Modeling and simulation of radiation in modern urban spaces

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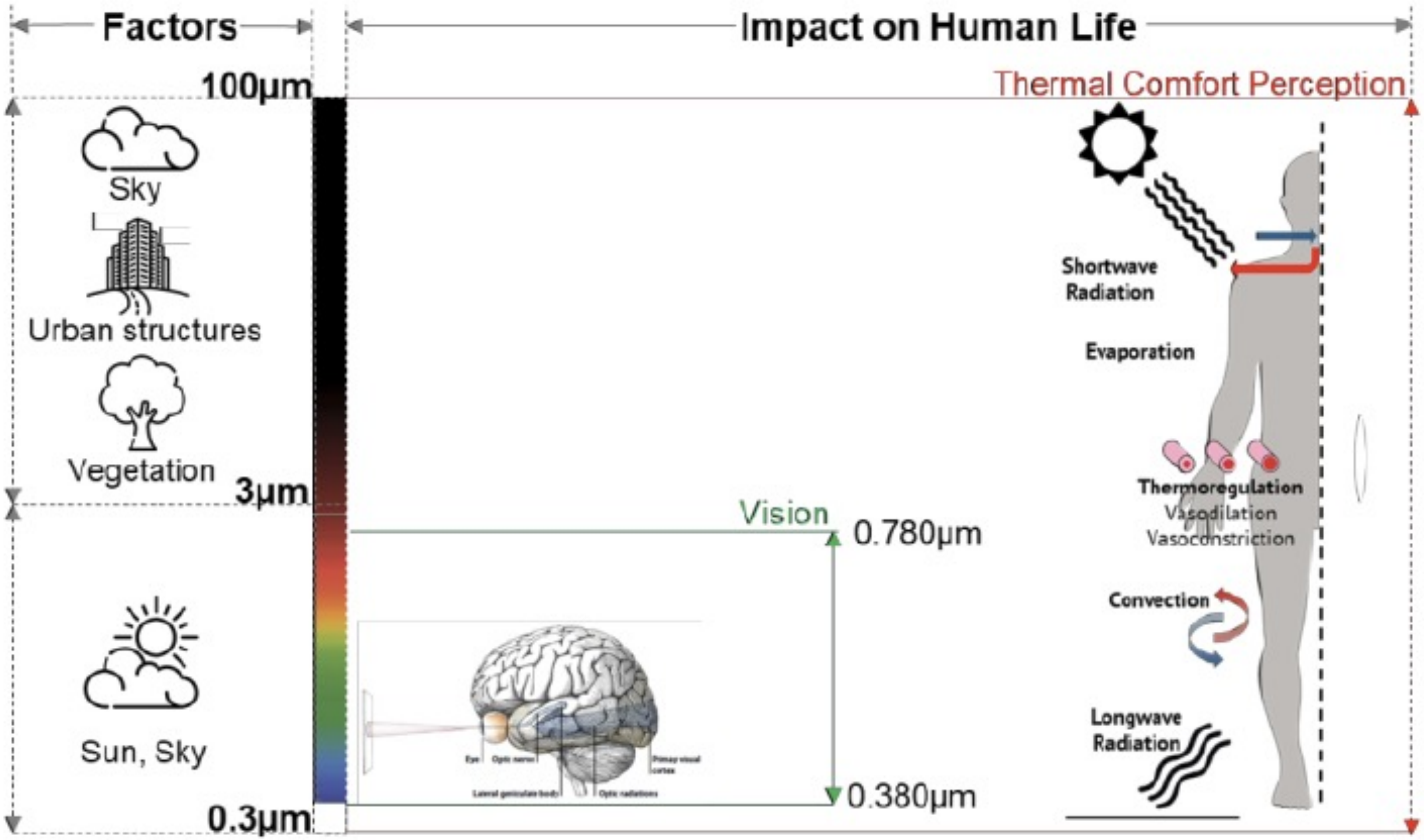

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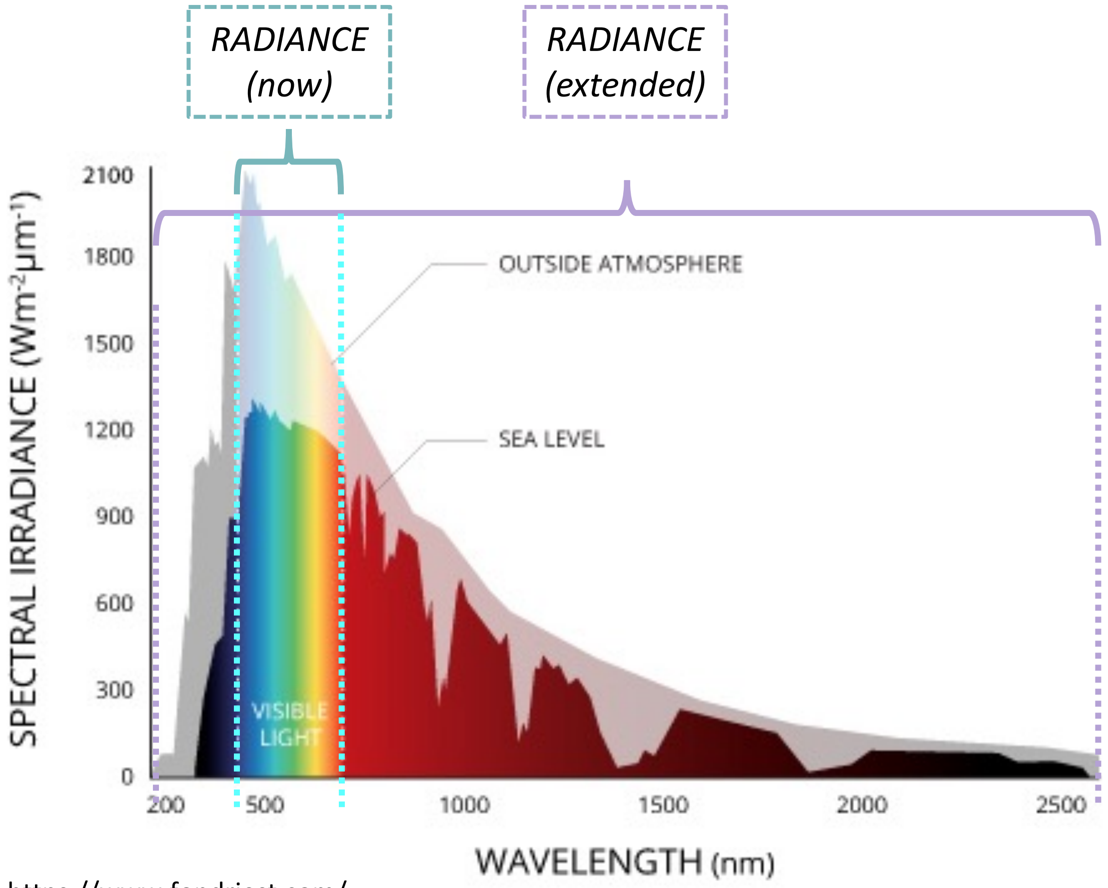
Modeling and simulation of radiation in modern urban spaces

Extension of RADIANCE simulations into the full solar spectrum
(instead of merely visible)



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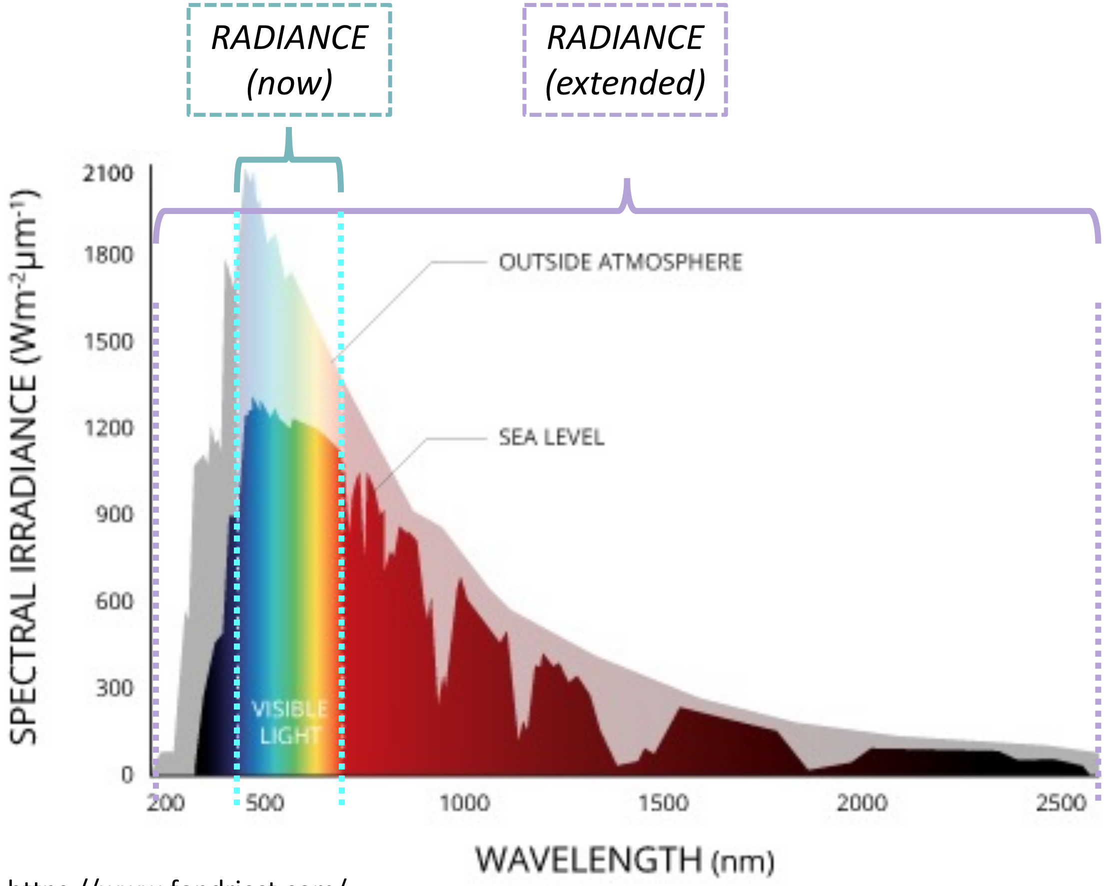

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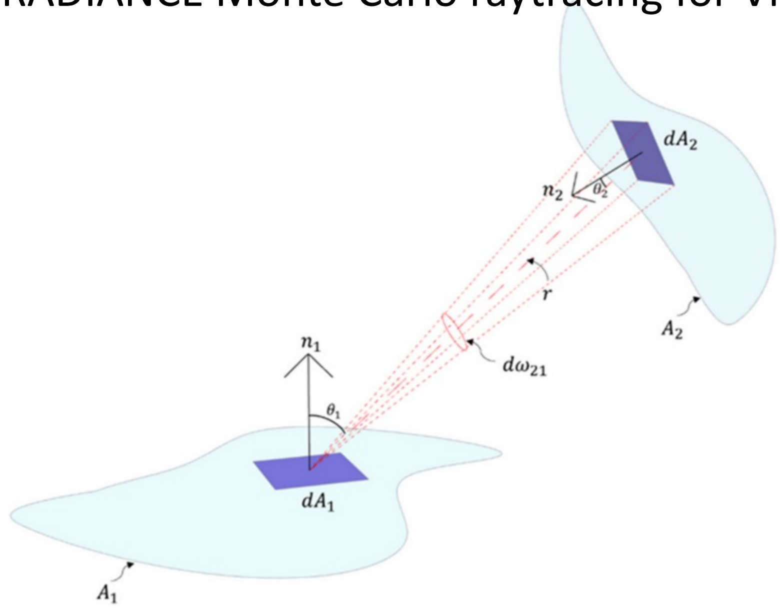
LW radiative heat exchange model through:

Radiosity approach +
RADIANCE Monte Carlo raytracing for View Factors (VF)



Subramaniam, Sarith, Sabine Hoffmann, Sridhar Thyageswaran, and Greg Ward. 2022. "Calculation of View Factors for Building Simulations with an Open-Source Raytracing Tool" *Applied Sciences* 12, no. 6: 2768.

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Radiation modeling

SW radiation model

RADIANCE

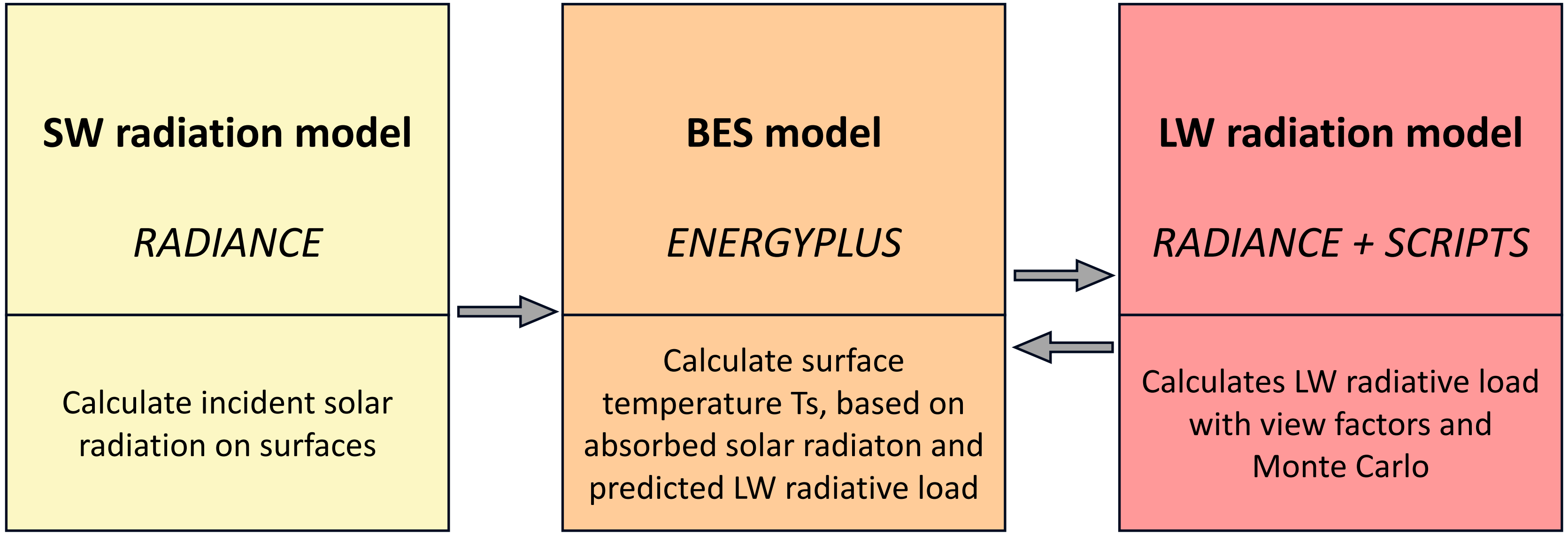
Calculate incident solar radiation on surfaces

LW radiation model

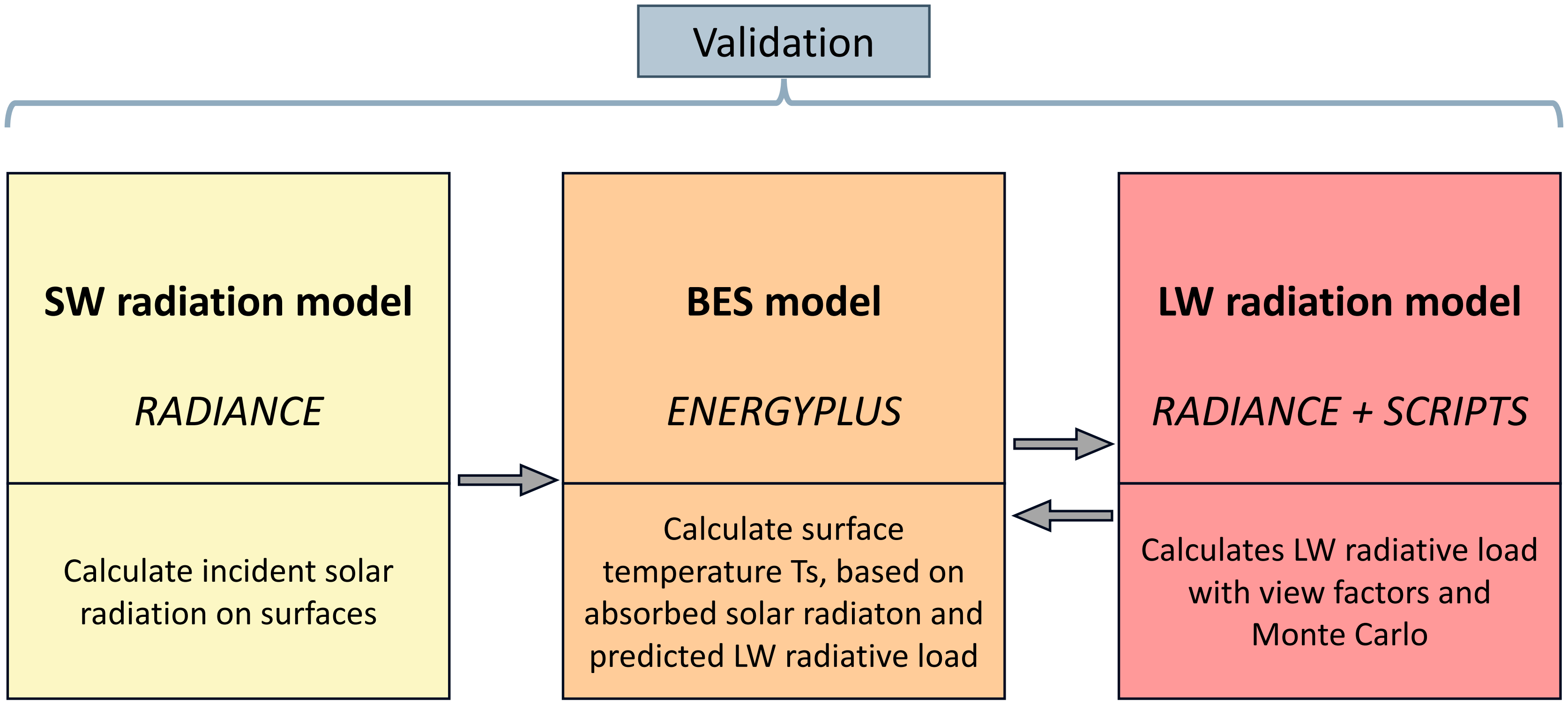
RADIANCE + SCRIPTS

Calculates LW radiative load with view factors and Monte Carlo

Radiation modeling



Radiation modeling



Radiation modeling

Validation

SW radiation model

RADIANCE

Calculate incident solar radiation on surfaces

BES model

ENERGYPLUS

Calculate surface temperature Ts, based on absorbed solar radiaton and predicted LW radiative load

LW radiation model

RADIANCE + SCRIPTS

Calculates LW radiative load with view factors and Monte Carlo

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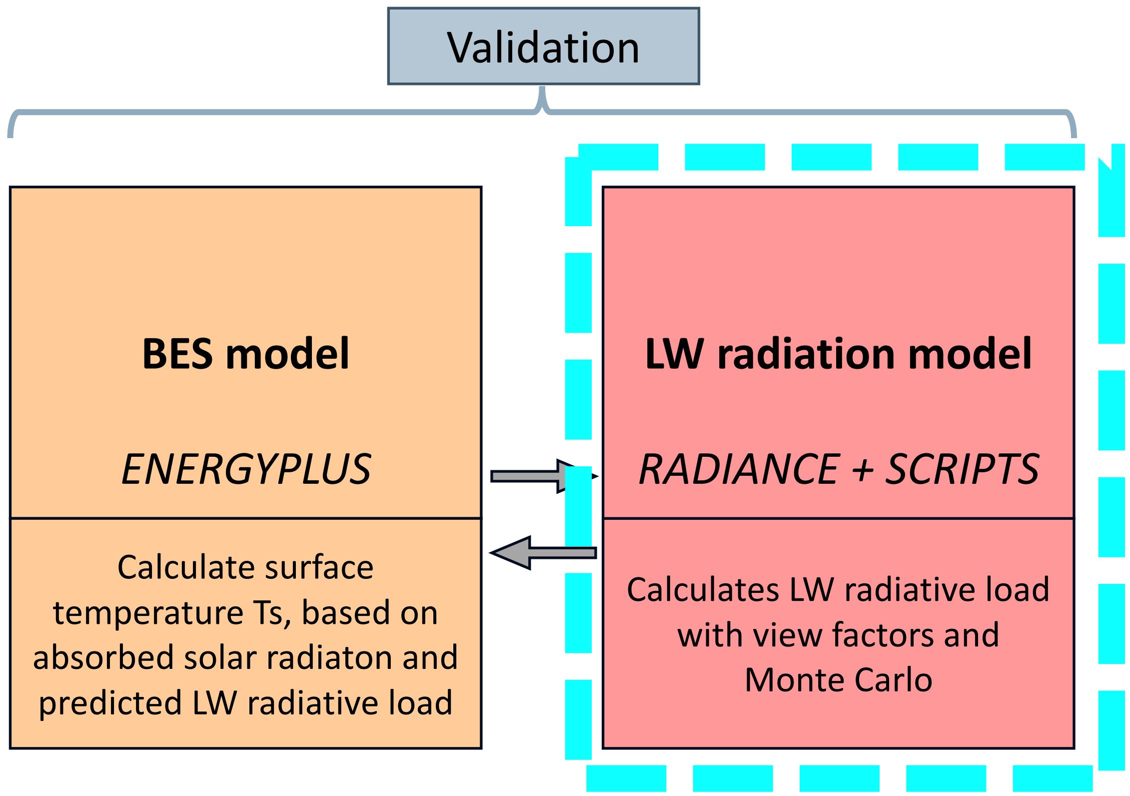
LW radiation modelling



LW Radiation Model

Radiosity approach:
Lambertian distribution of emitted radiance for each material

$$B_i = B_{e,i} + \rho_i \sum_{j=1}^{N} B_j \, F(i \to j)$$

Where:

- B_i — radiosity of patch i (**unknown**)
- $B_{e,i}$ — emission of patch i (**known**)
- ρ_i — reflectivity of patch i (**known**)
- $F(i \to j)$ — form factor from patch i to patch j (**known**)
- N — total number of patches

Further assumptions/simplifications:
- Static emissivity values
- Only considering LW radiation larger than approx. 8 µm
- Non-spectral resolution => surfaces as perfect gray bodies

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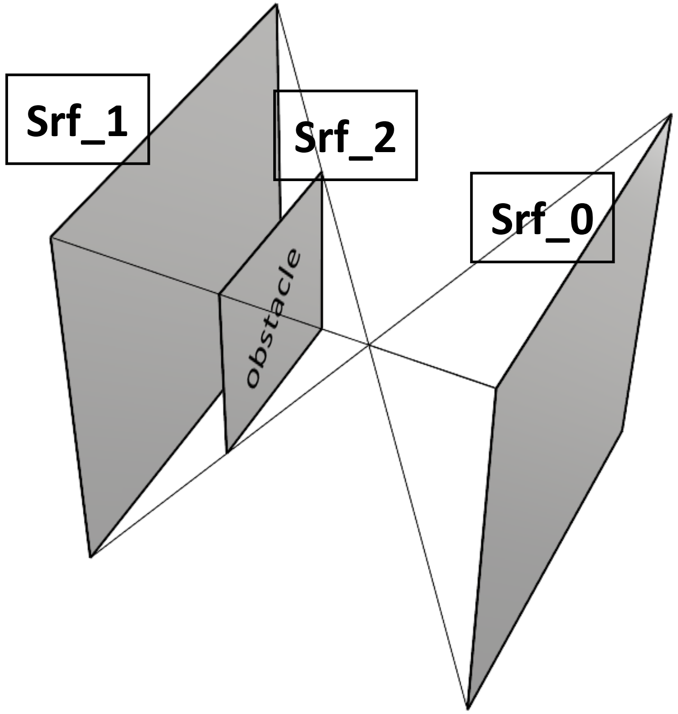
View factors in RADIANCE



Test case, as shown by
George N. Walton

	VF Analytical	VF RADIANCE Monte Carlo	Relative Error
Srf_0 > Srf_1	0.11562	0.11601	0.0034
Srf_0 > Srf_2	0.08420	0.08502	0.0097
Srf_1 > Srf_2	0.19861	0.20075	0.0108
Srf_2 > Srf_1	0.79445	0.80560	0.0140

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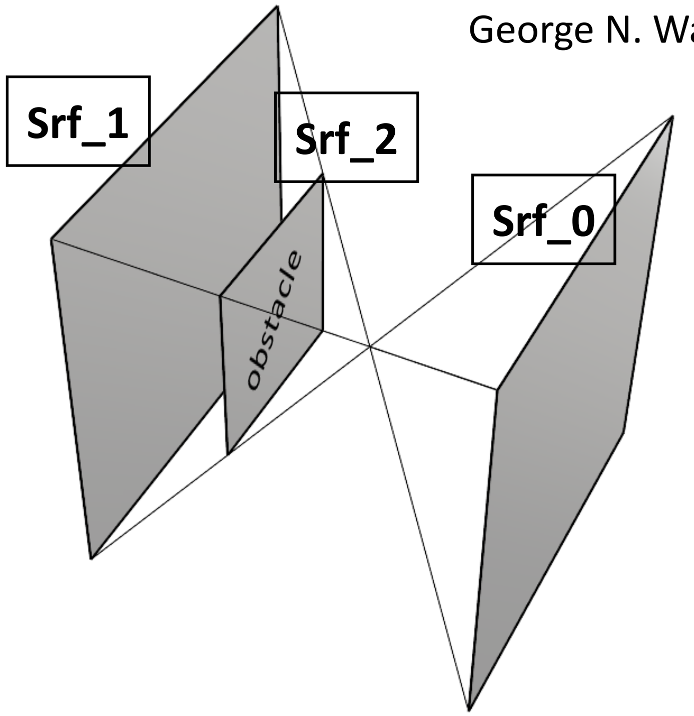
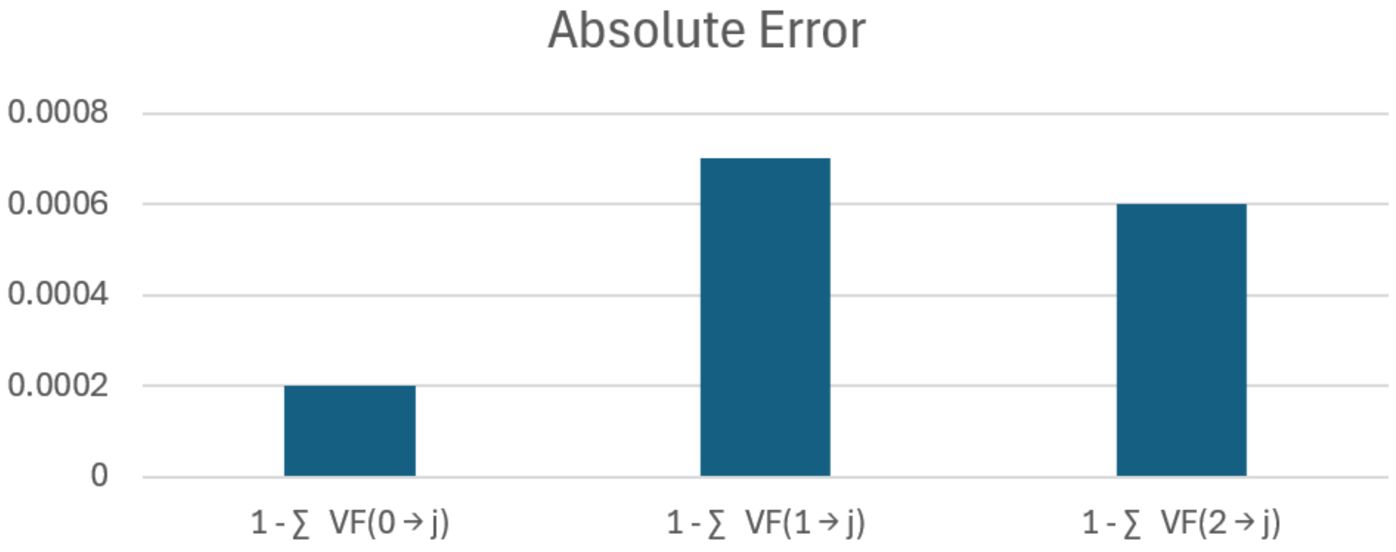
View factors in RADIANCE

Test case, as shown by
George N. Walton



$$\sum_{j=1}^{N} F_{i \to j} = 1$$



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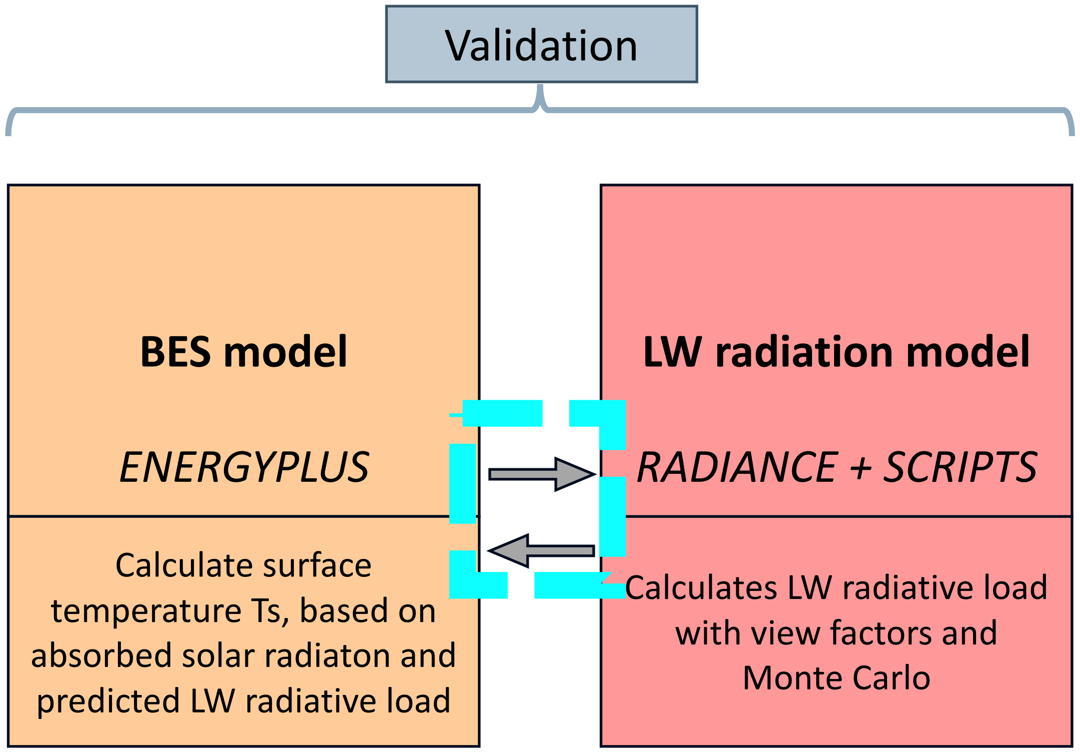
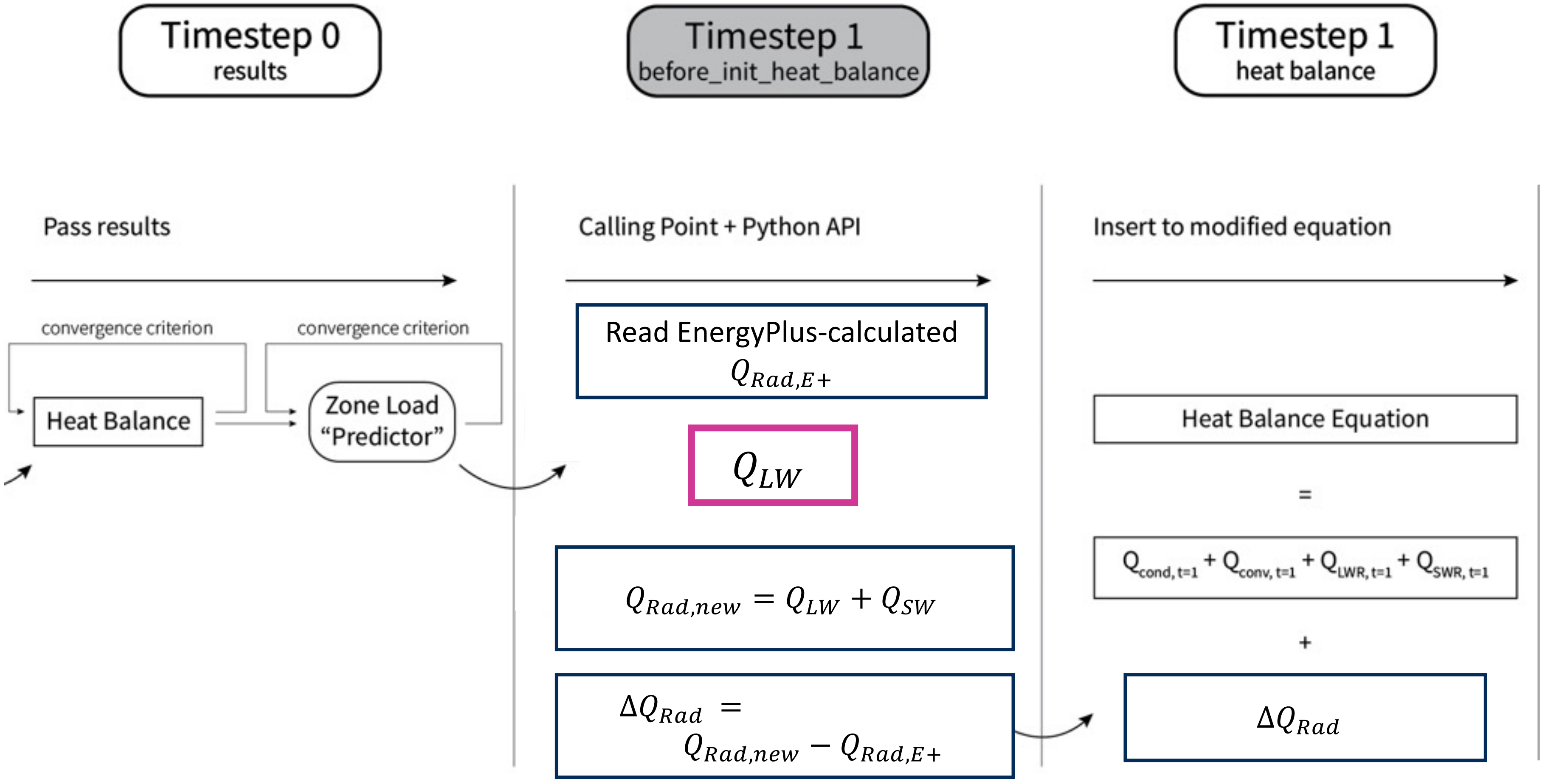
Coupling BES and LW radiation model



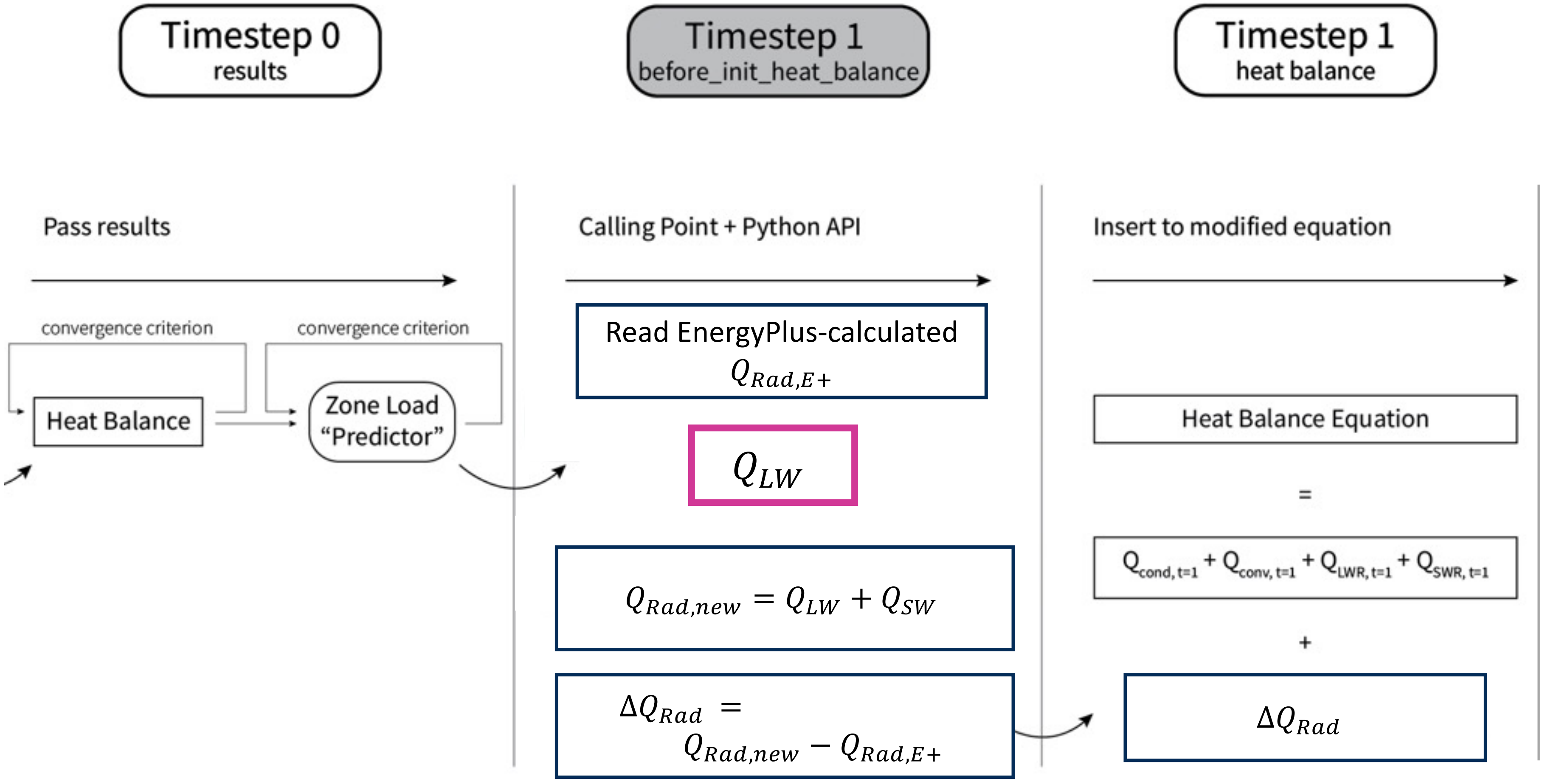
BES Model – LW/SW radiation integration



Q_{LW}:
LW radiation energy (RADIANCE VFs)

$Q_{Rad,new}$:
Calculated LW and SW radiation through RADIANCE

BES Model – LW/SW radiation integration



$$E = \varepsilon \, \sigma \, T^4$$

Where:

- E — radiant exitance $(\mathrm{W \cdot m^{-2}})$
- ε — emissivity
- σ — Stefan-Boltzmann constant
- T — surface temperature (K)

Q_{LW}:
LW radiation energy (RADIANCE VFs)

$Q_{Rad,\,new}$:
Calculated LW and SW radiation through RADIANCE

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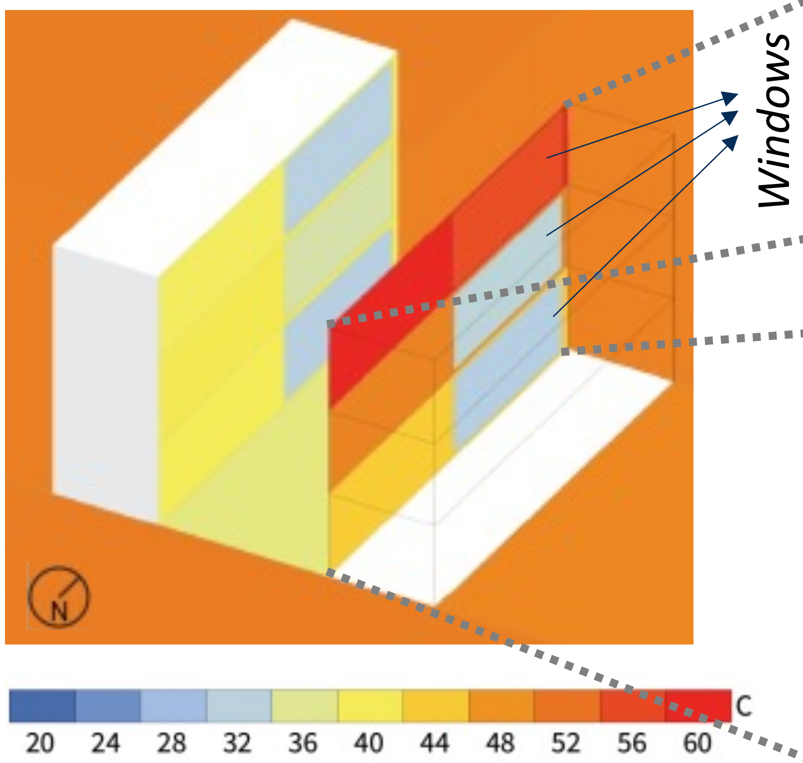
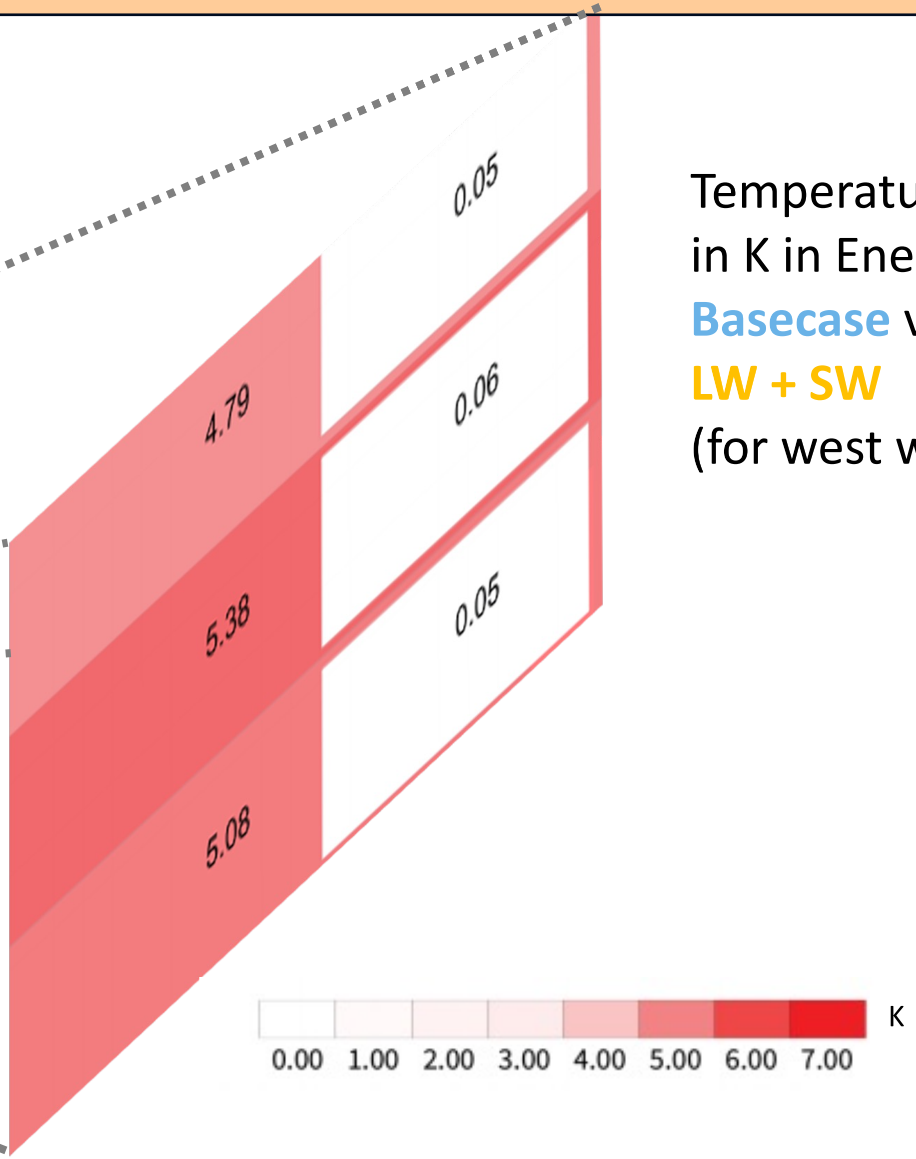
Coupling RADIANCE and EnergyPlus

EnergyPlus surface temperatures in C°, here:
Caclulated LW + SW





Temperature differences in K in EnergyPlus Basecase vs. Caclulated LW + SW (for west wall)

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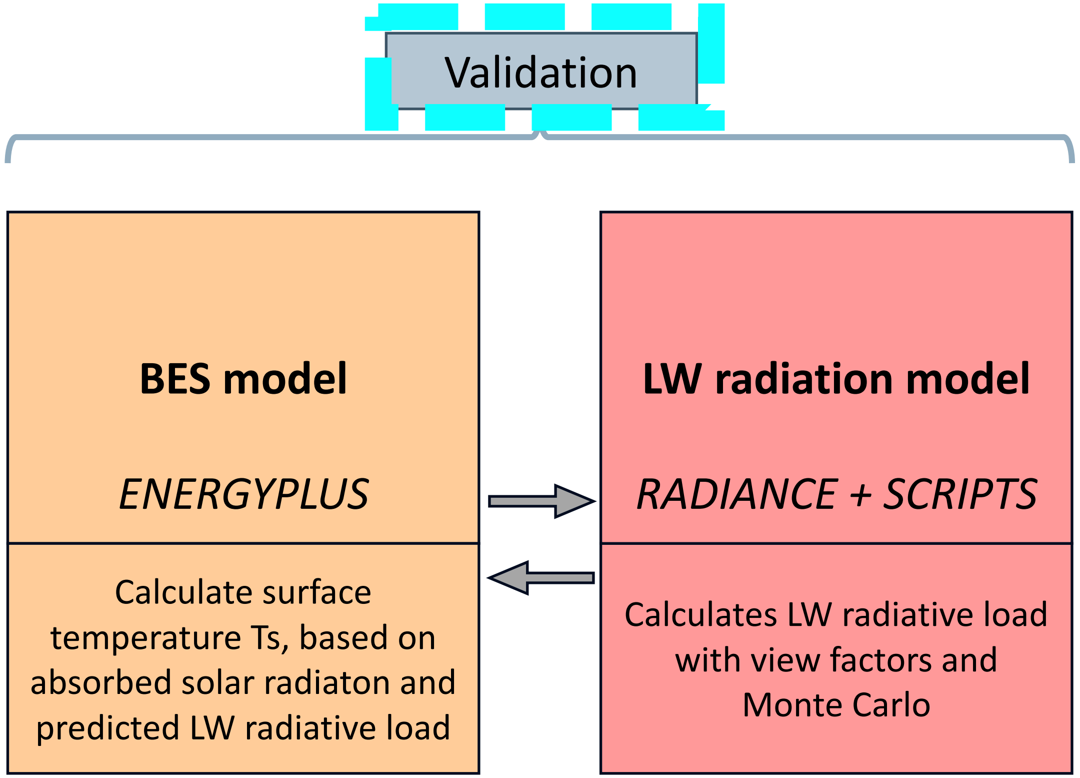
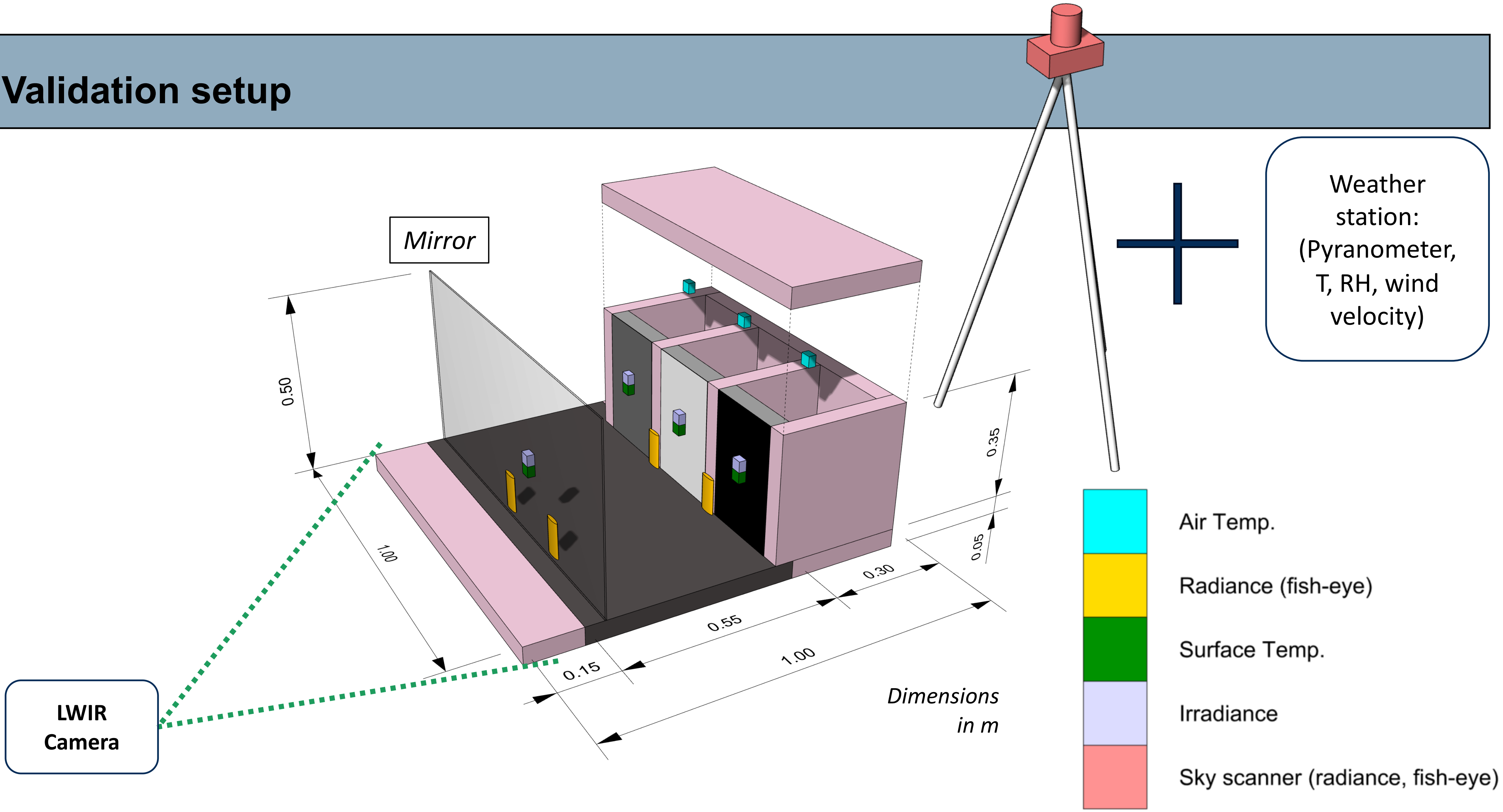
Validation setup

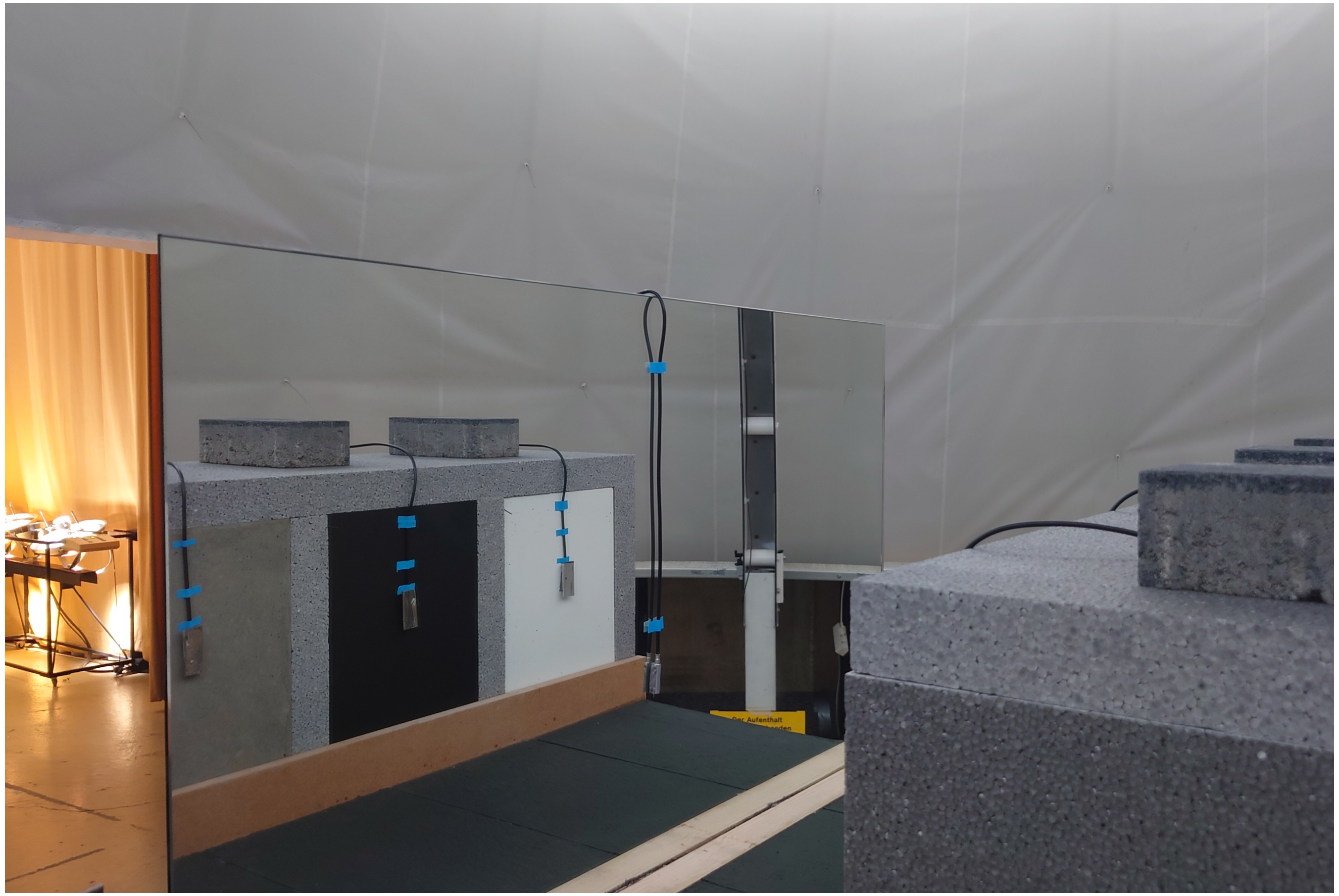


Validation setup



Validation setup – measurements at Bartenbach Lichtlabor

- Direct Normal Irradiance: approx. 160 W/m²
- Sun was positioned at 30° altitude at a static position
- Measurements during a time span of several hours



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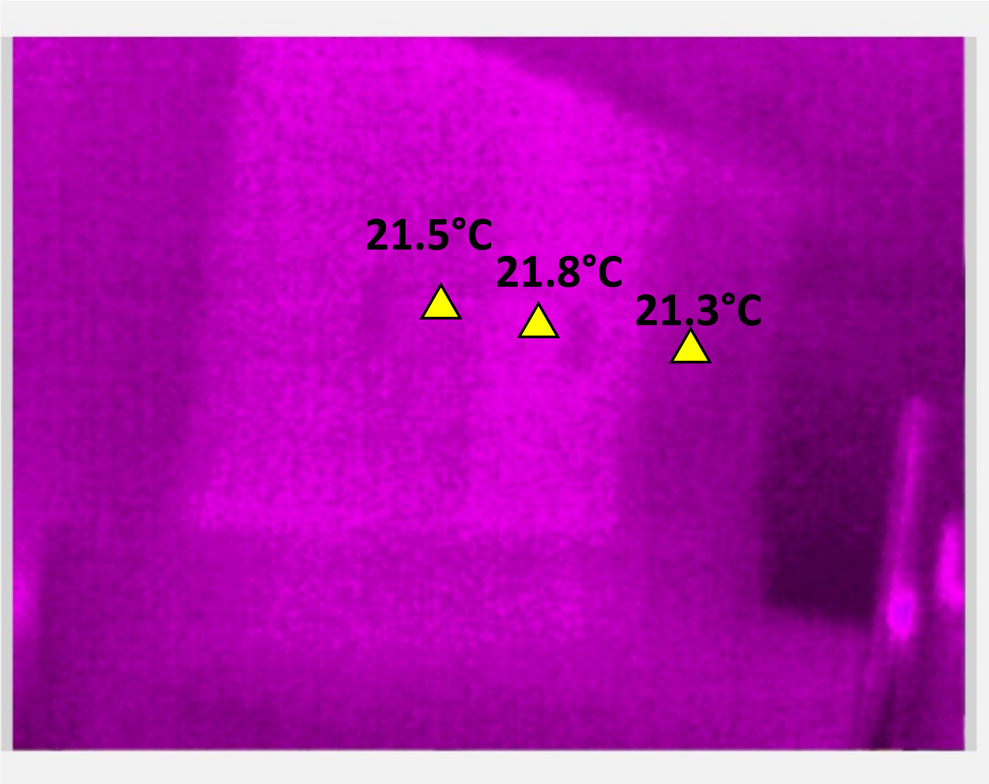
Validation setup – measurements at Bartenbach Lichtlabor



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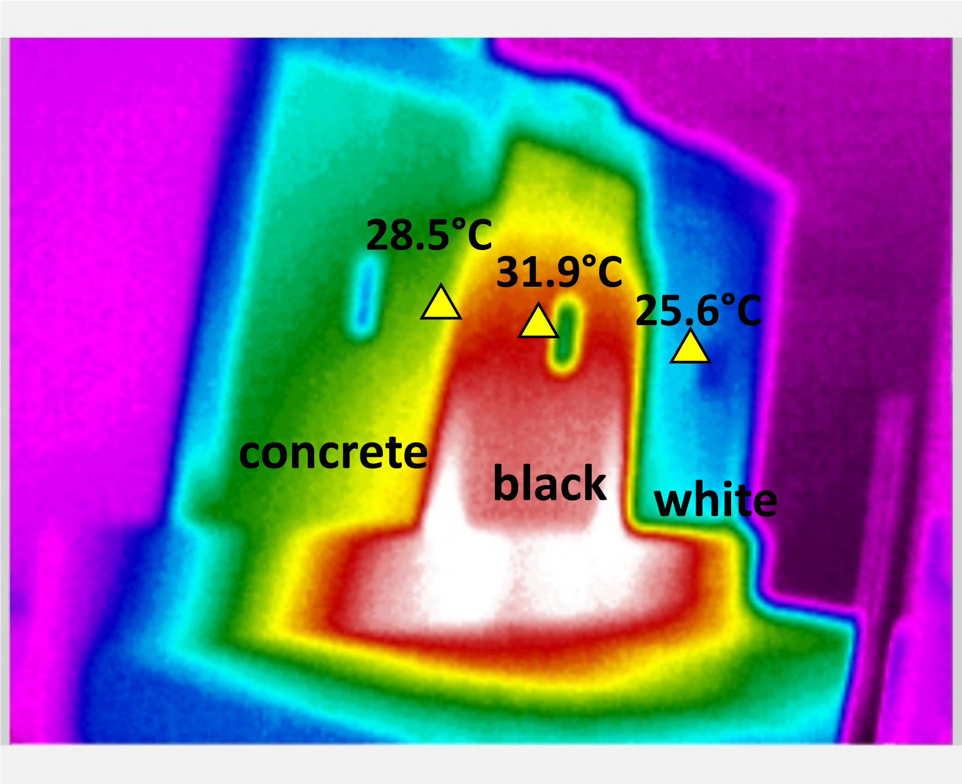
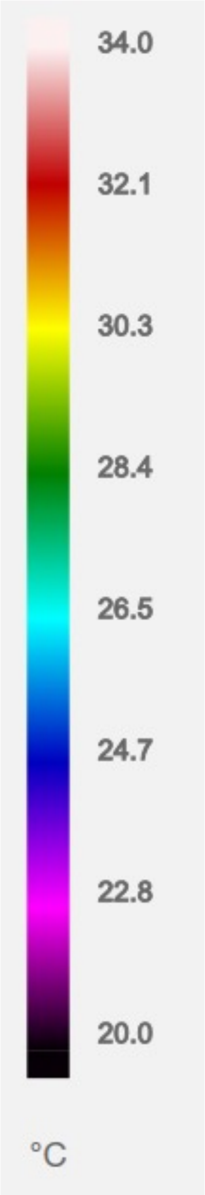


Time: 06:00 AM



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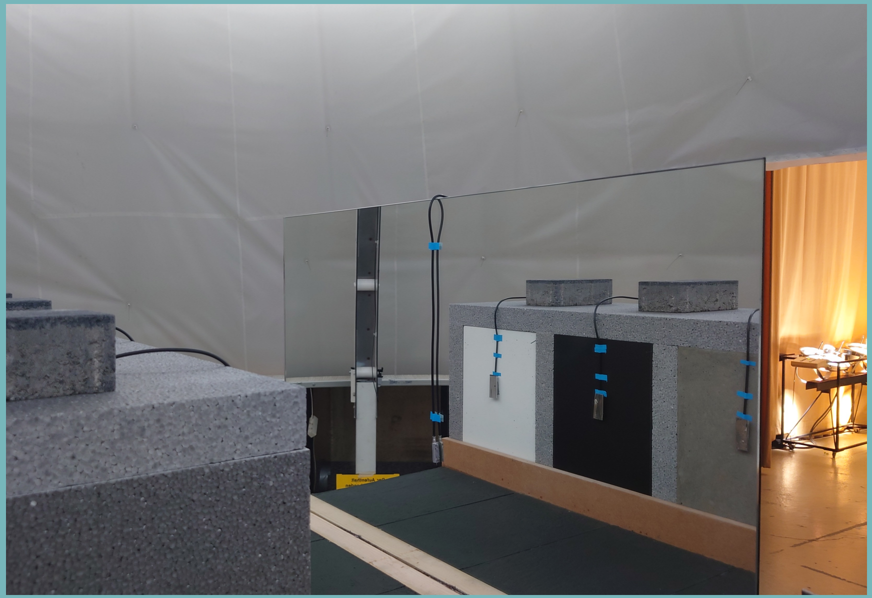
Conclusions

- Accurate view factors can be computed through RADIANCE Monte Carlo algorithms for complex geometry
- Our calculated LW (and SW) radiation significantly alters surface temperatures in BES (compared to default)
- Experimental results showed significant temperature differences depending on the surface reflectances

Outlook

- Validation of the simulation workflow based on our measurement at Bartenbach's artificial sun
- Building a LW radiation measurement device, for obtaining angular-dependent LW sky radiation

THANK YOU!



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