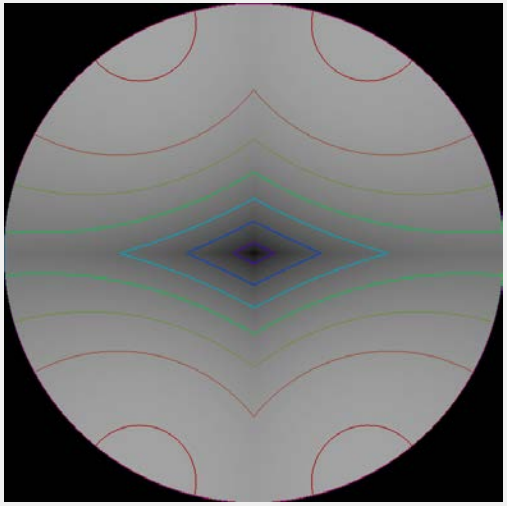
location surface normal sample area in [m^2]

Combining eff. env. area pictures:

These pictures can be scaled, rotated and summed!

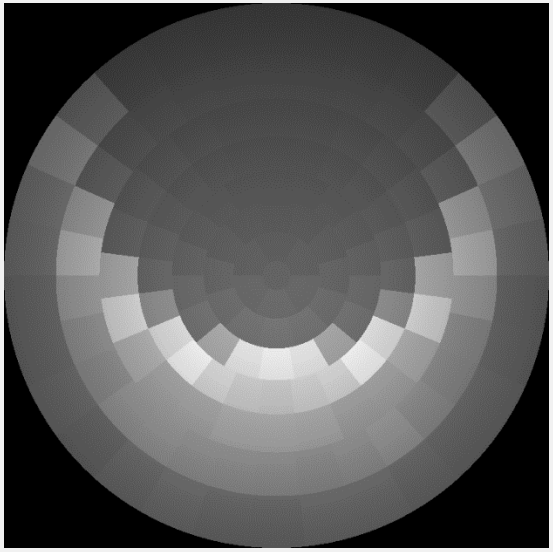


$$\sum =$$

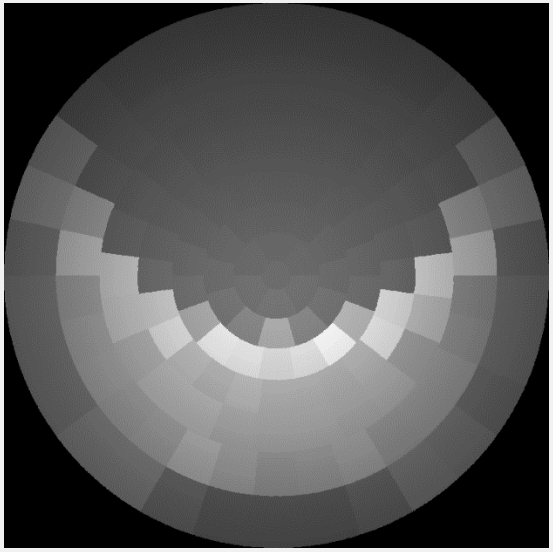


Sky model pictures (full year)

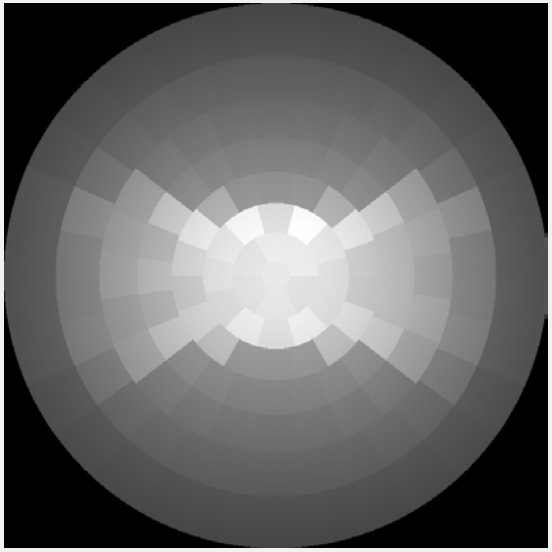
Helsinki (year)



London (year)

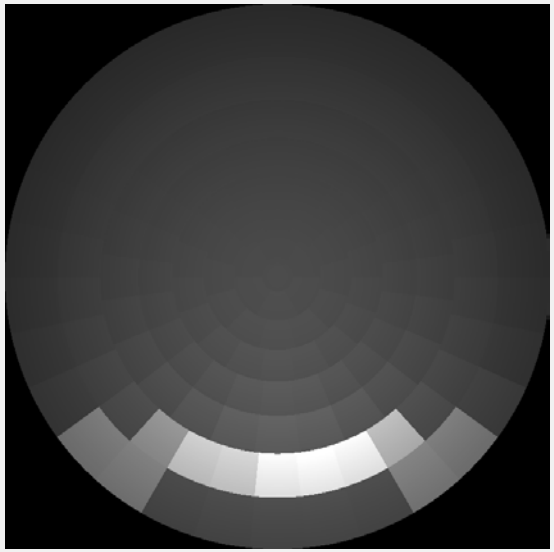


Singapore (year)

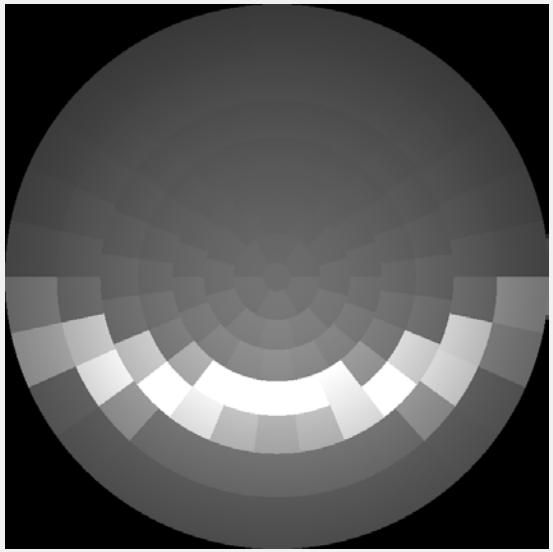


Sky model pictures (monthly models)

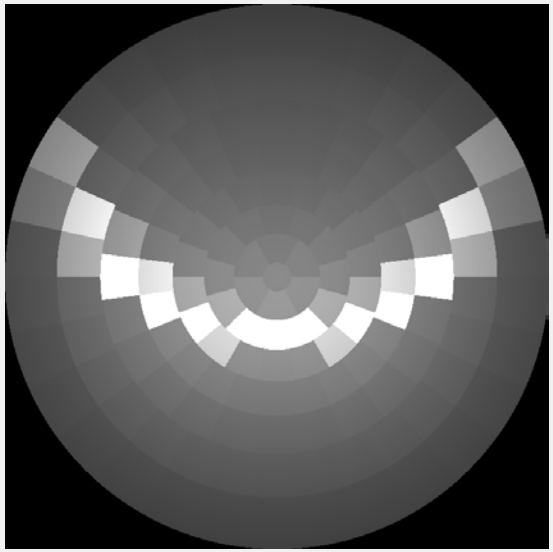
Fribourg (December)



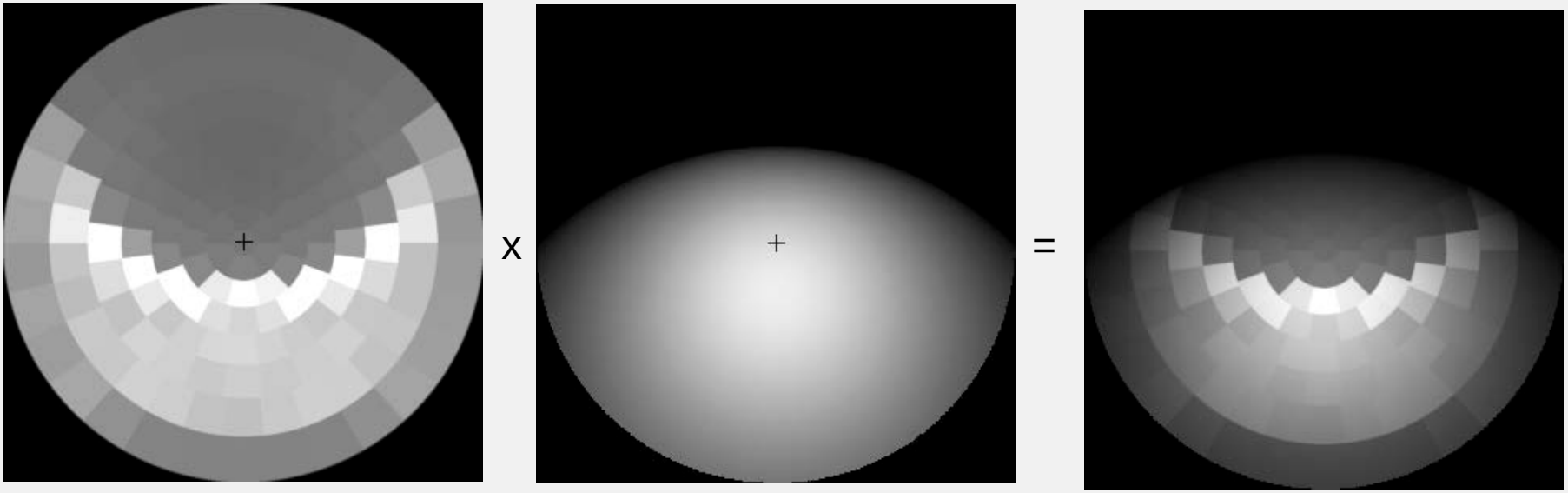
Fribourg (March)



Fribourg (June)



Superimposing with sky model



The overall brightness of the resulting picture is proportional to the total irradiation received by the surface!

Tip 3 for Radiance geeks:

- How to generate a «sky model picture»?

rpict -vts -vh 180 -vv 180 -vp *x y z* -vd 0 0 1 -vu 0 1 0 …
skymodel.oct | \

pcomb -e ‘ro=ri(1)*S(1);go=gi(1)*S(1);bo=bi(1)*S(1)’ -
> temp.pic

pflip -h temp.pic > sky.pic

Tip 4 for Radiance geeks:

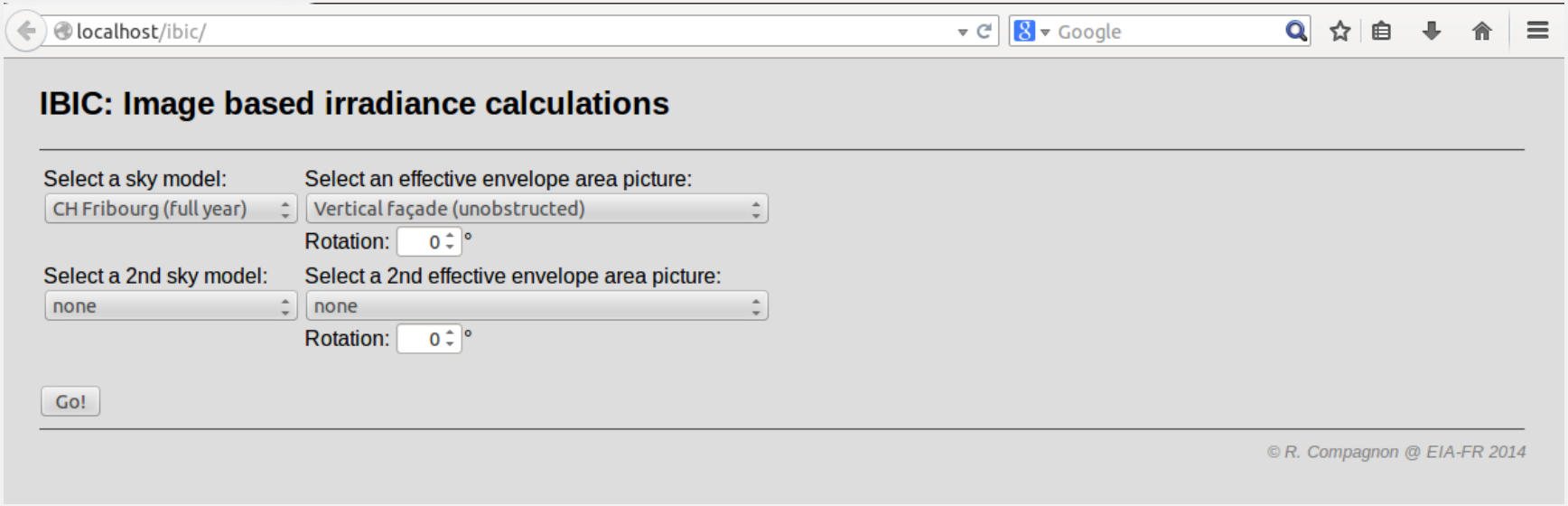
- How to compute a «product picture»?

```
pcomb -e 'ro=ri(1)/le(1)*ri(2)/le(2);
          go=gi(1)/le(1)*gi(2)/le(2);
          bo=bi(1)/le(1)*bi(2)/le(2);'
          sky.pic eea.pic > pp.pic
```

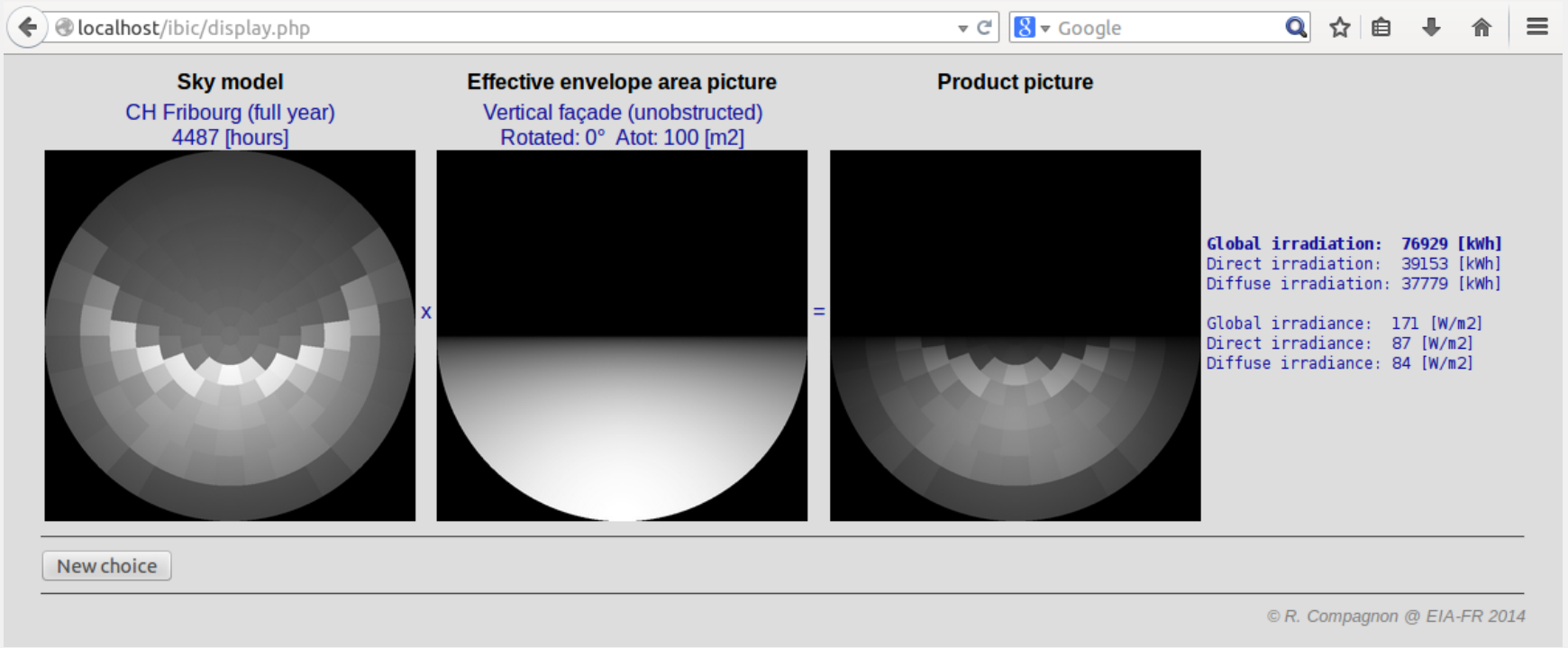
- How to compute total irradiances?

```
pvalue -h -H pp.pic | total
```

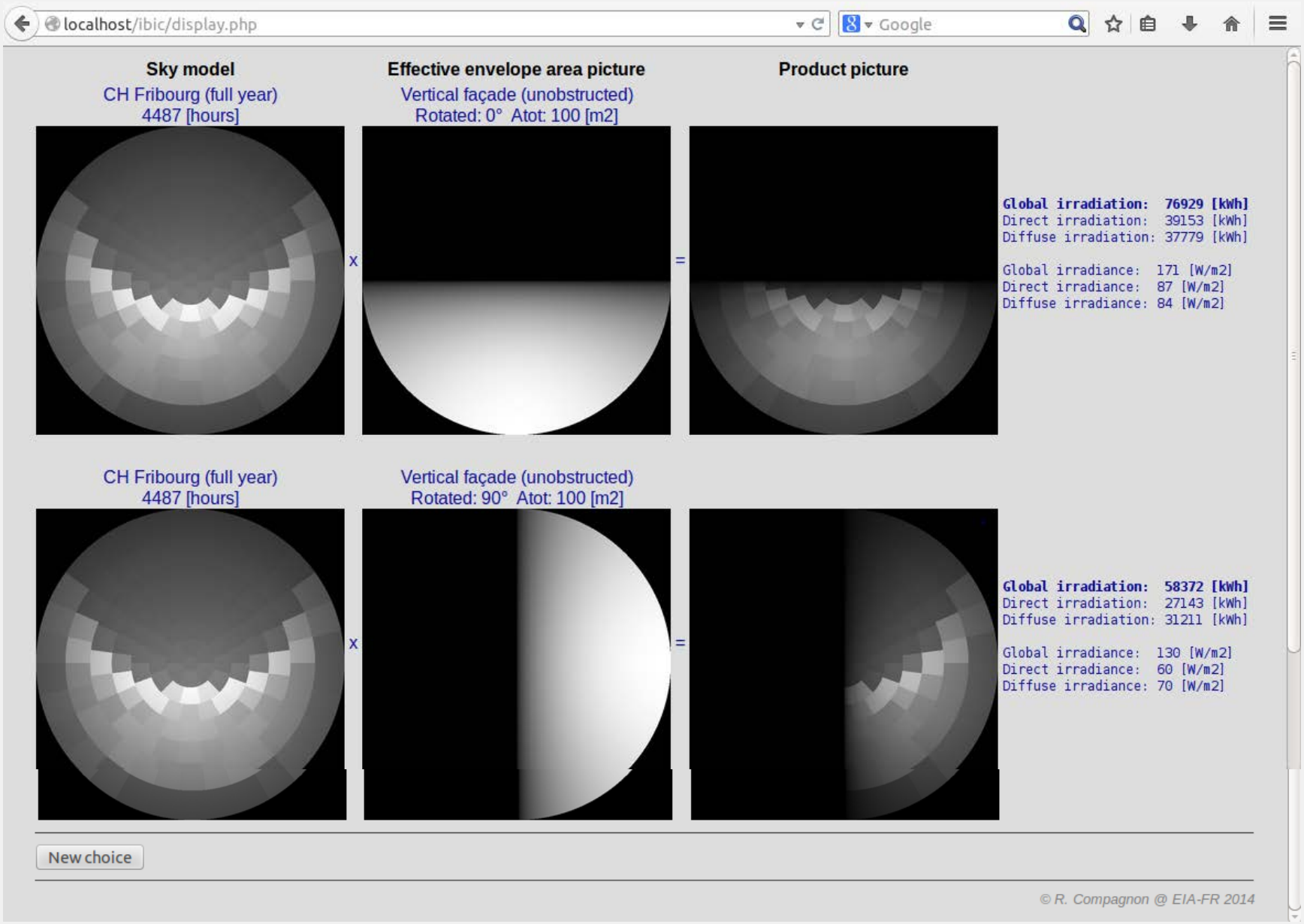
Interactive web tool



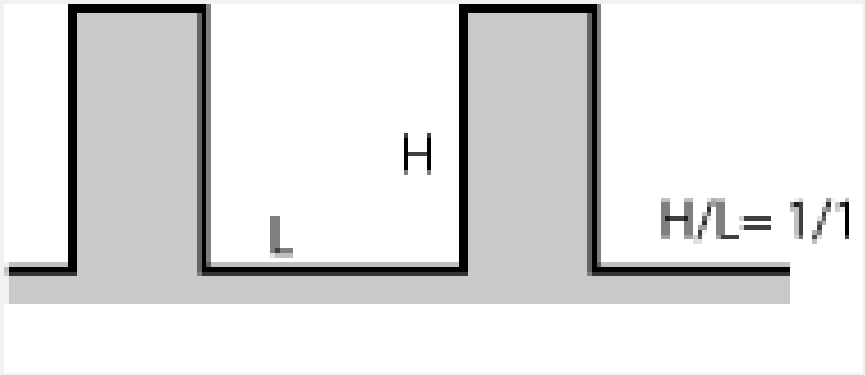
Interactive web tool

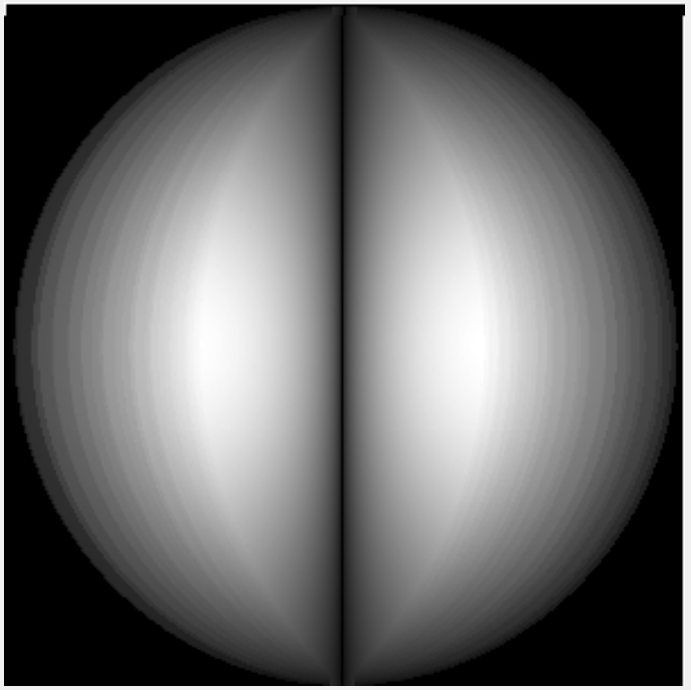


Interactive web tool

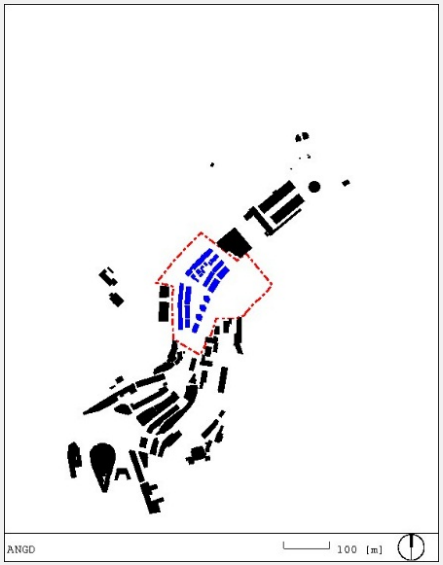


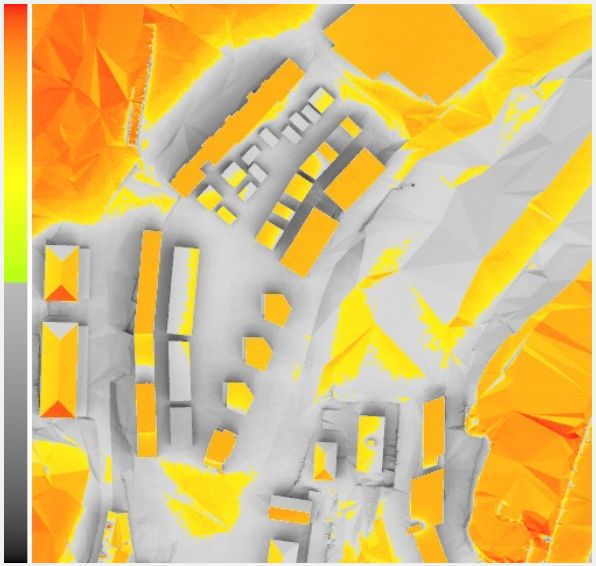
Analysing several surfaces: e.g.: facades of an urban canyon

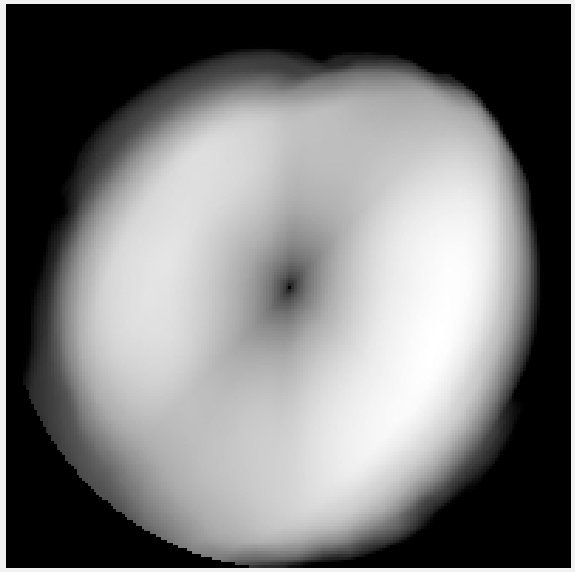


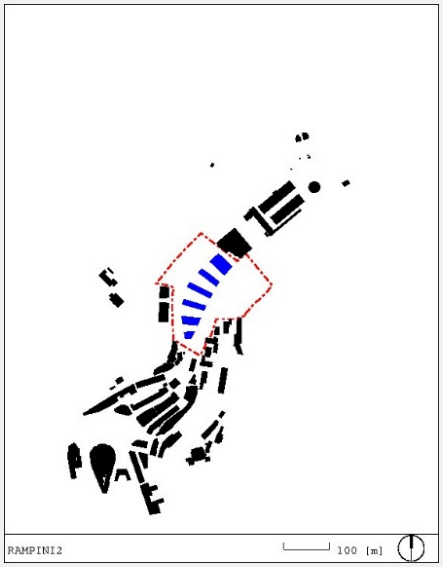


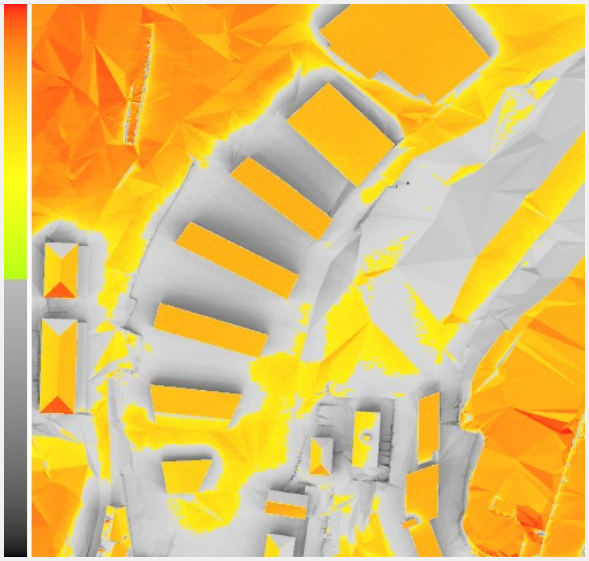
Analysing groups of buildings

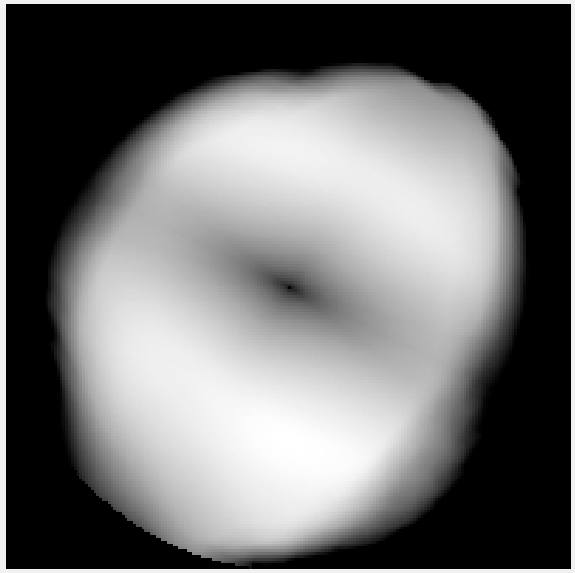






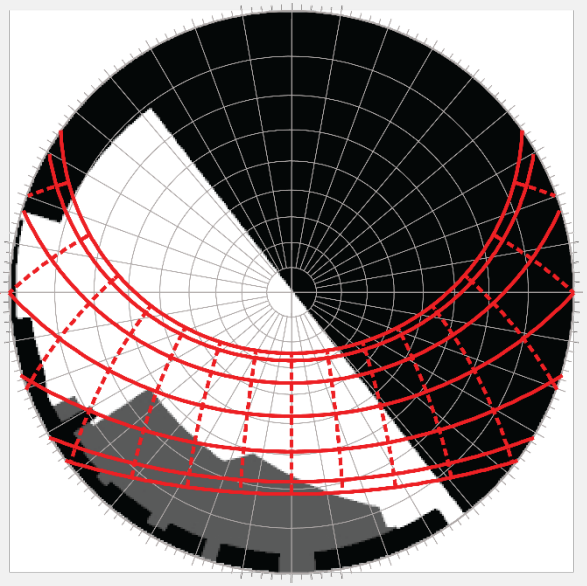


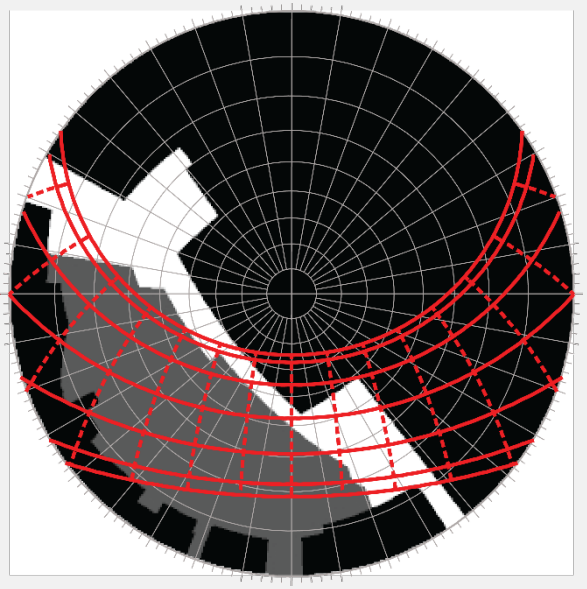




Solar access case study

Problem: estimate the overshadowing effect for this south-west façade by a planned nearby large building



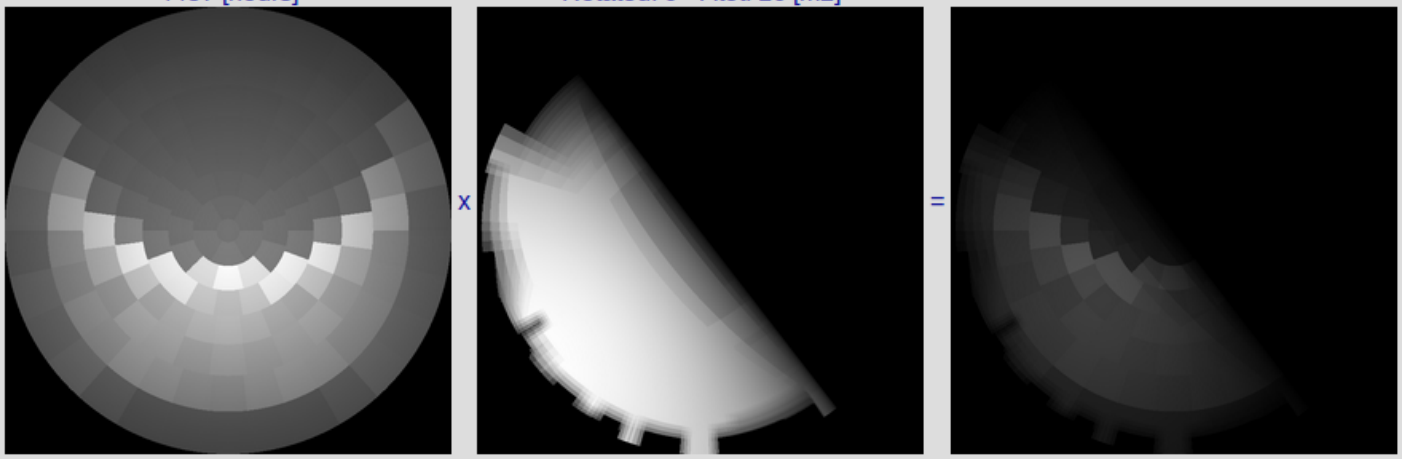


Solar access case study

Sky model
CH Fribourg (full year)
4487 [hours]

Effective envelope area picture
Industrie 2 case study (existing)
Rotated: 0° Atot: 16 [m2]

Product picture

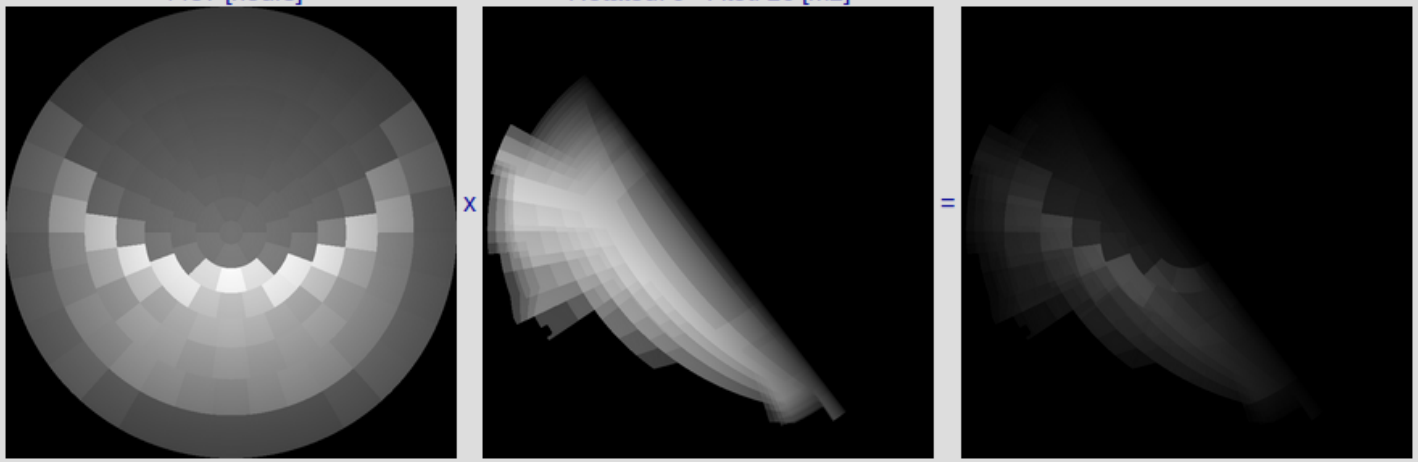


Global irradiation: 10289 [kWh]
Direct irradiation: 5514 [kWh]
Diffuse irradiation: 4776 [kWh]

Global irradiance: 143 [W/m2]
Direct irradiance: 77 [W/m2]
Diffuse irradiance: 67 [W/m2]

CH Fribourg (full year)
4487 [hours]

Industrie 2 case study (+new buildings)
Rotated: 0° Atot: 16 [m2]



Global irradiation: 5498 [kWh]
Direct irradiation: 3141 [kWh]
Diffuse irradiation: 2359 [kWh]

Global irradiance: 77 [W/m2]
Direct irradiance: 44 [W/m2]
Diffuse irradiance: 33 [W/m2]

Advantages / Limitations

- «effective envelope area» pictures as well as «sky model» pictures can be pre-computed separately
- «intuitive» visual estimation of the irradiance/irradiation values by comparing overall brightness
  (good for teaching purposes…)
- Interreflections not yet taken into account (but still possible within the same method)

Further work

- Making the «online tool» available on the web
- Publish a paper
- Refining and documenting the uppict program
- Include interreflections

- New R&D project for using this method in building control systems

Thank you for your attention!

- The main part of this research was sponsored by Singapore's National Research Foundation (NRF) and has been conducted with Prof. Stephen Wittkopf at the Solar Research Institute of Singapore (SERIS) in 2012

- Prior research:
  R. Compagnon, *Solar and daylight availability in the urban fabric*, Energy and Buildings 36 (4) pp. 321-328 (2004)
- A similar approach applied to open spaces:
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