Pacific Northwest
NATIONAL LABORATORY

Improving Lighting Simulations for Application Efficiency

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U.S. DEPARTMENT OF ENERGY BATTELLE

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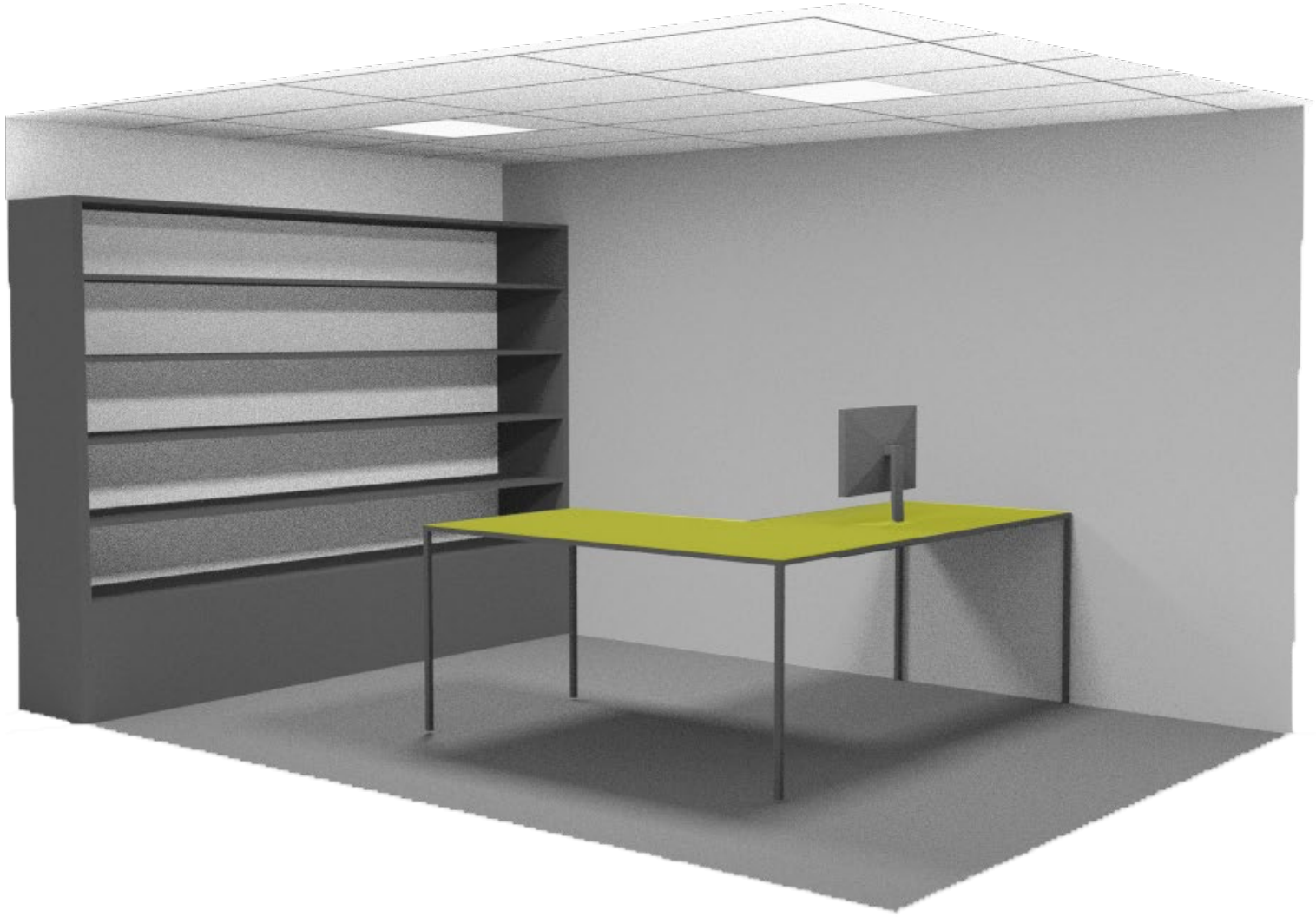
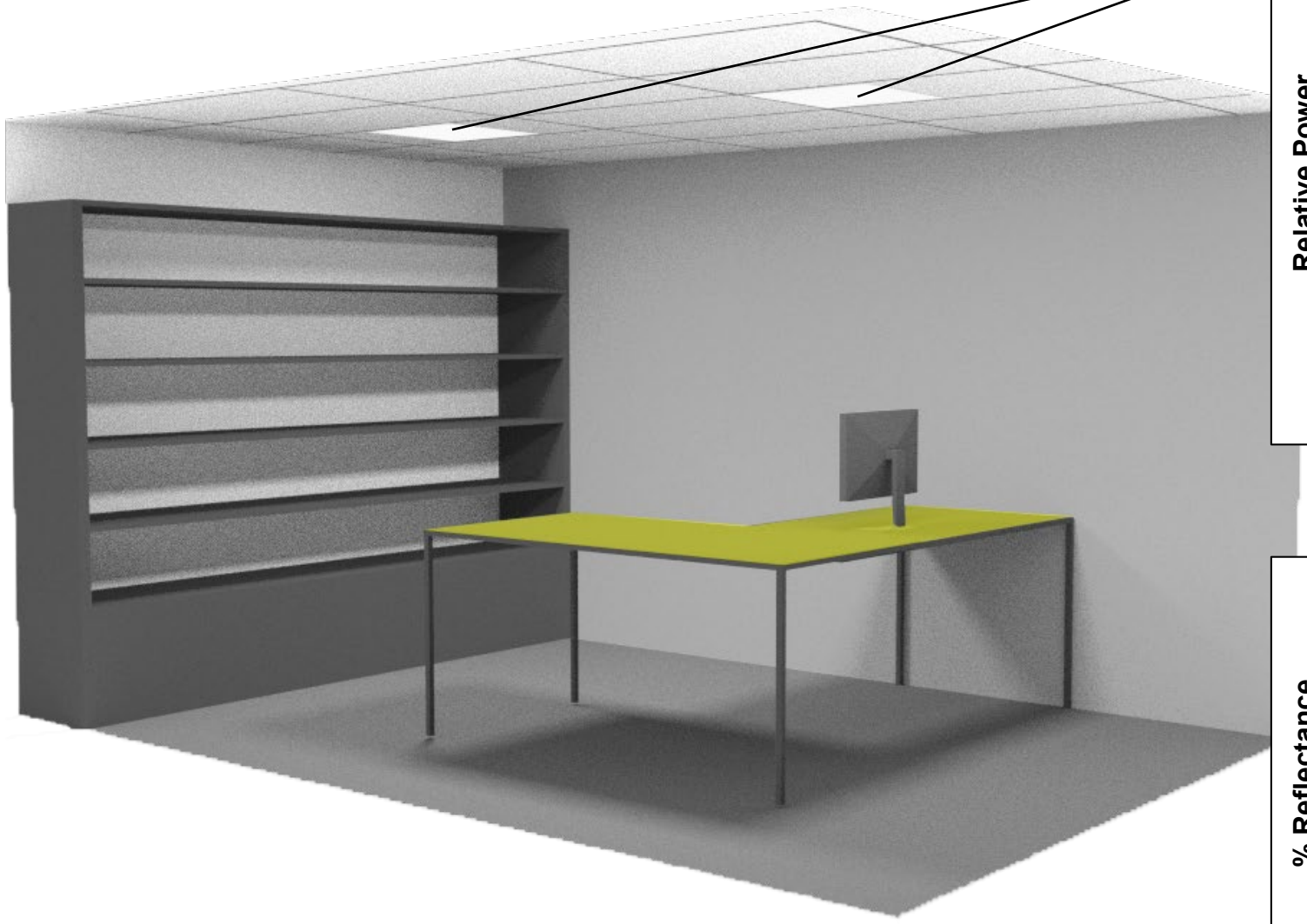
Simulation Tools for Lighting Design



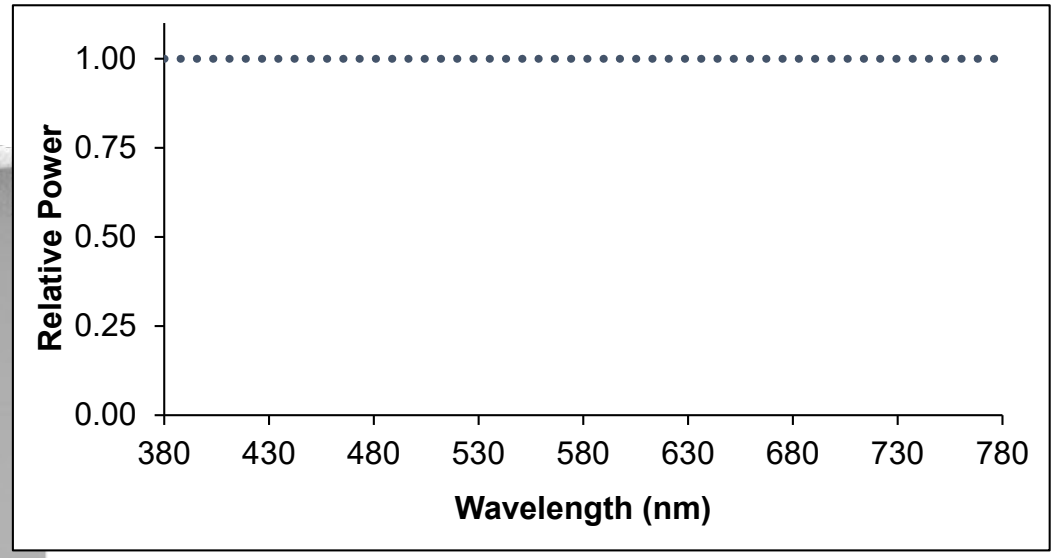
Lighting recommendations for visual needs:

- Horizontal or vertical illuminance on target surface

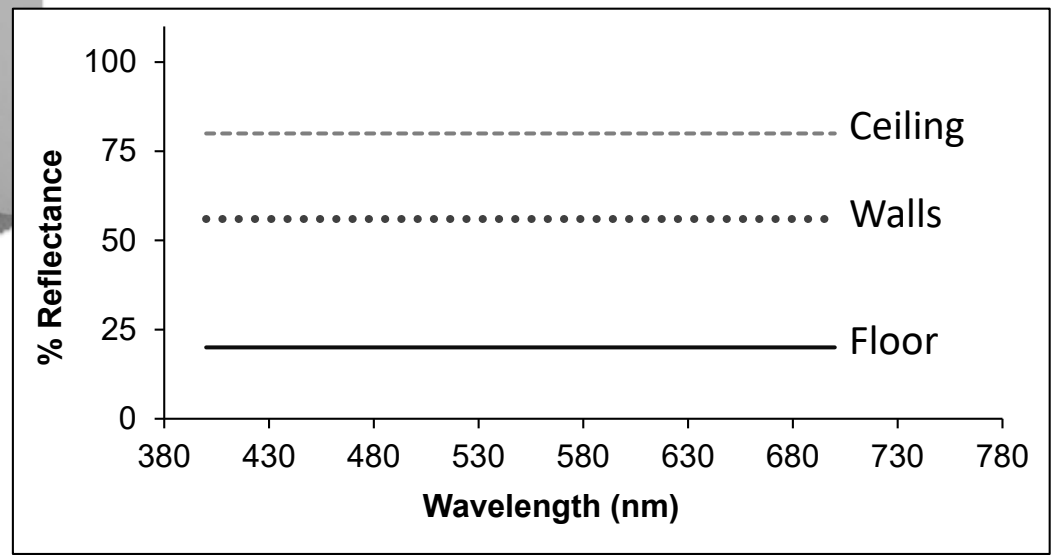
Simulation Tools for Lighting Design



Luminaire Spectral Power Distribution

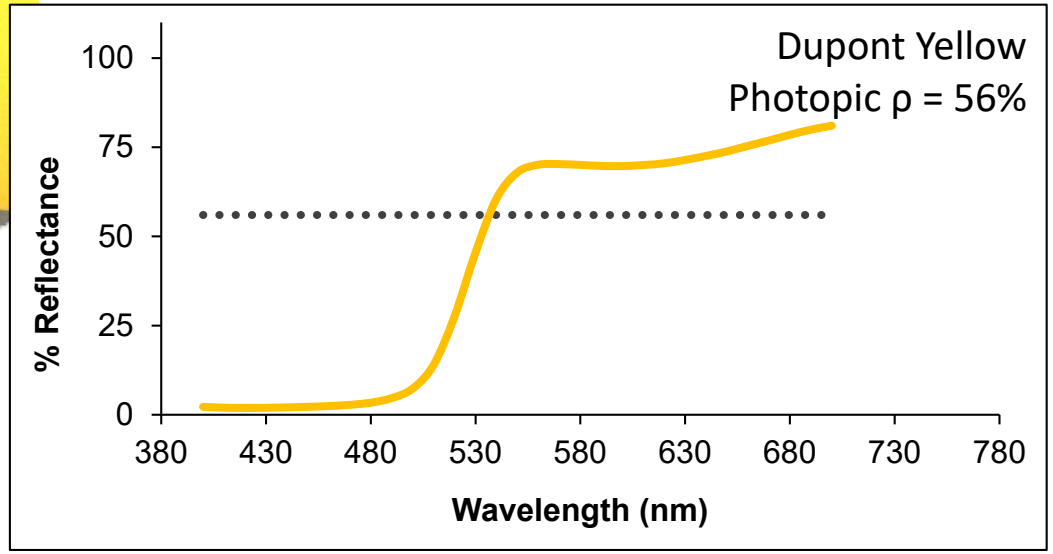


Surface Reflectance Distributions

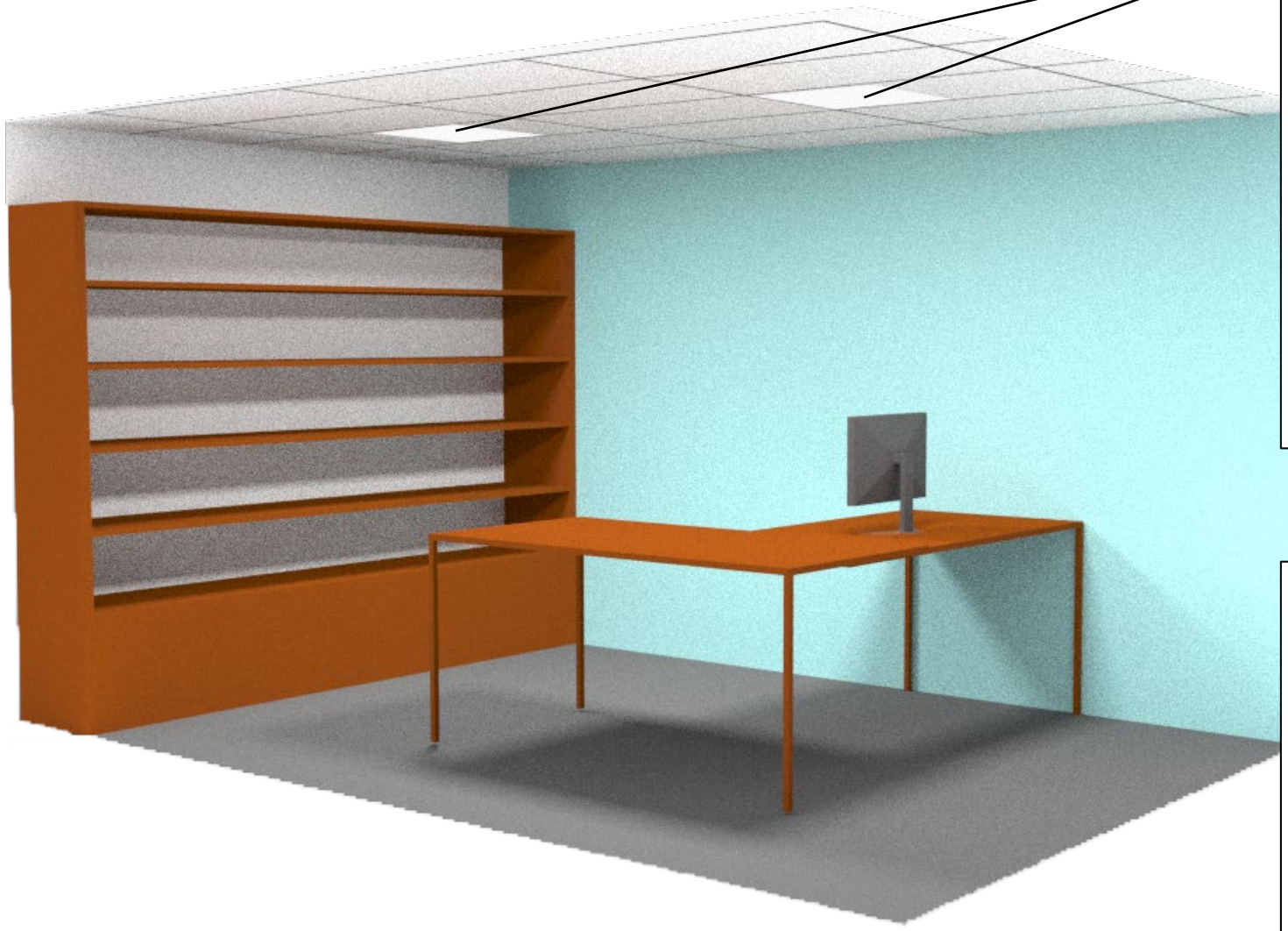


Simulation Tools for Lighting Design

Surface Reflectance Distributions



Simulation Tools for Lighting Design



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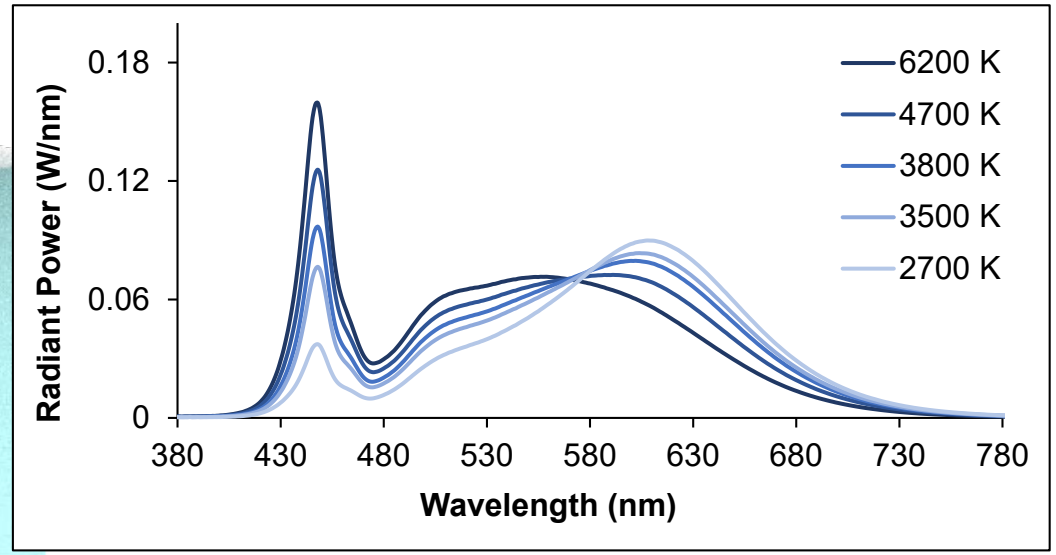

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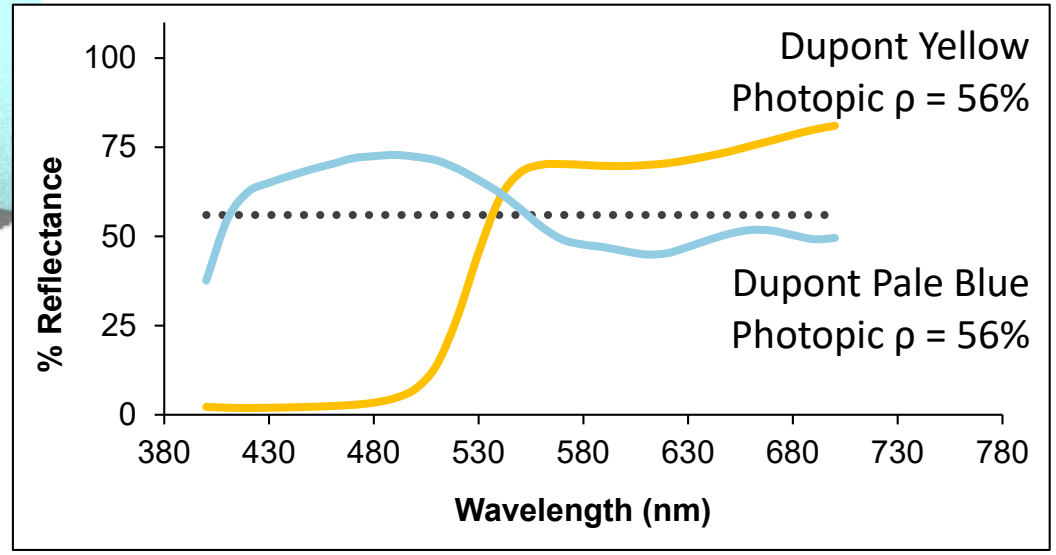


Lighting Recommendations – Beyond Visual Needs

- **Equivalent Melanopic Lux (EML)**
  - WELL Building Standard, from Lucas paper, ipRGCs, m-lx
- **Melanopic Irradiance**
  - CIE, micro-W/cm^2
- **Circadian Stimulus (CS)**
  - Lighting Research Center, ipRGCs + rods & cones

Intensity, spectrum, duration, timing, prior exposure, individual differences, etc.

Lighting recommendations – Beyond visual needs

Equivalent Melanopic Lux (EML) & Circadian Stimulus (CS) Recommendations

- WELL Building Standard v1 (May 2016)

  ≥250 EML *at 75% of view positions, 4’ AFF, 4 hours*

- WELL Building Standard v1 (Q3 2017)

  ≥200 EML *at 75% of view positions, 4’ AFF, 9 AM – 1 PM*

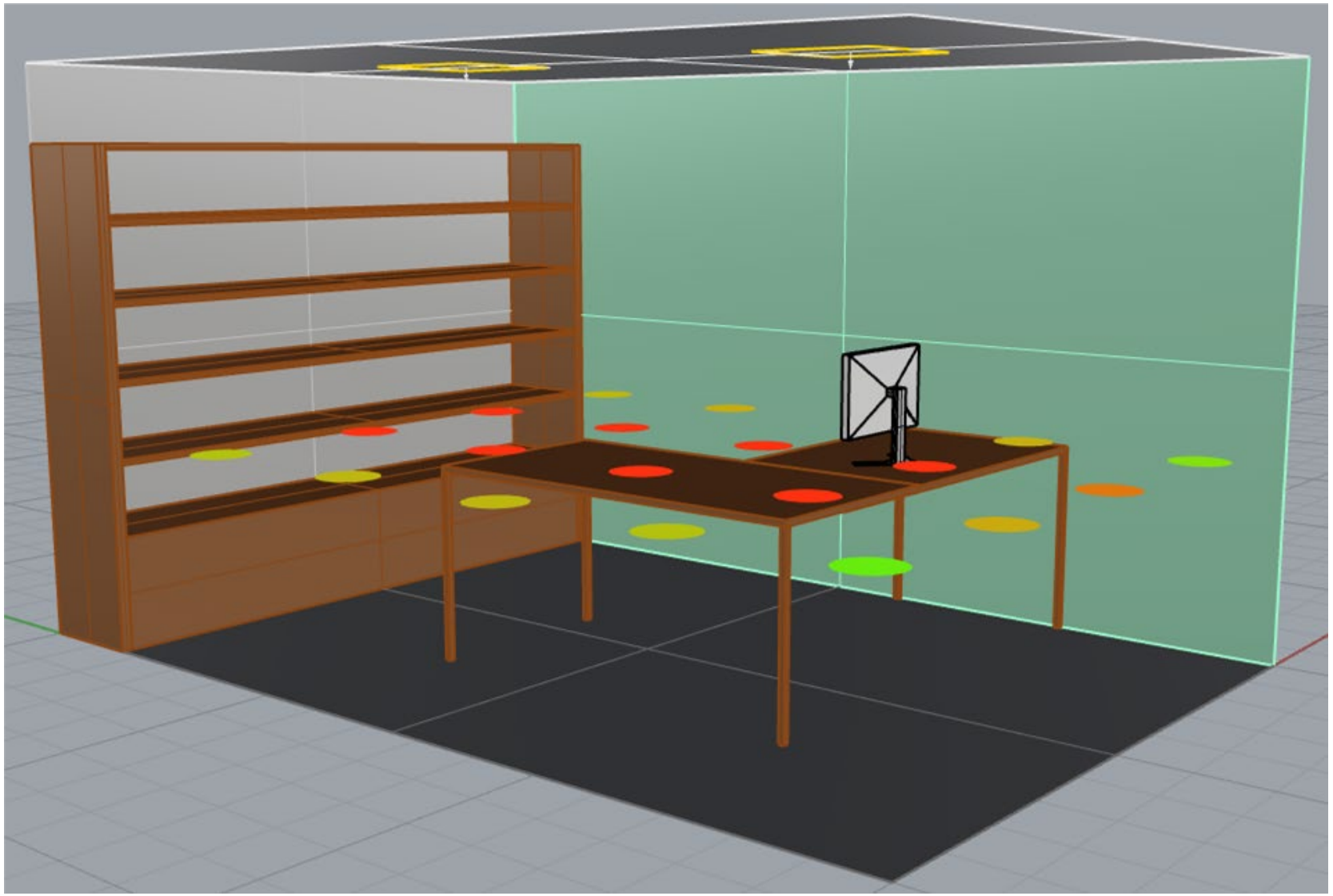
- WELL Building Standard v2 (Q2 2019)

  1 pt: ***≥150 EML*** *OR* ***≥0.3 CS*** *at 100% view positions, 4’ AFF, 9 AM – 1 PM*

  3 pts: ***≥240 EML*** *at 100% view positions, 4’ AFF, 9 AM – 1 PM*

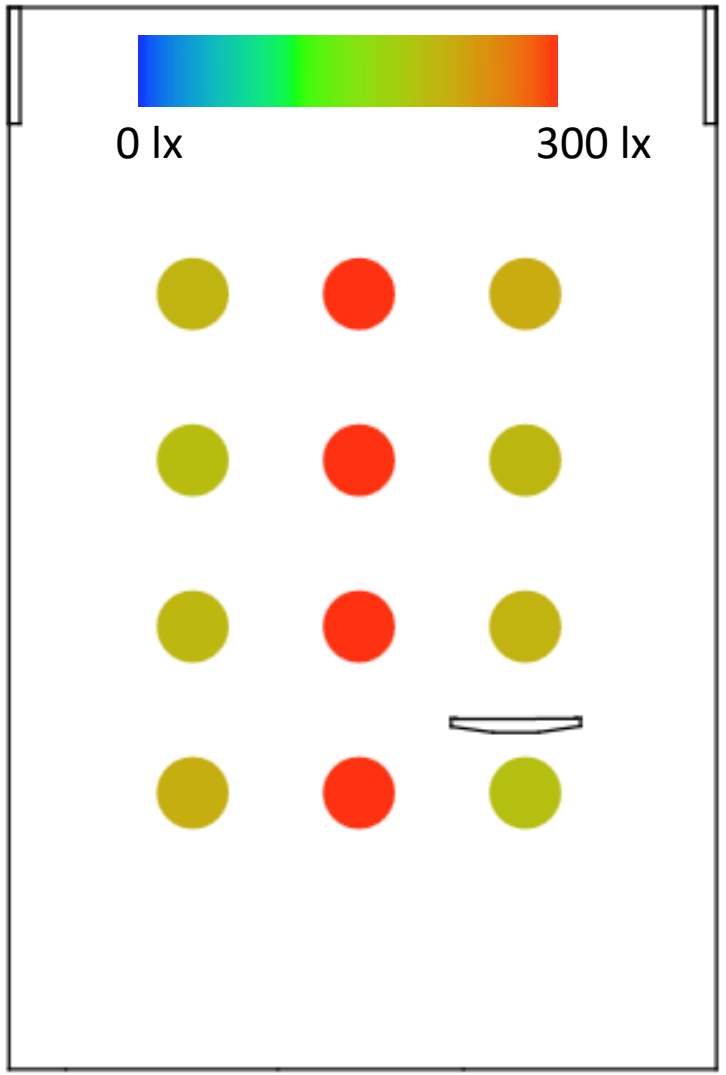
- UL Design Guideline 24480 (2020)

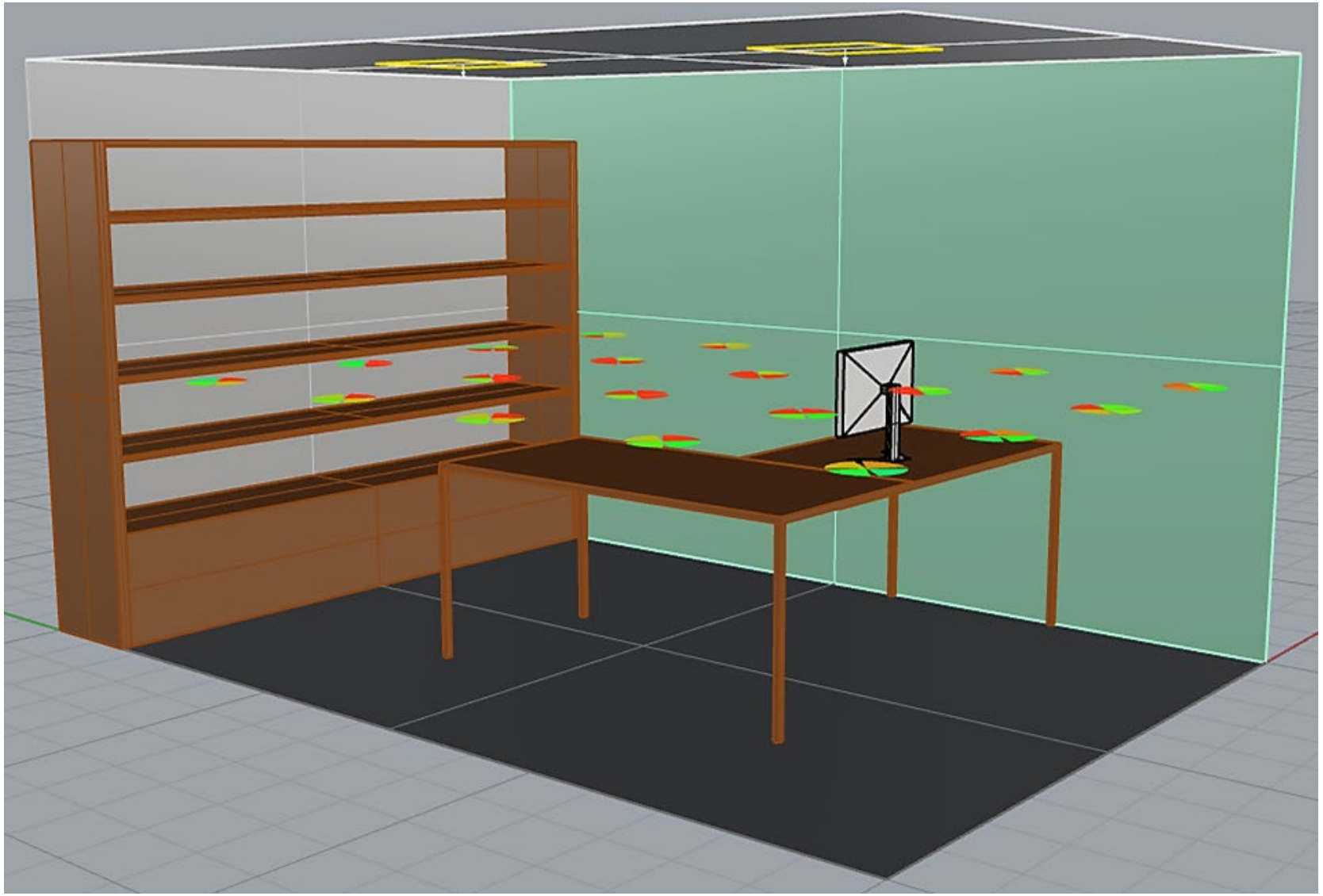
  ≥0.3 CS *at 100% view positions, 43” AFF, 2+ hours between 7 AM – 4 PM*



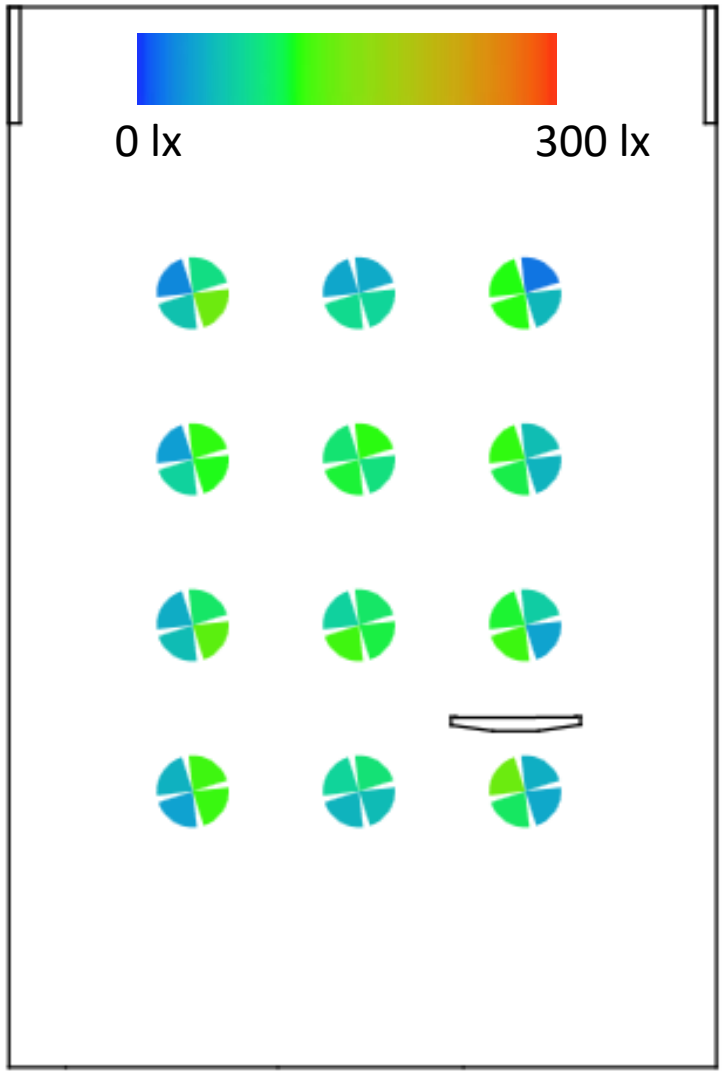
Horizontal Point Illuminance Calculations

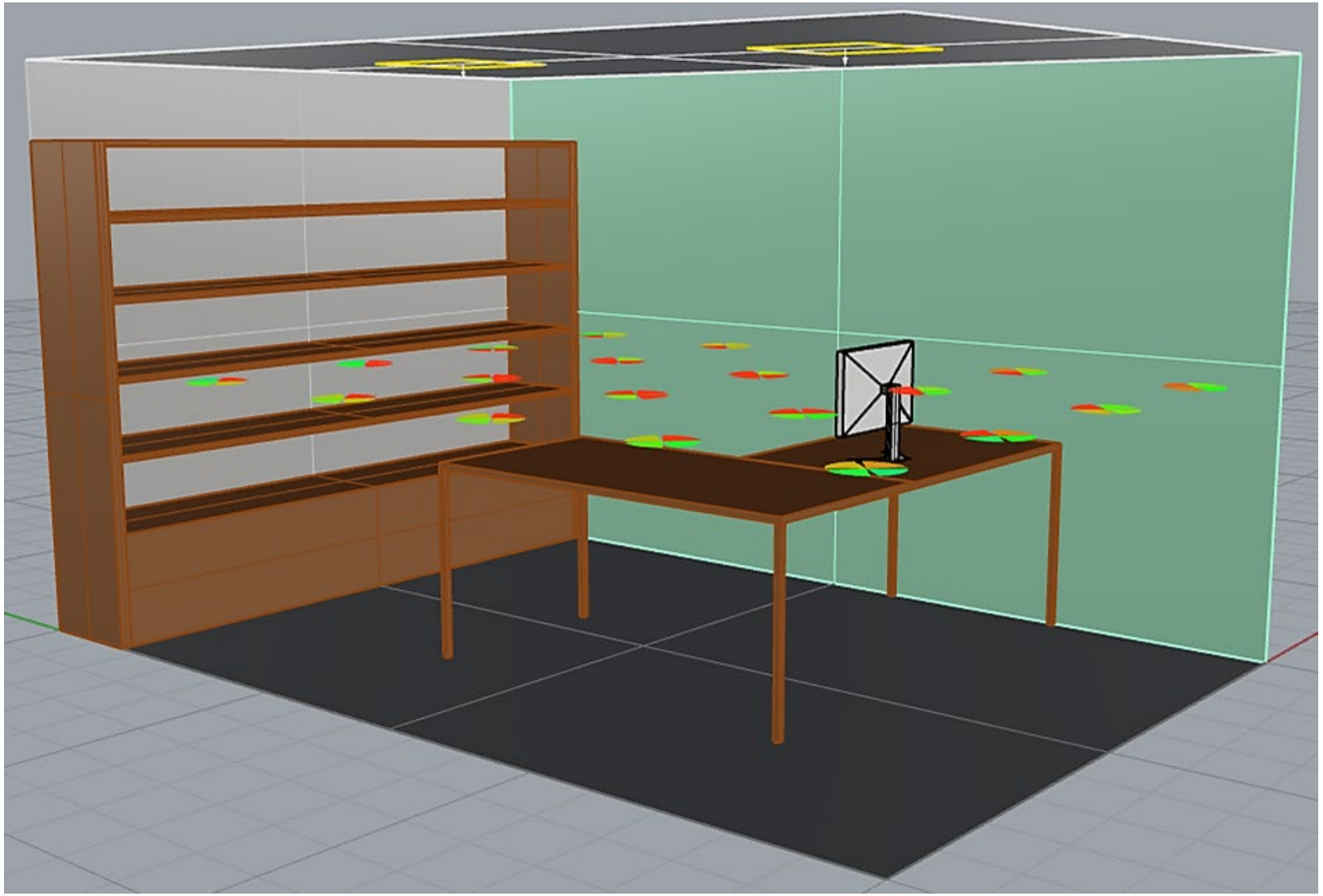
3’ AFF



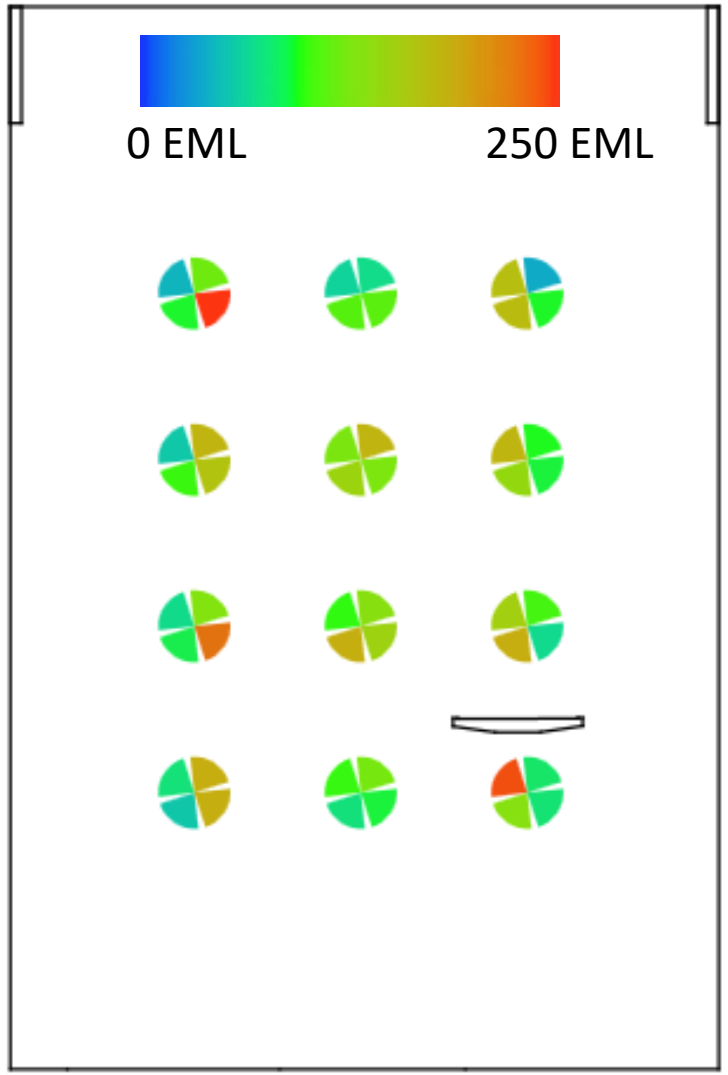


Vertical View
Illuminance Calculations
4.5’ AFF

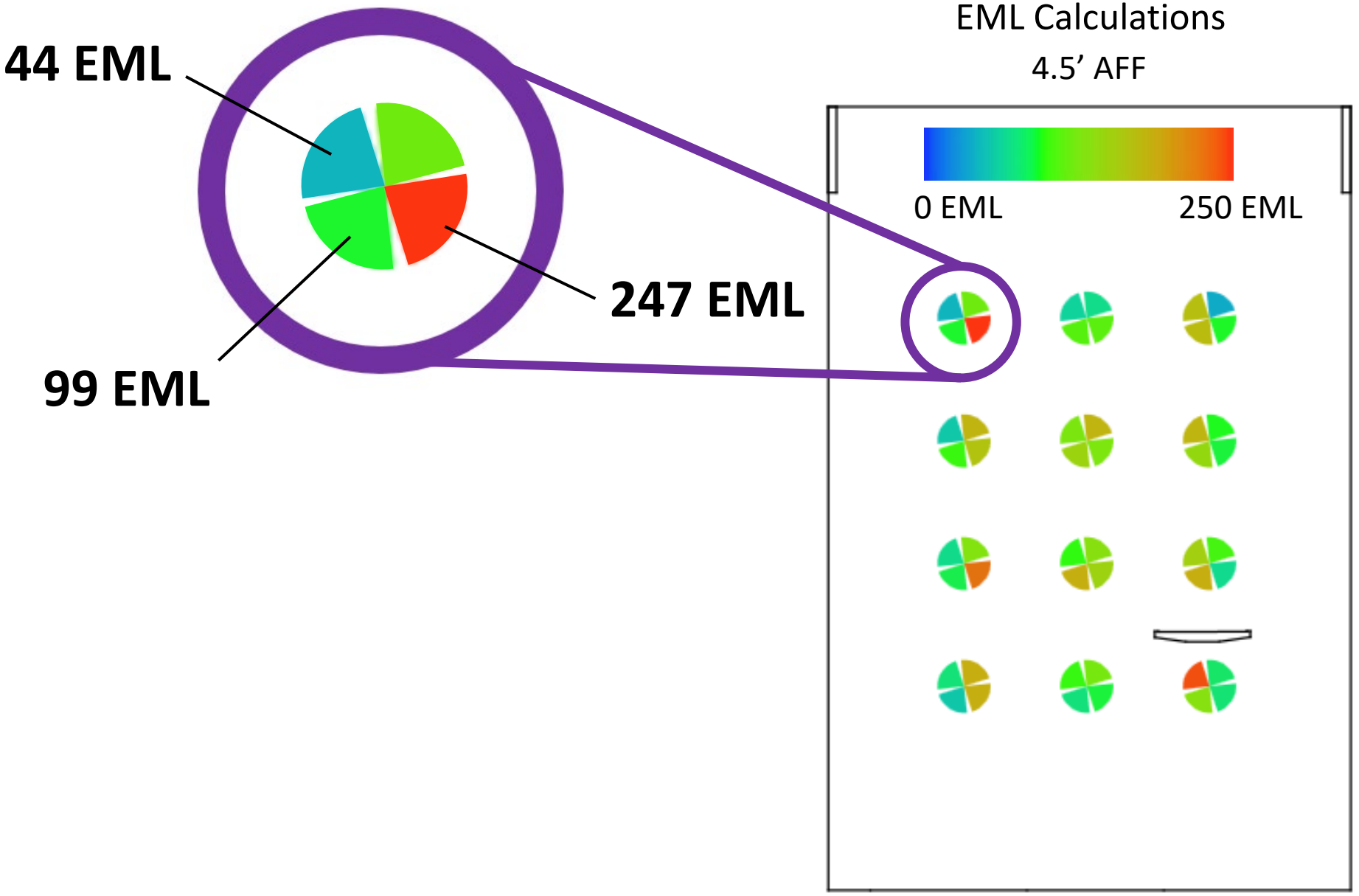


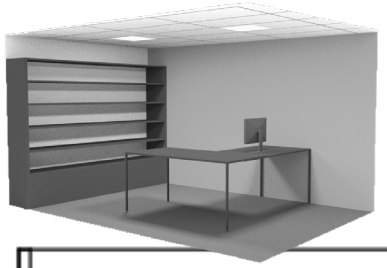


Vertical View
EML Calculations
4.5’ AFF



Vertical View
EML Calculations
4.5’ AFF



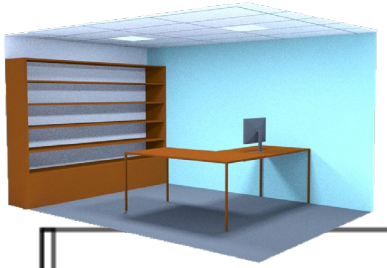


CCT = N/A
Avg. EML = 181

0 EML 250 EML

CCT = 3800K
Avg. EML = 98

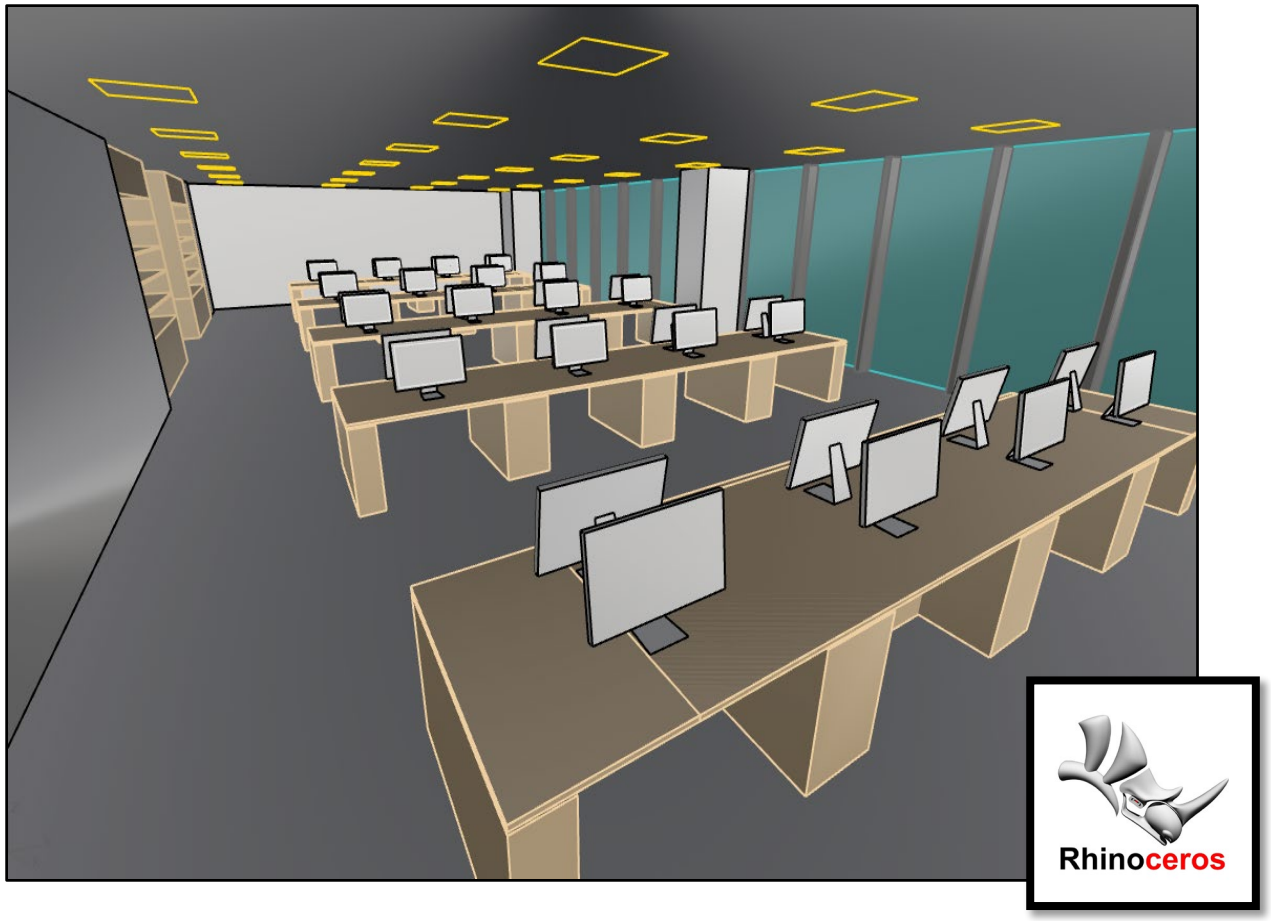
0 EML 250 EML



CCT = 6200K
Avg. EML = 137

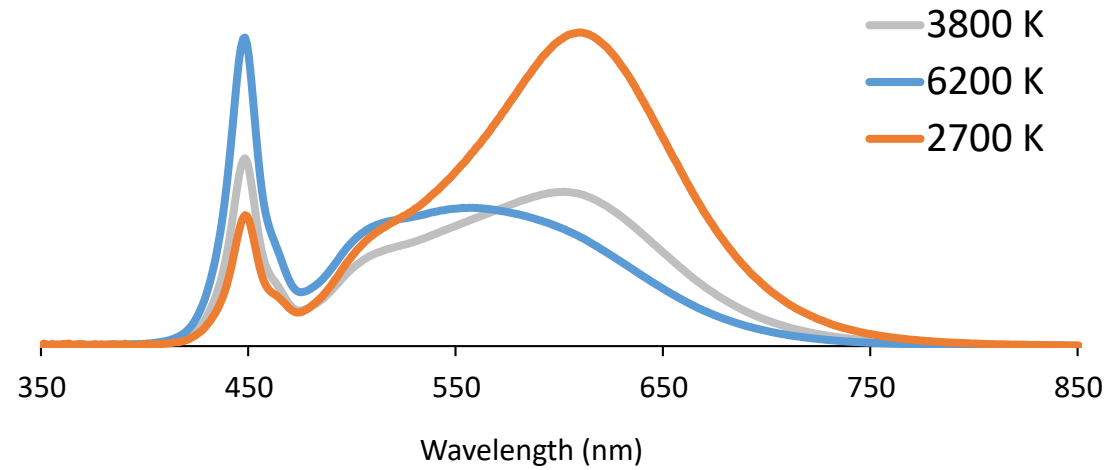
0 EML 250 EML

Rhino Model

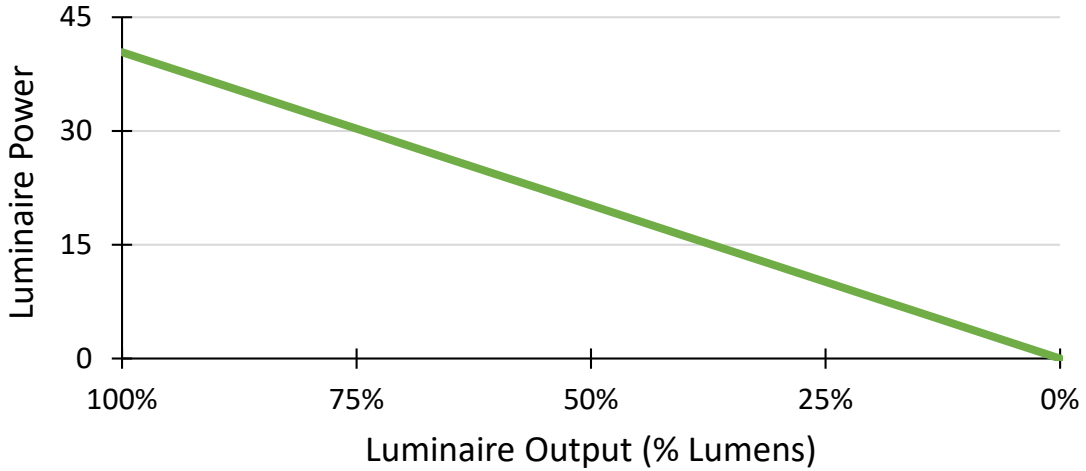


Measured Luminaire Information

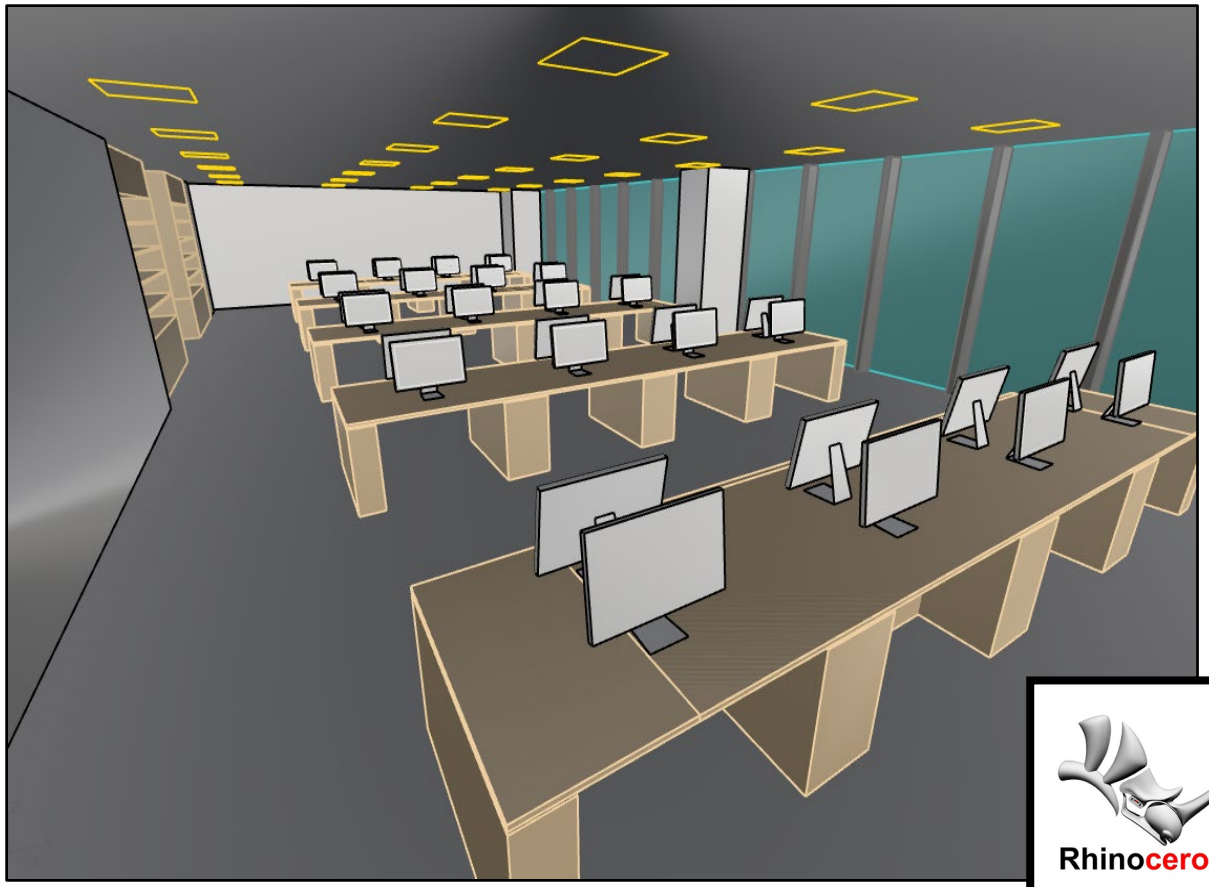
SPDs of white-tunable LED luminaire



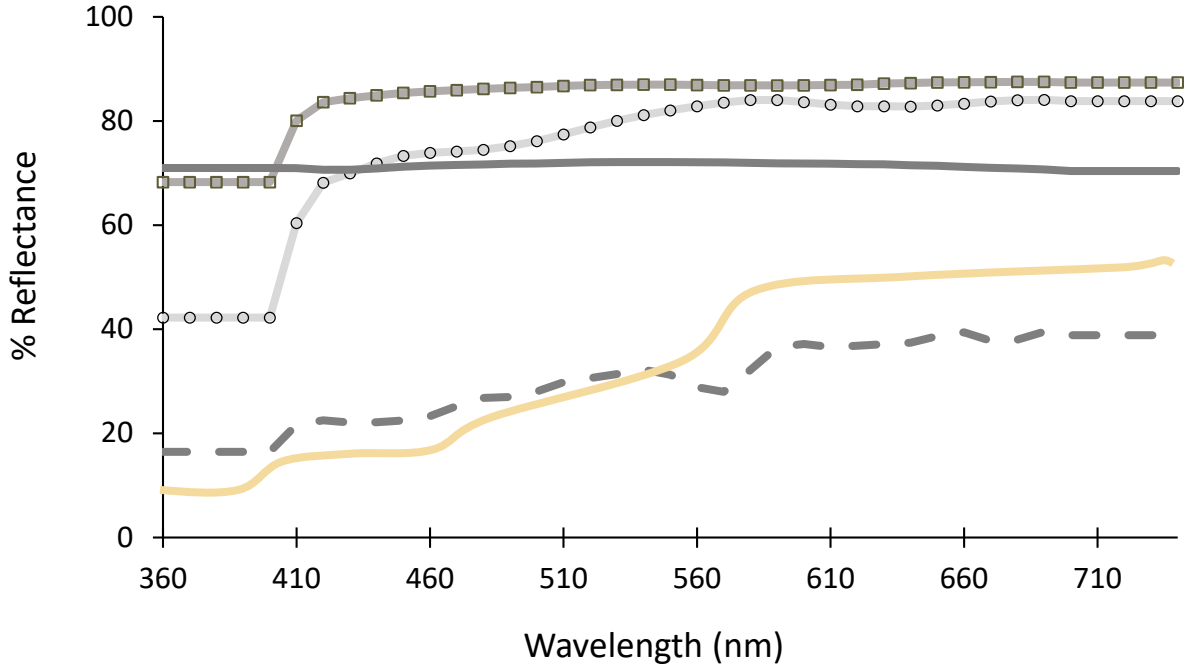
Power draw across range of intensity settings



Rhino Model



Measured Surface Information



Surfaces	Avg. Reflectance
White Paint	0.75
Flooring - Dark Grey	0.30
White Ceiling Tile	0.84
Silver Window Frame	0.71
Blonde Wood Furniture	0.37

Baseline Condition

Simulation Goals:

- Lighting meets IES visual requirements
  - **300** lx horizontal 30" above floor
  - **150** lx vertical 18" above work plane
- Lighting meets WELL v2 Pilot (2019) Circadian Lighting Design Credit
  - **100%** of desk locations receive at least **150 EML *OR* CS > 0.3** (1 point)
  - OR **100%** of desk locations receive at least **240 EML** (3 points)

Simulation Input:

- 5000 annual operating hours
- Typical lighting solution
  - 3800 K
  - (32) 2x2 Recessed LED Luminaires

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Simulation Results:

System Output (% lumens)	CCT (K)
50	3800

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Simulation Results:

System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)
50	3800	**389**	**191**

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Simulation Results:

System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML
50	3800	**389**	**191**	0.12	112

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Simulation Results:

System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML	% Views 150+ EML	% Views 240+ EML	% Views CS > 0.3	Meet WELL Requirement?
50	3800	**389**	**191**	0.12	112	**0%**	**0%**	**0%**	**N**

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System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML	% Views 150+ EML	% Views 240+ EML	% Views CS > 0.3	Meet WELL Requirement?	Annual Energy Usage (kWh)
50	3800	**389**	**191**	0.12	112	**0%**	**0%**	**0%**	**N**	3239

Baseline Condition

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- Lighting meets IES visual requirements
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50	3800	**389**	**191**	0.12	112	**0%**	**0%**	**0%**	**N**	3239
100	3800	**780**	**378**	0.2	223	**100%**	**30%**	**0%**	**Y – 1 point**	6478

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Simulation Input:

- 5000 annual operating hours
- Typical lighting solution
  - ~~**3800 K**~~ → **6200 K**
  - (32) 2x2 Recessed LED Luminaires

Simulation Results:

System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML	% Views 150+ EML	% Views 240+ EML	% Views CS > 0.3	Meet WELL Requirement?	Annual Energy Usage (kWh)
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100	3800	**780**	**378**	0.2	223	**100%**	**30%**	**0%**	**Y – 1 point**	6478
100	6200	**773**	**369**	0.36	305	**100%**	**98%**	**100%**	**Y – 1 point**	6478

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Simulation Input:

- 5000 annual operating hours
- Typical lighting solution
  - ~~**3800 K**~~ → **6200 K**
  - (32) 2x2 Recessed LED Luminaires

Simulation Results:

100% Increase in annual energy usage

System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML	% Views 150+ EML	% Views 240+ EML	% Views CS > 0.3	Meet WELL Requirement?	Annual Energy Usage (kWh)
50	3800	**389**	**191**	0.12	112	**0%**	**0%**	**0%**	**N**	3239
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Simulation Input:

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- Typical lighting solution
  - ~~**3800 K**~~ → **6200 K**
  - (32) 2x2 Recessed LED Luminaires

ALTERNATE USAGE SCENARIO

30% Increase in annual energy usage

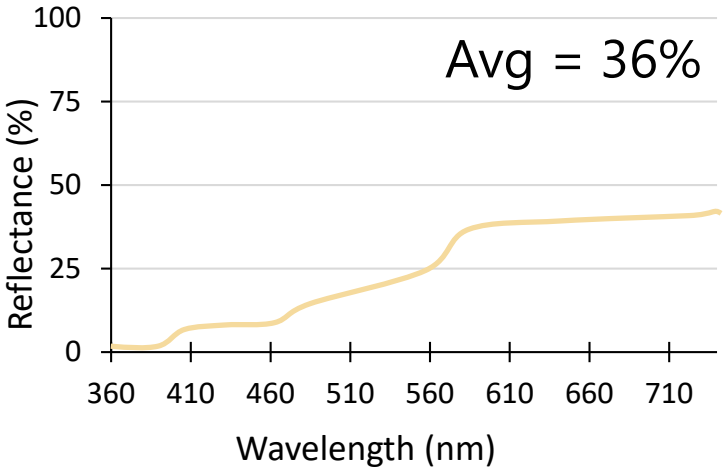
Annual Energy Usage w/ 4hr limit (kWh)
4185

Simulation Results:

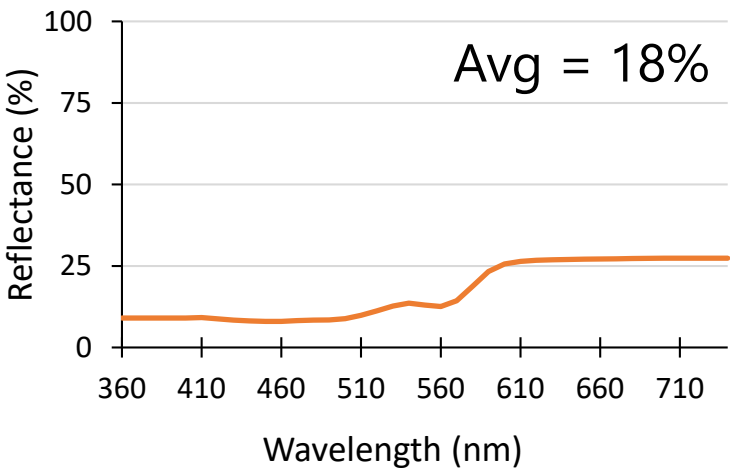
System Output (% lumens)	CCT (K)	Avg E_h (lux)	Avg E_v (lux)	Avg CS	Avg EML	% Views 150+ EML	% Views 240+ EML	% Views CS > 0.3	Meet WELL Requirement?	Annual Energy Usage (kWh)
50	3800	**389**	**191**	0.12	112	**0%**	**0%**	**0%**	**N**	3239
100	3800	**780**	**378**	0.2	223	**100%**	**30%**	**0%**	**Y – 1 point**	6478
100	6200	**773**	**369**	0.36	305	**100%**	**98%**	**100%**	**Y – 1 point**	6478

Effects of Surface Reflectance

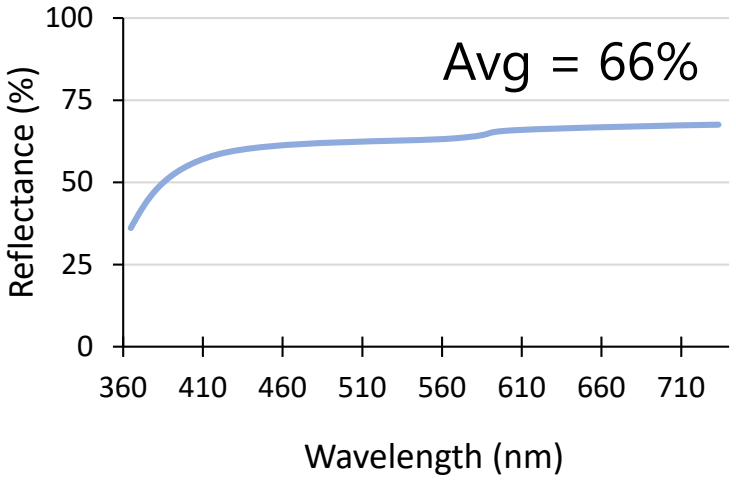
Blonde Finishes



Warm Finishes



Cool Finishes



Effects of Surface Reflectance

Blonde Finishes

CCT [K]	Avg EML	Avg CS	WELL v2 1 point via EML	WELL v2 1 point via CS	WELL v2 3 points via EML
6200	305	0.36	Y	Y	N
3800	223	0.20	Y	N	N
2700	150	0.30	N	N	N

Warm Finishes

CCT [K]	Avg EML	Avg CS	WELL v2 1 point via EML	WELL v2 1 point via CS	WELL v2 3 points via EML
6200	284	0.35	Y	N	N
3800	202	0.21	Y	N	N
2700	136	0.28	N	N	N

Cool Finishes

CCT [K]	Avg EML	Avg CS	WELL v2 1 point via EML	WELL v2 1 point via CS	WELL v2 3 points via EML
6200	382	0.40	Y	Y	Y
3800	276	0.26	Y	N	N
2700	181	0.33	N	N	N

@ 100% Lumen Output

Lighting recommendations – Beyond visual needs

Equivalent Melanopic Lux (EML) & Circadian Stimulus (CS) Recommendations

- WELL Building Standard v1 (May 2016)
  *≥**250 EML** at 75% view positions, 4’ AFF, 4 hours*

- WELL Building Standard v1 (Q3 2017)
  *≥**200 EML** at 75% view positions, 4’ AFF, 9 AM – 1 PM*

- WELL Building Standard v2 (Q2 2019)
  *1 pt: ≥**150 EML** OR ≥**0.3 CS** at 100% view positions, 4’ AFF, 9 AM – 1 PM*
  *3 pts: ≥**240 EML** at 100% view positions, 4’ AFF, 9 AM – 1 PM*

- WELL Building Standard v1 (Q4 2019)?
  *≥**150 EML** at 100% view positions, 4’ AFF, 9 AM – 1 PM (Electric light only)*
  *≥**200 EML** at 75% view positions, 4’ AFF, 9 AM – 1 PM (Electric light and daylight)*

- UL Design Guideline 24480 (2020)
  *≥**0.3 CS** at 100% view positions, 43” AFF, 2+ hours between 7 AM – 4 PM*

Effects of Surface Reflectance – Adjusted for WELL v2 2020

Blonde Finishes

% Lumens	CCT [K]	Avg E_h [lux]	Avg EML	Avg CS
100	6200	773	305	0.36
100	3800	780	223	0.20
75	6200	579	232	0.30

Warm Finishes

% Lumens	CCT [K]	Avg E_h [lux]	Avg EML	Avg CS
100	6200	331	284	0.35
100	3800	331	202	0.21
75	6200	248	212	0.29

Cool Finishes

% Lumens	CCT [K]	Avg E_h [lux]	Avg EML	Avg CS
100	6200	812	382	0.40
100	3800	817	276	0.26
75	6200	609	286	0.35
75	3800	611	205	0.21

(All conditions achieve 150 EML at all view positions)

Key Takeaways

- **It’s still the early days!**
  - Science, software, and recommendations are still developing
- **Know your limits**
  - Limitations of simulation tools may have broader impact
- **Spectrum matters**
  - Many surfaces attenuate short wavelengths
- **Optimizing lighting application efficiency requires new tools**
  - Improved software tools allow for more data driven decisions