Artlight 2.0 – an optimized TRNSYS-model for coupled thermal and daylight simulation based on the 3PM

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Martin Hauer[1], David Geisler-Moroder[2]

[1] University of Innsbruck, Unit for Energy Efficient Buildings
[2] Bartenbach GmbH, Aldrans

Outline

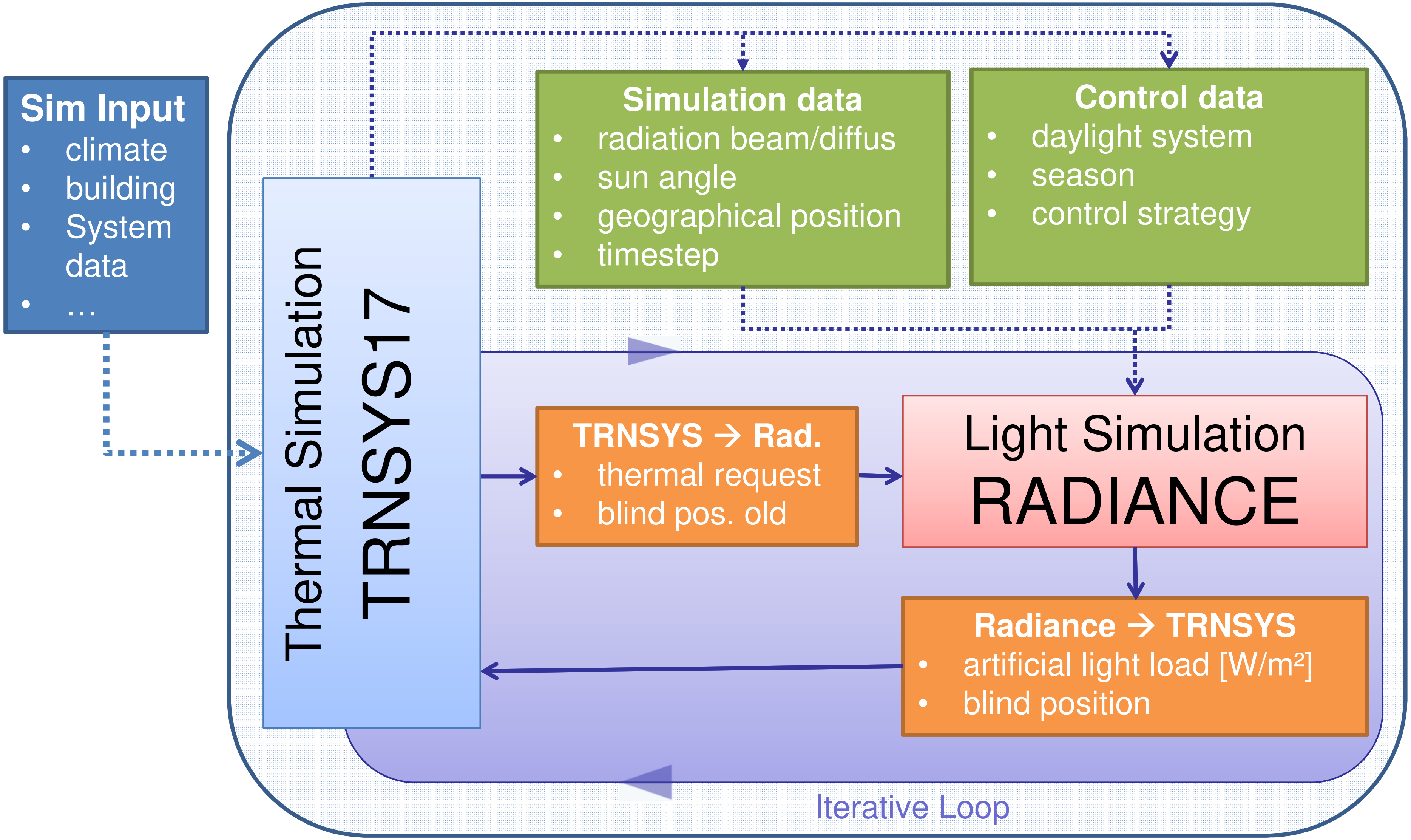
- State of the art in coupled T&D simulations
- Limitations and „bottle necks“
- Artlight 2.0: Concept & Improvements
- Comparative resuts: Artlight 2.0 vs. Artlight 1.0
- Conclusions / Working outlook

Starting point in 2011 with Artlight 1.0

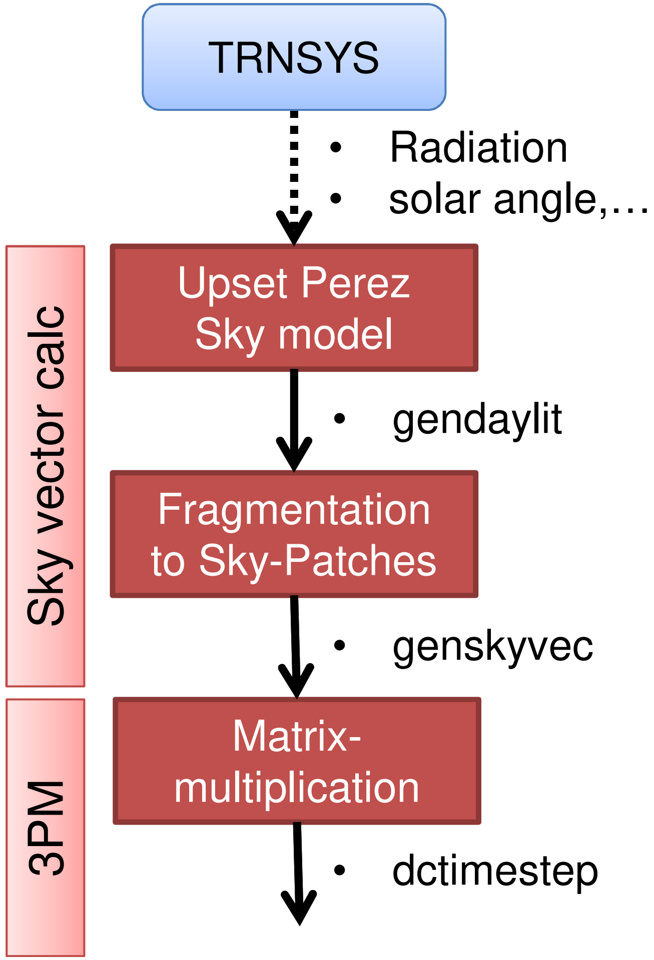
Bartenbach LichtLabor

Presentation by
David Geisler-Moroder at
10th Radiance Workshop

TYPE 205


Sim Input
climate
building
System data
…
Thermal Simulation
TRNSYS17
Simulation data
radiation beam/diffus
sun angle
geographical position
timestep
Control data
daylight system
season
control strategy
TRNSYS → Rad.
thermal request
blind pos. old
Light Simulation
RADIANCE
Radiance → TRNSYS
artificial light load [W/m²]
blind position
Iterative Loop

Three phase simulation routine in Python



Type 205:	Main TRNSYS model (in FORTRAN)
„artlight.for“:	Wrapper script, Call: „artlight.py“ (in FORTRAN)
„artlight.py“:	Radiance 3PM simulation and control strategy (in Python)

Matrix multiplication:

i = VTDs

i…point in time illuminance / luminance result

Pre-calculated flux matrices (externally):

V...View Matrix (VMX)

T…Bidirectional Scattering Distribution Function (BSDF)

D…Daylight matrix (DMX)

Coupled daylight simulation within TRNSYS

Model development „Artlight 2.0“

Run-time analyze:

Upset Perez Sky model
- gendaylit

Fragmentation to Sky-Patches
- genskyvec → 1...2 sec.

Matrix-multiplication
- dctimestep → 3…8 sec.

Upcoming „bottle – necks“

- Inefficient run-time according to matrix re-loadings at each simulation timestep (and iteration!)
- Timestep based Skyvector-calculations
- Own model setup for each orientation and window(group)
- Multi-zone (and -orientation) modeling barely handable
- No capabilities for 3PM-matrices pre-processing implemented
- External implementation by Phyton scripting

Daylighting status at widely used tools for BPS

- OpenStudio / EnergyPlus
  - Three-phase method included since version 1.9.0
    (Presentation R. Guglielmetti, Radiance Workshop 2015)
- IDA-ICE
  - Three-phase method included since version 4.7
- TRNSYS
  - Artlight (inhouse tool)
  - Type DLT (EURAC), free available at GitHub
    (Presentation G. deMichele, Radiance Workshop 2015)
- …?

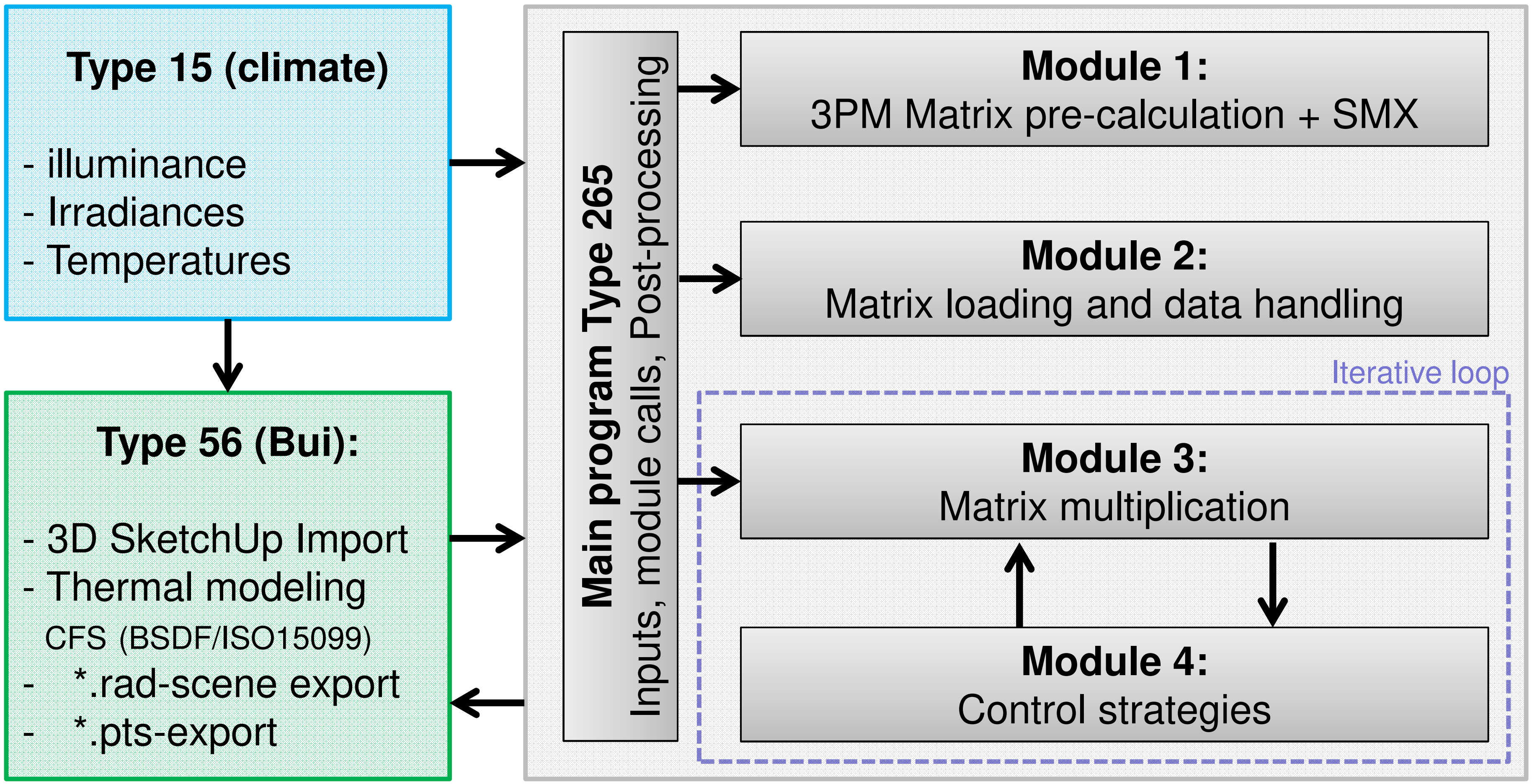
Coupled daylight simulation within TRNSYS

Model development „Artlight 2.0“

Artlight 2.0 (Type 265) – Core benefits:

- Full 3PM-implementation: „matrix generation – multiplication – evaluation“
- Skymatrix calculation implemented (Switchable mode to Skyvector)
- „Manual“ matrix calculation of 3PM for significant run-time optimization in yearly simulations (replacement of dctimestep routine)
- Illuminance / luminance evaluation („glare“) by user-defined sensor grids
- Iterative control loop with „BSDF-switch“ for optimize blind positions
- Calculations up to 4 orientations with flexible window subdivisions
- Compatible to geometry export (rad-scene+windows) and sensor grid file export from Type56, individually for each thermal zone
- Flexibile structure for further implementations (controls, varying resolutions 5PM,…)
- Coding done in Fortran95

Artlight 2.0 - model structure



Module 1

3-phase matrix pre-calculation

- DMX [2306 x 145] (for each orientation)

```
genklemsamp.pl -c 1000 -vd 0 -1 0 misc/window_glow.rad |
rcontrib -c 1000 -e MF:4 -f reinhart.cal -b rbin -bn Nrbins -m
sky_glow -faa oct/scene_dmx.oct > matrix/south.dmx
```

- VMX [145 x n-sensors] (for each grid and window(-subdivision))

```
rcontrib -n 8 -f klems_int.cal -b kbinS -bn Nkbins -m windowlight -I+
-ab 8 -ad 10000 -lw 1e-8 oct/scene_vmx.oct < grids/grid_workpane.pts
rcontrib -n 8 -f klems_int.cal -b kbinS -bn Nkbins -m windowlight
-ab 3 -ad 2000 -lw 1e-6 oct/scene_vmx.oct < grids/view1.pts
```

- SMX [2306 x 8760] / SKV [2306 x 1] (optional)

```
epw2wea Innsbruck_Univ_hour.epw Innsbruck.wea
gendaymtx -m 4 -c 1 1 1 Innsbruck.wea > matrix/skymtx.smx
gendaylit -ang [alt] [azi] -W [Ibnorm] [Ibhoriz] -a Lat -o Lon -m
Meridian | genskyvec.pl -m 4 -c 1 1 1 > matrix/skysun.skv
```

BSDFs are generated externally (WINDOW7, genBSDF,…)

Module 2: matrix loading and handling

- Fully matrix loads for all variants as RGB:

$$SMX_{RGB} = \begin{bmatrix} 1 & .. & 6918 \\ .. & .. & .. \\ .. & .. & .. \\ 8760 & .. & .. \end{bmatrix}$$

$$DMX_{RGB} = \begin{bmatrix} 1 & .. & 6918 \\ .. & .. & .. \\ 145 & .. & .. \\ .. & .. & .. \\ \gamma * 145 & .. & .. \end{bmatrix}$$

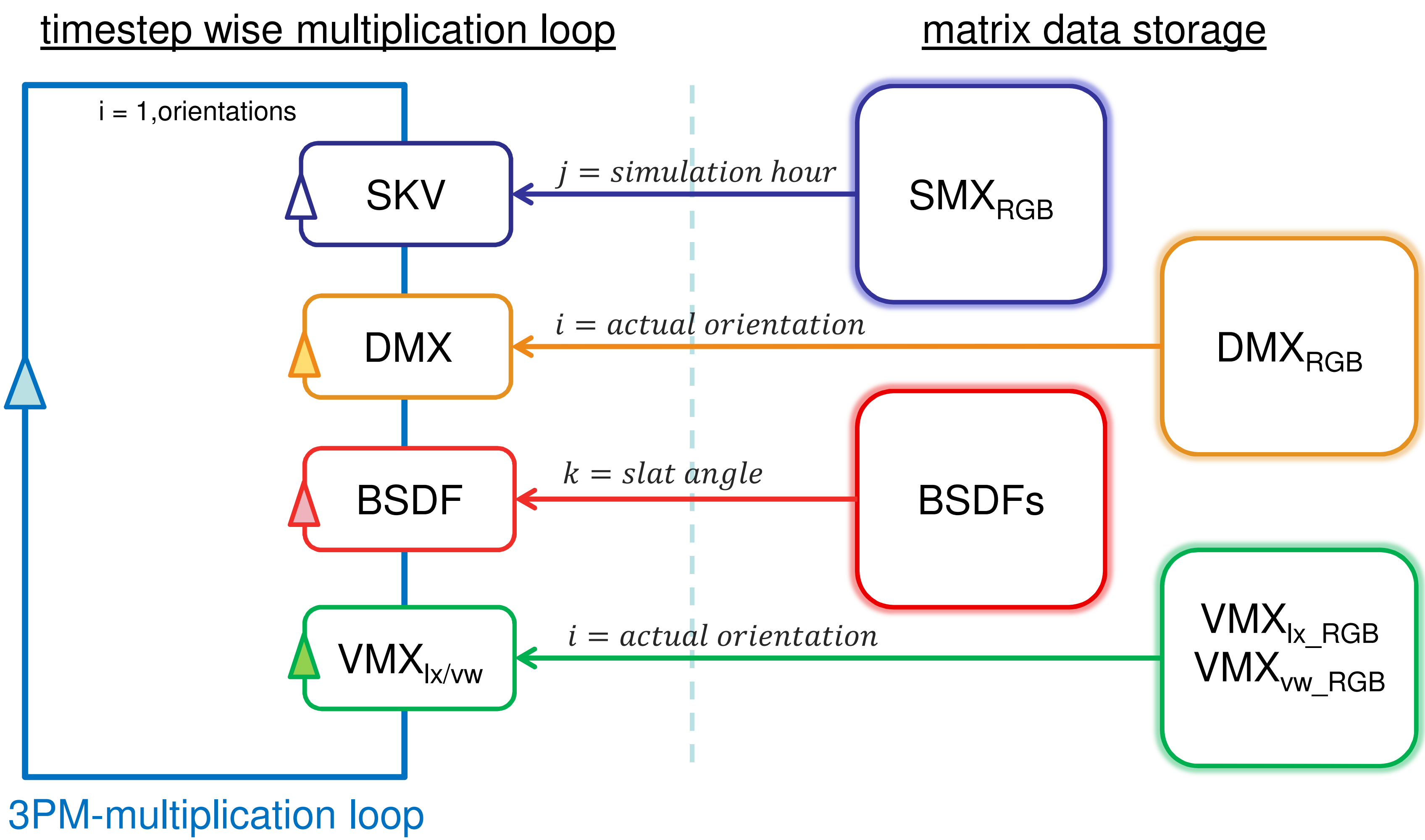
$$BSDF_s = \begin{bmatrix} 1 & .. & 145 \\ .. & .. & .. \\ 145 & .. & .. \\ .. & .. & .. \\ \beta * 145 & .. & .. \end{bmatrix}$$

$$VMX_{illum} = VMX_{lum} = \begin{bmatrix} 1 & .. & 435 \\ .. & .. & .. \\ \alpha & .. & .. \\ .. & .. & .. \\ \gamma * \alpha & .. & .. \end{bmatrix}$$

$\alpha = number\ of\ sensor\ points\ (illum, lum)$
$\beta = number\ of\ slat\ positions\ and\ systems$
$\gamma = number\ of\ orientations$

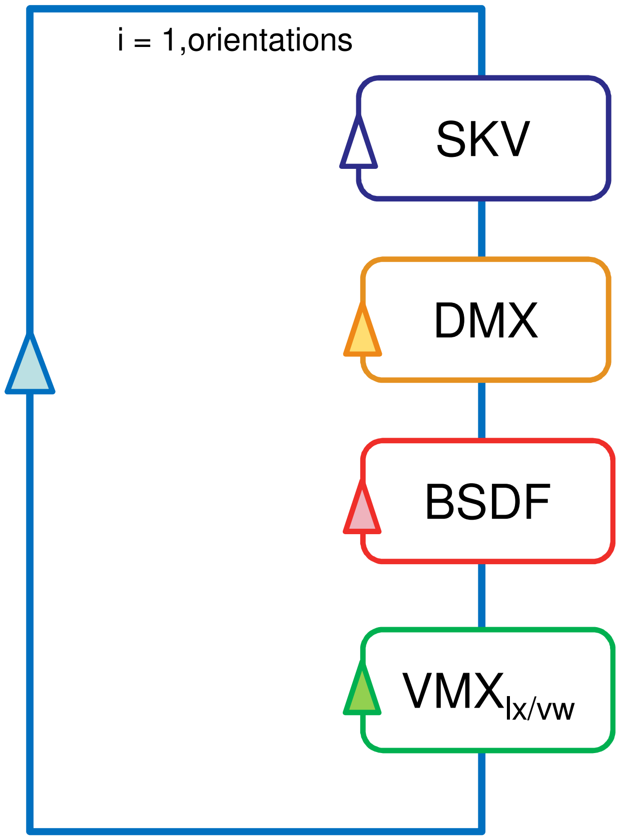
→ flexible matrix storage allocation according to model input parameters
→ splitting into R/G/B-components for latter multiplication
→ reloading into original 3PM-matrix forms depending on orientation and slat angle

Module 3: matrix multiplication loop



Module 3: matrix multiplication

<u>timestep wise multiplication loop</u>



3PM-multiplication loop

Coherent matrix multiplication (separate for R/G/B):

$$Z = \begin{bmatrix} 1 \\ .. \\ 2306 \end{bmatrix} * \begin{bmatrix} 1 & 2306 \\ .. & .. \\ 145 & .. \end{bmatrix} * \begin{bmatrix} 1 & 145 \\ .. & .. \\ 145 & .. \end{bmatrix} * \begin{bmatrix} 1 & 145 \\ .. & .. \\ s & .. \end{bmatrix}$$

time step result for illuminance on work pane:

$$E_{s,sum} = Z_{lx\_R} * 0.265 + Z_{lx\_G} * 0.67 + Z_{lx\_B} * 0.065$$

time step result for luminance on the facade:

$$L_{s,o} = Z_{vw\_R} * 0.265 + Z_{vw\_G} * 0.67 + Z_{vw\_B} * 0.065$$

Module 4: Control strategies

for one orientation and window (group)

- Treshold criteria check - illuminance:

$$\left[\frac{\sum_{i=1}^{s} E_i}{s} \geq 500lx)\right] \xrightarrow{then} true$$

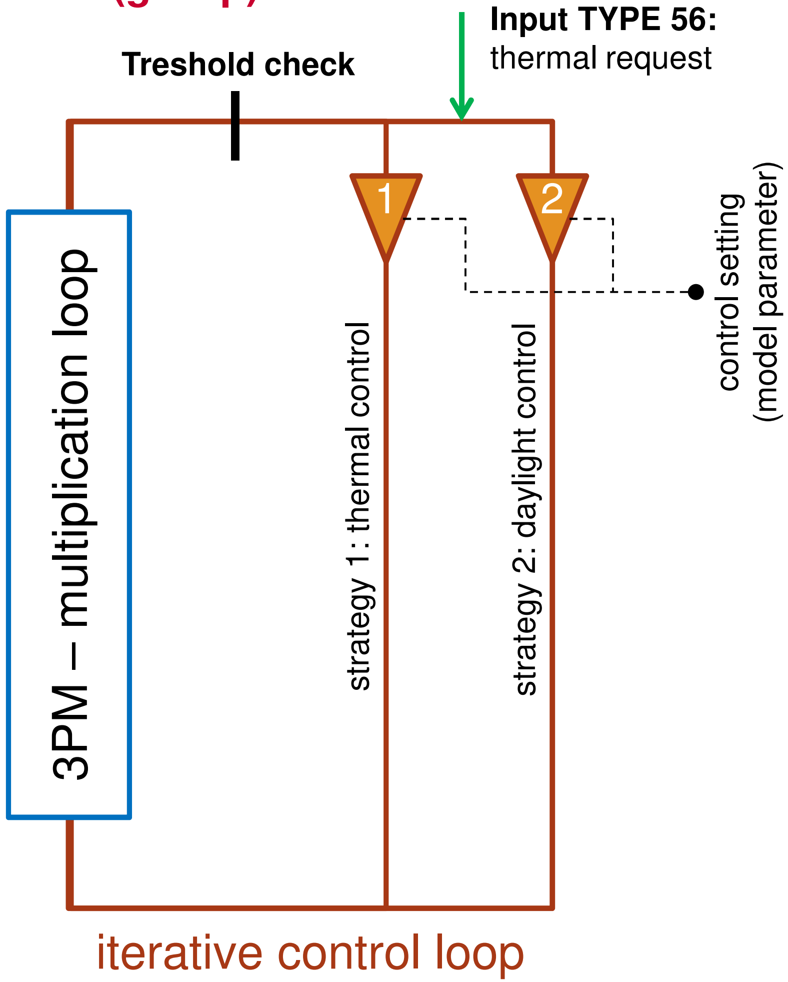
- Treshold criteria check - luminance:

$$\left[\sum_{i=1}^{s} (L_{s,o} \leq 1000 \frac{cd}{m^2}) = 0\right] \xrightarrow{then} true$$

- Artificial light: responsive control

$$MAX(\frac{500lx - \frac{\sum_{i=1}^{s} E_i}{s}}{40lm/W}, 0)$$

Treshold values adjustable as model input parameter



Module 4: Control strategies
for more orientation and window (groups)

Things to take care:

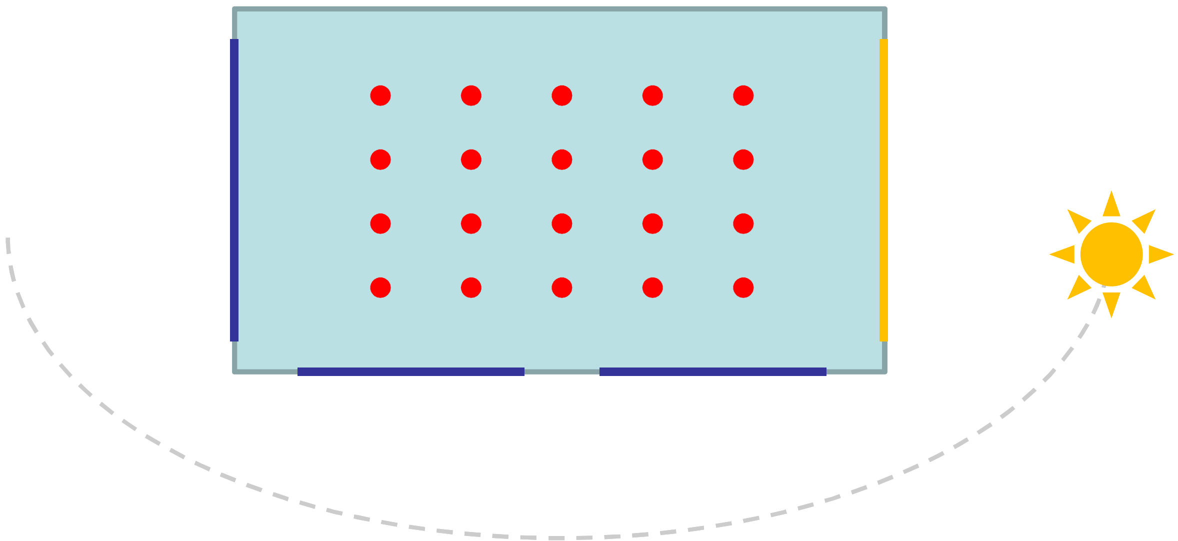
- individual control of each orientation is necessary
- Optimizing without priority resulting in no goal (cross influences)
  → strategy for priority is needed!

First simplified approach:

- Priority control only on facades with direct sun radiation
- All other orientations blinds fully open
- All direct radiated facades are controlled equally
  → sensitivity studies are necessary to verify!

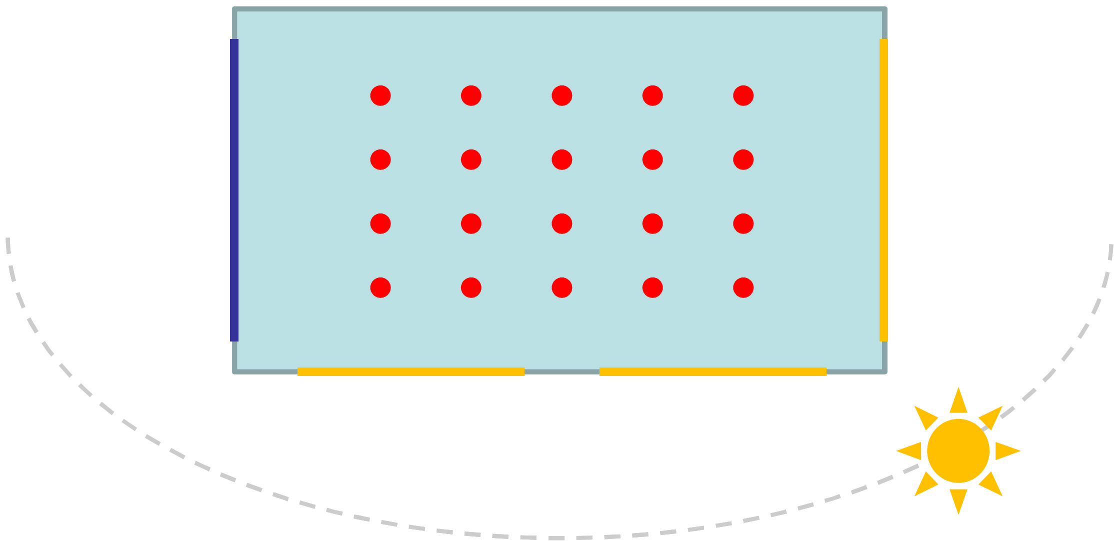
Module 4: Control strategies

for more orientation and window (groups)



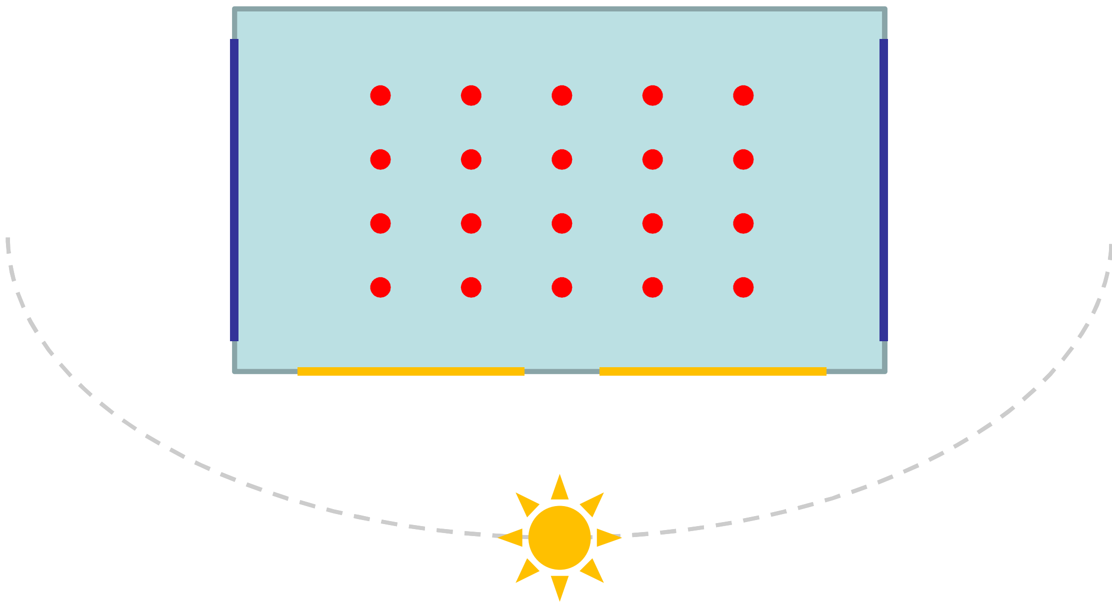
Module 4: Control strategies

for more orientation and window (groups)

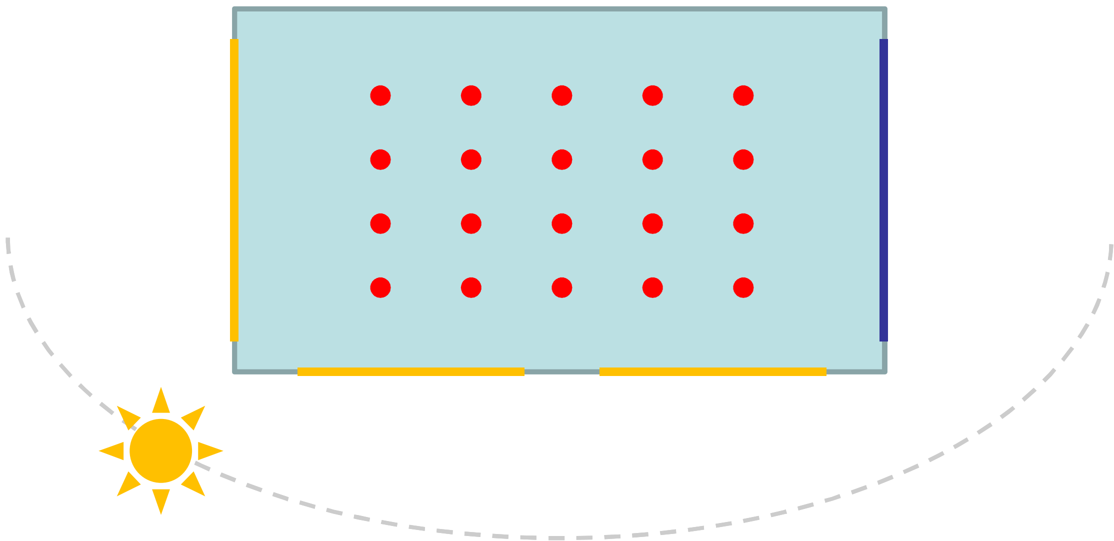


Module 4: Control strategies

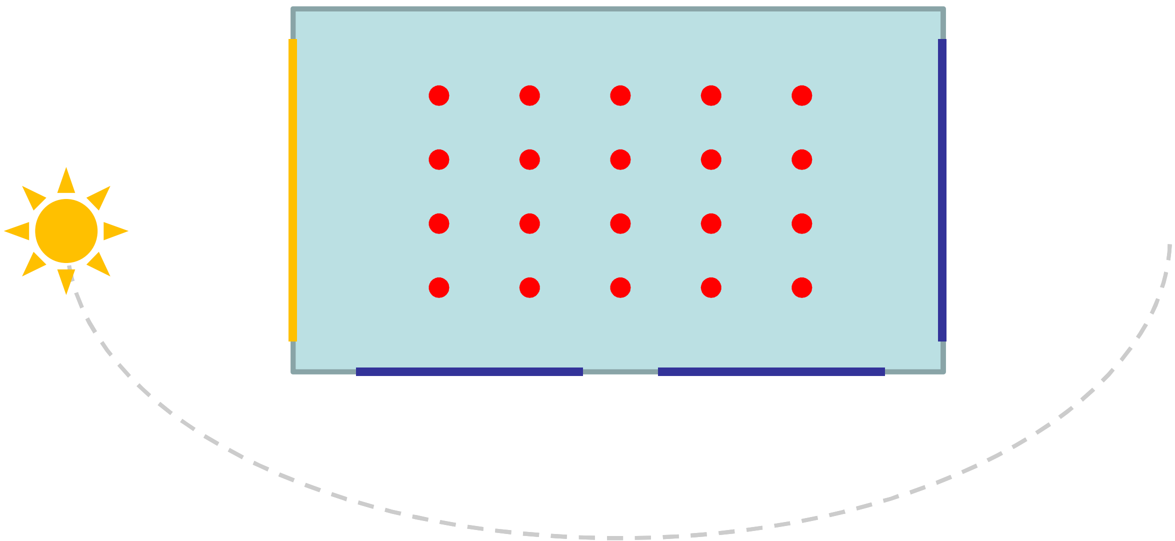
for more orientation and window (groups)



Module 4: Control strategies
for more orientation and window (groups)



Module 4: Control strategies
for more orientation and window (groups)

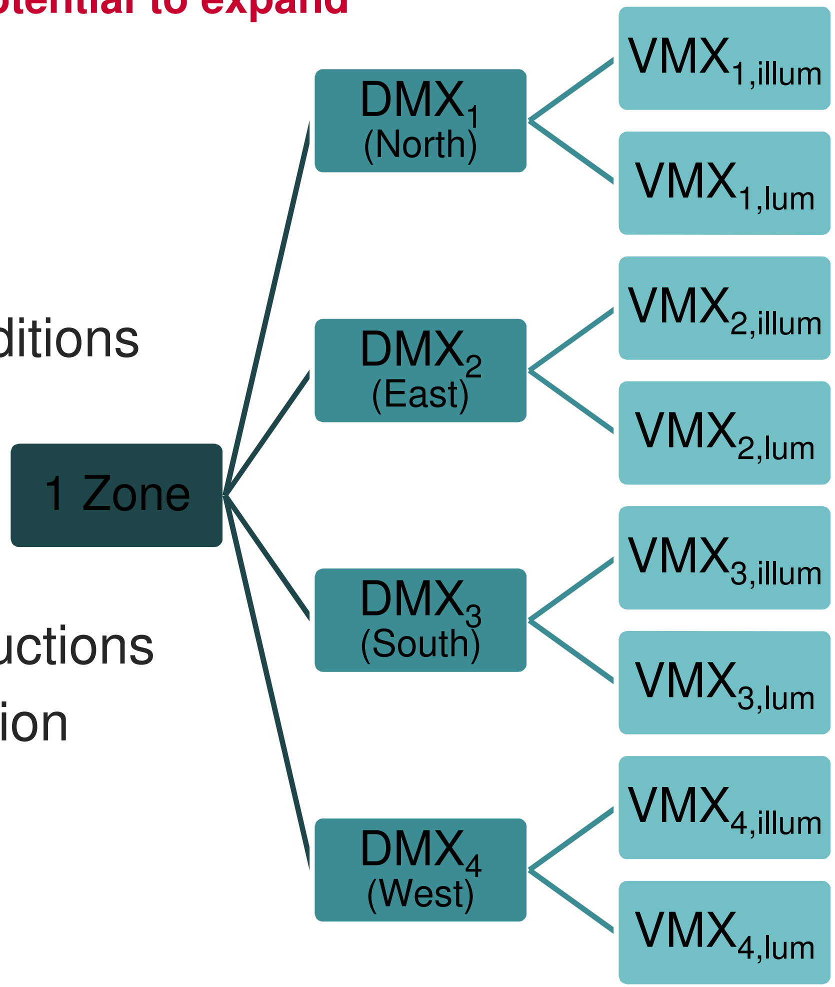


Scaleable hirachy for 3PM matrices

current status…with potential to expand

Advantage:

- flexible for all space definitions
- automated grid generation possible
  → comparable through fix basic conditions
  → daylight metrics!



Limitations:

- no additional DMX for external obstructions
- same control for all windows/orientation
  → additional Type-version with more flexibility is planned

Post-processing and Output

Standard Online plots:

- Illuminance mean values for each sensor plane $E_{mean} = \frac{\sum_{i=1}^{s} E_i}{s}$
- Nr. of sensors over/under the treshold values
- Actual slat position
- Artificial light demand
- flags status and iteration number from control strategy
- Daylight metrics? (has to be defined!)

- **Output files: (at the end of the simulation as ascii)**
- time step illuminance results / luminance results for all sensors
- …

Type 265: Parameter/Inputs/Outputs

Parameter:

Longitude	[deg] N = +
Latitude	[deg] E = -
Meridian	[deg] E = -
No. of Orientations	1…4
No. of BSDFs	to read in
Skymode	1=skyvec / 2=skymtx
Control strategy	1=dayl. control / 2= th. control
Min illuminance	lx on workdesk plane
Min illuminance	lx on space area
Max luminace	cd/m² on facade

Input:

Direct normal irradiance [W/m²]	
Diffuse horizontal irradiance [W/m²]	
Solar zenith angle	0= horiz, 90= vert. [deg]
Solar azimuth angle	South = 0 [deg]
Control request	1 = more solar gains
Occupancy	set 1 for inactive
Weekend control	set 0 for inactive

Output:

- ...previous slide!
- rather flexible…

First validations…

Radiation input

- Skymtx vs. Skyvec (different modes: -W / -L)

Cross check against Type DLT (EURAC)

- Comparison on certain Illuminance values

Cross check agains Artlight 1.0 (dctimstep-method)

- Comparison of Illuminance / luminance values on different skymodes
- Comparison on resulting artificial light demand

- First yearly results with coupled thermal simulation to TRNSYS Type56-BSDF

Skyvec (-W / -L mode) vs. Skymtx

exemplarily for July 2nd, Innsbruck

Differential values for certain sky patches:

- Skyvec calulation in (-W)-mode show better agreement
  → perez model is used for illuminance calculation
- …But still small deviations…!?
- Illuminance values in epw-file corresponds to measurements?

Jul 02	*day hours*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Skyvec -W	patch 1	0.008	1.165	1.865	2.473	2.601	2.329	1.819	1.563	1.296	1.267	1.615	2.057	2.278	2.069	1.618
	patch 500	0.028	-0.098	0.143	-0.729	-0.818	-0.864	-0.793	-0.790	-0.969	-1.216	-0.882	-0.967	-0.794	-0.630	-0.266
	patch 1000	-0.025	0.011	0.466	0.427	0.186	-0.743	-1.362	-1.216	-0.582	-0.646	-0.085	-0.081	-0.042	-0.071	0.017
	patch 1500	-0.037	0.113	0.360	0.348	0.379	0.299	0.320	0.039	-0.312	-1.510	0.308	0.789	0.596	0.361	0.279
	patch 2000	-0.045	0.206	0.290	0.411	0.422	0.378	0.457	0.317	0.439	0.657	3.105	3.366	2.161	1.255	0.637
	patch 2306	-0.045	0.246	0.315	0.506	0.511	0.623	0.594	0.690	1.424	1.062	1.301	0.880	0.676	0.517	0.380
Skyvec -L	patch 1	-0.009	0.669	0.719	1.438	1.269	1.134	0.271	0.351	1.062	2.168	2.587	3.513	3.946	3.522	2.259
	patch 500	-0.029	10.064	20.950	13.436	7.807	3.521	0.140	-1.549	0.586	3.297	-0.036	0.336	0.956	1.466	2.893
	patch 1000	-0.109	-0.914	-2.371	-8.048	-13.723	-12.494	-3.244	1.620	5.942	2.193	1.351	0.523	-0.015	-1.298	0.106
	patch 1500	-0.133	0.840	0.124	-1.064	-3.095	-7.636	-15.826	-28.963	-23.080	-22.919	14.101	11.336	4.580	0.428	-0.416
	patch 2000	-0.151	1.131	0.061	-0.839	-2.605	-6.200	-11.848	-20.138	-14.058	-19.779	-6.750	8.605	5.169	1.987	-1.755
	patch 2306	-0.153	1.248	-0.472	-2.461	-6.574	-14.270	-22.823	-22.791	3.601	10.130	4.591	1.591	-0.121	-1.394	-2.171

Skyvec vs. Skymtx

time basis

```
place Innsbruck Univ._-
latitude 47.267
longitude -11.40
time_zone -15
site_elevation 582
weather_data_file_units 1
1 1 0.500 0 0
1 1 1.500 0 0
1 1 2.500 0 0
1 1 3.500 0 0
1 1 4.500 0 0
1 1 5.500 0 0
1 1 6.500 0 0
1 1 7.500 0 0
1 1 8.500 0 17
1 1 9.500 375 86
1 1 10.500 777 46
1 1 11.500 835 51
1 1 12.500 842 50
1 1 13.500 802 46
1 1 14.500 710 43
1 1 15.500 519 34
```

epw2wea output

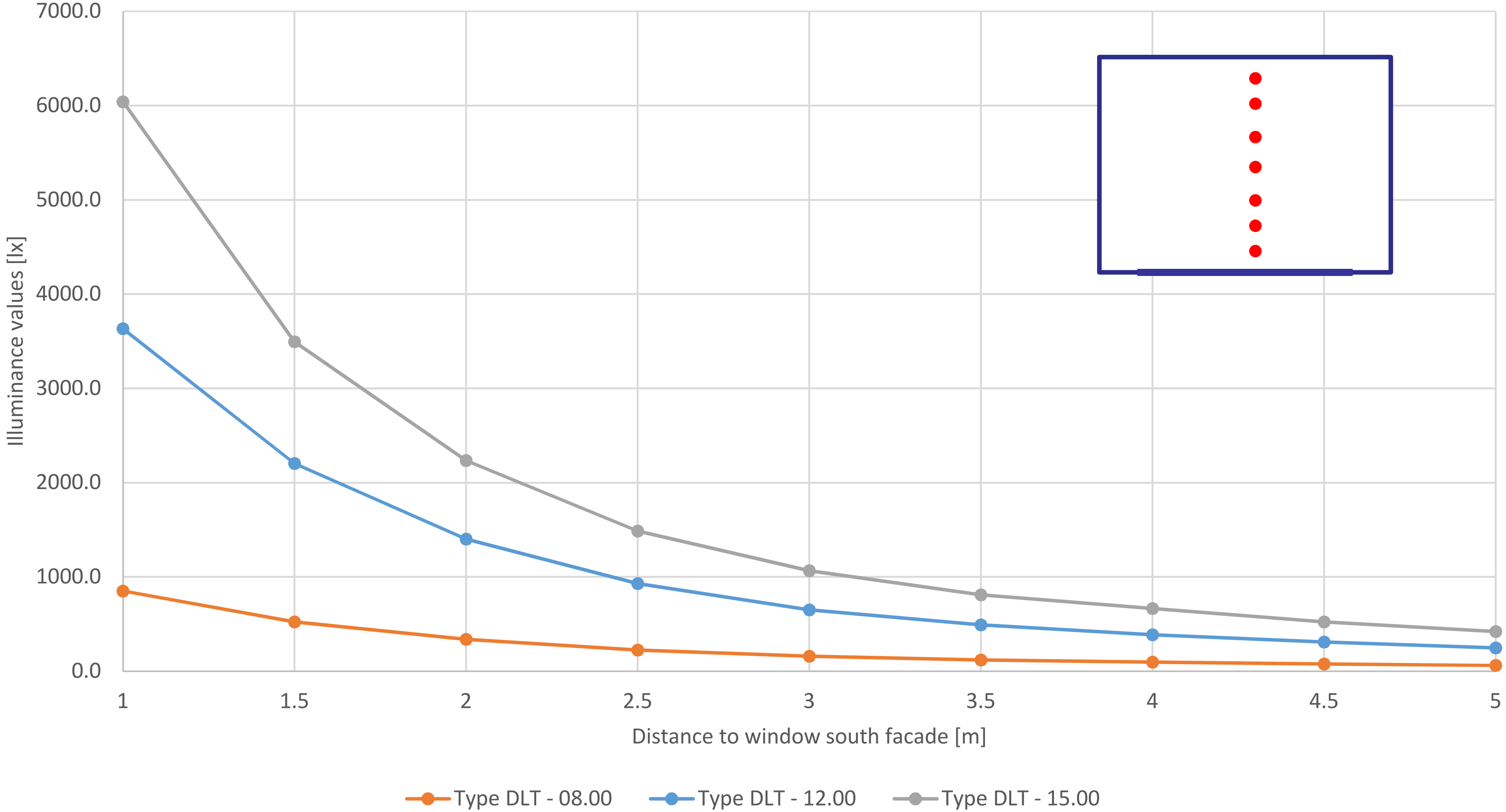
```
#?RADIANCE
genskyvec -m 4 -c 1 1 1
NROWS=2306
NCOLS=1
NCOMP=3
FORMAT=ascii

0.0414814794  0.0414814794  0.0414814794
0.135044813 0.135044813 0.135044813
0.133581706 0.133581706 0.133581706
0.132776875 0.132776875 0.132776875
0.133073781 0.133073781 0.133073781
0.137650369 0.137650369 0.137650369
0.137840244 0.137840244 0.137840244
0.137777406 0.137777406 0.137777406
0.140129338 0.140129338 0.140129338
0.144766844 0.144766844 0.144766844
0.13516325  0.13516325  0.13516325
0.141789775 0.141789775 0.141789775
0.137088581 0.137088581 0.137088581
0.137318881 0.137318881 0.137318881
0.139182125 0.139182125 0.139182125
```

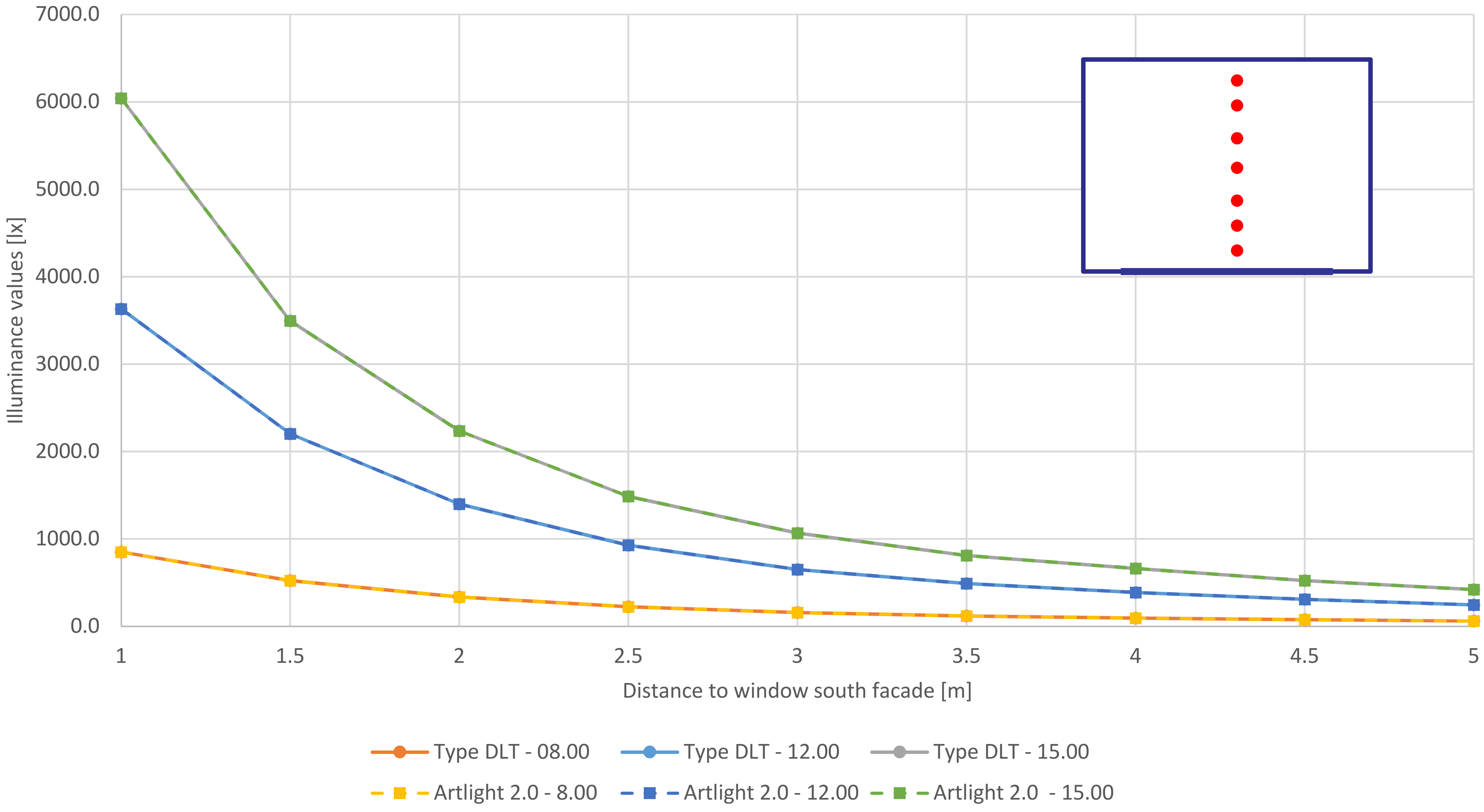
genskyvec output

Validation 1: Type DLT vs. Artlight 2.0

Results from Type DLT

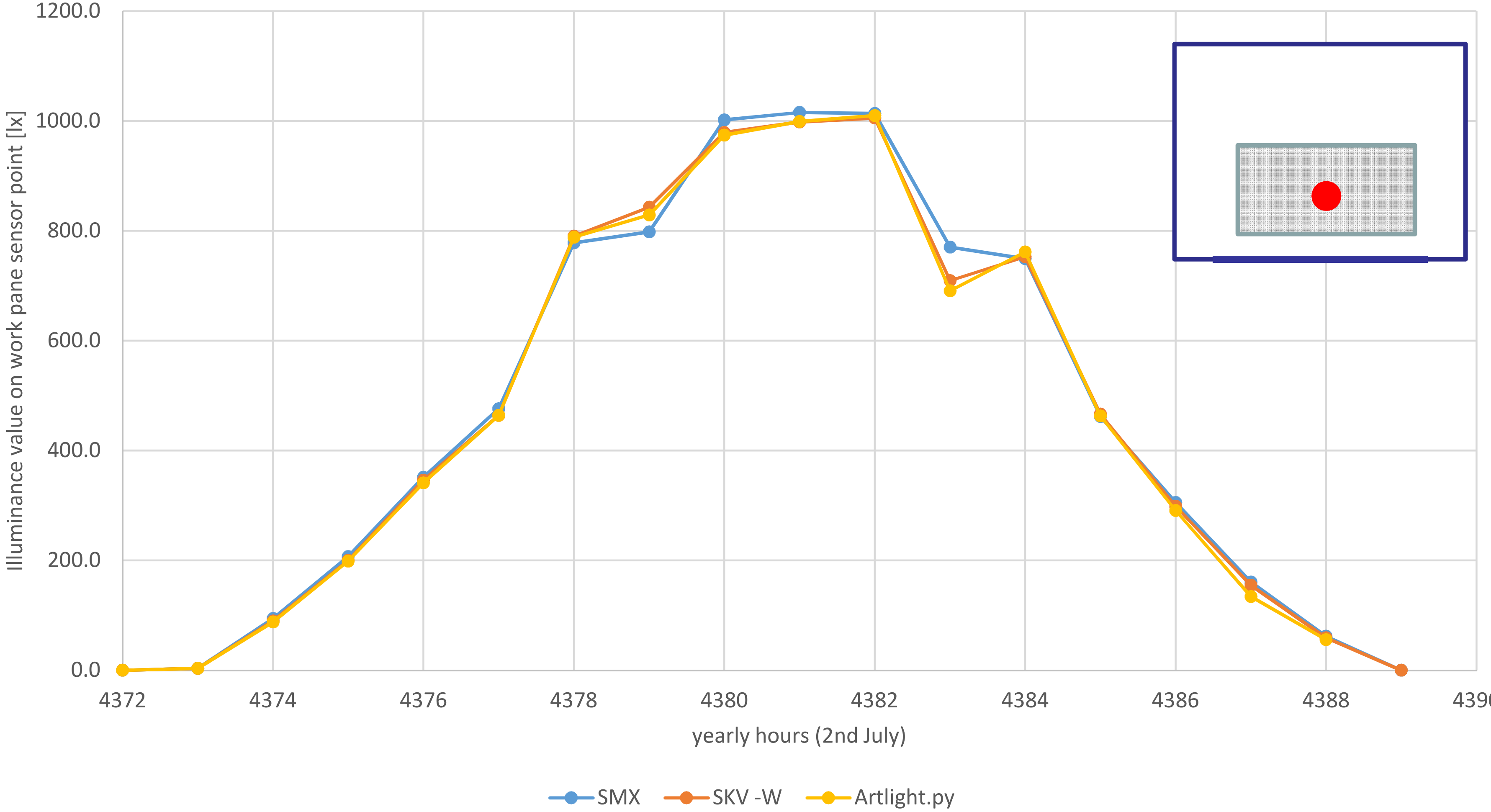


Validation 1: Type DLT vs. Artlight 2.0
comparative results



Validation 2: illuminance value on work pane

against Artlight 1.0

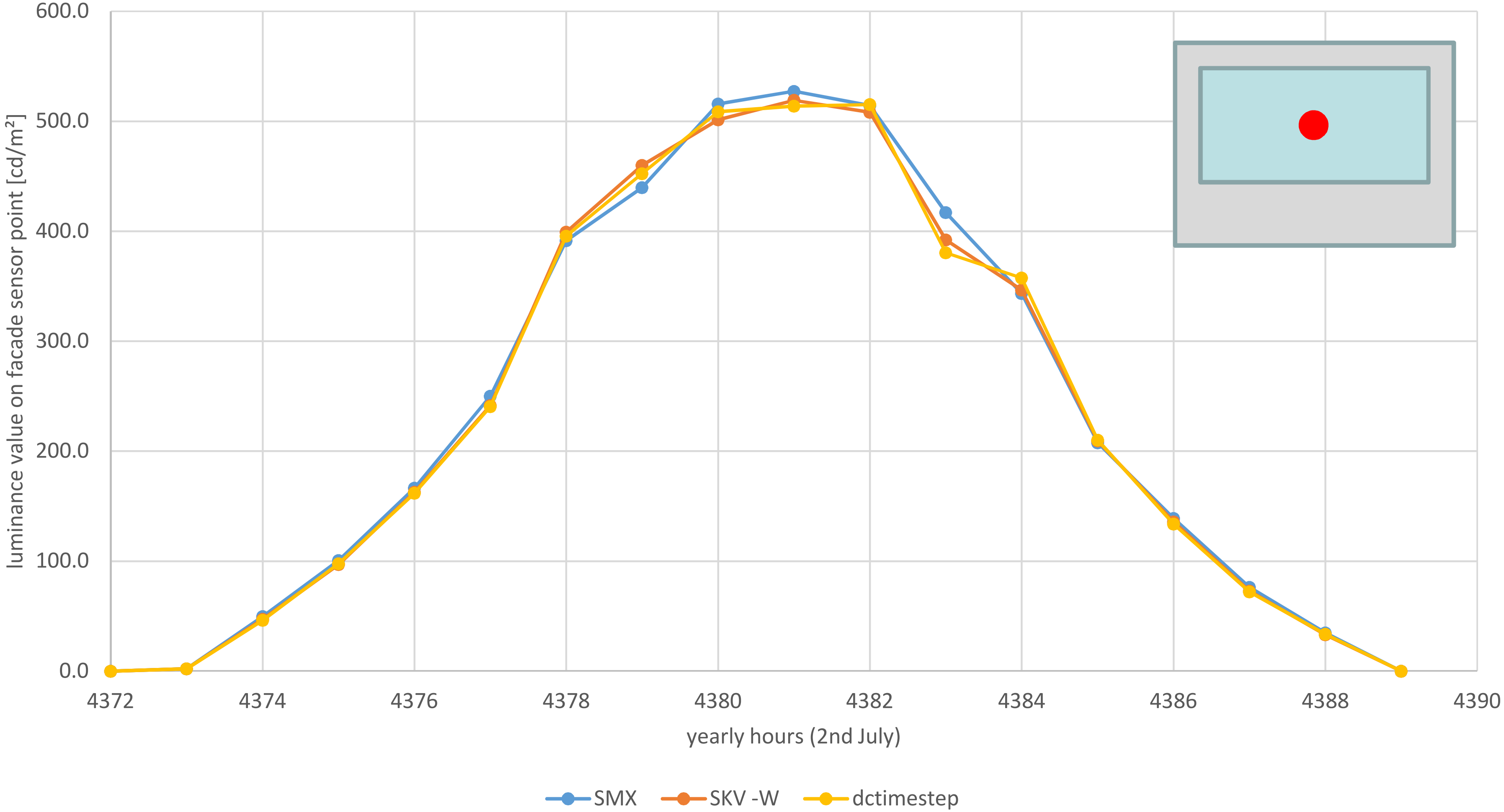


Validation 1: illuminance value on work pane

against Artlight 1.0

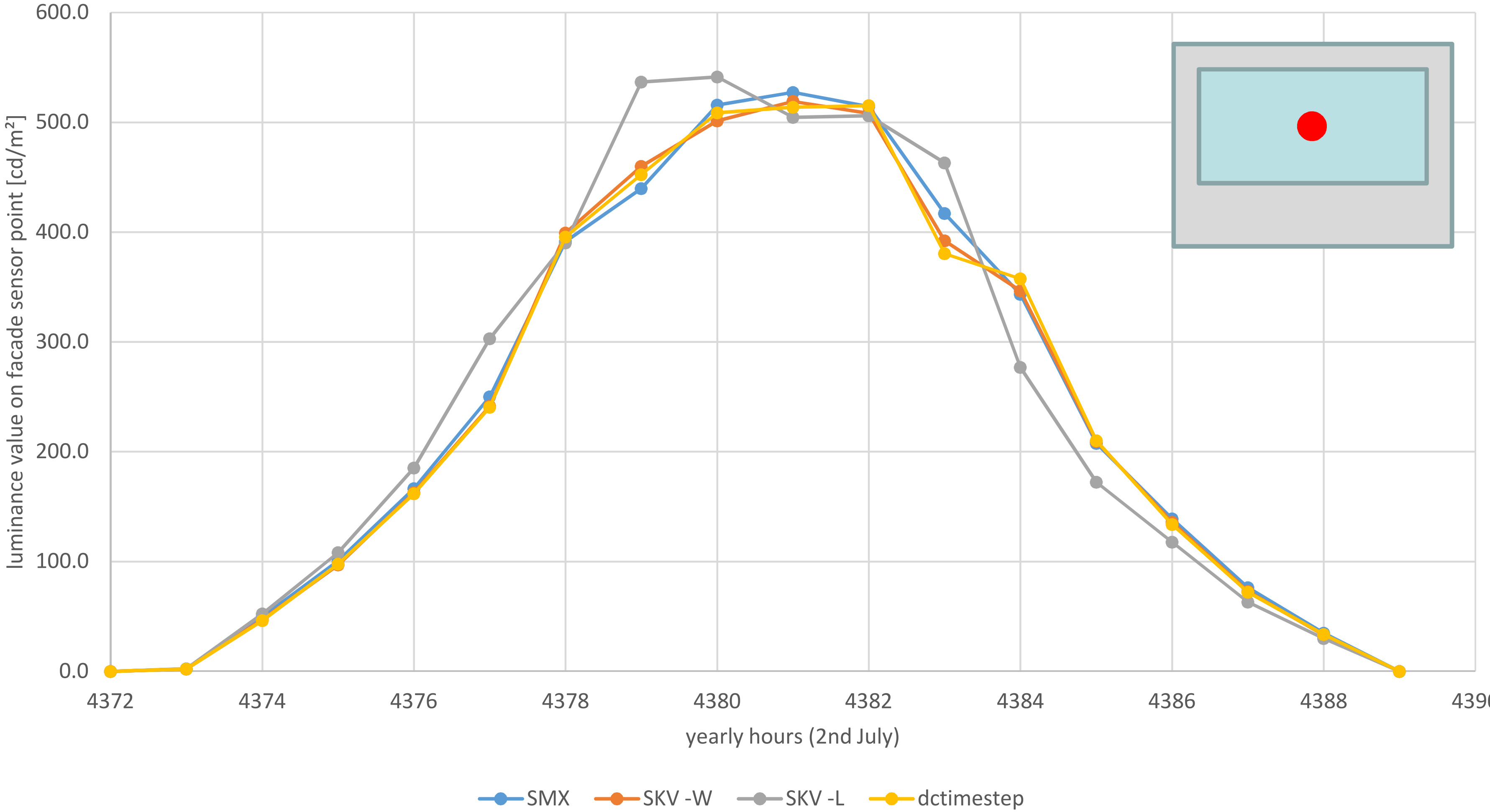
Validation 2: luminance value on facade

against Artlight 1.0



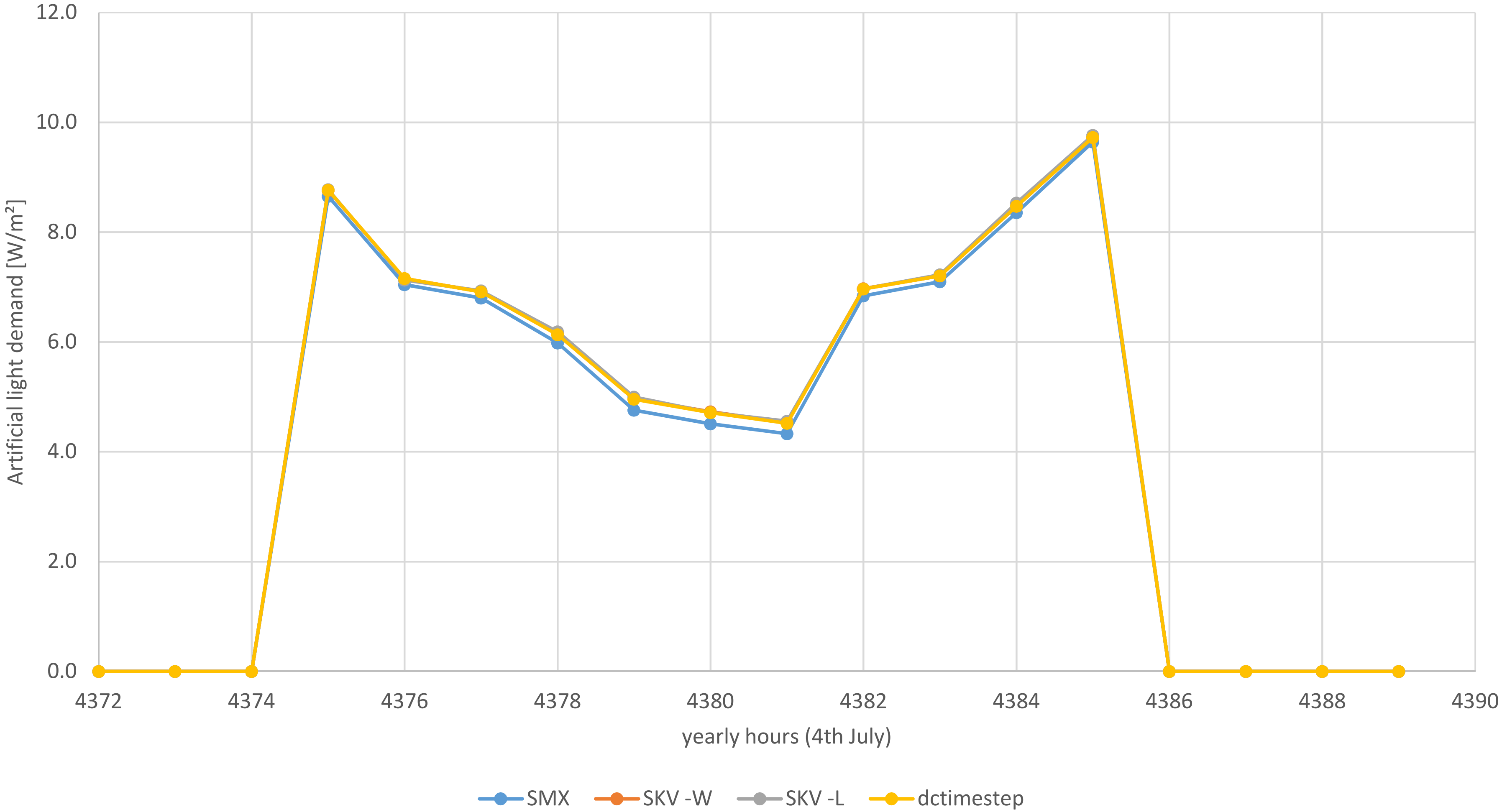
Validation 2: luminance value on facade

against Artlight 1.0



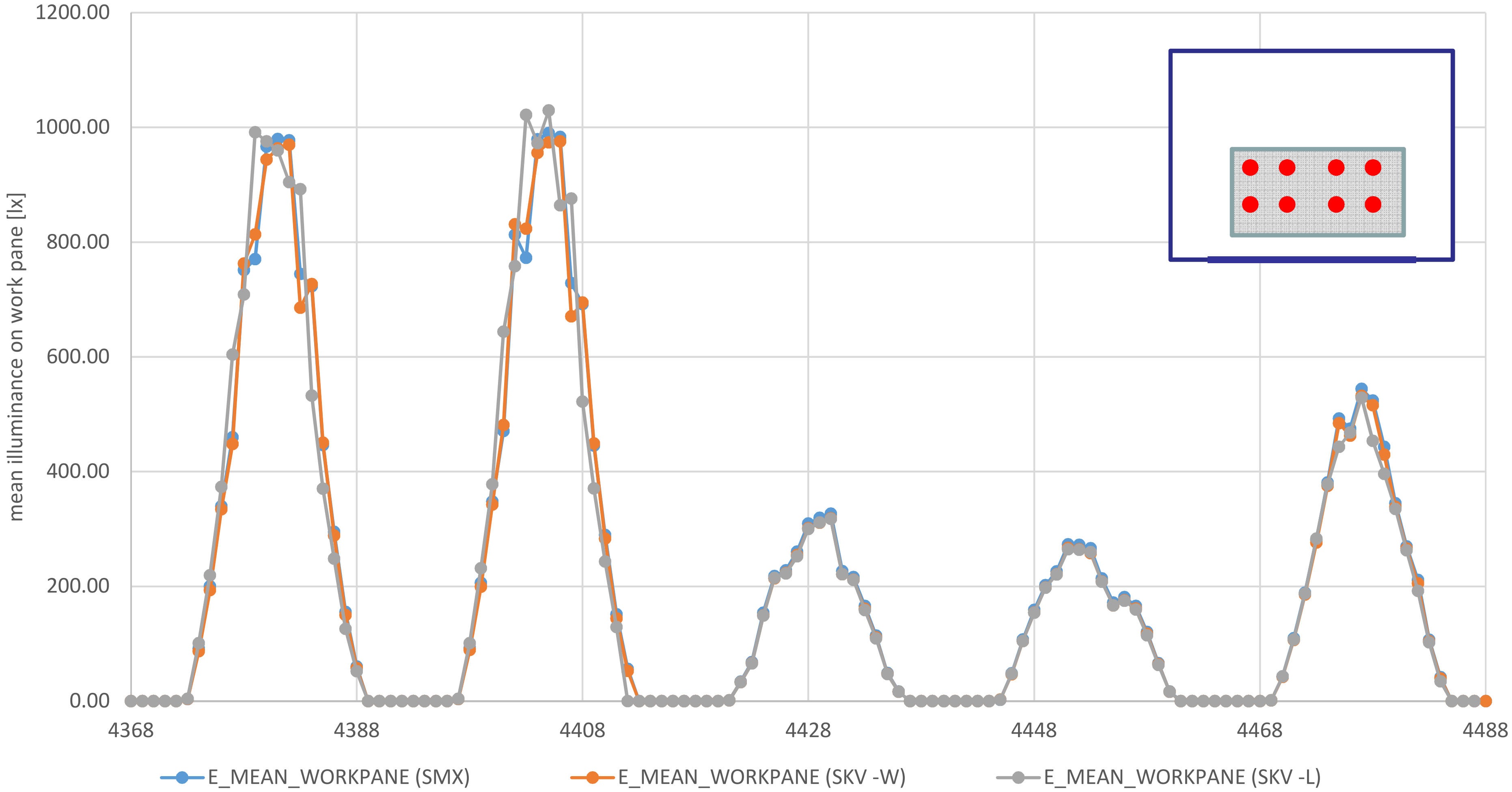
Validation 3: Artifical light demand

against Artlight 1.0



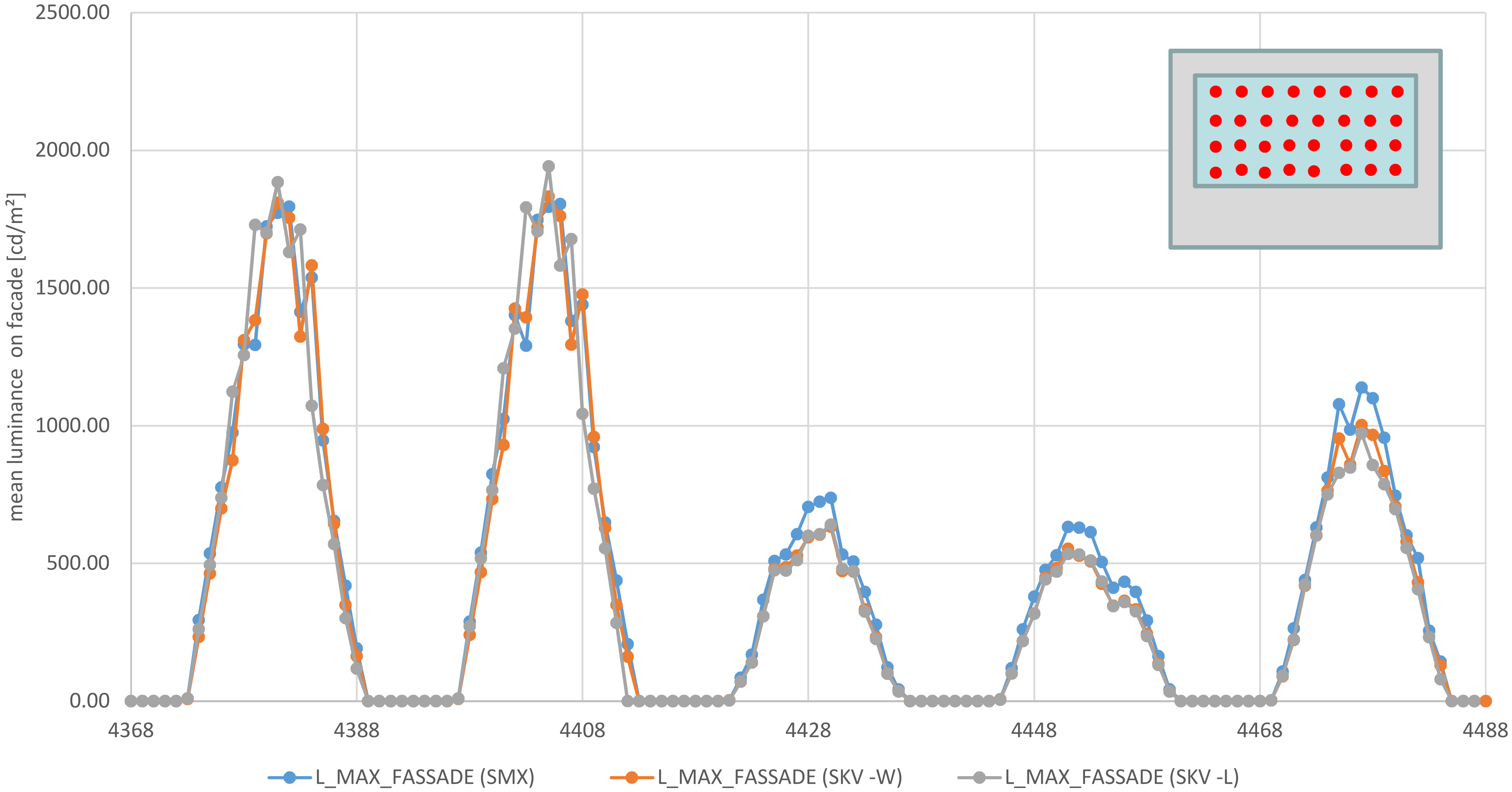
mean illuminance values on working pane

5-days period



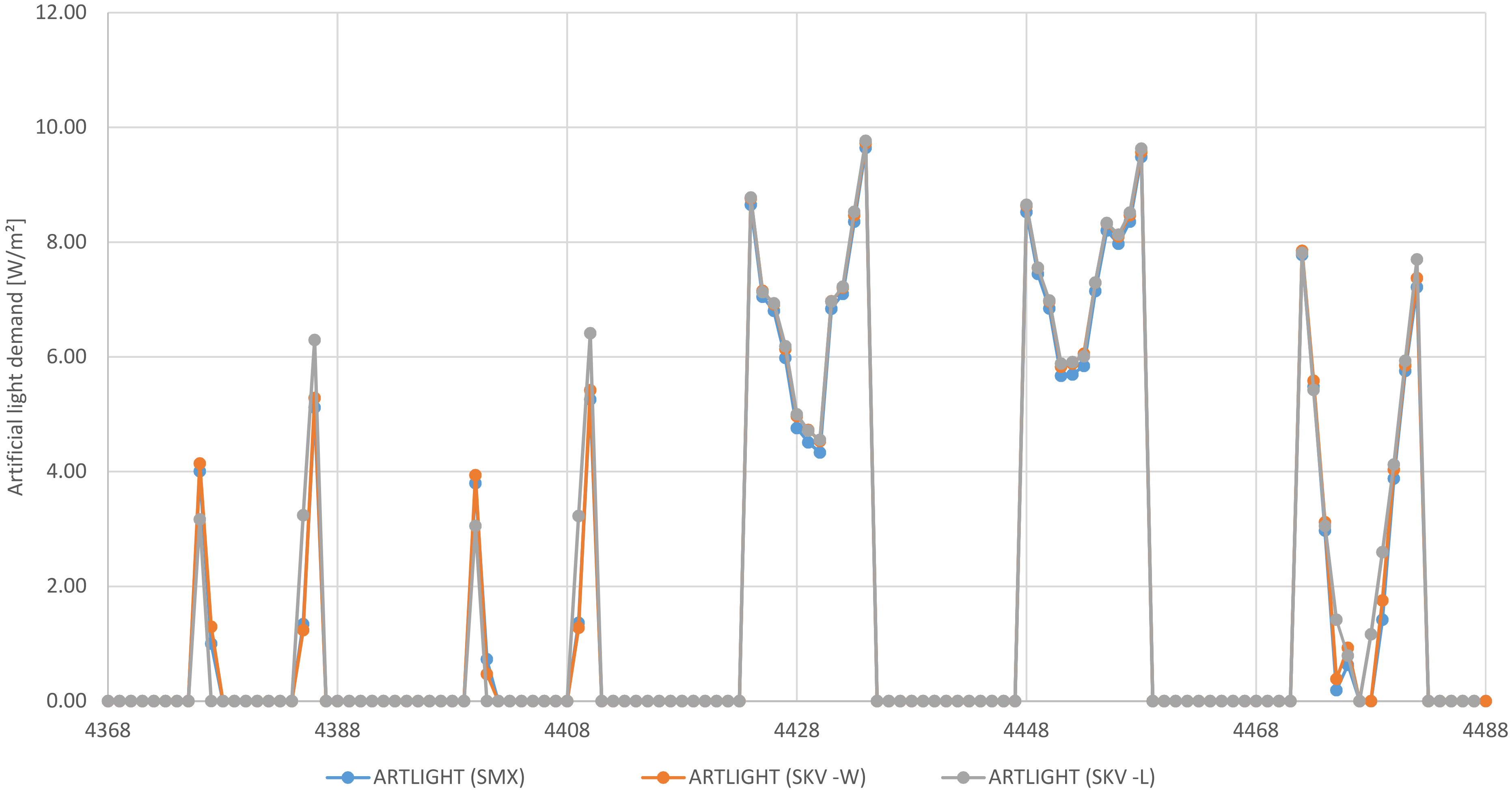
mean luminance values on facade

5-days period

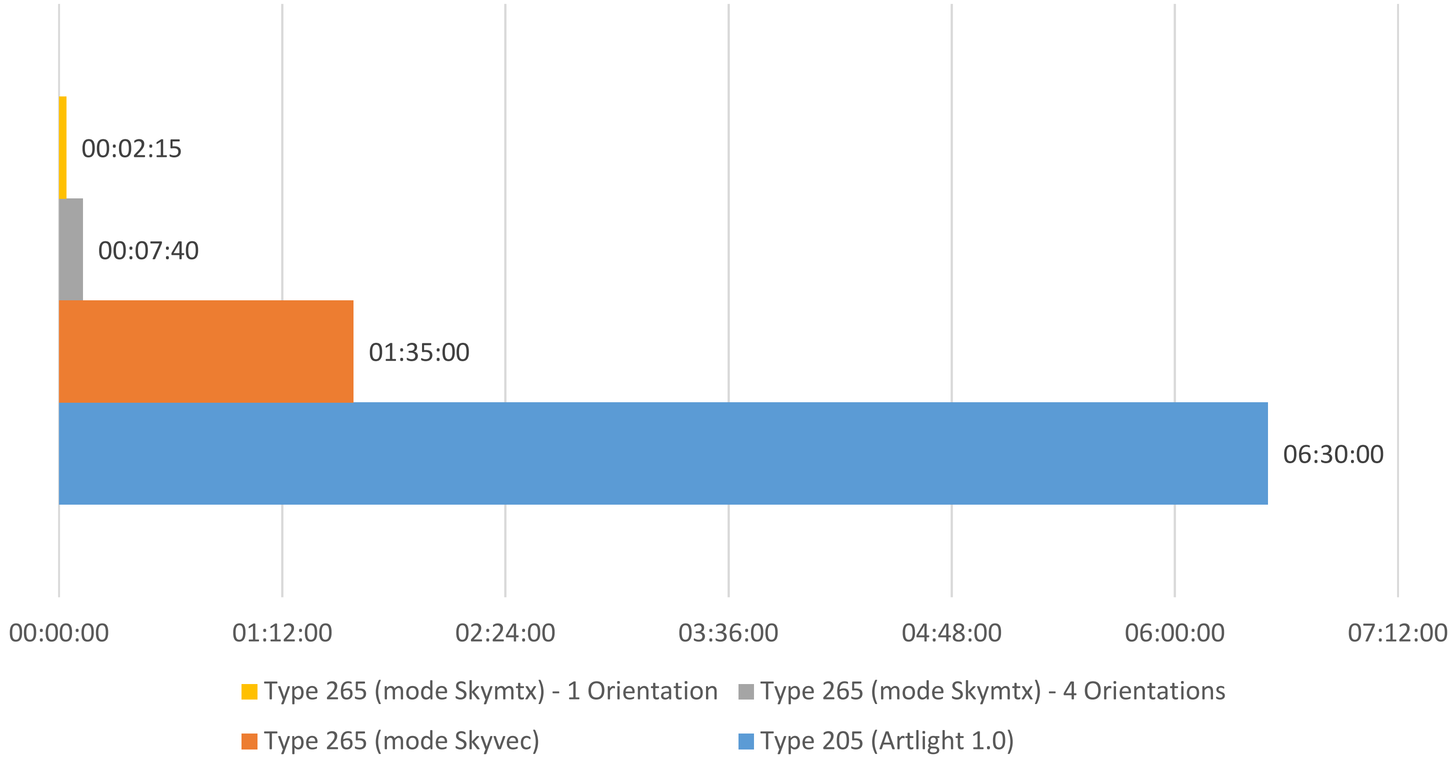


Artifical light demand

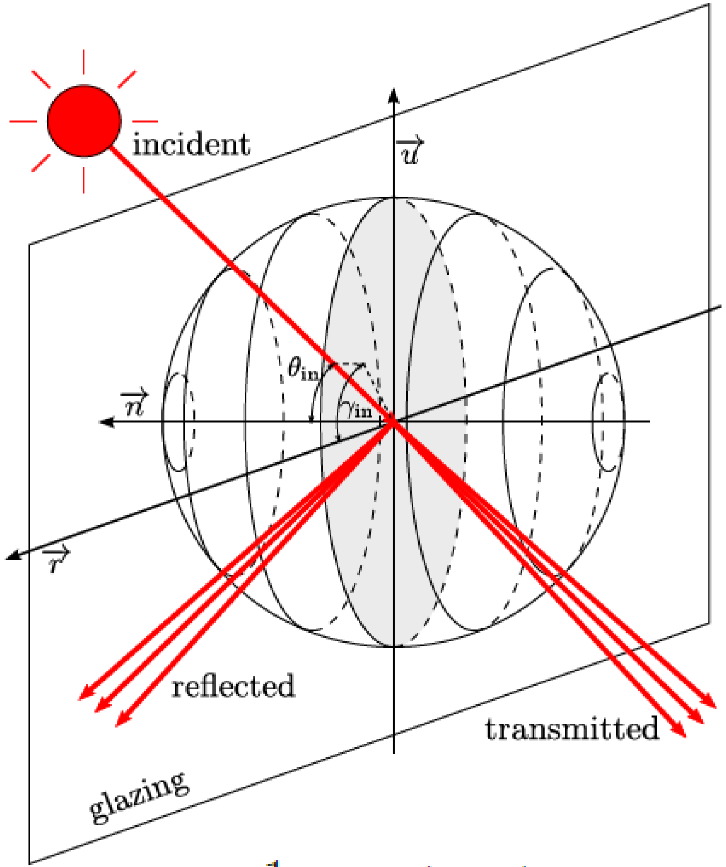
5-days period



Run-time improvement



(1) Short wave radiation modeling by BSDF Data



$$1 = \alpha + \tau + r$$

- *BSDF = 145 x 145 matrix*
  $(\theta,\gamma)_{in} \text{ x } (\theta,\gamma)_{out}$
- *Beam radiation:*
  - Transmission (vis/nonvis)
  - Reflexion (vis/nonvis)
  - forward and backward
  - → *8 BSDF matrices*
- Diffuse radiation:
  - no angle information
  - → *scalar value*

Source: Transsolar

Optical definition of the blind layer

BSDF-XML data

BSDF-XML-file:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<WindowElement xmlns="http://windows.lbl.gov" xmlns:xsi="http://www.
<!-- File produced by: genBSDF -n 12 -c 145000 +f +b -mgf +geom mill
<WindowElementType>System</WindowElementType>
<Optical>
<Layer>
  <Material>
    <Name>Name</Name>
    <Manufacturer>Manufacturer</Manufacturer>
    <Thickness unit="millimeter">80.000</Thickness>
    <Width unit="millimeter">100.000</Width>
    <Height unit="millimeter">100.000</Height>
    <DeviceType>Integral</DeviceType>
      <ThermalConductivity>0.15</ThermalConductivity>
      <EmissivityFront>0.7817</EmissivityFront>
      <EmissivityBack>0.7817</EmissivityBack>
      <TIR>0.8</TIR>
      <EffectiveOpennessFraction>0.8</EffectiveOpennessFraction>
      <Color>Black</Color>
      <Comments></Comments>
  </Material>
```

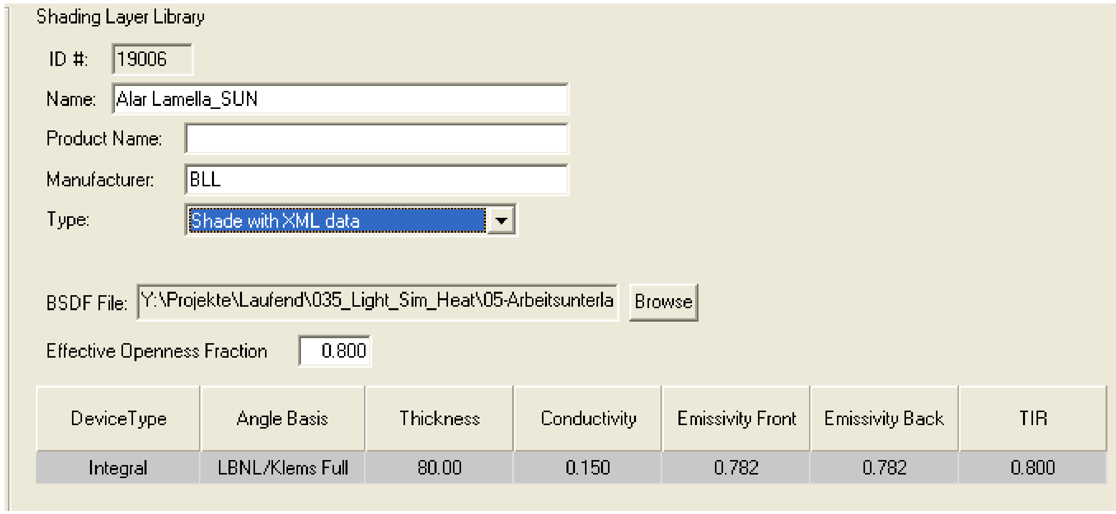
BSDF data for shortwave radiation calculation = 145x145 Klems matrices:

- Transmission front/back (visible/solar)
- Reflection front/back (visible/solar)

= 8 data matrices

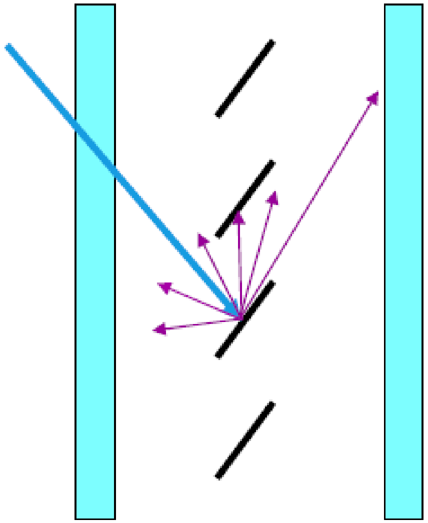
Thermal layer properties for the longwave radiation calculation:

- Emissivity front
- Emissivity back
- Transmission IR
- Effective Openess Fraction



Thermal characterization of CFS

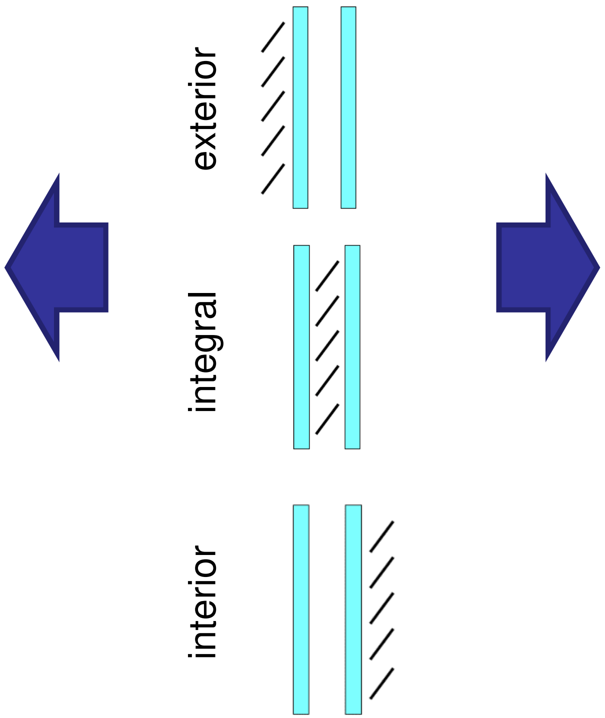
Optical



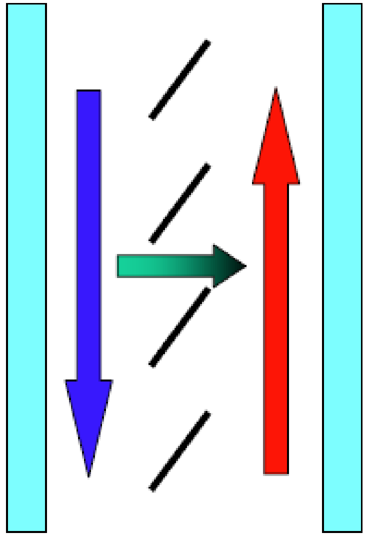
- Visible & NIR
- FIR

- Venetian blind model
- BSDF-XML Input

Systems



Thermal



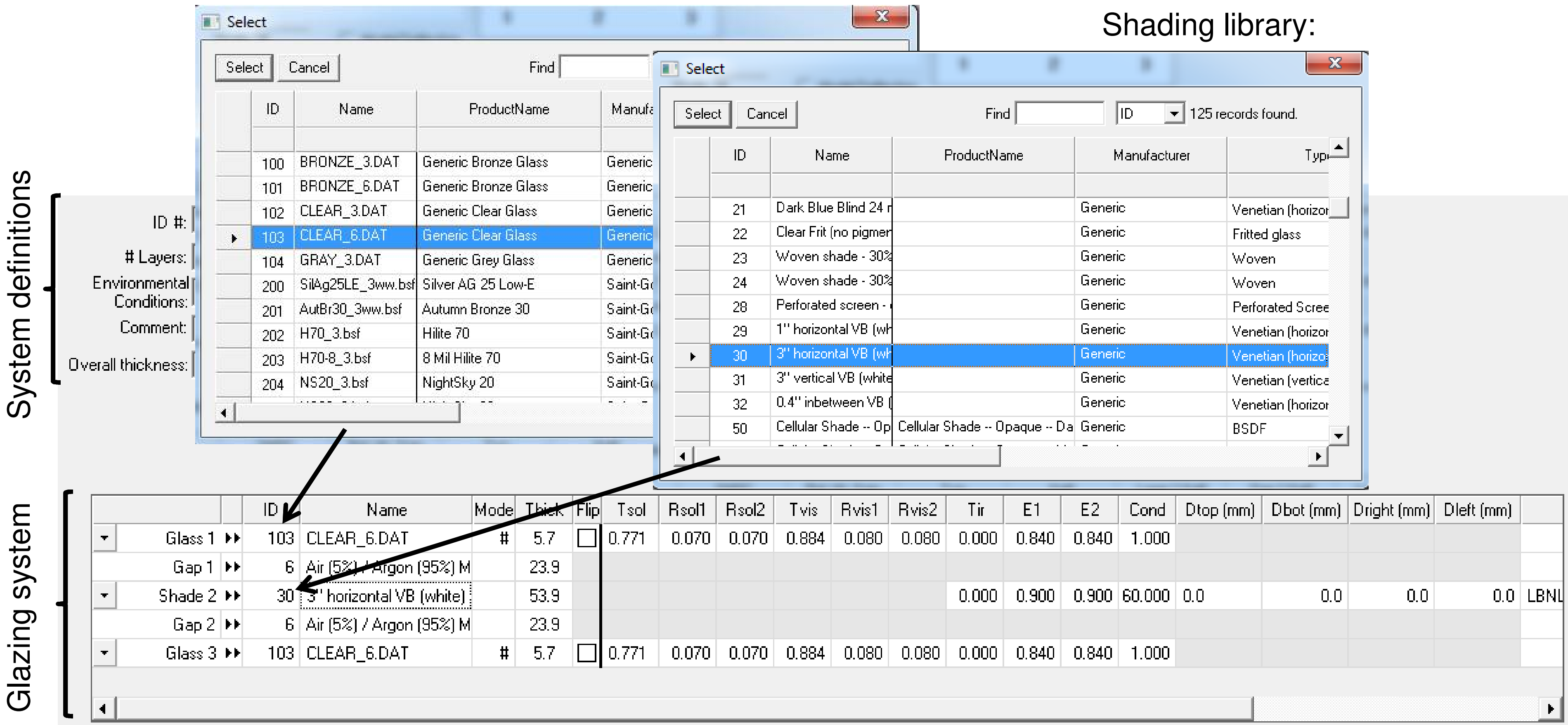
- LWR
- Convection
- Conduction

- ISO 15099

Model data setup in WINDOW7

Glazing library:

Shading library:



Conclusions and further tasks

- New Artlight-routine shows accurate modeling results
- A clearly improvement in run-time efficiency compared to state-of-the-art methods could be achieved
- Reached capabilities for flexible multi-zone calculations including different orientations and window subdivisions
- High flexibility in terms of:
  - Implementing and testing different control strategies
  - Expansion to Five-Phase method, flexible matrix resolutions
  - …

- Further tasks:
- Coupling with new Rad-file output in TRNSYS18 – Type56
- Comparision against measuring data on test site
- Further optimizations on software architecture and structure

Thanks for your attention !

Acnowledgement

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Contact

Martin Hauer
University of Innsbruck, Faculty for Technical Sciences
Institute for Construction und Material Science
Unit for Energy Efficient Buildings
Technikerstrasse 13
6020 Innsbruck, Austria

Tel.: +43 512 507 - 63654
martin.hauer@uibk.ac.at