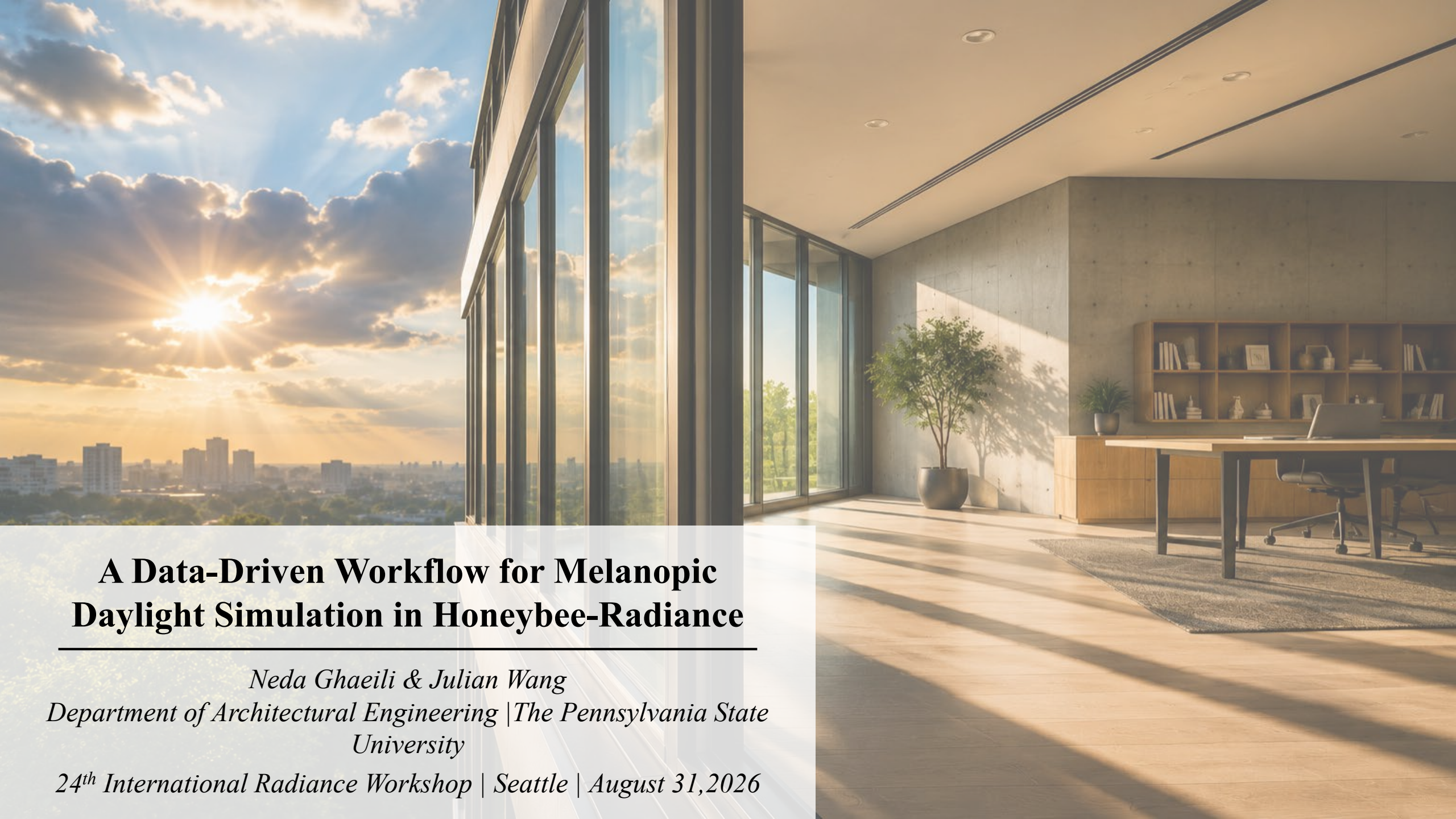




A Data-Driven Workflow for Melanopic Daylight Simulation in Honeybee-Radiance

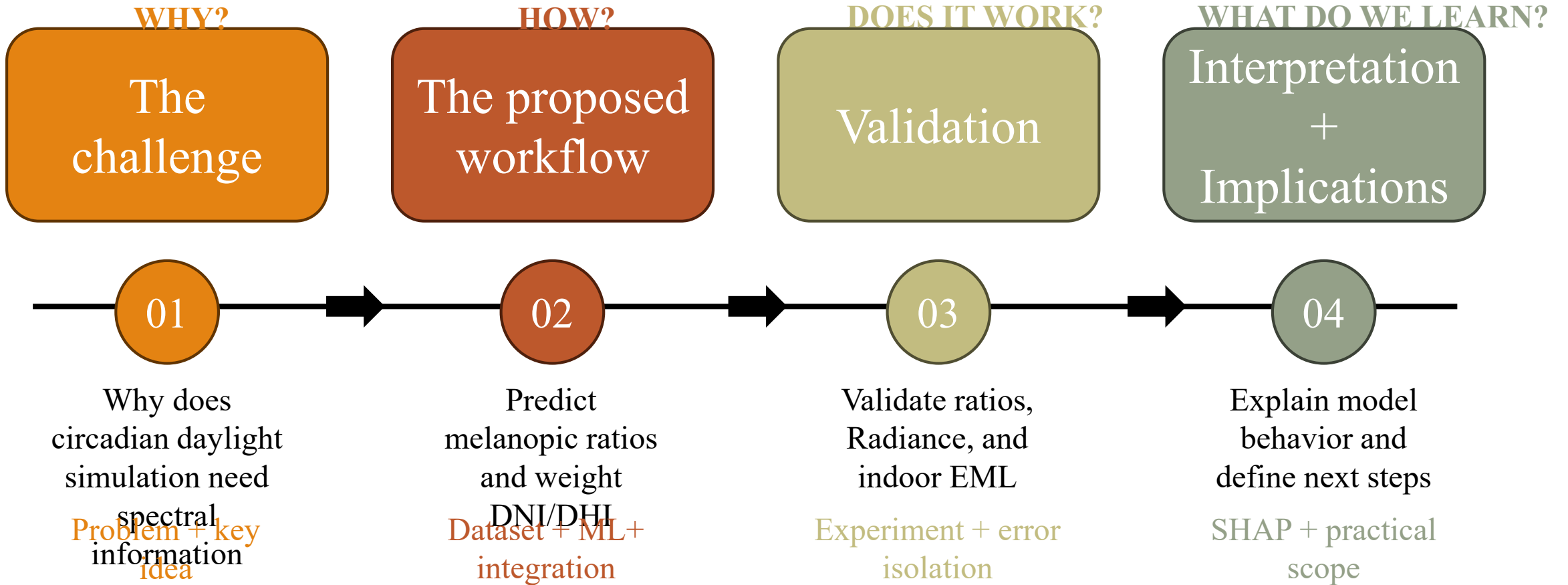
Neda Ghaeili & Julian Wang

*Department of Architectural Engineering | The Pennsylvania State
University*

24th International Radiance Workshop | Seattle | August 31, 2026

Talk

From the spectral challenge to a practical, validated Radiance workflow
roadmap

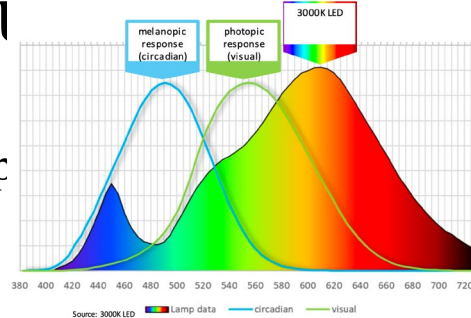


Core question: Can melanopic daylight be simulated in Radiance without reconstructing a full spectral sky?

Why is circadian daylight

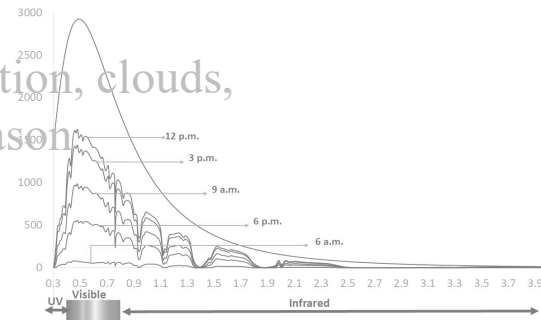
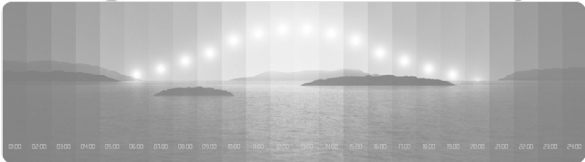
1. Spectral dependence

Melanopic response depends on the spectral composition of light.



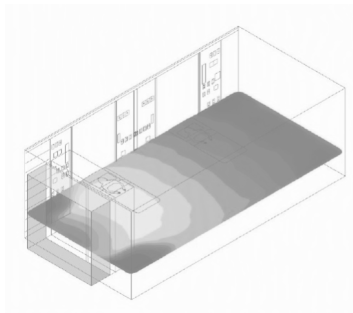
2. Dynamic daylight spectra

Daylight SPD changes by solar position, clouds, atmosphere, and time of day and season.



3. Detailed spectral analysis

Full-spectral workflows require spectral sky, glazing, and material definitions. Adds input burden, ray-tracing cost, and uncertainty to routine design analysis.



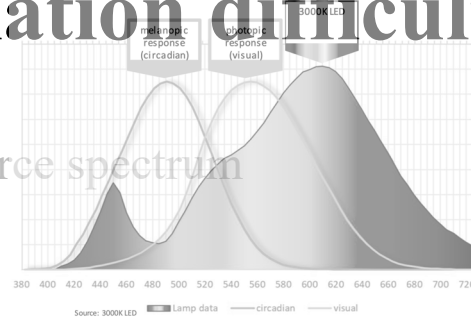
Can we retain a conventional Radiance workflow without reconstructing full daylight spectrum?

Goal
Direct indoor EML
=
Preserve Radiance's practical workflow while reducing the spectral input

Why is circadian daylight simulation difficult?

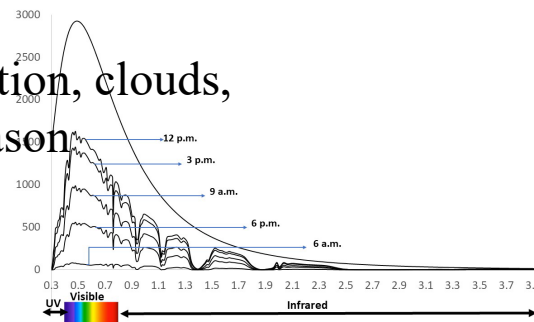
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Melanopic light depends on the light source spectrum



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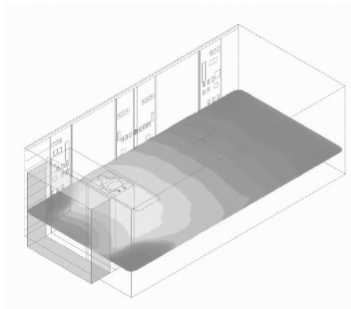
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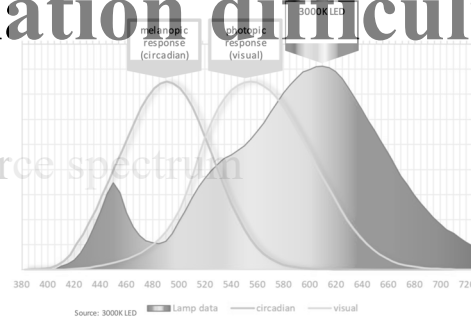
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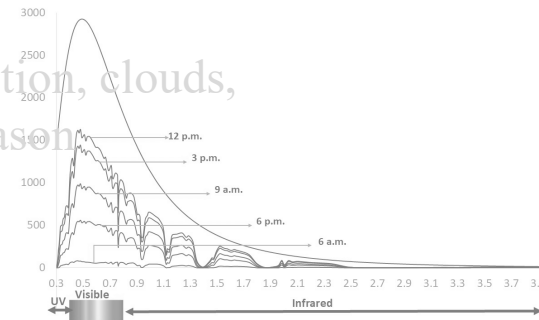
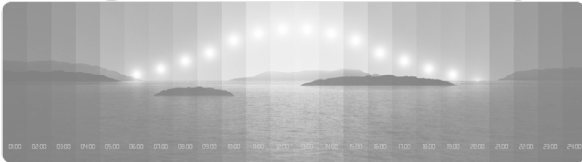
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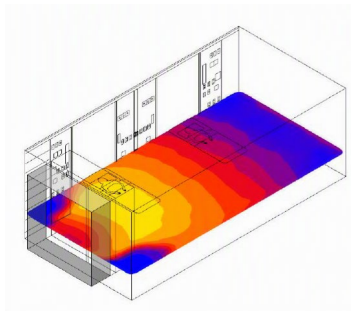
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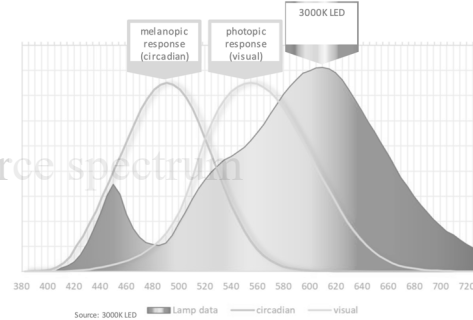
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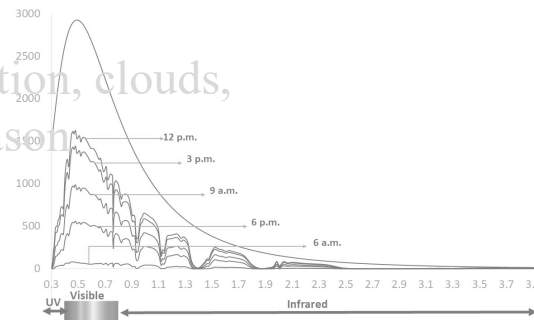
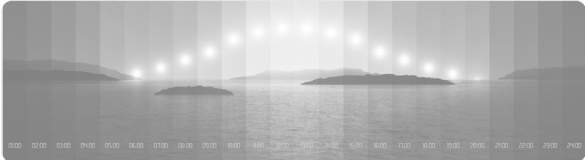
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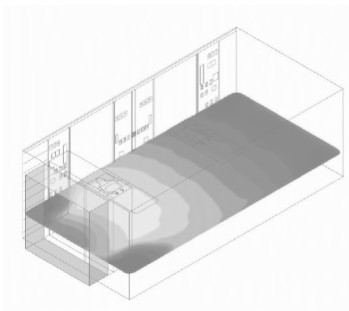
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analysis

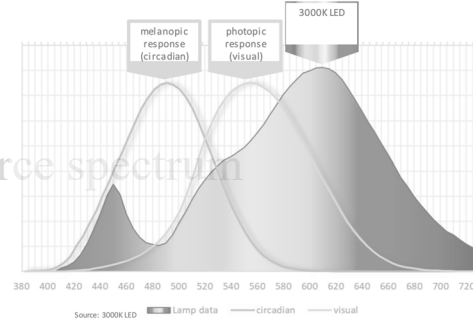
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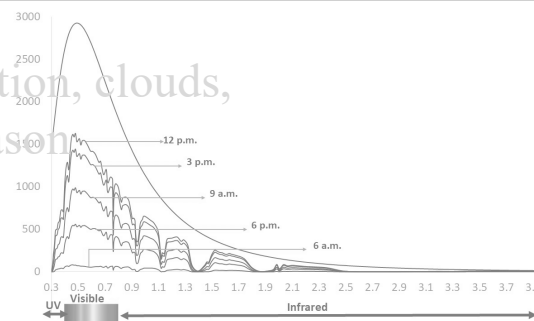
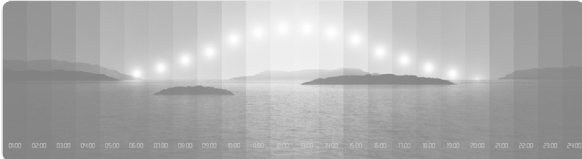
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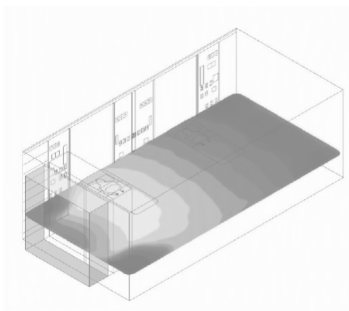
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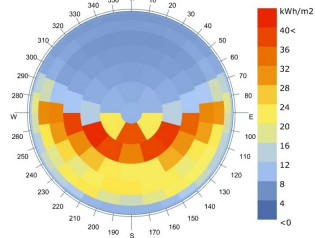
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The key idea

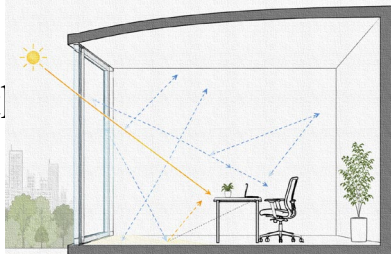
Transform the outdoor irradiance components before simulation

Conventional daylight simulation

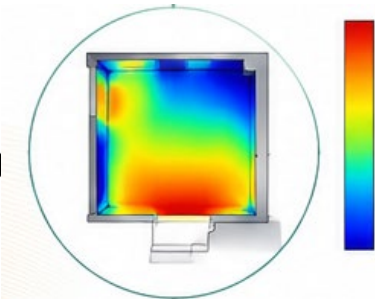
1. Radiance sky generation:
DNI, DHI, Solar altitude and ~~azimuth~~



2. Ray tracing through the sky
3. Illuminance calculation at the sensor point



4. Daylight metrics



Sun + Sky

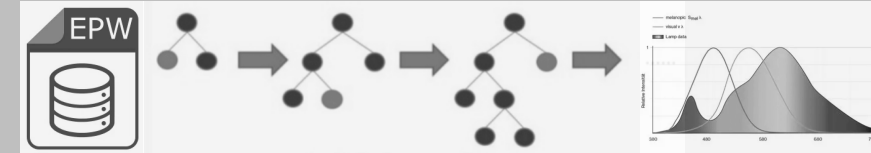


Can we avoid reconstructing a full spectral sky?

Weight DNI and DHI before sky generation

Proposed melanopic workflow

1. Predict DNI and DHI melanopic weighting available weather variables



2. Transform the EPW irradiance

$$\text{Melanopic Ratio (R)} = \frac{\int_{380}^{780} E(\lambda) M(\lambda) d\lambda}{\int_{380}^{780} E(\lambda) V(\lambda) d\lambda}$$

$$\text{DNI}_{\text{mel}} = \text{DNI} \times$$

$$\text{DHI}_{\text{mel}} = \text{DHI} \times$$

$$R(\text{DHI}_{\text{mel}})$$

3. Run the familiar Radiance workflow

Melanopic sky →

Ray tracing

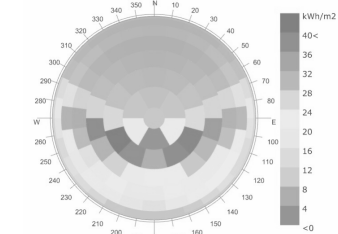
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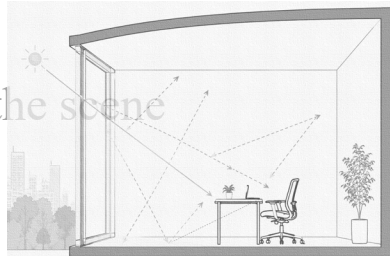
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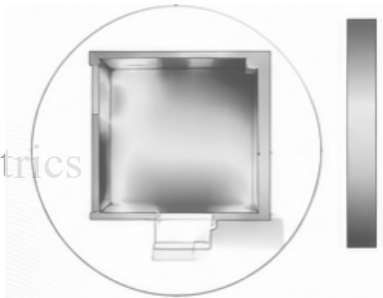
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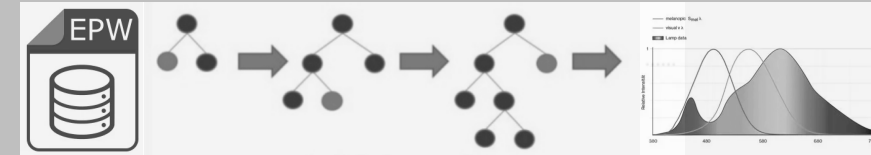


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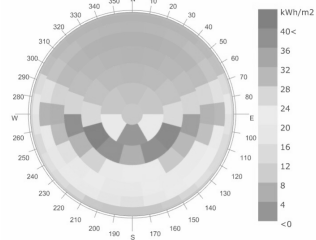
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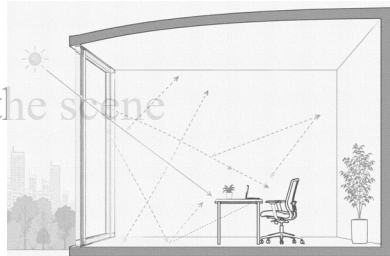
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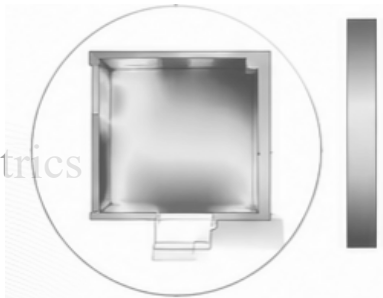
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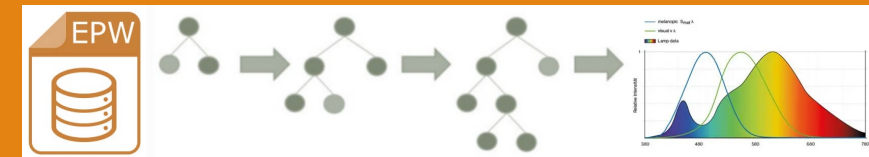
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3. Run the familiar Radiance workflow
Melanopic sky → Ray tracing → In

Overall

Four stages from data development to explainable validation

1. Dataset development

NREL data (2015-2025)

- NREL spectra: GHI, DNI, DHI
- Meteorological data

Target

Final dataset: 34,341 hourly observations, 13 predictors, and 2 target variables

2. ML model development

Data split (chronological)



Algorithms

Random Forest

XGBoost

LightGBM

3. Integration with daylight simulation

Predict melanopic ratios

- R-DHI
- R-DNI

Weighted DNI/DHI

$\text{DHI-mel} = \text{R-DHI} \times \text{DHI}$

$\text{DNI-mel} = \text{R-DNI} \times \text{DNI}$

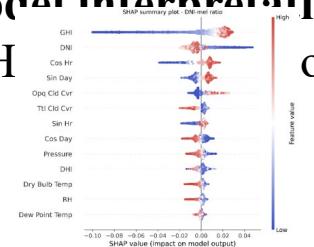
Honeybee Radiance Indoor EML

4. Validation & interpretation

- Predicted vs. calculated ratios
- Simulated vs. measured EML
- LARK benchmark

Model interpretation

- SHapley on

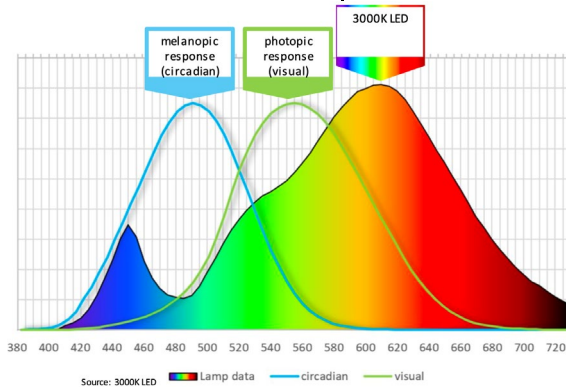


Dataset

d NREL SRRL input

Meteorological data

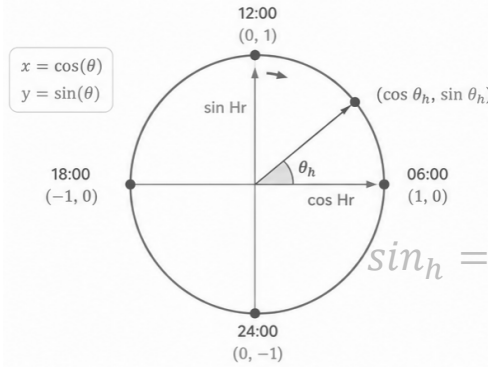
Temperature | Dew point
temperature | RH
Cloud cover | Pressure



Spectral irradiance reference
melanopic ratios

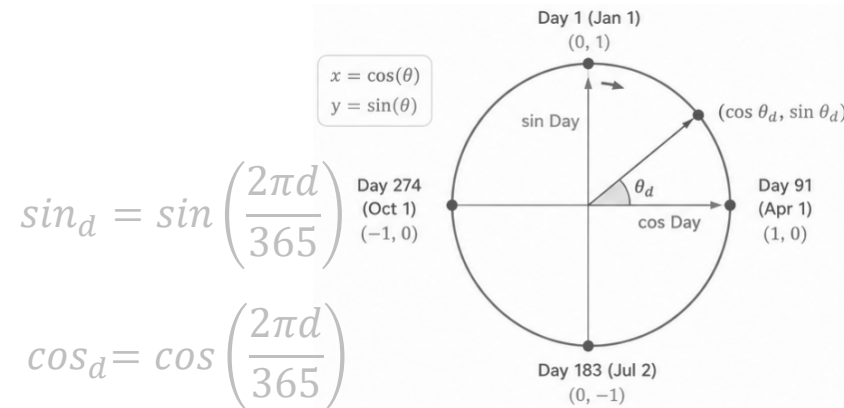
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Preprocessing & feature eng



$$\sin_h = \sin\left(\frac{\pi}{12} \times (h - 12)\right)$$

$$\cos_h = \cos\left(\frac{\pi}{12} \times (h - 12)\right)$$



$$\sin_d = \sin\left(\frac{2\pi d}{365}\right)$$

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Missing values and outlier
filtering



Final ML
Dataset

34,341 observa
tions

13 predictors

2 targets

Golden, Colorado • 2015–2025

2015-
2023

2024

2025

Independent

Experimental

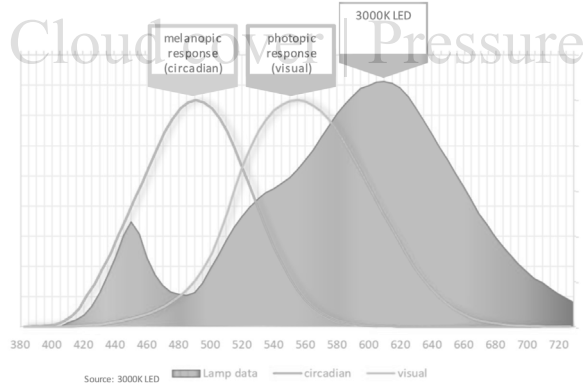
Dataset

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Meteorological data

GHI | DNI | DHI

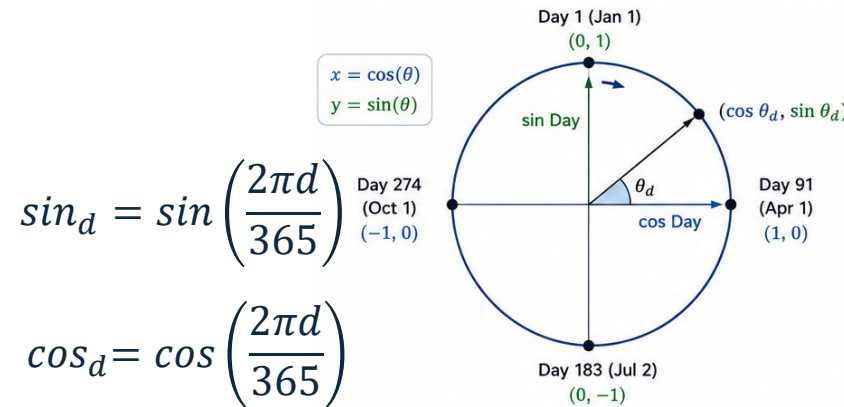
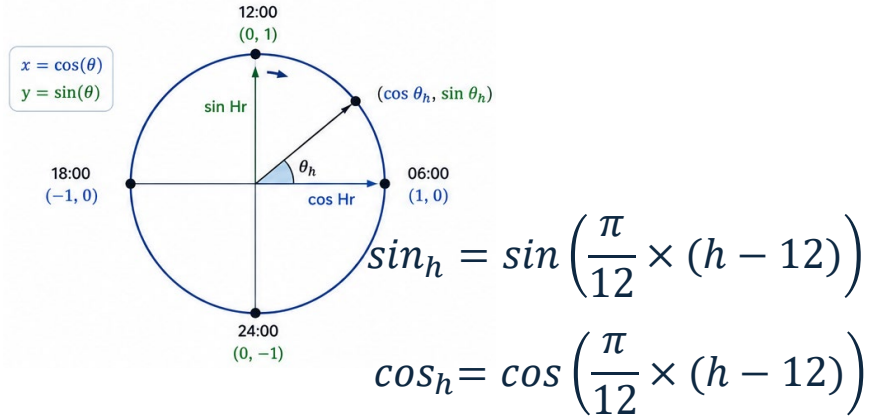
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Golden, Colorado • 2015–2025

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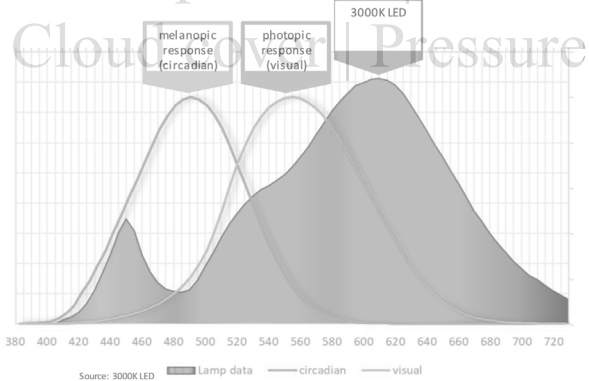
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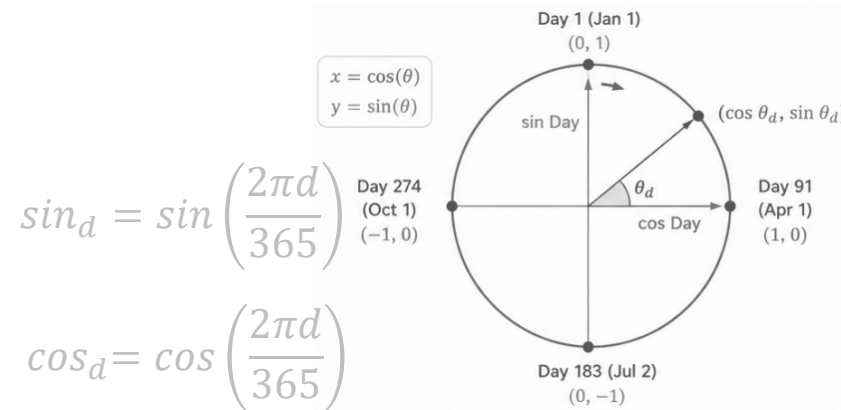
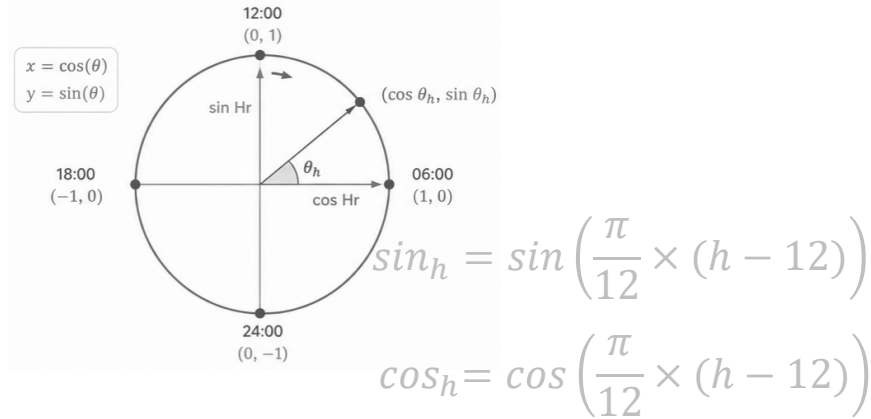
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**Final ML
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13 predictors
1 target

Golden, Colorado • 2015–2025

2015–
2023

2024

2025

Independent

Experimental

Machine learning

03

strategy
Compare three tree-based models; carry one consistent model into the daylight workflow

Compare candidate models

Random Forest

DHI-mel	DNI-mel
Test $R^2 =$	Test $R^2 =$
0.93	0.827

XGBoost

DHI-mel	DNI-mel
Test $R^2 =$	Test $R^2 =$
0.907	0.843

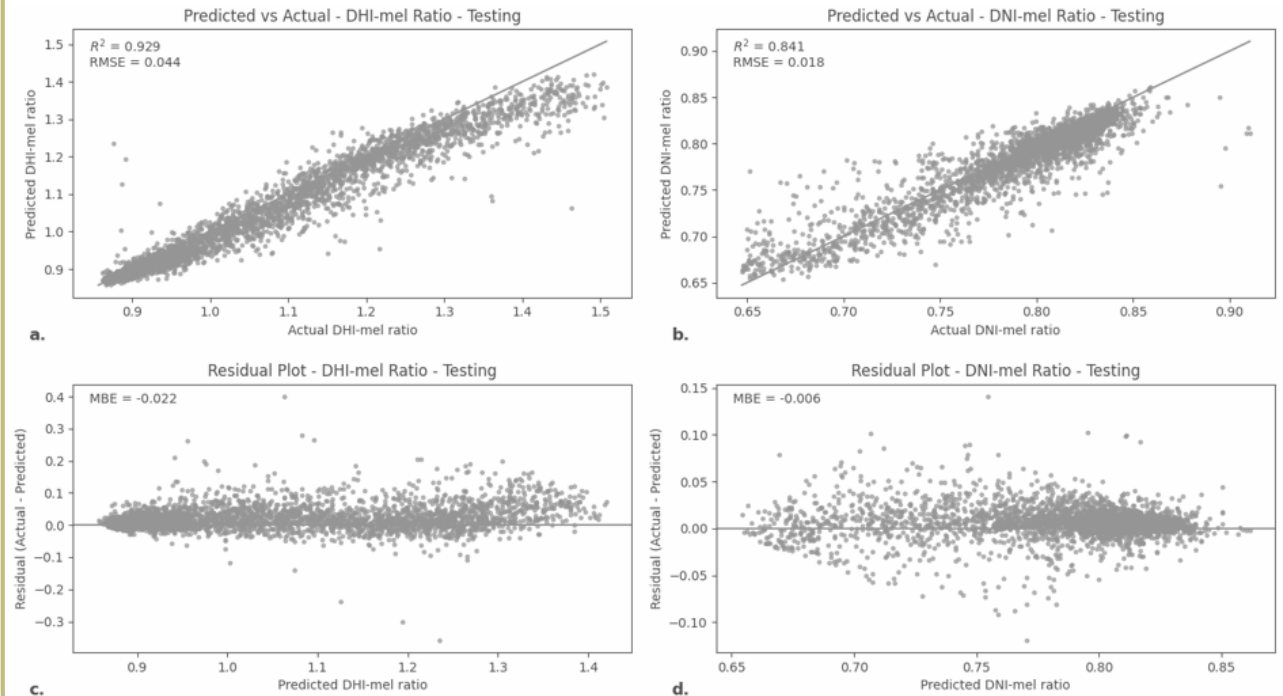
LightGBM

DHI-mel	DNI-mel
Test $R^2 =$	Test $R^2 =$
0.92	0.842

Optimization: Randomized search + 10-fold CV

Select the workflow model

LightGBM Comparable accuracy
+
Computational efficiency



Performance differences were small, so LightGBM was retrained as one efficient model for both melanopic ratios

Machine learning

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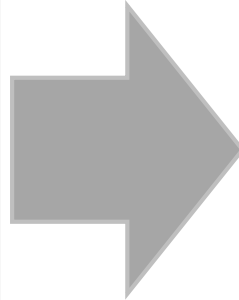
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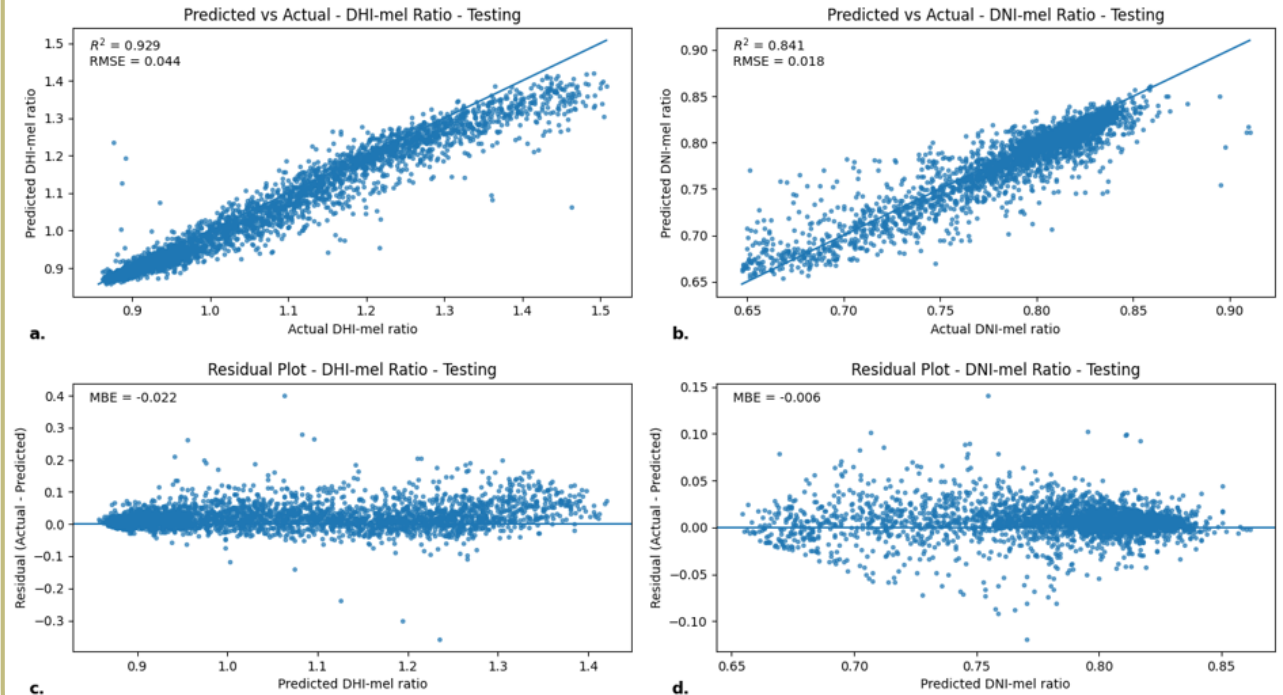
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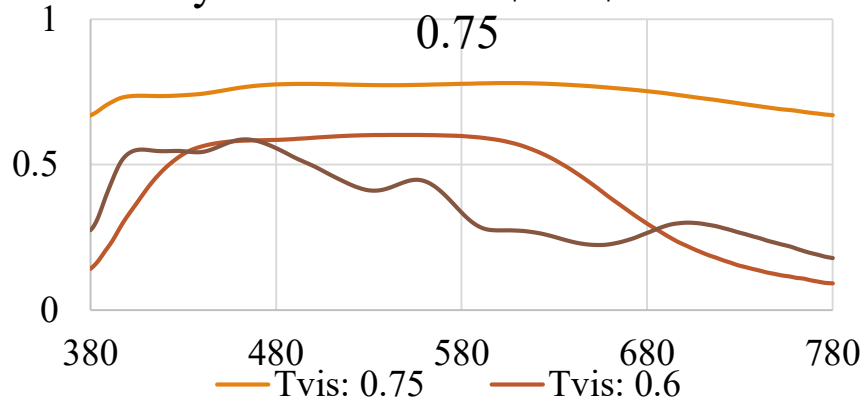
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Experimental

Test the complete
validation workflow

Measurement setup

1:10 scale test box | 3 glazing systems
 T_{vis} : 0.39 | 0.6 | 0.75

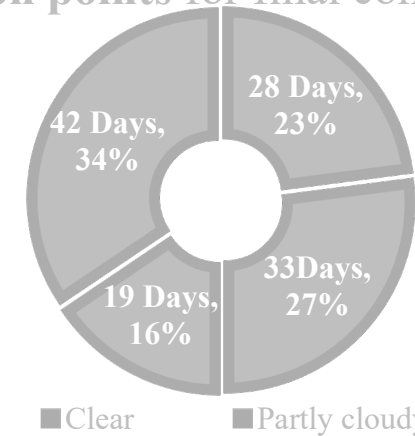


Golden, CO | Konica Minolta
CL-500A

Collected data

13 measurement days in 2025 spanning clear, partly cloudy, cloudy, and overcast conditions

118 hourly validation points for final comparison



Same geometry and daylight conditions replicated in **Rhino-Grasshopper**
Honeybee Radiance

comparison

Measured vs.
simulated E_v

Measured vs.
simulated EML

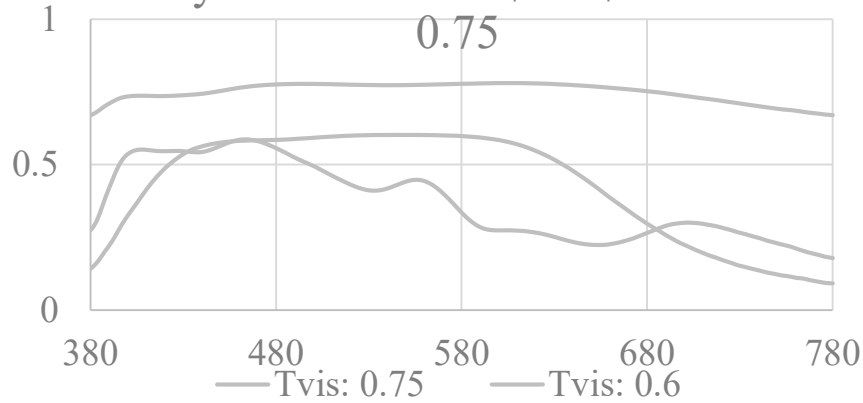
Validation spans multiple glazing spectra and sky conditions, linking the field experiment directly to the Radiance simulation

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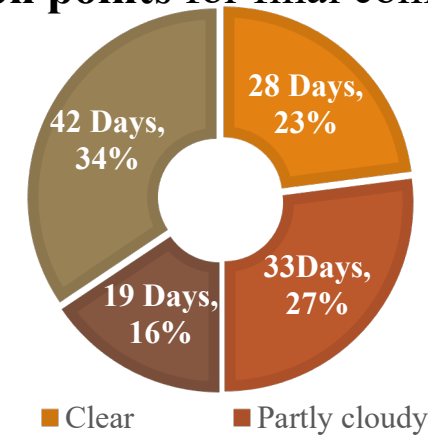


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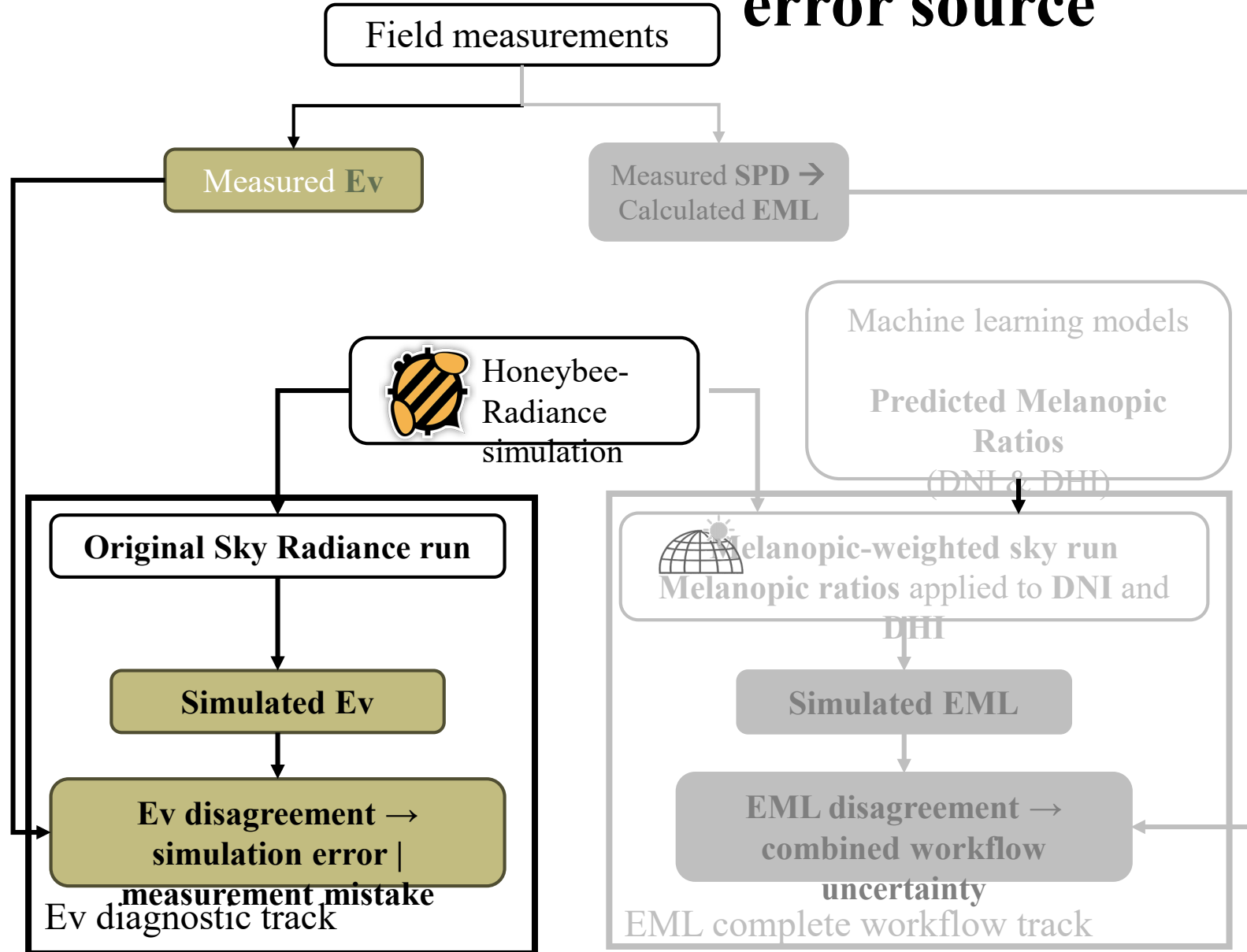
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Validation logic: Isolating the error source

Use the same validation dataset twice: first to diagnose conventional daylight simulation, then to test the melanopic workflow

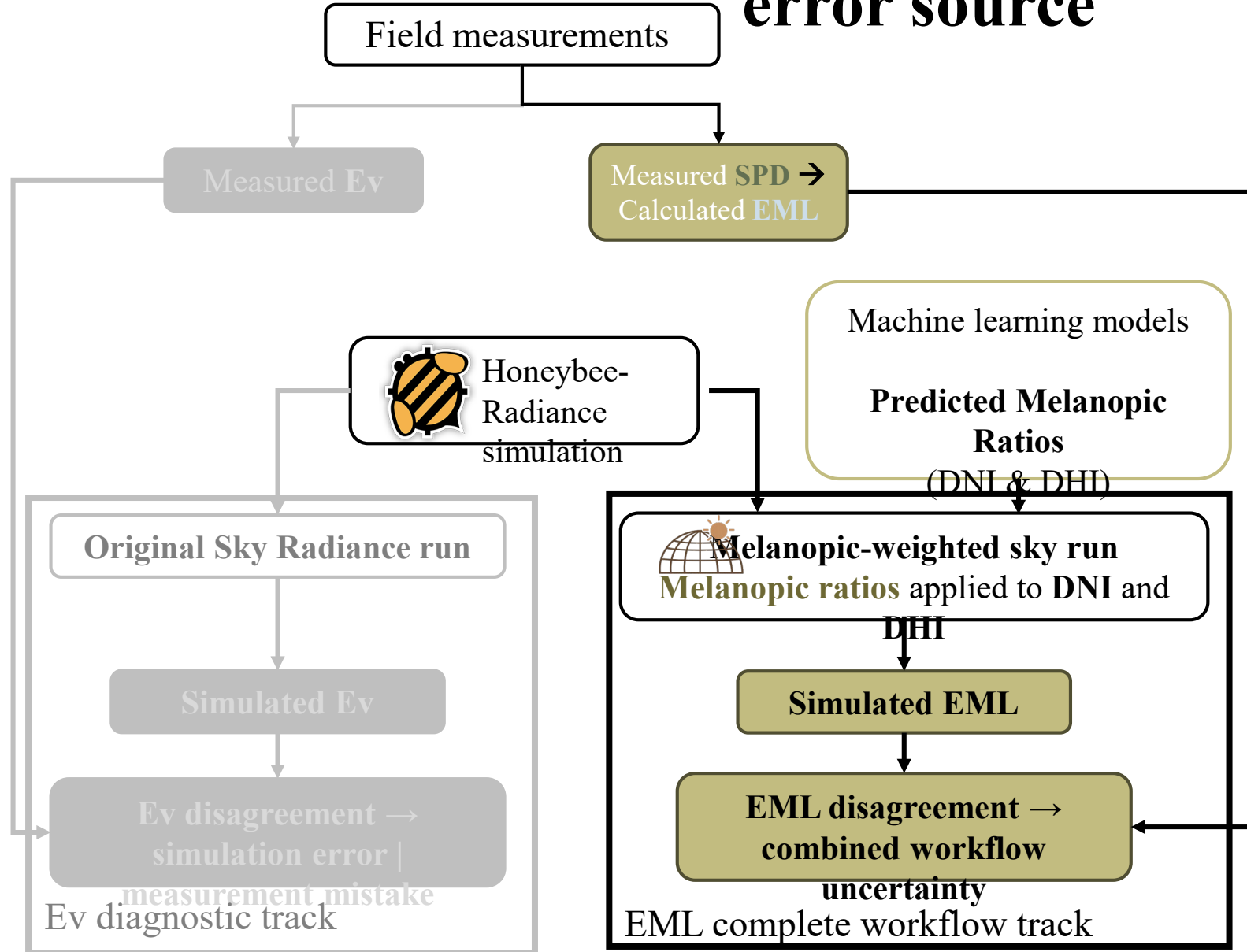


How to read the validation

- **E_v | diagnostic track**
Tests conventional Radiance simulation against measured illuminance.
- **EML | complete workflow track**
Tests predicted ratios + melanopic weighting + Radiance against reference EML.
- **Interpretation rule**
Strong E_v agreement but weaker EML agreement points toward uncertainty introduced by the melanopic weighting stage.

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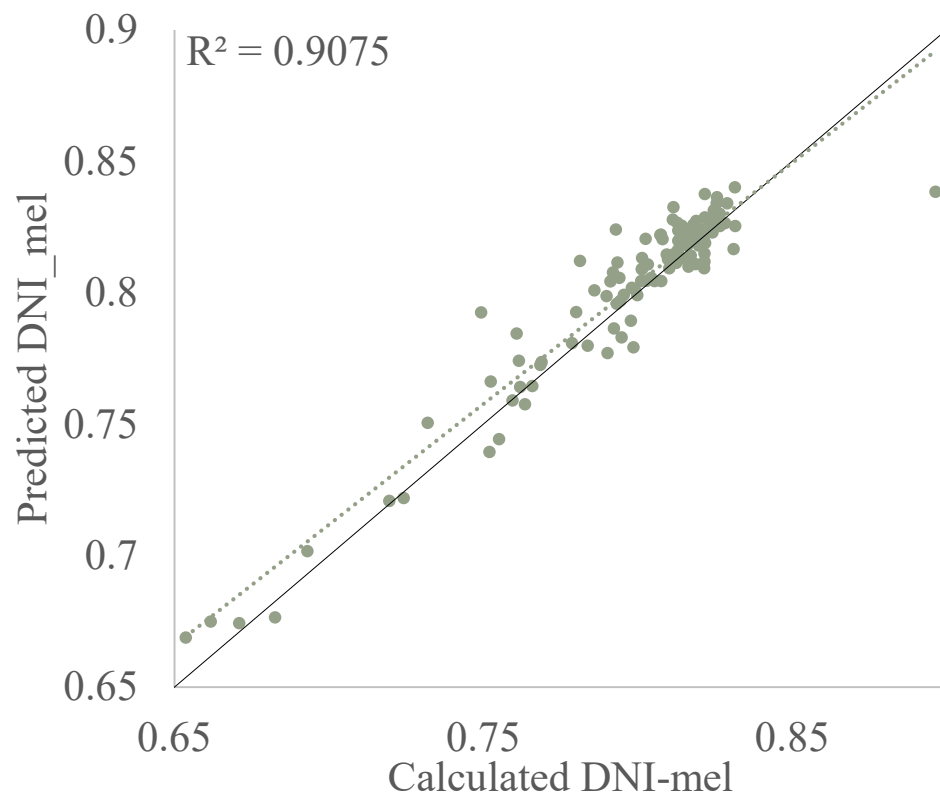
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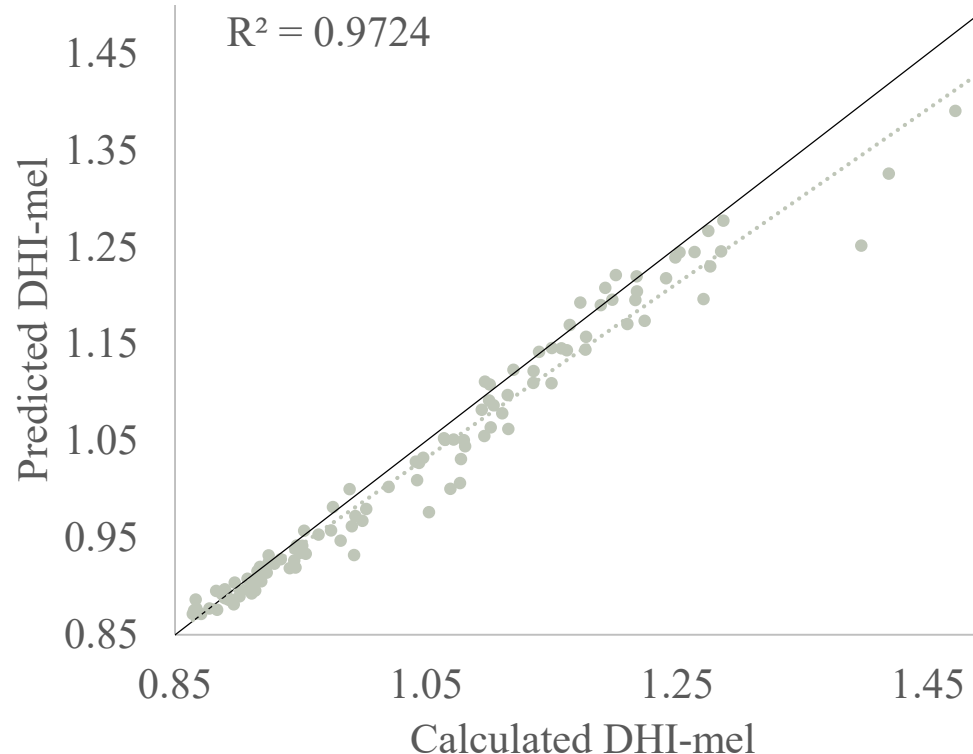
Validation result 1: melanopic

Strong agreement with reference ratios on the 2025 validation days

Model agreement plot for DNI-mel



Model agreement plot for DHI-mel



236 ratio predictions in total (**118 direct** + **118 diffuse**)

Only **one** prediction deviated by more than **10%**

Mean differences were approximately **-0.5% for DNI-mel** and **+1.5% for DHI-mel**



The predicted ratios
show sufficient
agreement to proceed
with the Radiance

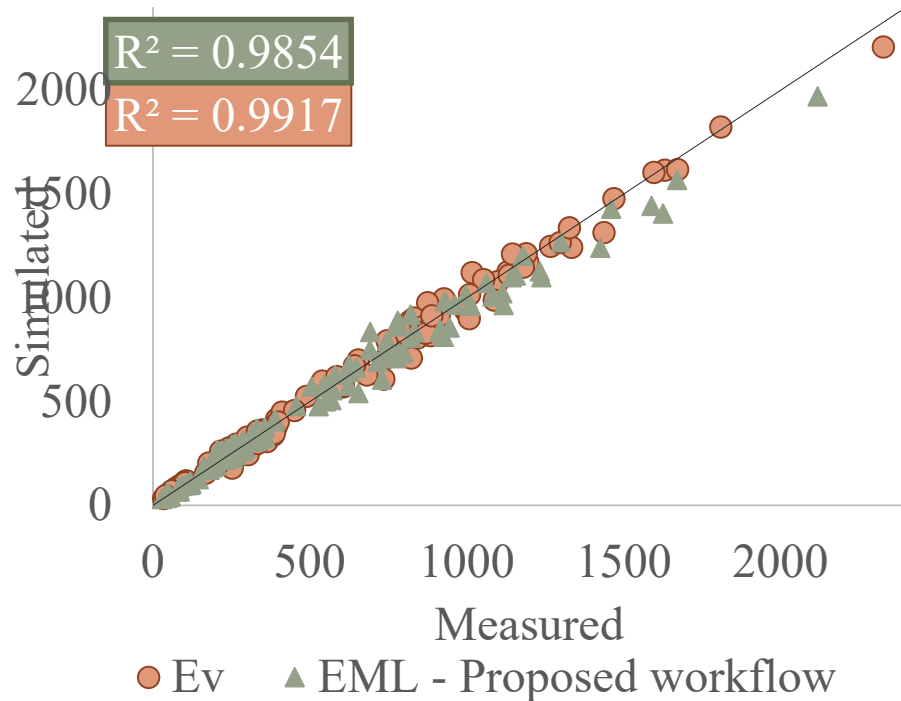
Validation result 2:

The complete workflow reproduces measured circadian daylight

indoor EML

Error by sky condi

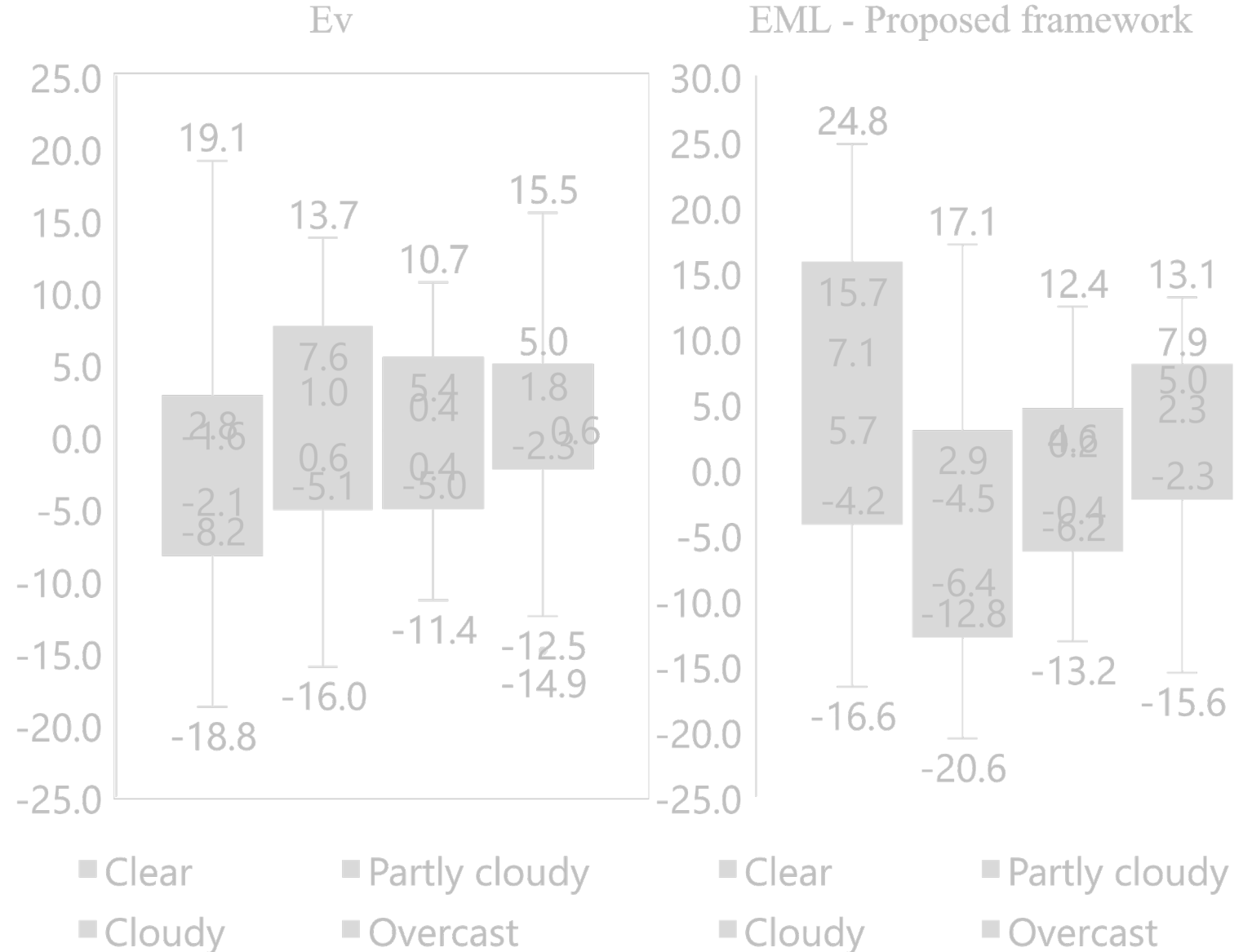
Overall agreement



Strong EML agreement supports the melanopic-weighted workflow without full spectral ray tracing

EML is sensitive to sky conditions.

Cloudy conditions show the most balanced EML errors, while partly cloudy conditions exhibit the strongest underestimation.

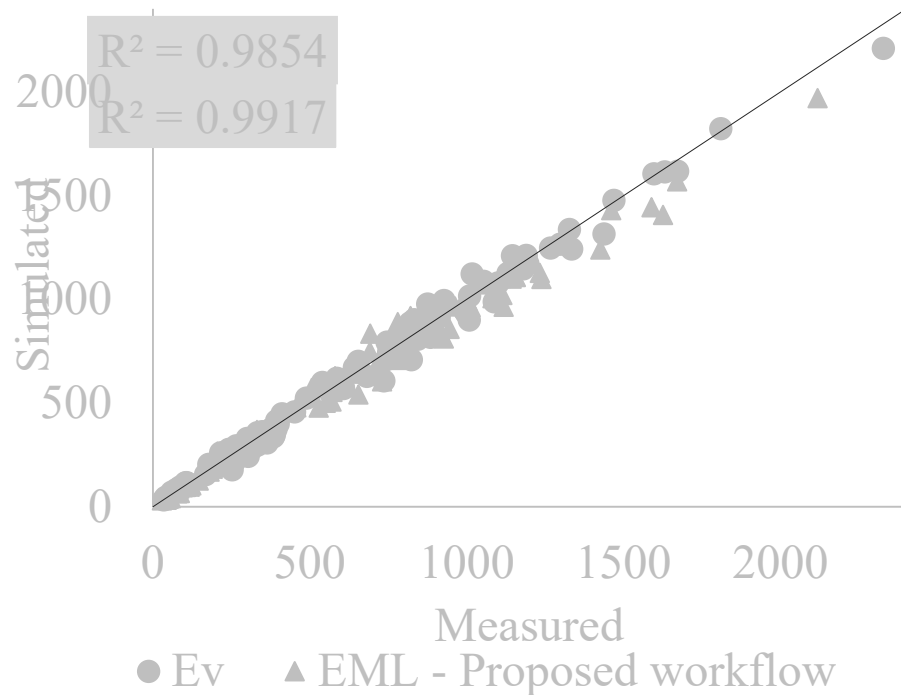


Validation result 2:

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Overall agreement

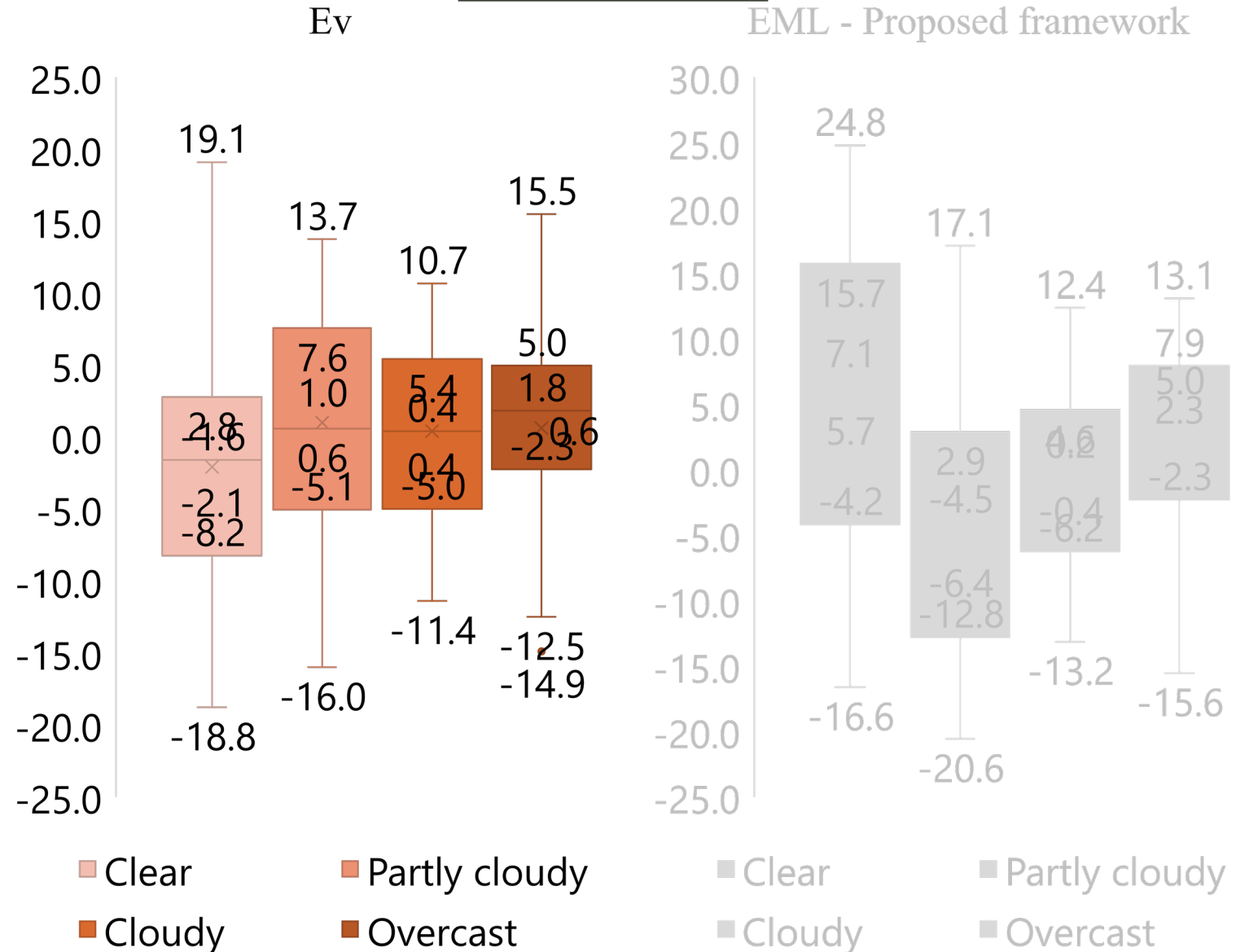


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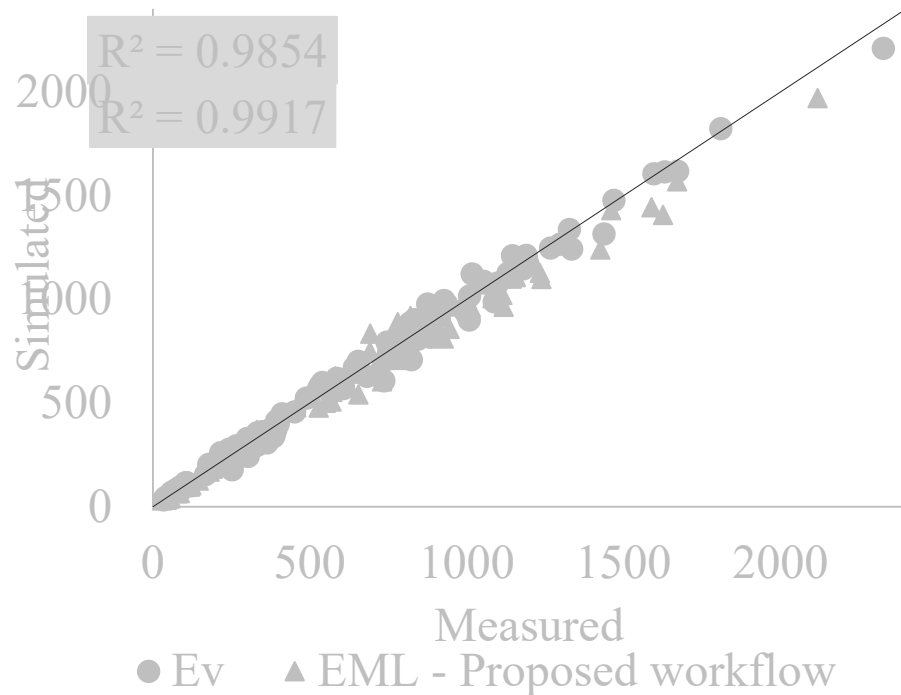
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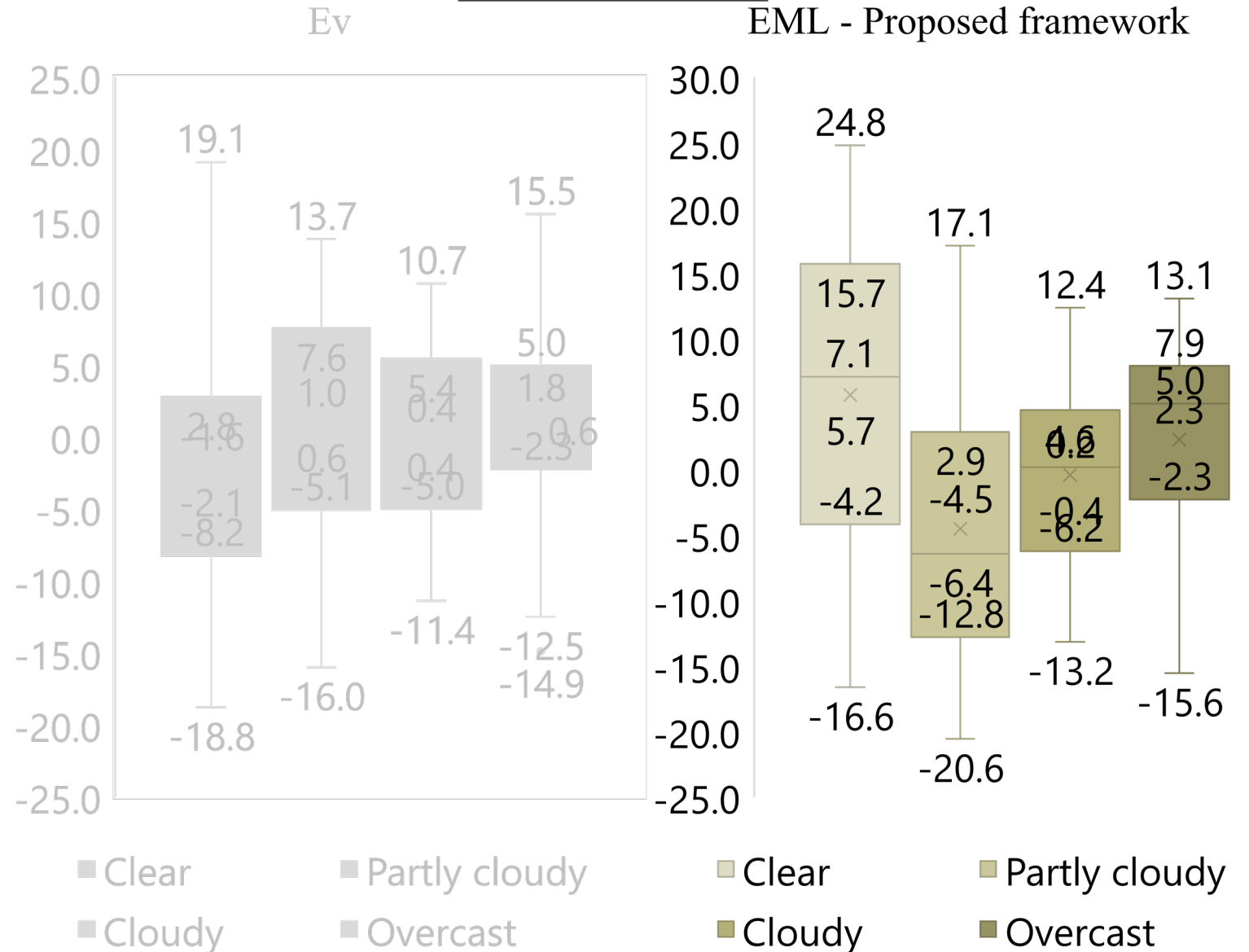
Overall agreement



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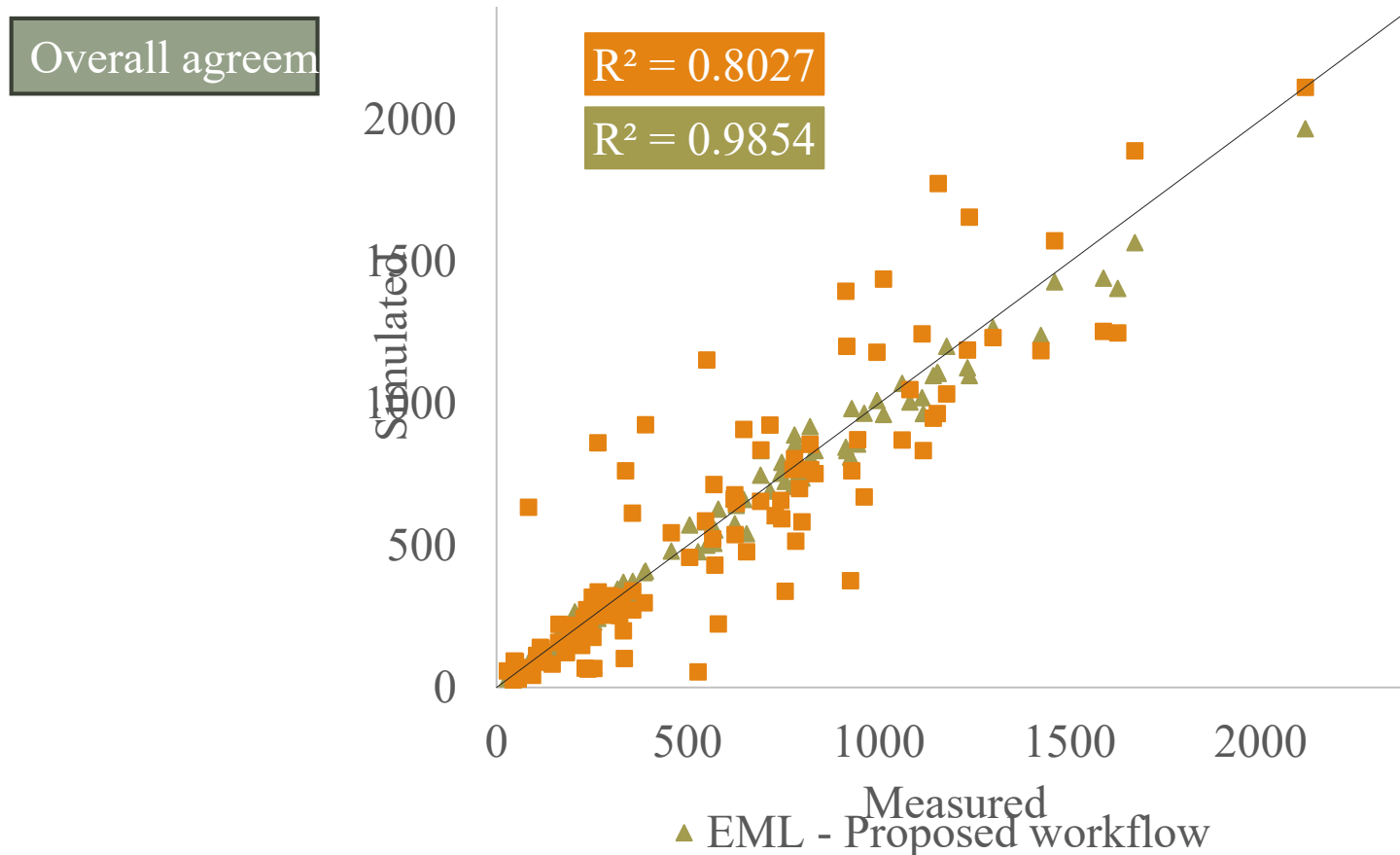
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Benchmark against full-spectral LARK

Under the evaluated conditions, the proposed workflow agrees more closely with measurements

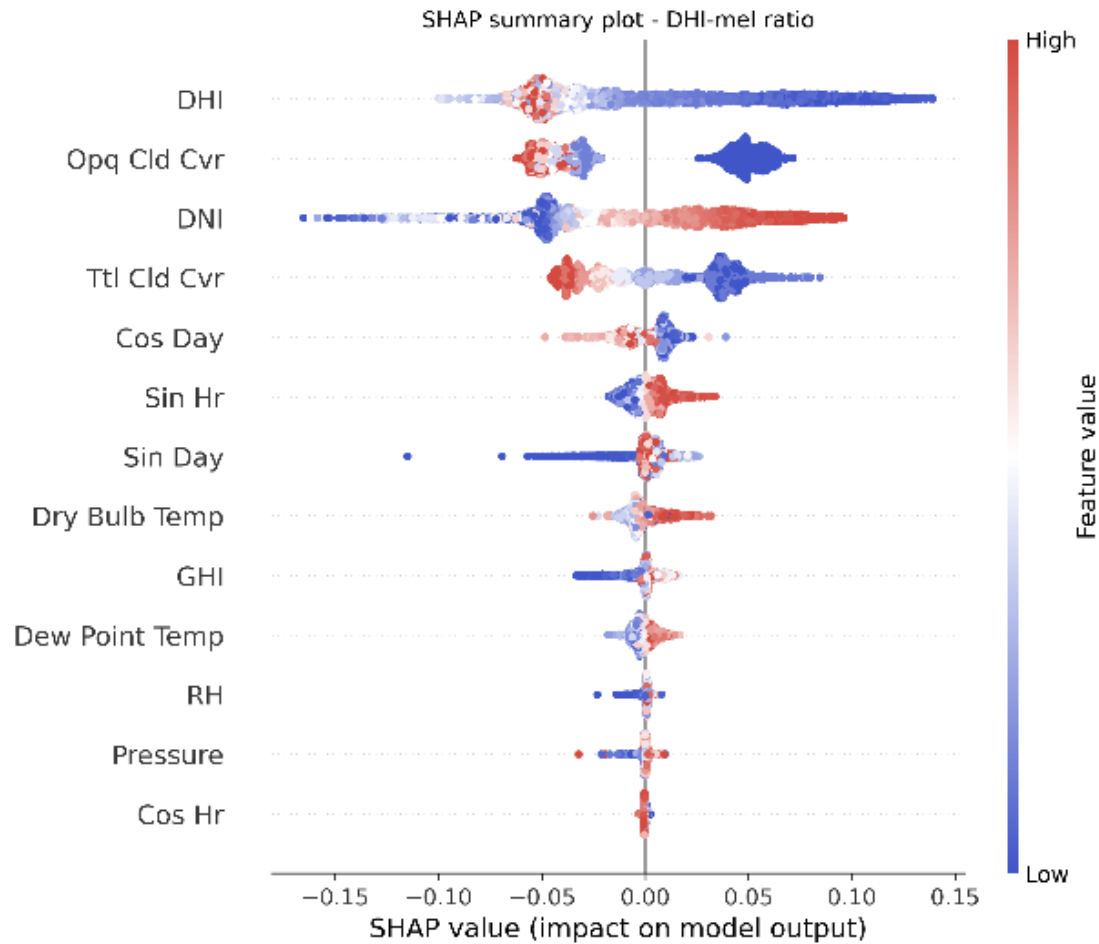


Under the evaluated conditions, the proposed workflow reproduced measured indoor EML more closely than the full-spectral LARK benchmark.

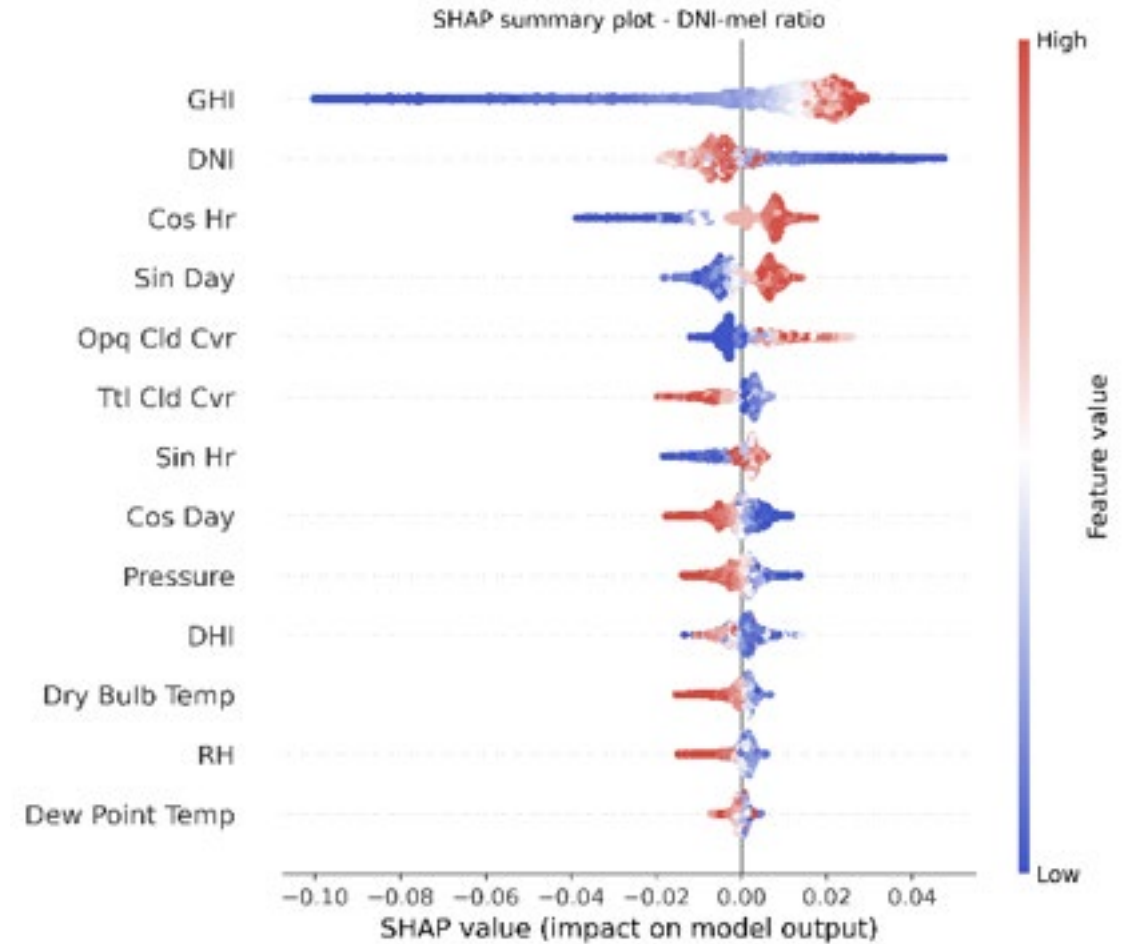
R^2 was 0.8027 for LARK and 0.9854 for the proposed workflow.

What controls the predictions?

SHAP interpretation links the ML model back to atmospheric physics



DHI-mel : cloud cover + irradiance



DNI-mel : irradiance + diurnal effects

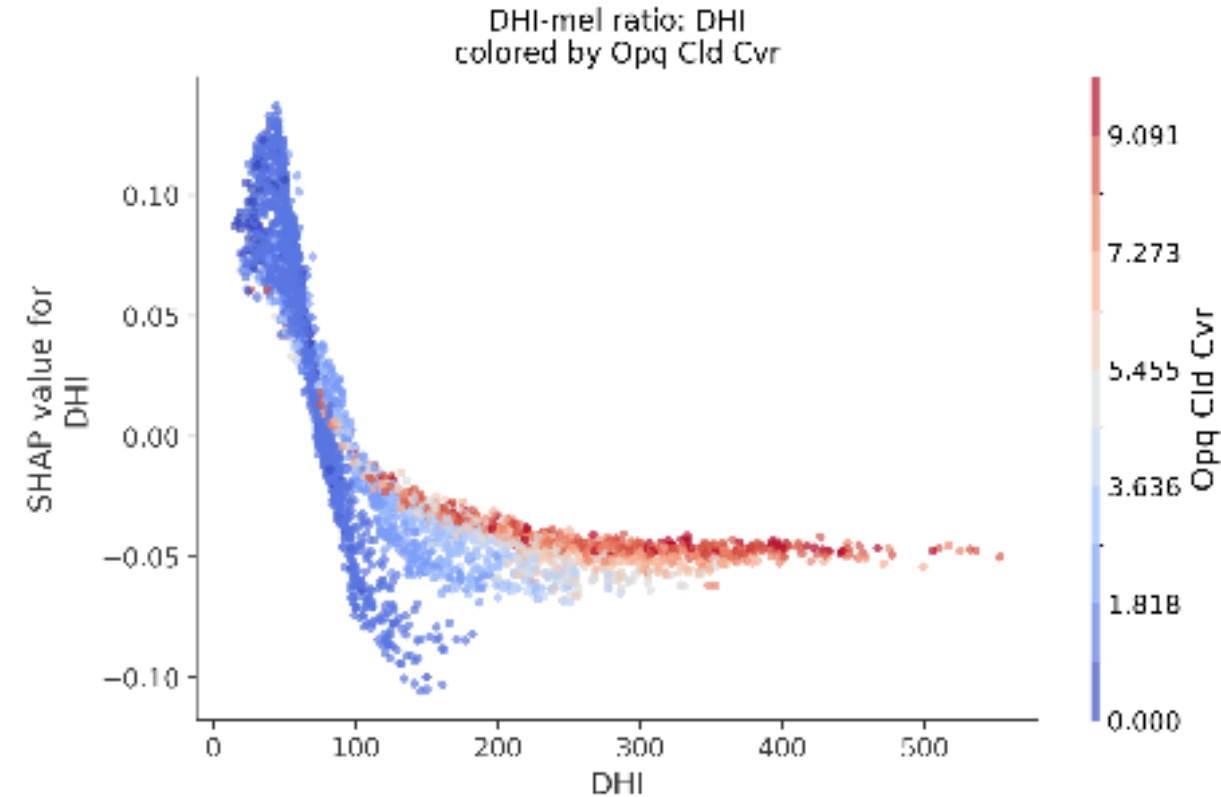
Minor variables: temperature, RH, pressure, and dew point temperature

A few interpretable

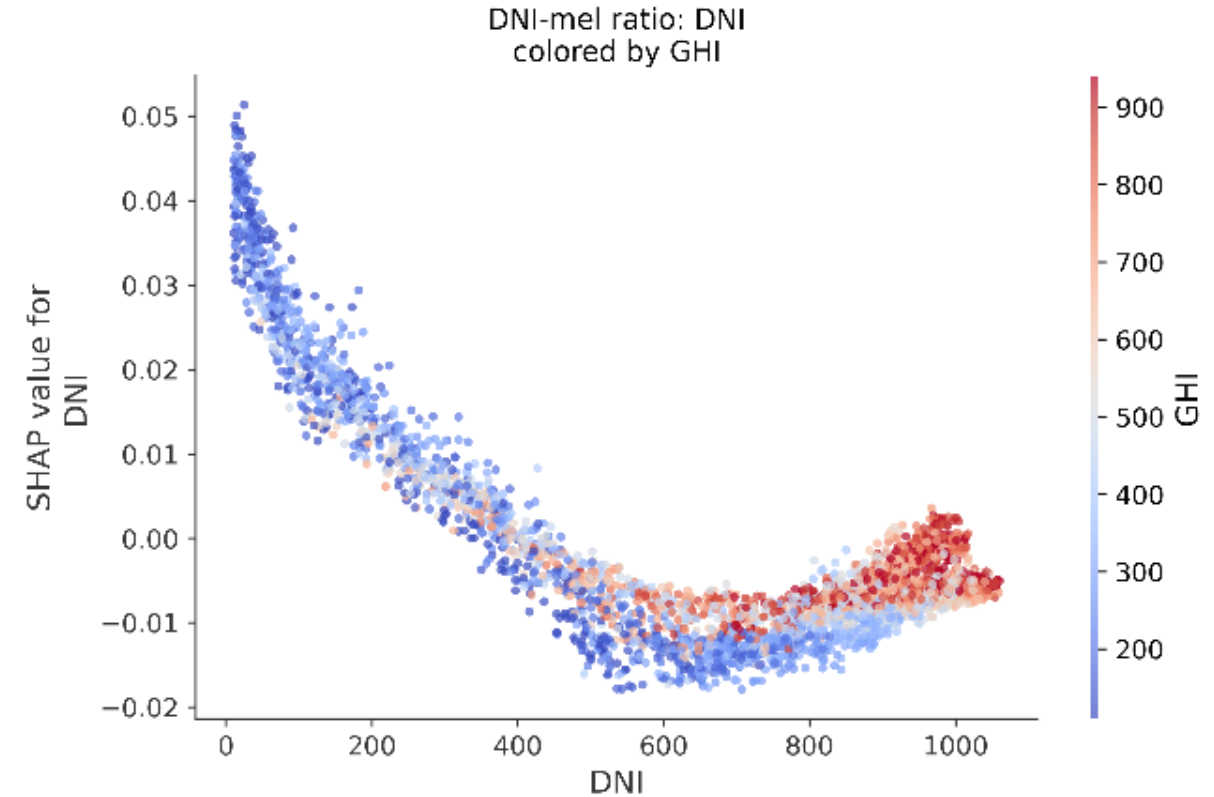
Predicted melanopic ratios show nonlinear irradiance effects that vary with concurrent sky conditions

DHI-mel | diffuse compo

DNI-mel | direct compo



DHI effect changes sign at $\sim 90\text{-}100 \text{ W/m}^2$
Opaque cloud cover shifts the response $\rightarrow$ DHI alone does not determine the DHI-mel ratio.



DNI shows a strong nonlinear response
GHI modulates the DNI contribution $\rightarrow$ the direct melanopic ratio depends on the Overall irradiance state

Implications, limitations, and

A practical Radiance pathway with the next steps direction for clear validation and implementation

What this enables

- Retains the conventional EPW-driven Honeybee-Radiance workflow.
- Avoids full spectral-sky reconstruction at every timestep
- Provides a practical pathway toward indoor melanopic daylight assessment

Current scope

- Developed and validated using data from Golden, Co.
- Experimental validation uses a controlled scale model and fixed viewing geometry
- The current framework modifies the outdoor daylight input; spectral effects of interior materials are not explicitly modeled

Next steps

- Evaluate different location and gaze direction
- Extend the framework to account for spectral properties of interior materials
- Streamline implementation for rapid use in Rhino/Grasshopper

A practical bridge between conventional Radiance simulation and melanopic daylight assessment, without requiring a full spectral workflow.

Thank you for your attention!

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PennState



**The 24th International Radiance
Workshop
August 31 – September 2, 2026**