LEDucation
Trade Show and Conference

Designers Lighting Forum

Recommendations vs Reality:

3 million eye-level spectral measurements taken in factory and office spaces have a thing or two to teach us about lighting for human health

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Learning Objectives

At the end of this course, participants will be able to:

1. Create a plan for characterizing light exposure at the eye of the occupants.

2. Recognize the variation in vertical light levels between seasons and work locations and apply findings to design work.

3. Describe the relationship between the measured lighting conditions and occupant outcomes reported via daily surveys

4. Utilize the new tools and research methods presented to conduct future research regarding light and health in buildings.

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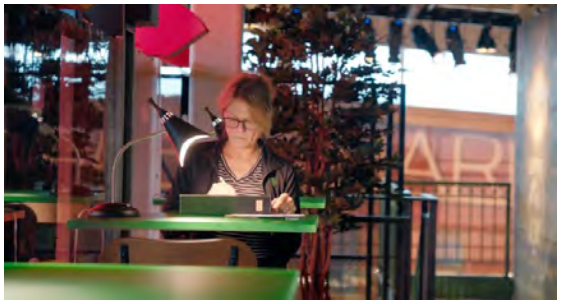
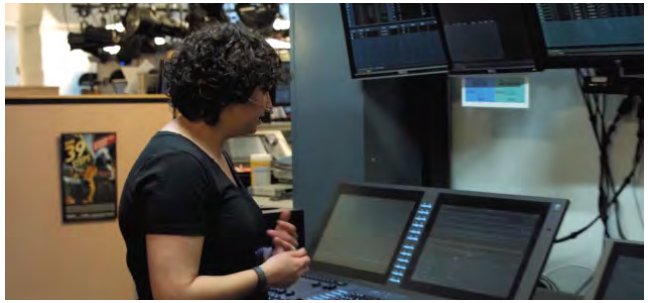
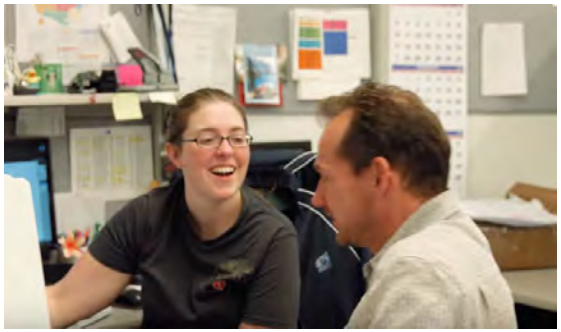
Project Background – Why did we do this?







How did we get here? The Recommendations

2001

Discovery of the intrinsically photosensitive retinal ganglion cell (ipRGC) which receives light and transmits signals to the internal biological clock.

This discovery sparked an interest in characterizing light exposure to understand how light interacts with our daily functioning.

New Metrics

New Recommendations

New Tools

ALFA

Light and Health

Lighting recommendations and metrics for visual needs: **ILLUMINANCE AT THE TASK**

Lighting recommendations and metrics affecting human health: **STIMULUS AT THE EYE**

INTENSITY

How much?

SPECTRUM

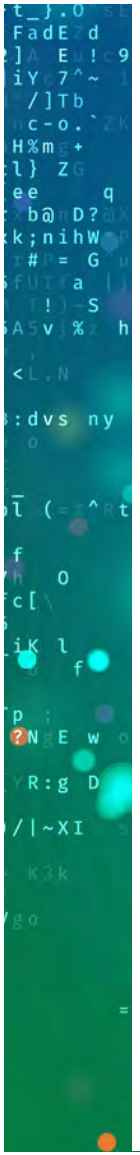
What composition?

DURATION/ TIMING

When?
How Often?

LIGHT HISTORY

What happened before?



Light and Health Metrics

Circadian Stimulus (CS)

Based on nocturnal melatonin suppression resulting from light stimulus. The metric value is the calculated effectiveness of the stimuli assuming a one-hour exposure.

Melanopic to Photopic Ratio (M/P)

Ratio of melanopic/photopic content in source spectrum, compared to melanopic/photopic content in equal energy reference spectrum.

Equivalent Melanopic Lux (EML)

Combines spectral qualities (M/P ratio) with stimulus intensity, provides a value to relate to photopic lux.

Melanopic Daylight Efficacy Ratio (mDER)

Ratio of melanopic/photopic content in source spectrum, compared to melanopic/photopic content in D65 daylight reference spectrum.

Melanopic Equivalent Daylight Illuminance (mEDI)

Combines spectral qualities (mDER) with stimulus intensity, provides a value to relate to photopic lux.

What does each metric consider?

INTENSITY	SPECTRUM	DURATION/ TIMING	LIGHT HISTORY
Circadian Stimulus (CS)			
	Melanopic to Photopic Ratio (M/P)		
Equivalent Melanopic Lux (EML)			
	Melanopic Daylight Efficacy Ratio (mDER)		
Melanopic Equivalent Daylight Illuminance (mEDI)			

Light and Health Recommendations

WELL Building Standard - Circadian Lighting Design

UL RP 24480 - Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People

2020 | ≥0.3 CS at 100% of workstations, 43” AFF, 2+ hours between 7 AM – 4 PM

Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults

Brown TM, Brainard GC, Cajochen C, Czeisler CA, Hanifin JP, Lockley SW, et al. (2022) Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. PLoS Biol 20(3): e3001571.

2022 | ≥250 mEDI throughout the daytime, 4’ AFF

WELL Education Pilot

2019 | ≥125 EML at 75% of desk locations, 4’ AFF, 4+ hours

Criteria for High Performance Schools (CHPS)

2019 | ≥250 EML OR ≥0.3 CS at 100% of desk locations, 4’ AFF, 4+ hours

Recommendations Over Time

WELL Building Standard – Circadian Lighting Design

Q2 2016 – v1 | ≥250 EML at 75% of workstations, 4’ AFF, 4 hours

Q3 2017 – v1 | ≥ 200 EML at 75% of workstations, 4’ AFF, 9 AM – 1 PM

Q2 2019 – v2 | 1 point: ≥150 EML OR ≥0.3 CS at 100% of workstations, 4’ AFF, 9 AM – 1 PM
3 points: ≥240 EML at 100% of workstations, 4’ AFF, 9 AM – 1 PM

Q3 2019 – v1 | Space type specific recommendations for Work Areas, Living Environments, Breakrooms, and Learning Areas

Q3 2020 – v2 | 1 point: ≥150 EML OR ~~≥0.3 CS~~ ≥136 mEDI at 100% of workstations, 4’ AFF, 9 AM – 1 PM
3 points: ≥240 EML OR 218 mEDI at 100% of workstations, 4’ AFF, 9 AM – 1 PM
Different thresholds for Projects with Enhanced Daylight

Q3 2021 – v2 | 1 point: ≥150 EML OR ≥136 mEDI at 100% of workstations, 4’ AFF, 9 AM – 1 PM
3 points: ≥275 EML OR ≥250 mEDI at 100% of workstations, 4’ AFF, 9 AM – 1 PM
Different thresholds for Projects with Enhanced Daylight

A Closer Look at Current WELL Guidance

CONCEPTS / LIGHT / FEATURE L03 OPTIMIZATION

Circadian Lighting Design

Support circadian and psychological health through indoor daylight exposure and outdoor views.

Max 3 Pts

For All Spaces Except Dwelling Units & Guest Rooms | For Dwelling Units & Guest Rooms

For workstations used during the daytime, electric lighting is used to achieve the following thresholds:

a. The following light levels are achieved for at least four hours (beginning by noon at the latest) at a height of 18 in above the work-plane for all workstations in regularly occupied spaces:

Tier	Threshold		Threshold for Projects with Enhanced Daylight	Points
1	At least 150 EML [136 M-EDI(D65)]	OR	The project achieves at least 120 EML [109 M-EDI(D65)] and either L05 Part 1 or L06 Part 1	1
2	At least 275 EML [250 lux M-EDI(D65)][11]	OR	The project achieves at least 180 EML [163 M-EDI(D65)] and either L05 Part 1 or L06 Part 1	3

b. The light levels are achieved on the vertical plane at eye level to simulate the light entering the eye of the occupant.

Verified by Performance Test

https://v2.wellcertified.com/en/wellv2/light/feature/3

A Closer Look at Current WELL Guidance

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SPECTRUM

DURATION/TIMING

MEASUREMENT TECHNIQUE

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Comparing Recommendations to Reality

CONCEPTS / LIGHT / FEATURE L03 OPTIMIZATION

Circadian Lighting Design

Verified by Performance Test

- Test Locations & Conditions
  - Vertical plane
  - Representative of common occupant position
  - 18” Above work surface, flexible for sitting/standing
  - Supplemental lighting, including computer screens, should be on if used
  - 50 workstations, n = 29 | 100 workstations, n = 41
  - Distributed in the space, across floors

- Reporting & Compliance
  - Report illuminance levels in lux and the spectral power. Calculate EML (EML = lux x M/P Ratio).
    - Calibrated spectrometer
  - The median light levels must meet the EML threshold and the lowest value must be at least half the threshold.

Capturing Baseline Reality

What quantity and spectral quality of light are employees exposed to at work?

https://www.etcconnect.com/Global/ETC-Site-Tour.aspx

ETC HQ – Middleton, WI

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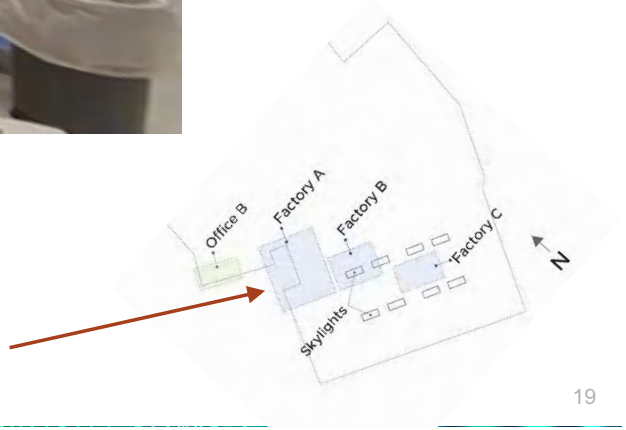
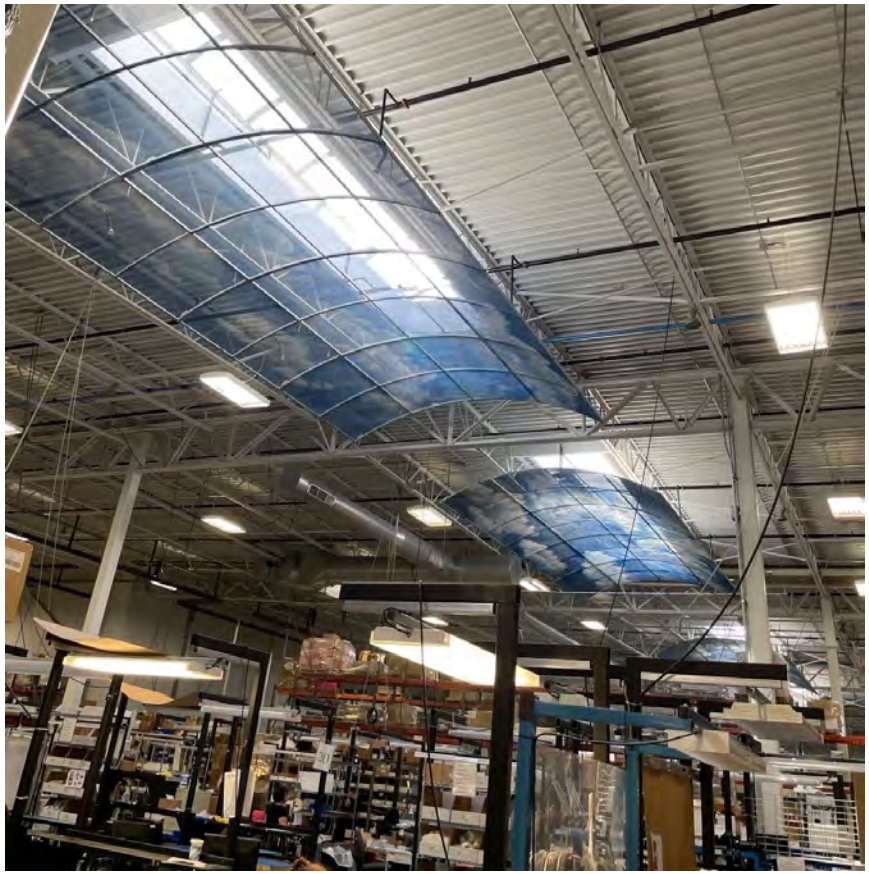
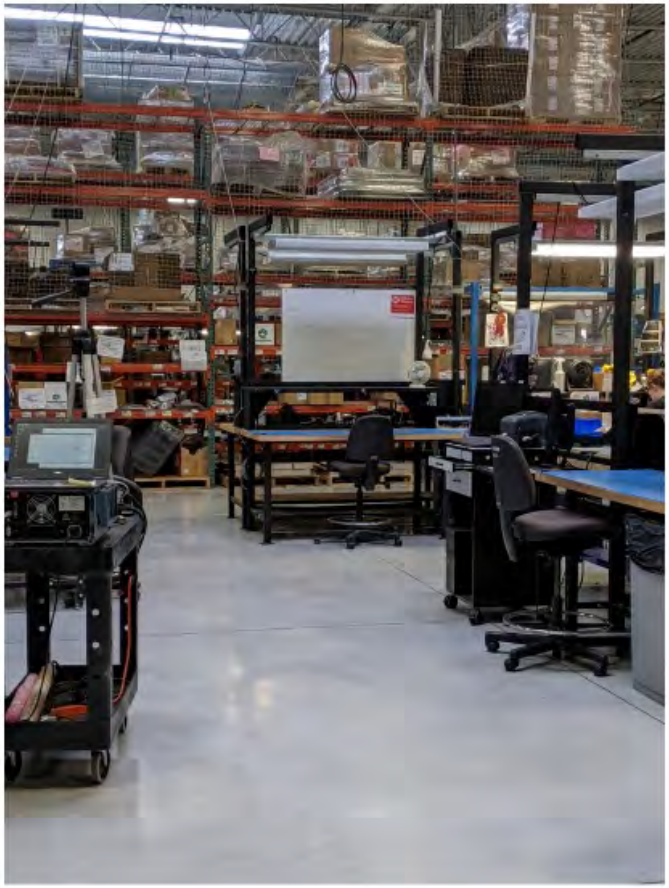


ETC HQ – Middleton, WI





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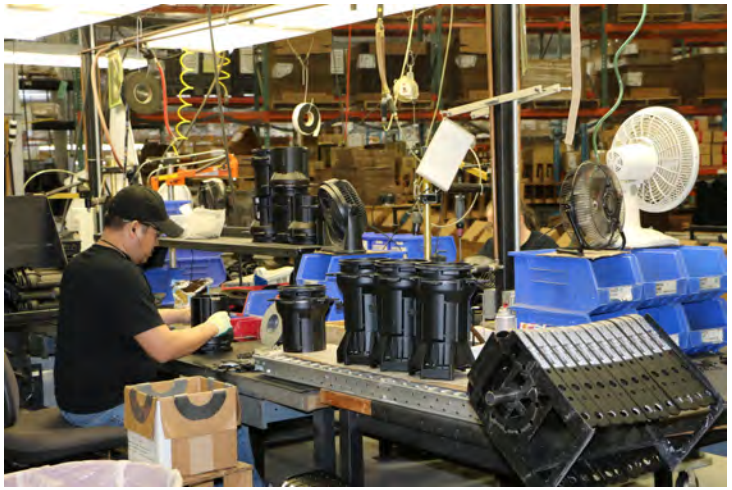

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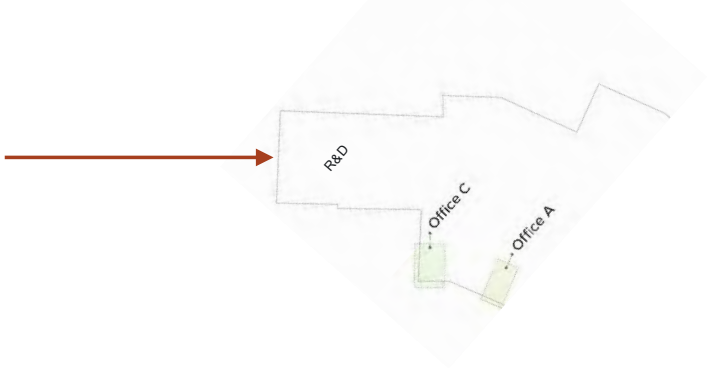

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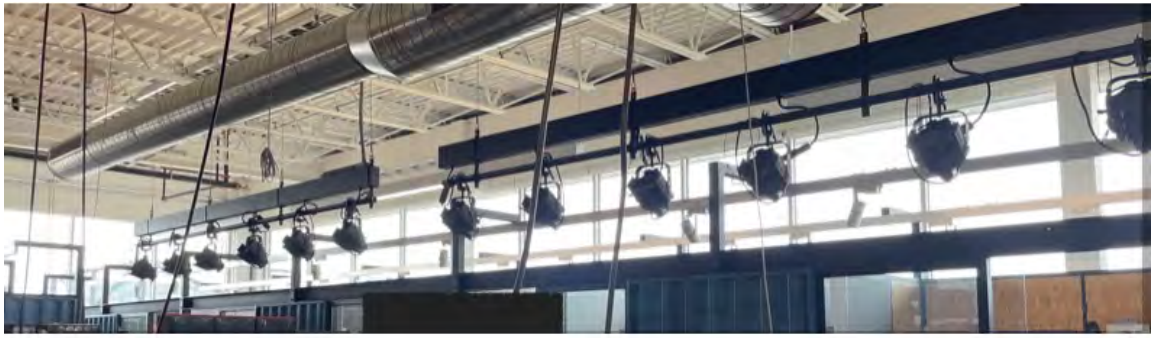
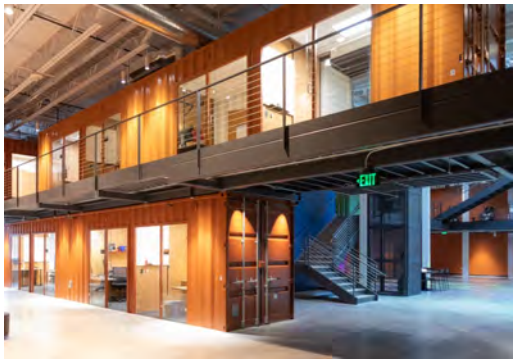


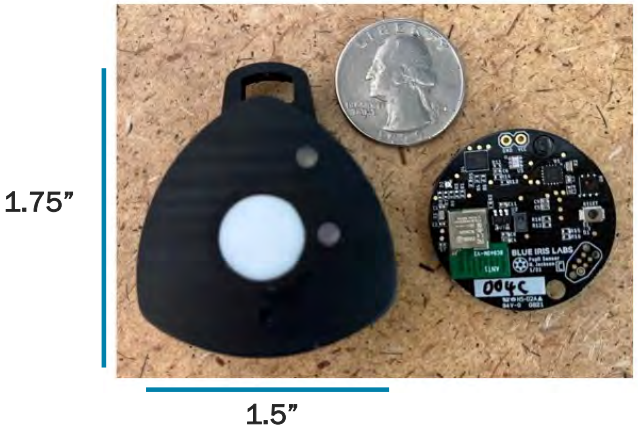


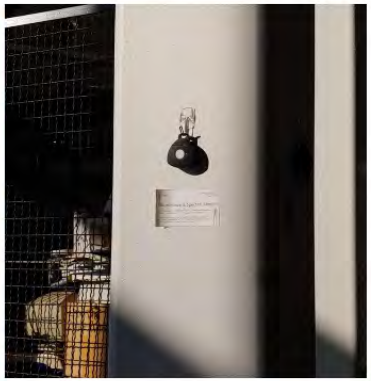
Project Timeline

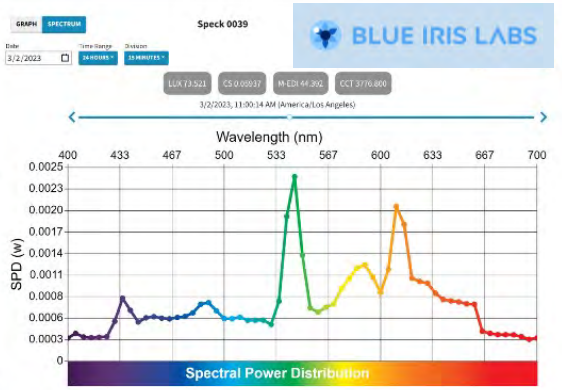
Lighting Measurements

Aug. 2022	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar. 2023
			Survey 1		Survey 2		Survey 3

Blue Iris Labs “Specks” Miniature Spectrometers







TECHNOLOGY

- Measures SPD in 8 channels
- Calculates lux, CCT, CS, and EML
- 60 second measurement interval

APPLICATION

- Mounted to architectural surfaces (not wearables)
  - 54” AFF in Factory Spaces
  - 48” AFF in Office Spaces
- 10 sensors for 2-3 weeks in each location + repeat

Speck Demo

Data Collection and Processing

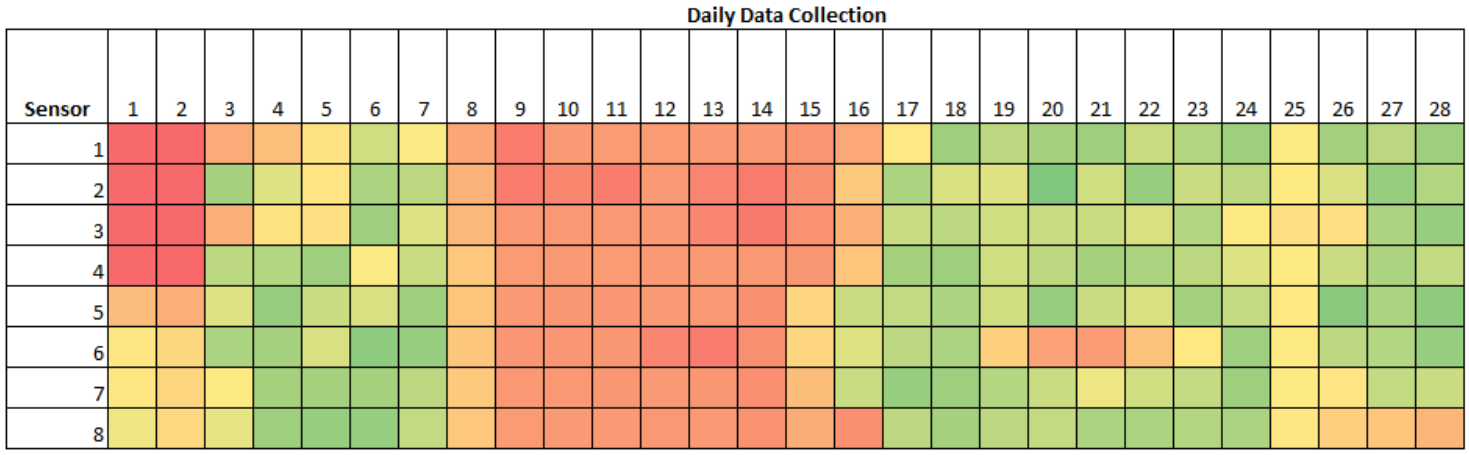
"Perfect" Dataset: **4,616,640**

- 1,198,673 Missing or Zero Measurements

Collected Dataset: **3,417,967**

- 2,521,459 Nights, Weekends, Holidays

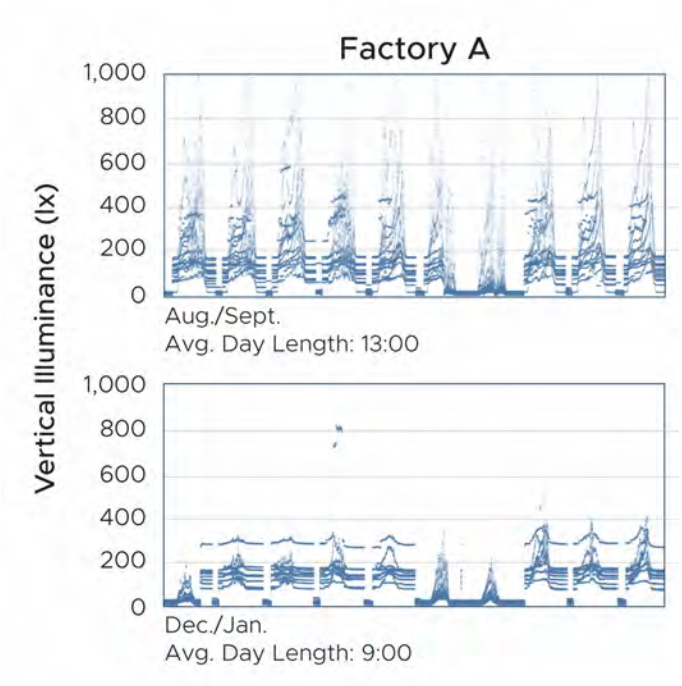
Final Dataset: **896,508**



75%
of expected data

0 — 1,440

Data Collection and Processing



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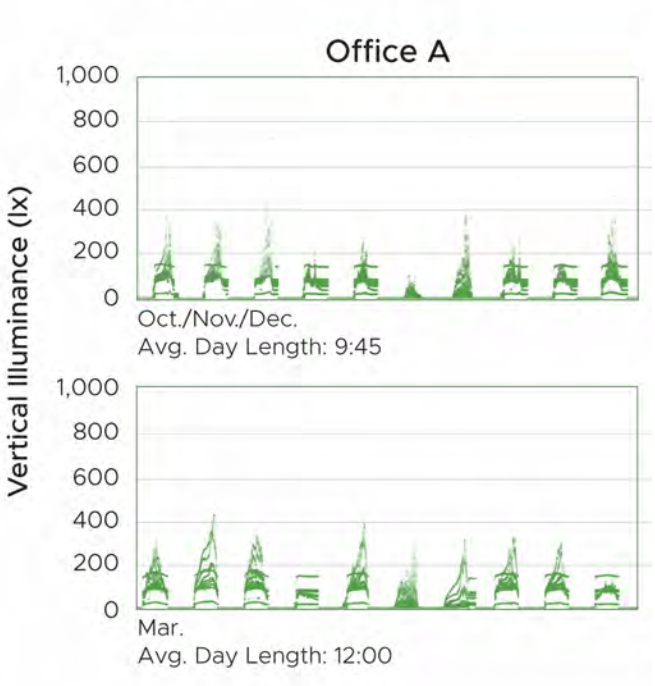
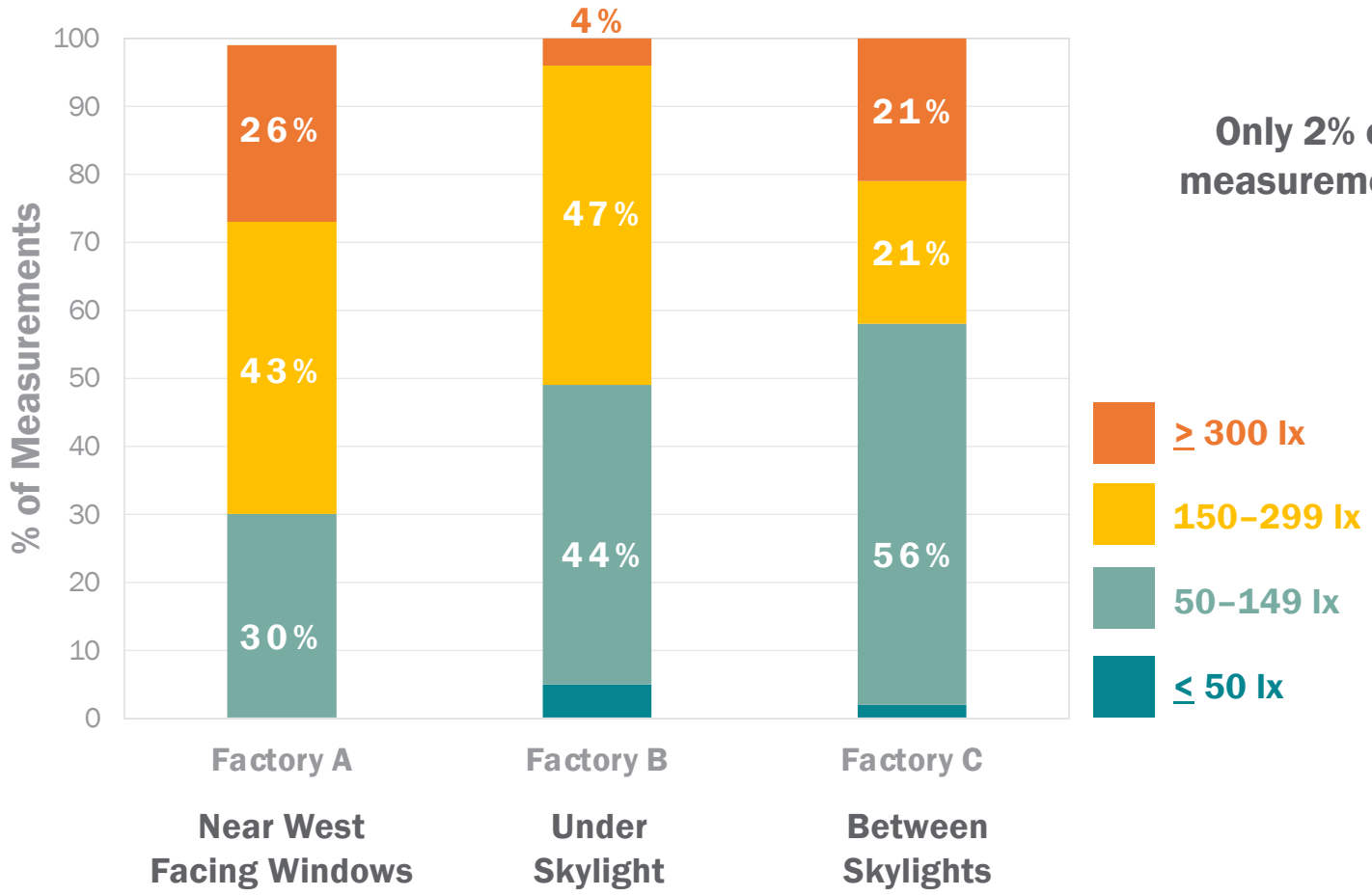
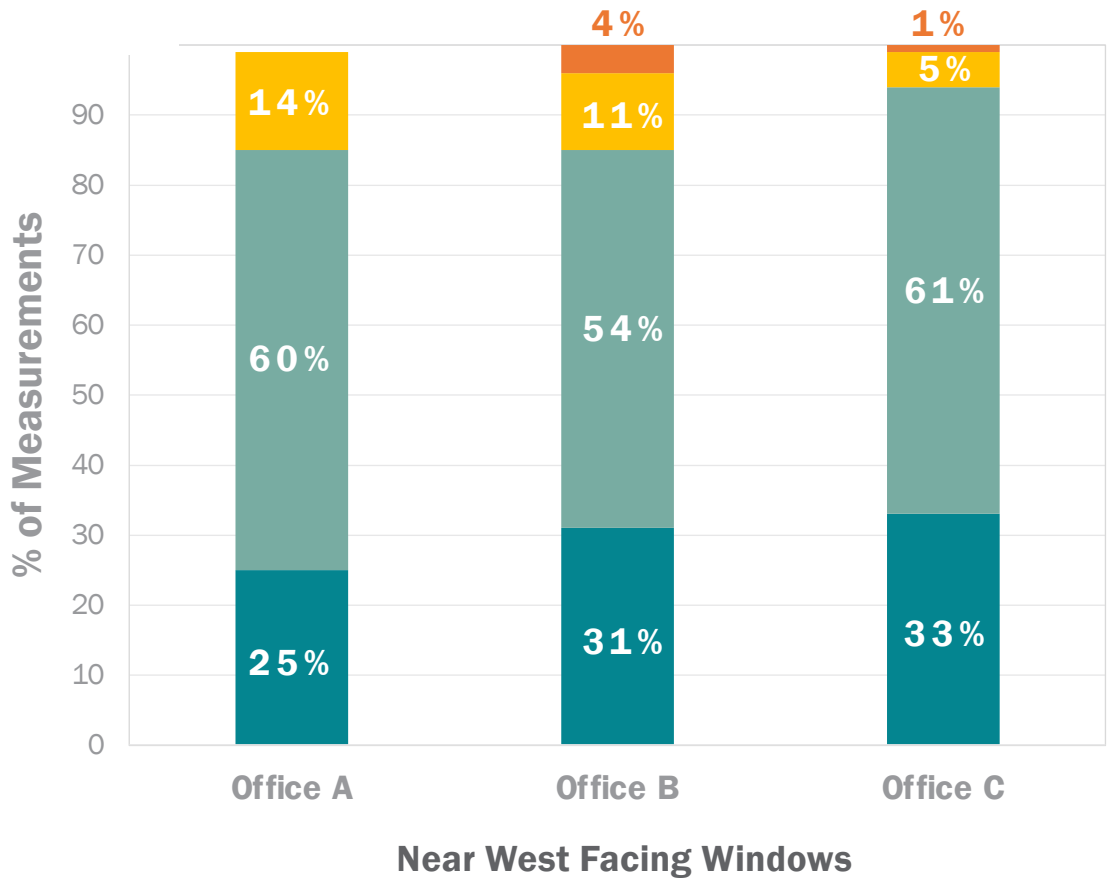


Light Levels in Factory Spaces – How much?



Only 2% of Factory measurements < 50 lx

Light Levels in Office Spaces – How much?

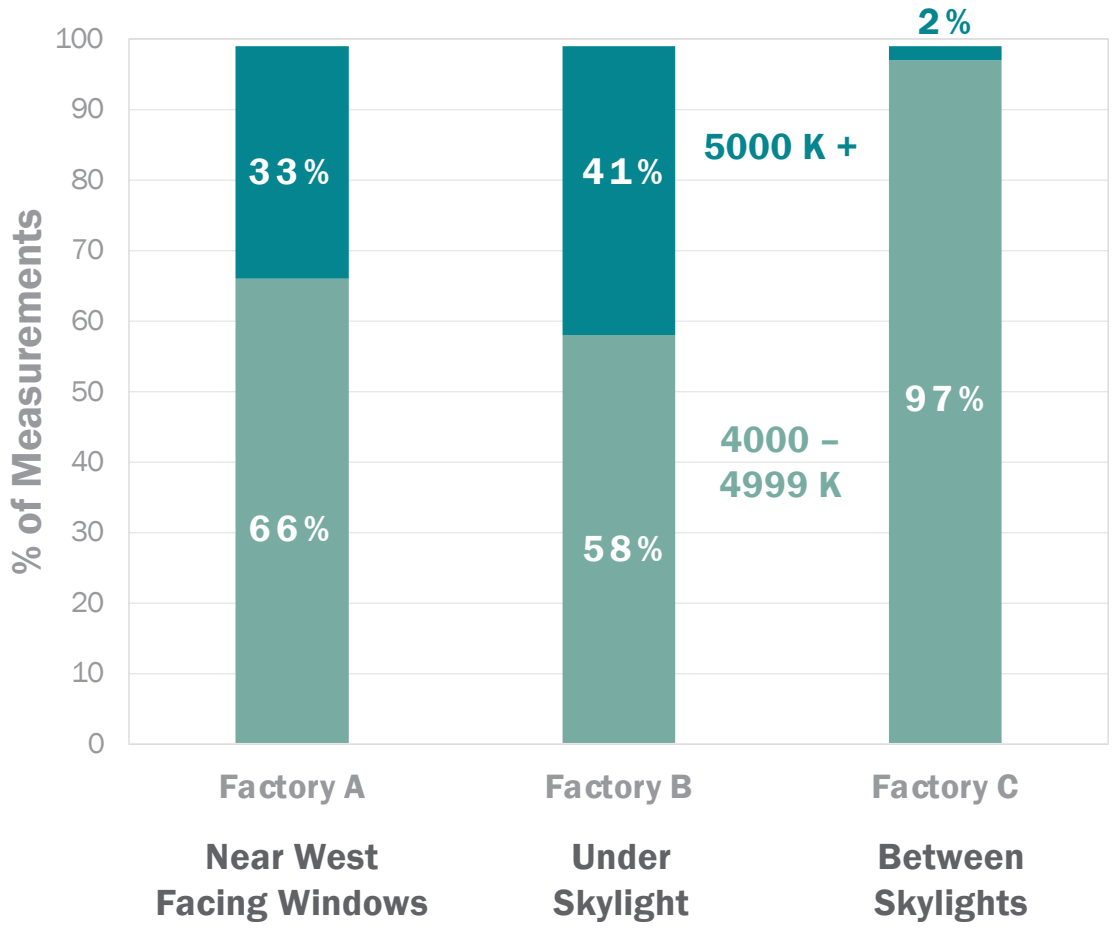


29% of Office measurements < 50 lx

88% of Office measurements < 150 lx

- ≥ 300 lx
- 150–299 lx
- 50–149 lx
- ≤ 50 lx

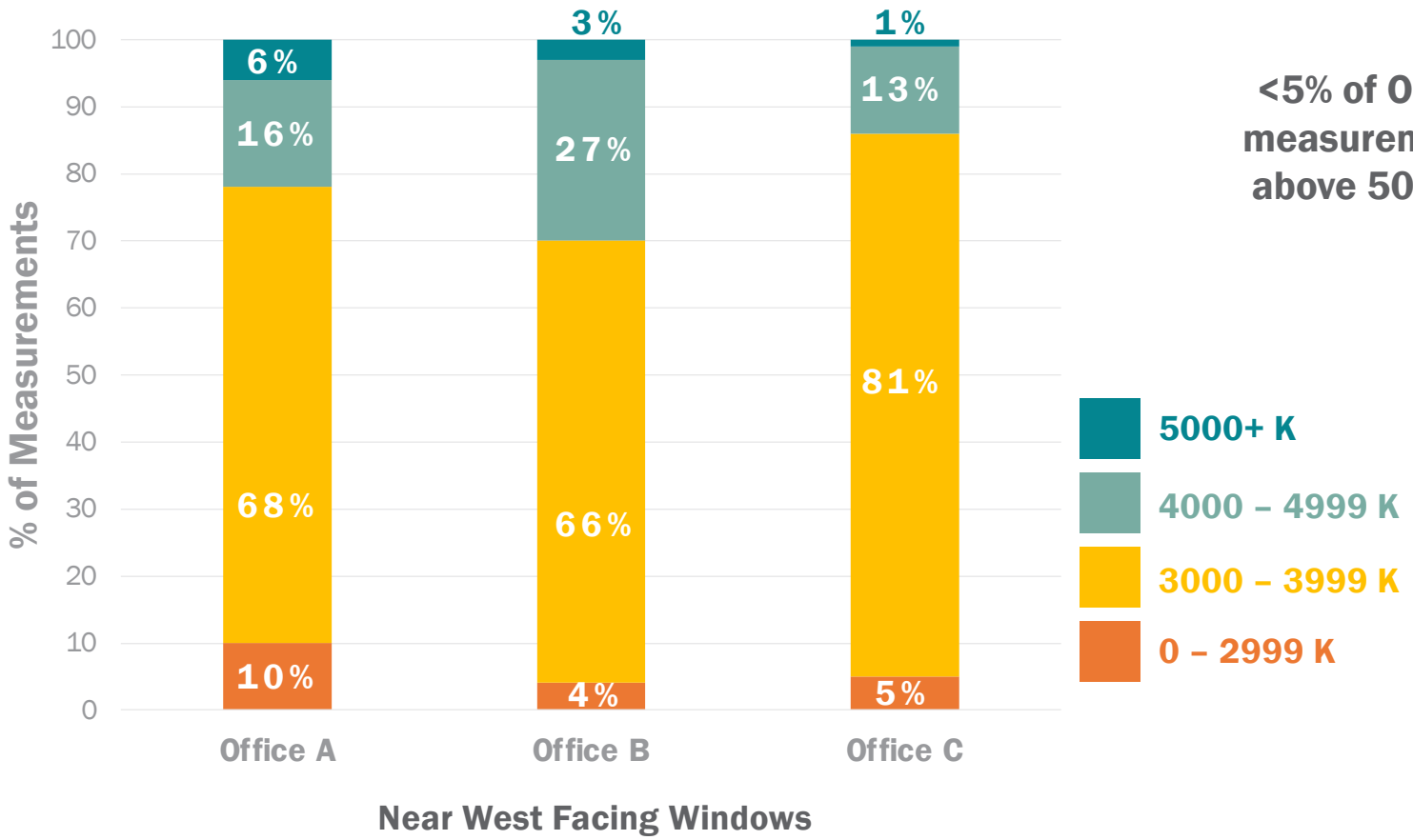
Spectral Measurements in Factory Spaces



<1% of Factory measurements below 4000 K

- 5000+ K
- 4000 – 4999 K
- 3000 – 3999 K
- 0 – 2999 K

Spectral Measurements in Office Spaces



<5% of Office measurements above 5000 K

Comparing Photopic Lux and mDER

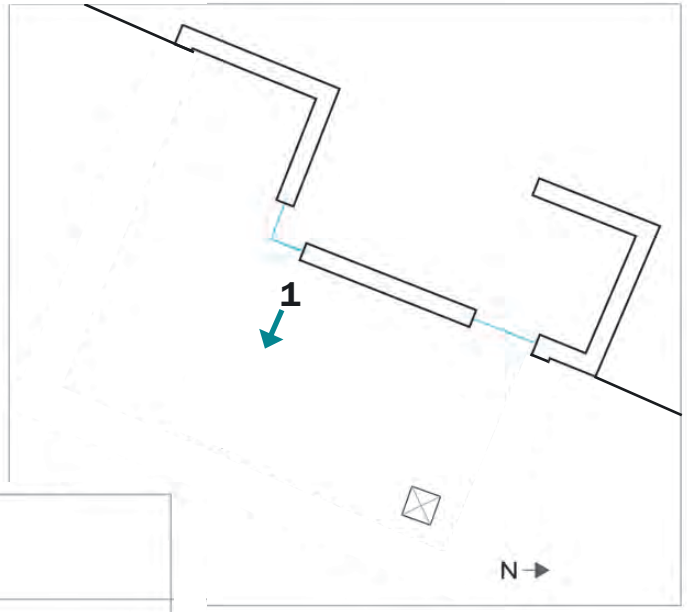
mEDI = lux*mDER

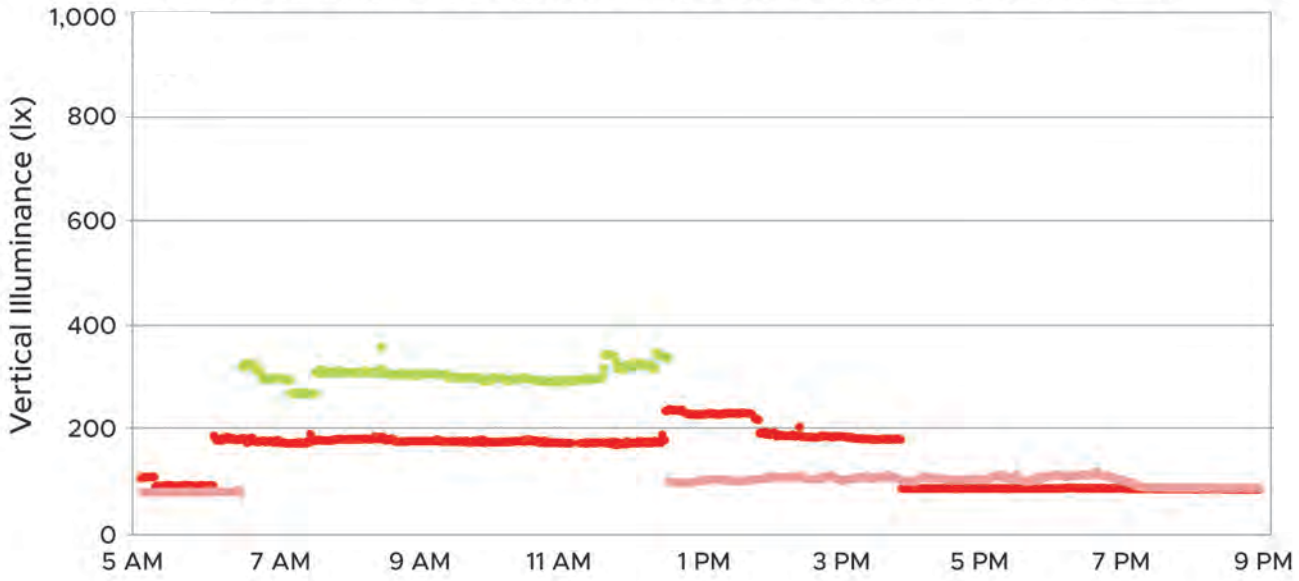
< 136 mEDI	136 – 250 mEDI	> 250 mEDI
(no points)	(1-point)	(3-points)

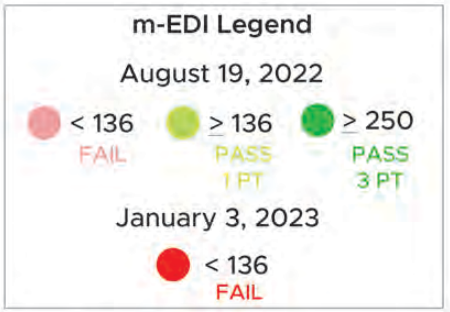
Baseline Reality vs. Recommendations

Factory	**36%** 136 – 250 mEDI	**17%** > 250 mEDI	**22%** CS > 0.3
Office	**5%** 136 – 250 mEDI	**1%** > 250 mEDI	**2%** CS > 0.3

Factory:
Illuminance Measurements







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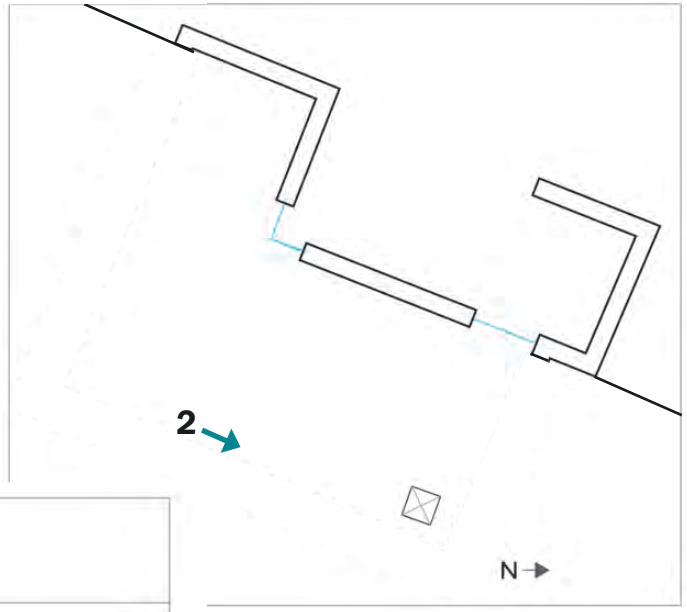

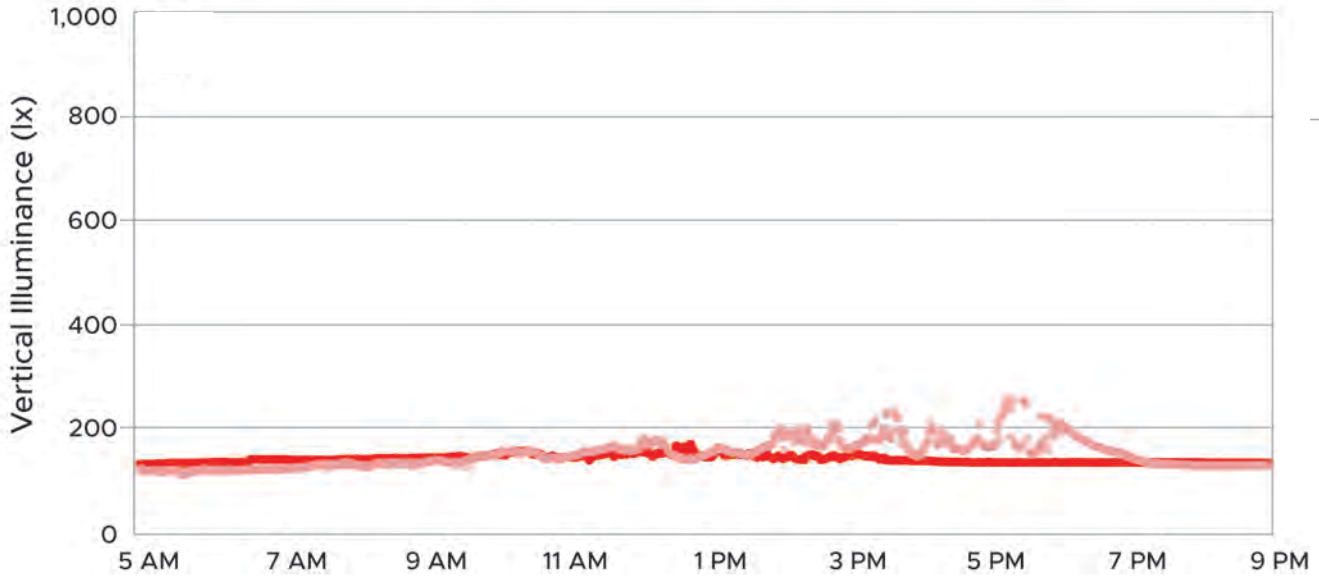

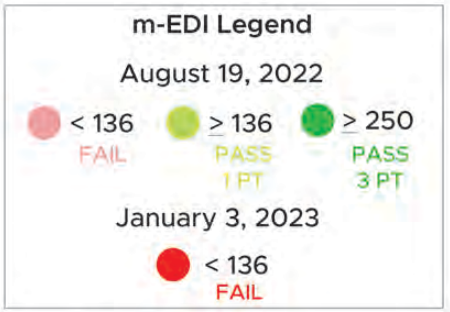

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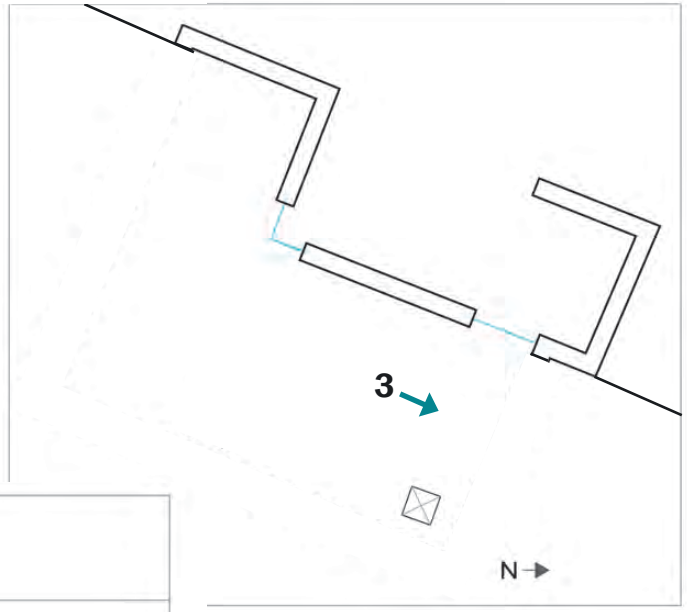

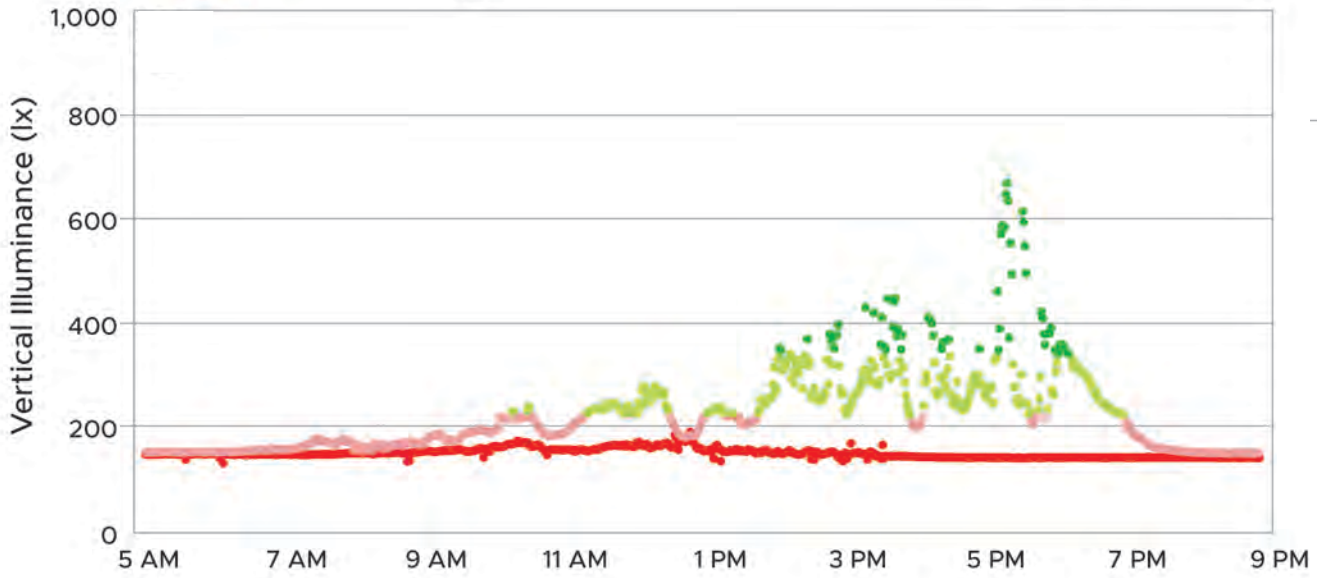

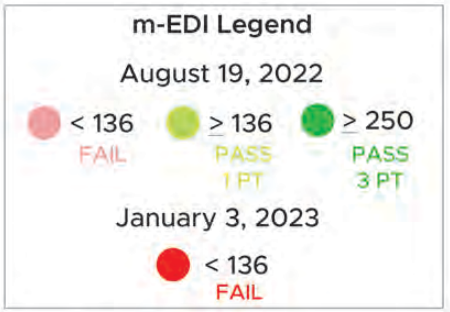

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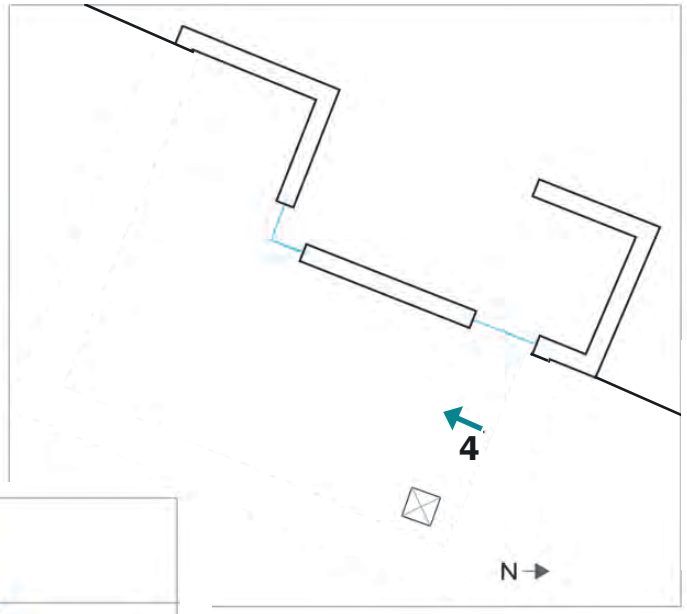
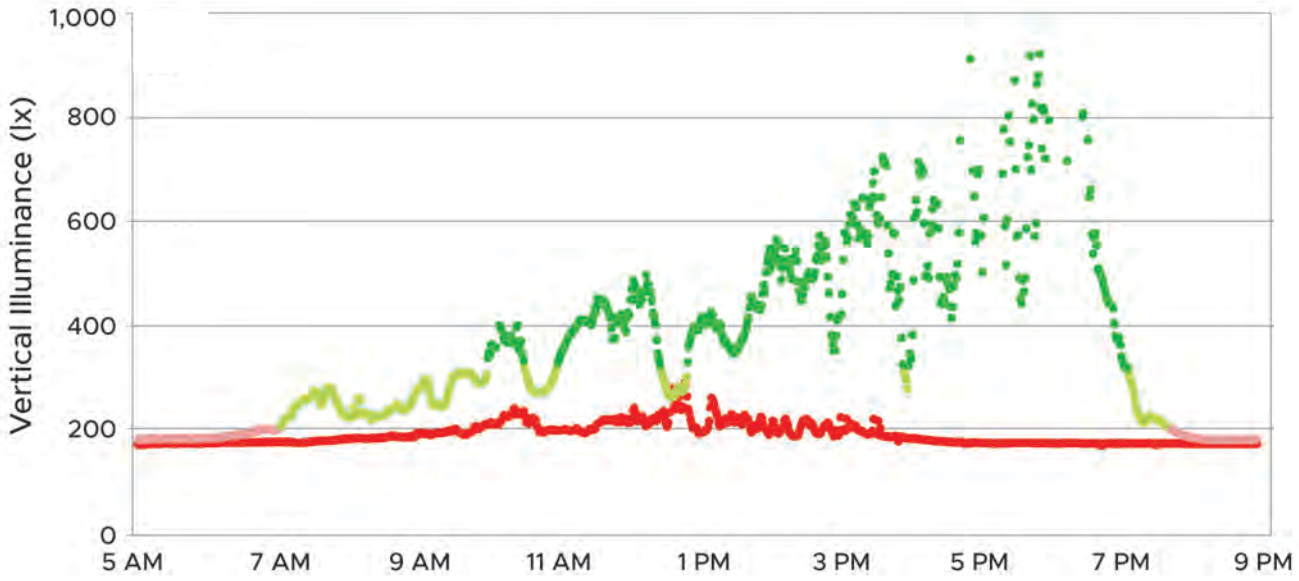
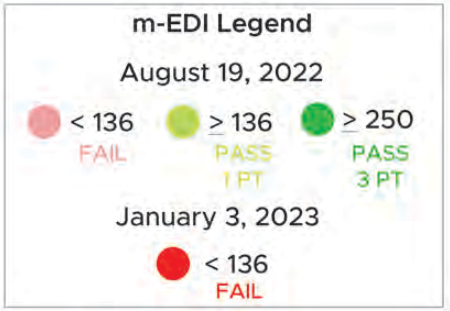
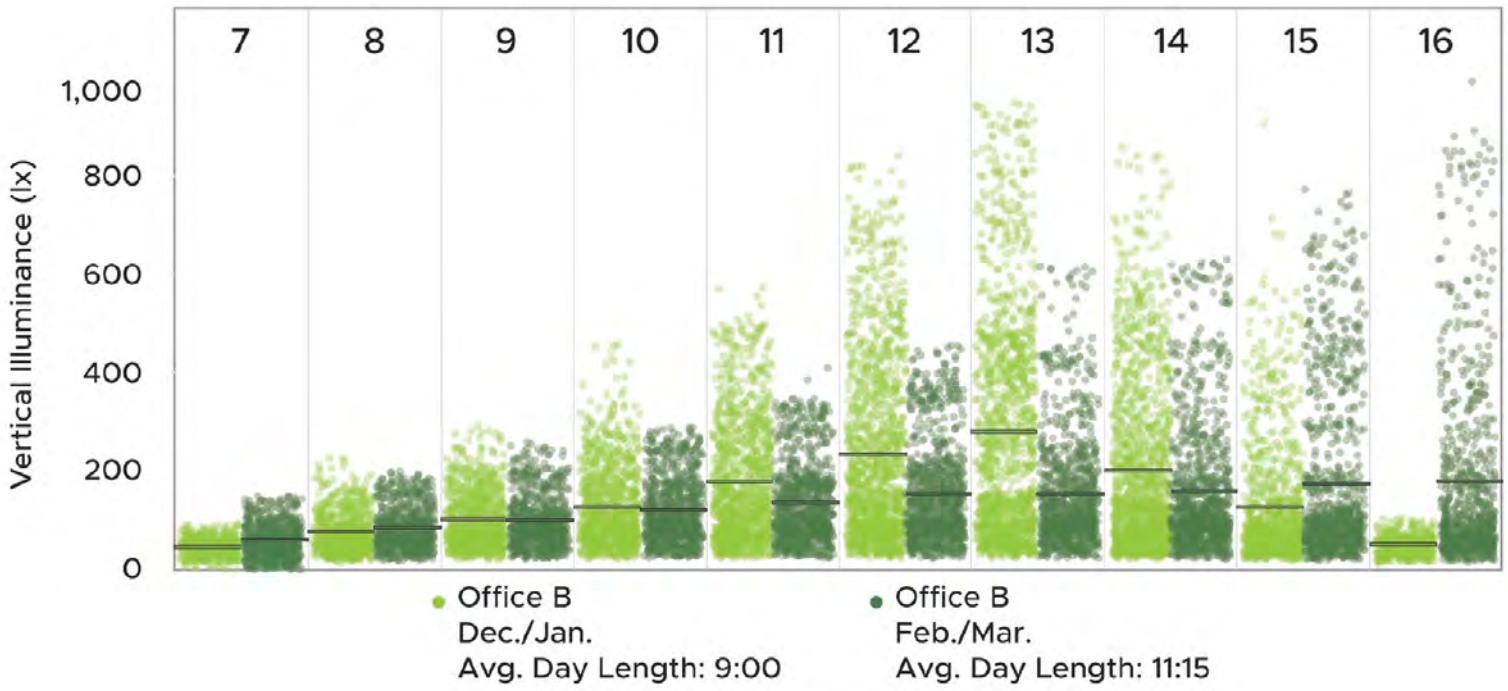
Illuminance Measurements



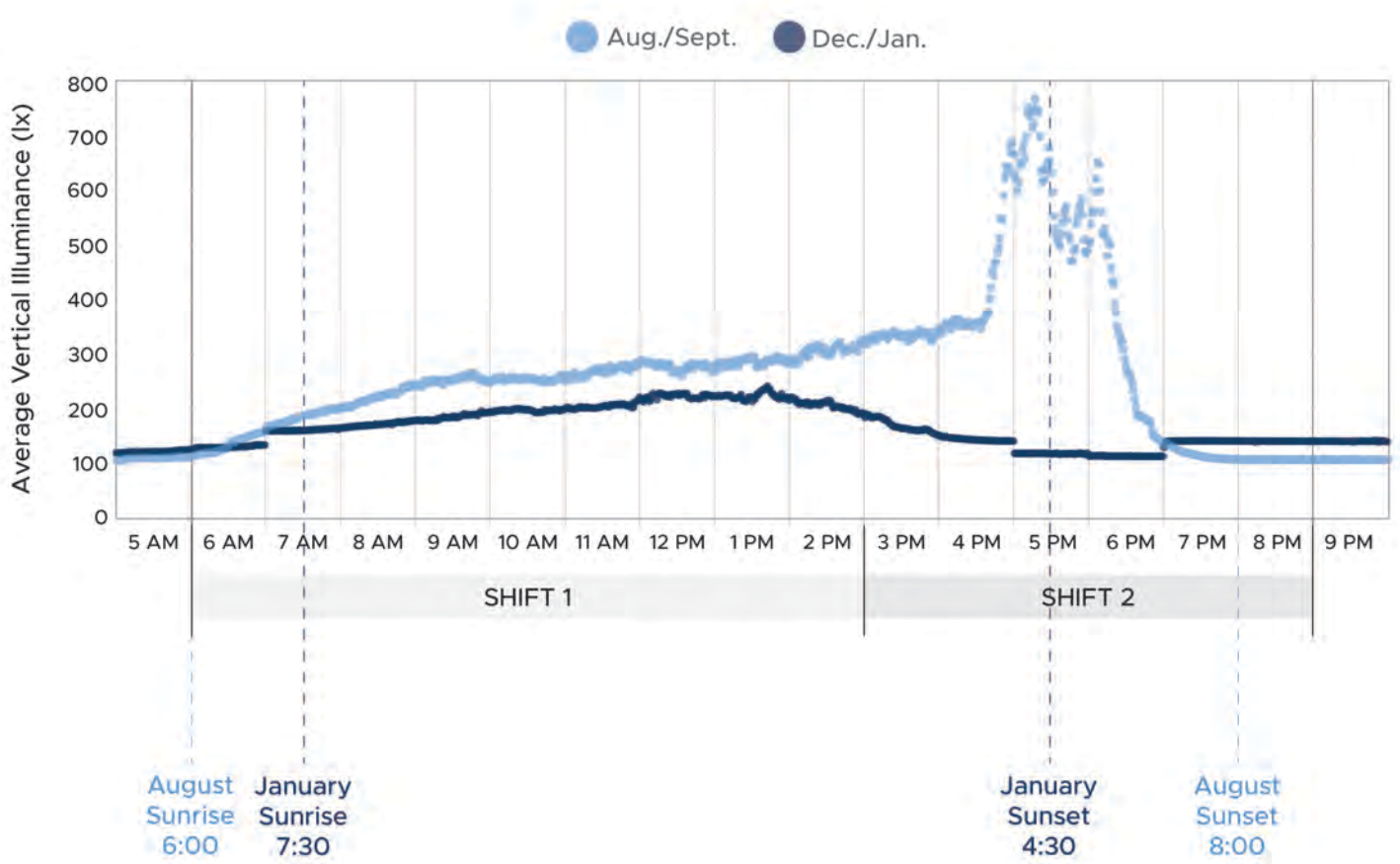




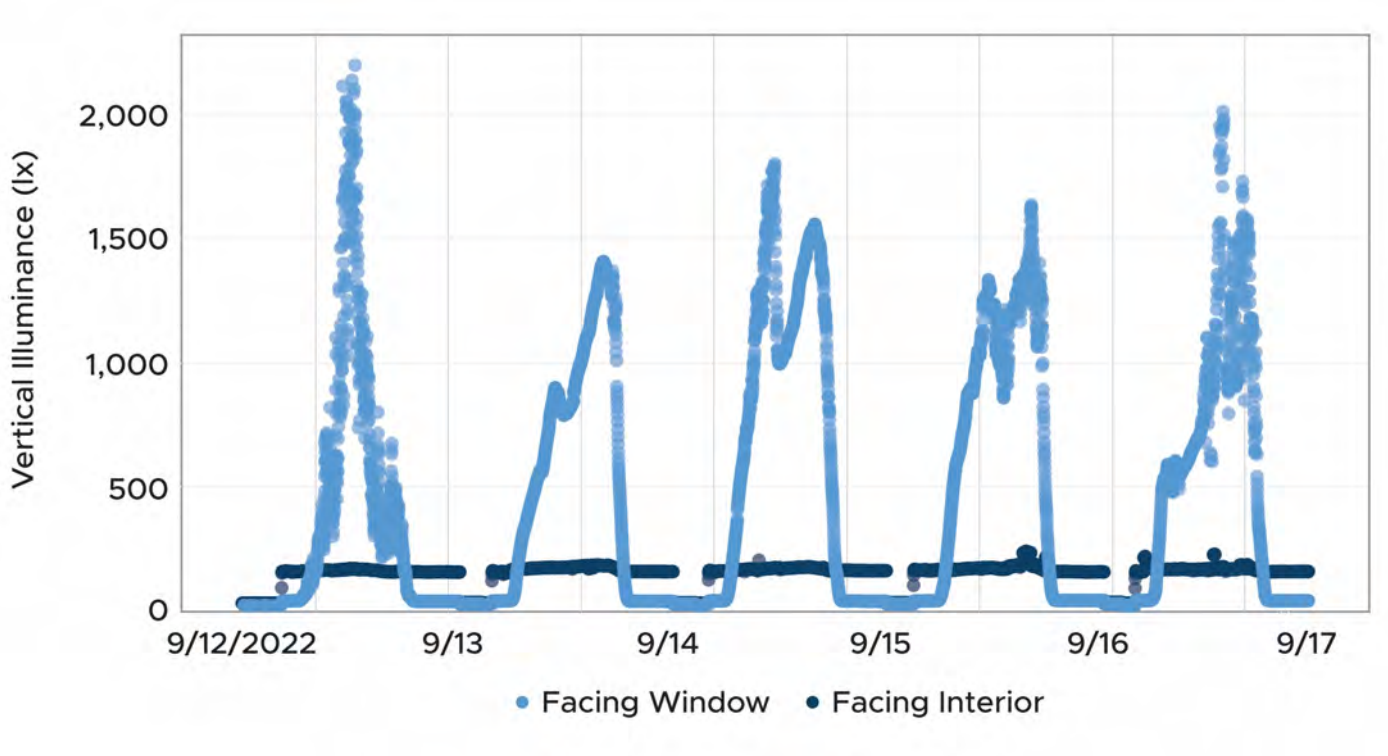
Measurements by the Hour in Office B



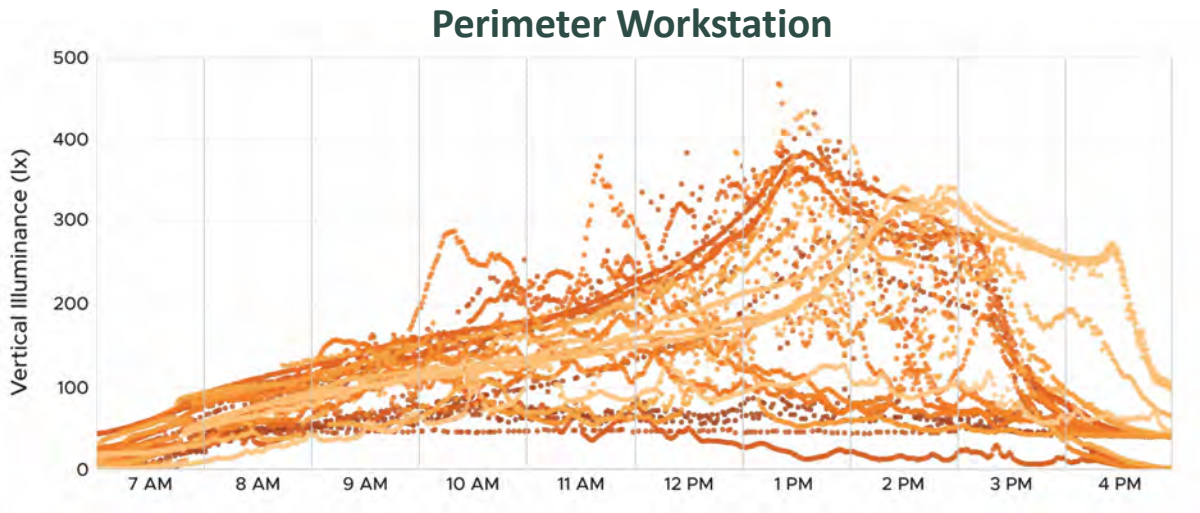
Other Influences - Seasonal Variation



View Direction



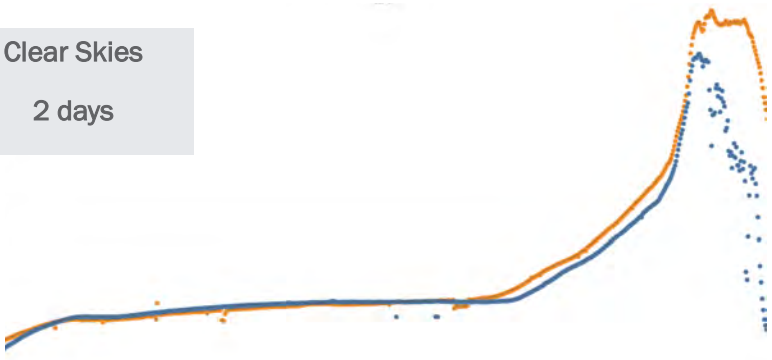
Perimeter vs. Core Workstations



Sky Conditions

Clear Skies

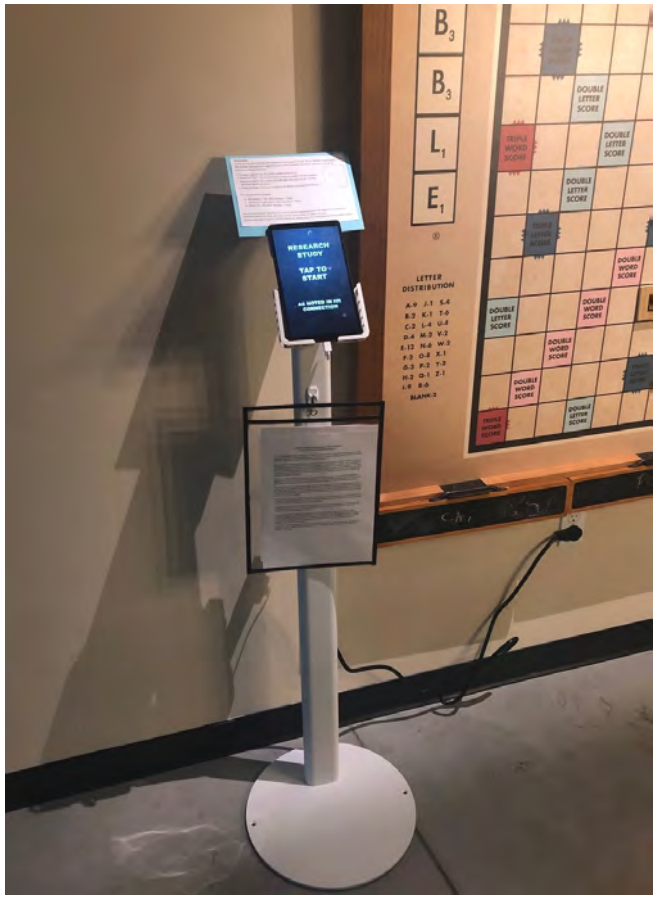
2 days



Survey Questions & Outcomes

804 Responses from factory, office, and R&D employees

Questionnaire Development



- Survey participation faster than tying your shoes
- Tablets in easy-access areas
- No personally identifiable information
- No impossible asks – the building isn't getting new windows
- 10 questions rotated for unique daily surveys
  - Time spent outside
  - Satisfaction with lighting, control, environment
  - Motivation, alertness
- Repeated for seasonal clues

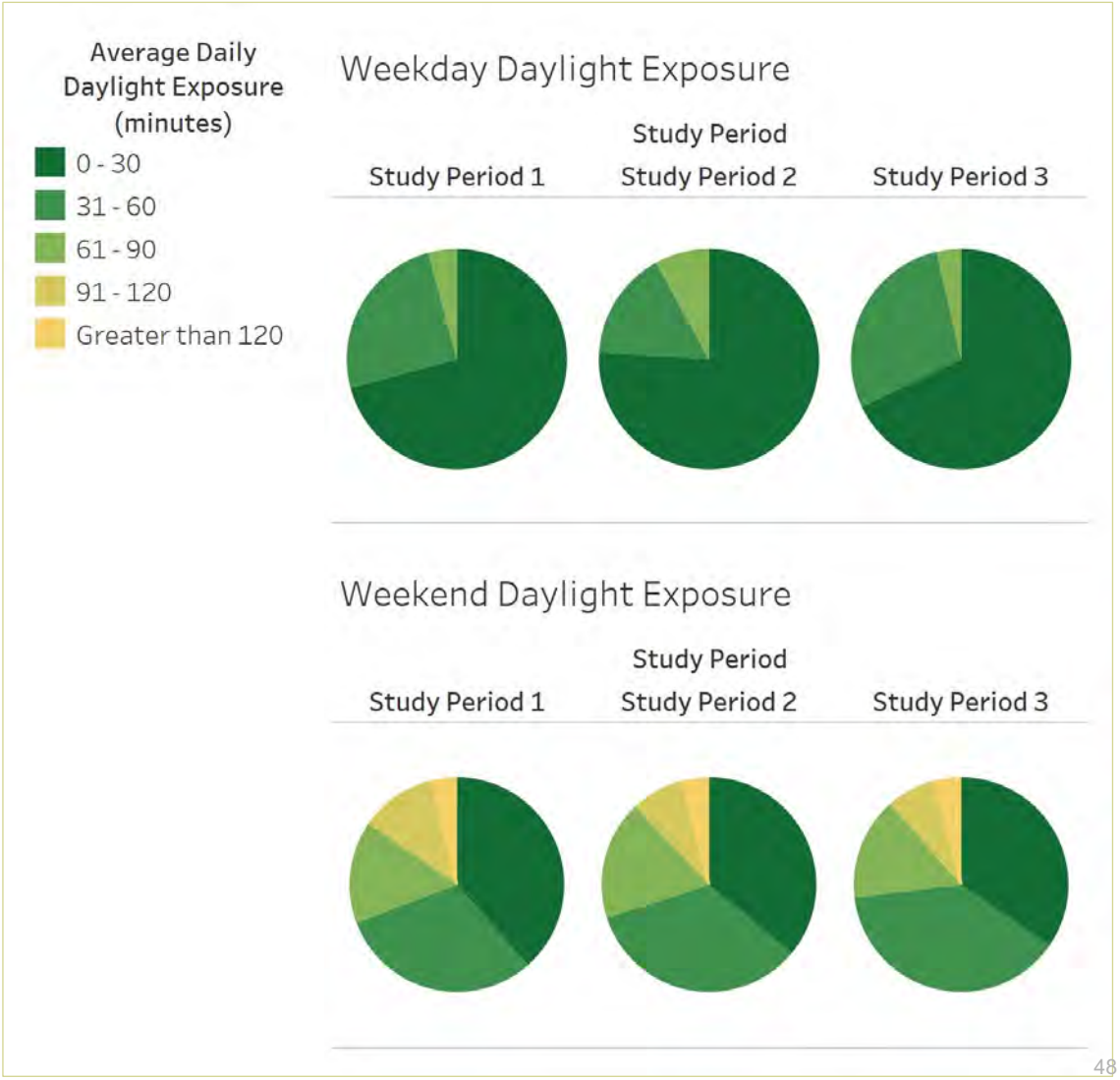
Questionnaire Development – Middleton, WI

Daylight Exposure

During the week, majority of participants spent 0-30 minutes outside.

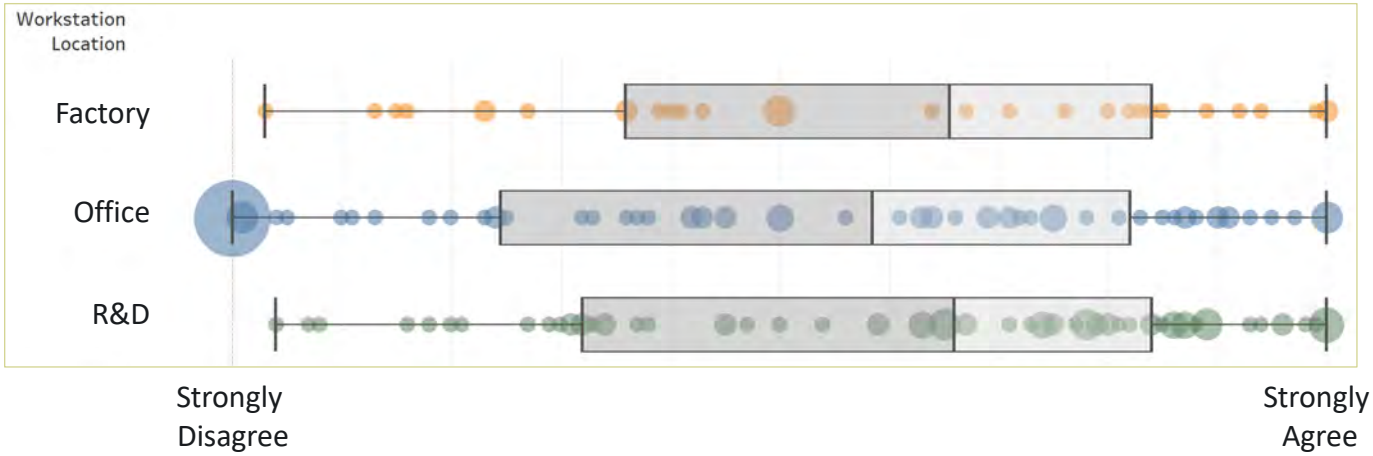
Participants reported spending more time exposed to daylight during the weekends.

How much is enough?



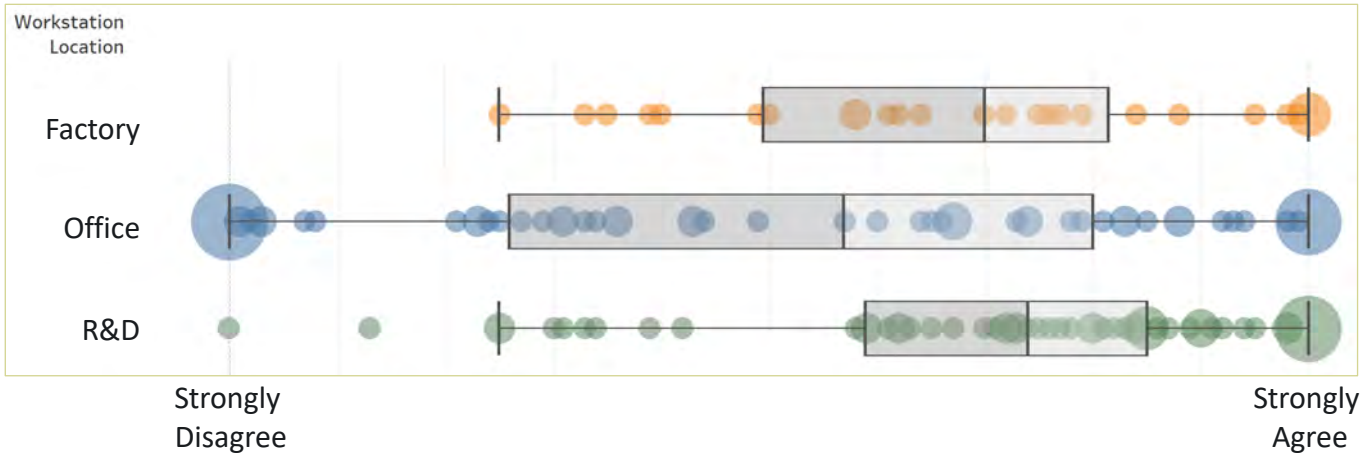
Lighting Satisfaction

Overall, I am satisfied with the lighting around my typical work area.



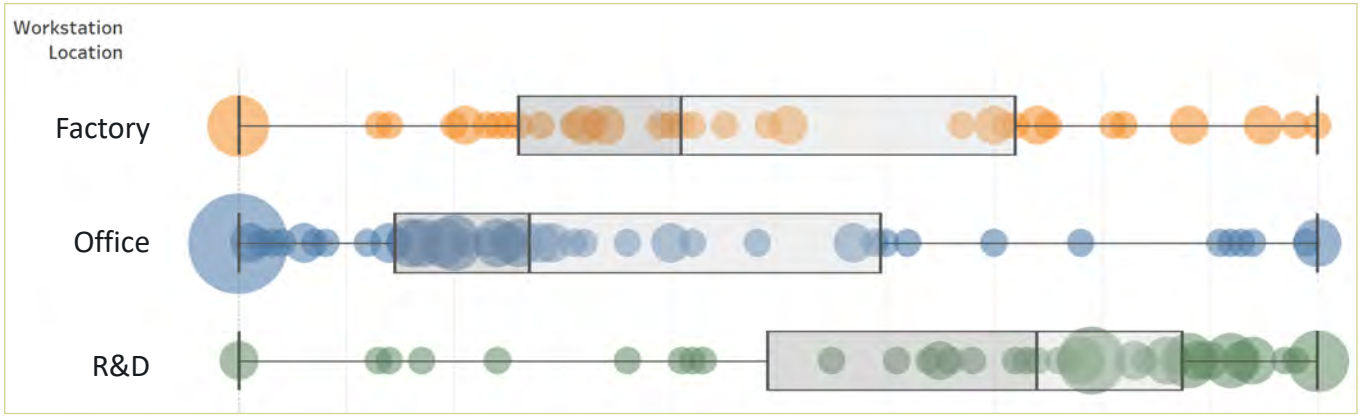
Lighting Satisfaction

There is an appropriate amount of light for my tasks.



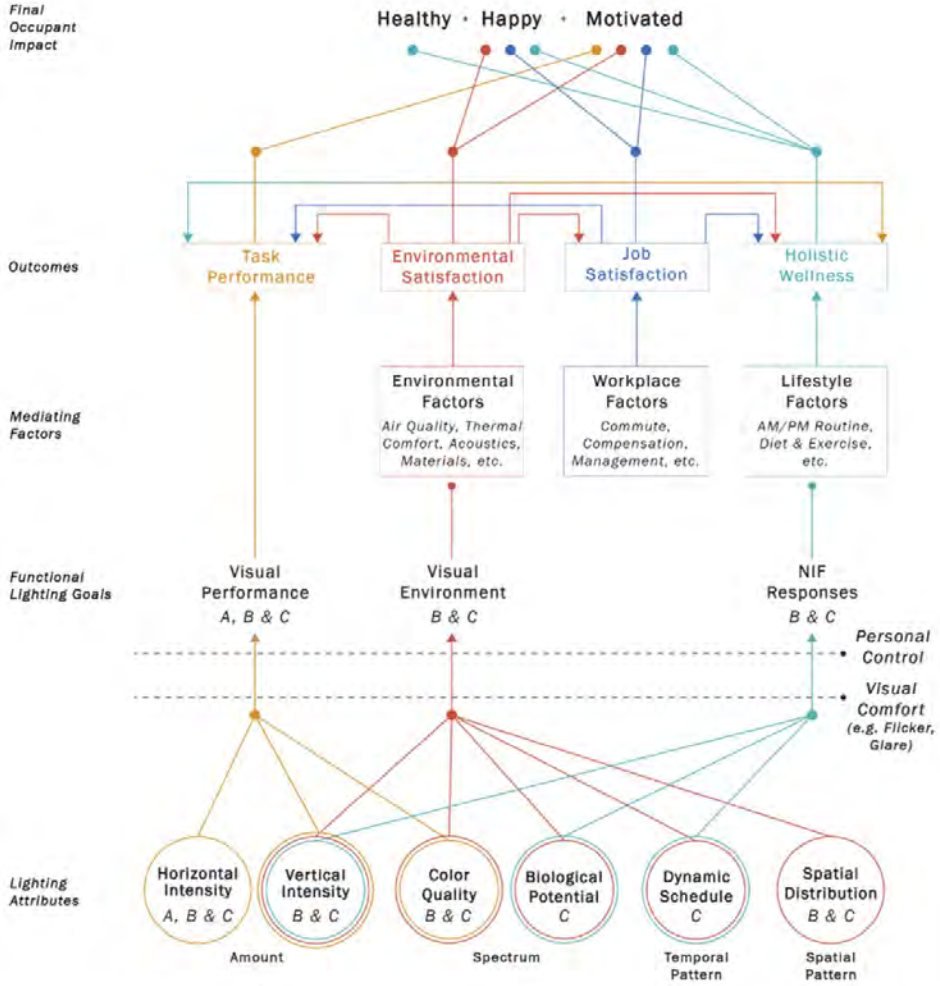
Personal Control

Overall, I am satisfied with my ability to adjust the lighting conditions.



Reality:
Lighting is one factor

10 WELL Concepts



Reality: Field research is challenging

Lighting in Offices

- In 2022, reviewed 12 office field studies since 2010
- 10 studies collected lighting time-series data

Read the article here

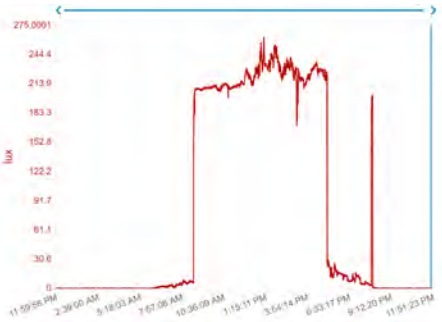
Dependent Measure	Items	1	2	3	4	5	6	7	8	9	10	11	12	Sum
Alertness, Fatigue Daytime														
Karolinska Sleepiness Scale (KSS)	1	X		X		X		X						4
Stanford Sleepiness Scale (SSS)	1		X											1
Checklist Individual Strength	20	X										X		2
Chronotype														
Munich Chronotype Question. (MCTQ)	19	X		X								X		3
Morningness-Eveningness Question. (MEQ)	19		X											1
Depression, Seasonal Sensitivity														
Center for Epidem. Studies - Depression (CES-D)	20			X					X	X				3
Seasonal Pattern Assessment Question. (SPAQ)													X	1
Seasonal Affective Disorder Sensitivity		X												1
Lighting, Environmental Satisfaction														
Cost-effective Open-Plan Envir. Quest. (COPE)			X											1
Daylight Deprivation/Satisfaction*							X				X			2
Lighting Beliefs*	24				X									1
Light Naturalness Scale	1		X											1
Lighting Satisfaction*	3-15	X			X	X								3
Headache and Eye Strain Scale (H and ES)	8		X			X								2
Subjective Light Sensitivity	2	X										X		2
Mental Well-being, Mood, Affect														
Big Five Question.												X		1
Positive and Negative Affect*	2											X		1
Positive and Negative Affect Schedule (PANAS)	20		X						X	X				3
Pleasure-Arousal-Dominance	18												X	1
Sleep														
Pittsburgh Sleep Quality Index (PSQI)	19	X	X	X		X	X		X	X	X	X		9
PROMIS Sleep Disturbances	8								X	X				2
Sleep Quality*	1-2		X					X					X	2
Stress														
Daily Subjective Stress*	2		X											1
Job Stress Scale	5		X											1
Need for Recovery Behavior Scale	45					X								1
Perceived Stress Scale (PSS-10)	10		X	X					X					3
Vitality														
Subjective Vitality, Valence, and Tension*	6	X										X		2
Trait Vitality Scale		X										X		2
Subjective Vitality Scale (SVS)	7			X										1

Significant finding related to lighting condition; Significant finding related to other factors (e.g., time of day, physical well-being, etc.); Demographics; X Administered as an Ecological Momentary Assessment (EMA); * Not a standardized scale.

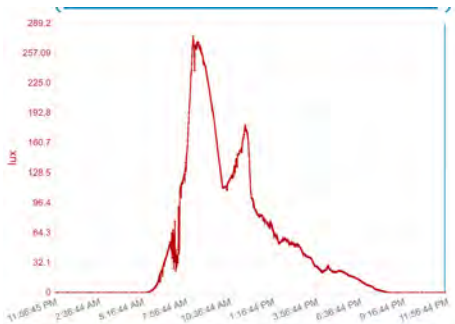
Reality:
Lighting is not a statistically significant factor in many studies

Reality:
More data is not always better

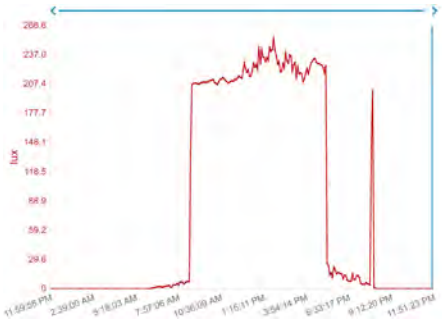
1 minute



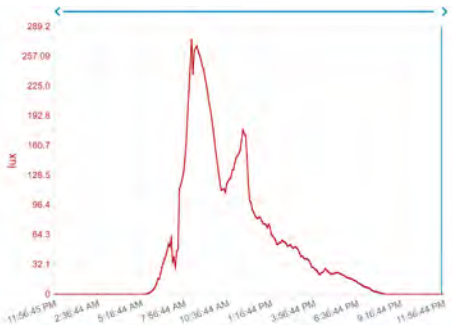
1440 measurements



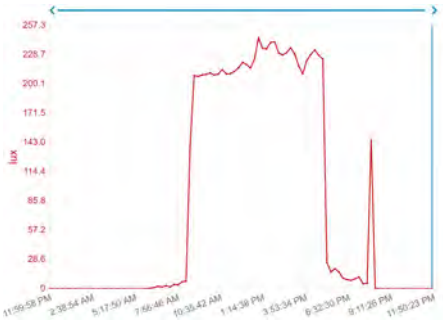
5 minutes



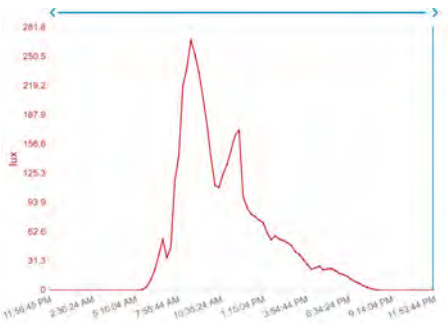
288 measurements



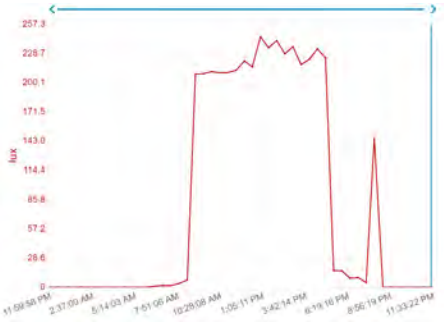
15 minutes



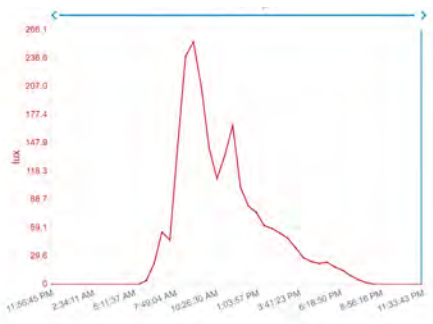
96 measurements



30 minutes



48 measurements



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Jason McDermott, extensive experience in molecular and structural virology and data resource design, data integration and prediction of biological networks, and bridging experimental and computational biology.

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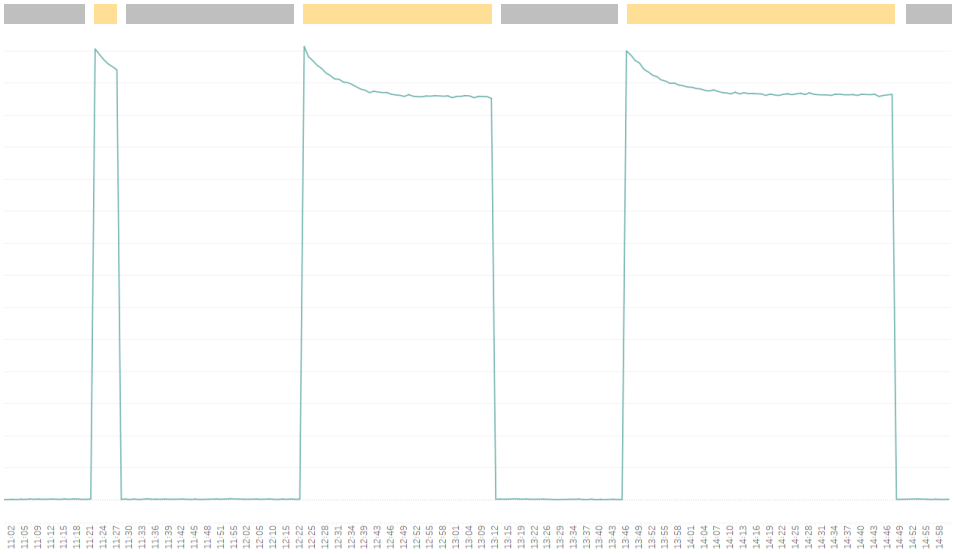
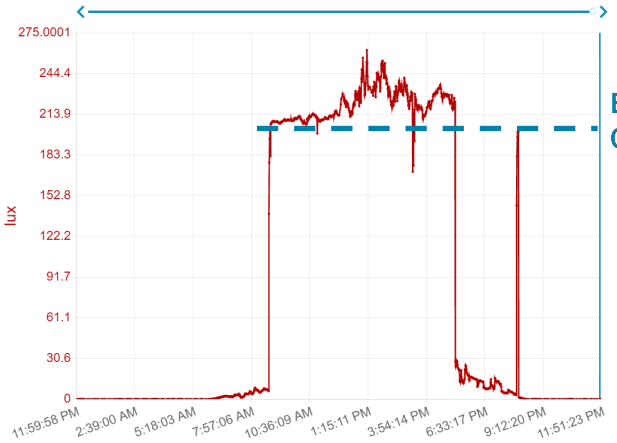
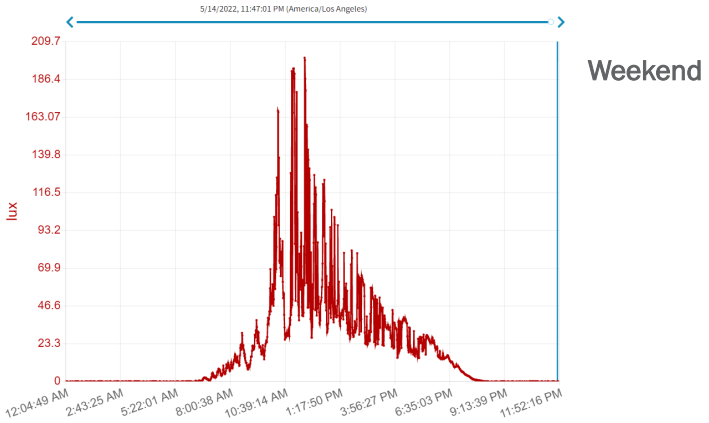
Data Cleaning







Data Cleaning

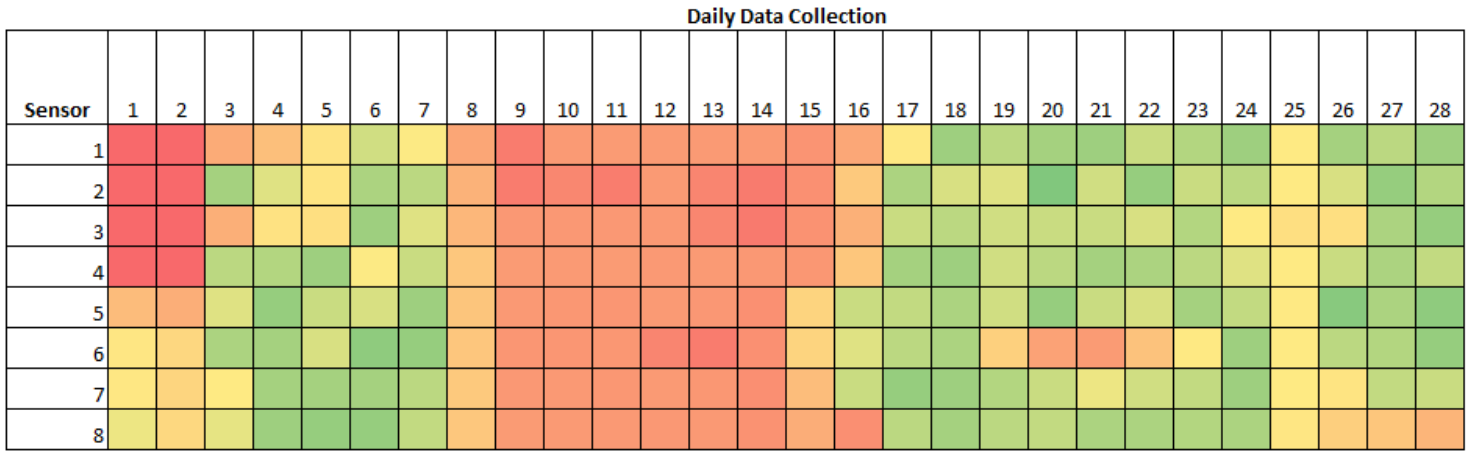
"Perfect" Dataset: **4,616,640**

- 1,198,673 Missing or Zero Measurements

Collected Dataset: **3,417,967**

- 2,521,459 Nights, Weekends, Holidays

Final Dataset: **896,508**



75%
of expected data

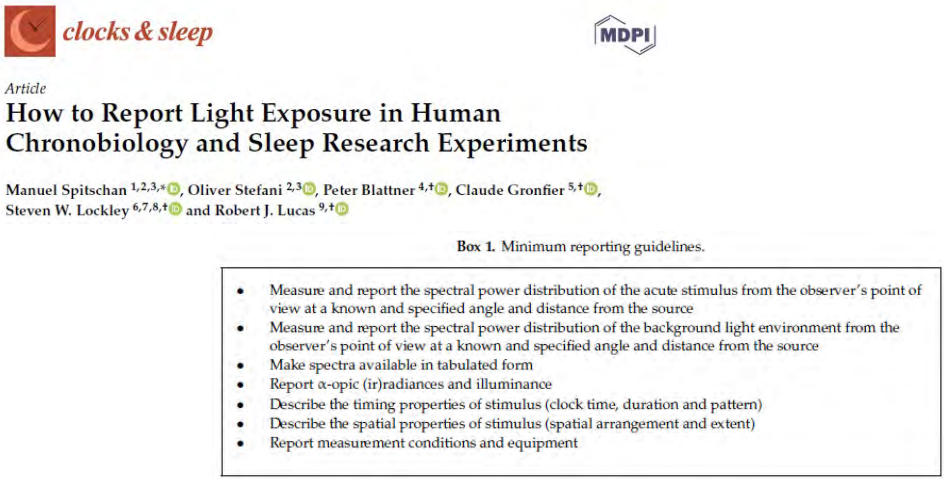
0 — 1,440

What is Realistic for a Designer? A Researcher?

CONCEPTS / LIGHT / FEATURE L03 OPTIMIZATION

Circadian Lighting Design

- Test Locations & Conditions
  - Vertical plane
  - Representative of common occupant position
  - 18” Above work surface, flexible for sitting/standing
  - Supplemental lighting, including computer screens, should be on if used
  - 50 workstations, n = 29 | 100 workstations, n = 41
  - Distributed in the space, across floors
- Reporting & Compliance
  - Report illuminance levels in lux and the spectral power. Calculate EML (EML = lux x M/P Ratio).
    - Calibrated spectrometer ← Realistic?
  - The median light levels must meet the EML threshold and the lowest value must be at least half the threshold.



clocks & sleep

MDPI

Article

How to Report Light Exposure in Human Chronobiology and Sleep Research Experiments

Manuel Spitschan [1,2,3,*], Oliver Stefani [2,3], Peter Blattner [4,†], Claude Gronfier [5,†], Steven W. Lockley [6,7,8,†] and Robert J. Lucas [9,†]

Box 1. Minimum reporting guidelines.

- Measure and report the spectral power distribution of the acute stimulus from the observer’s point of view at a known and specified angle and distance from the source
- Measure and report the spectral power distribution of the background light environment from the observer’s point of view at a known and specified angle and distance from the source
- Make spectra available in tabulated form
- Report α-opic (ir)radiances and illuminance
- Describe the timing properties of stimulus (clock time, duration and pattern)
- Describe the spatial properties of stimulus (spatial arrangement and extent)
- Report measurement conditions and equipment

ENLIGHT: A consensus checklist for reporting laboratory-based studies on the non-visual effects of light in humans

Manuel Spitschan, Laura Kervezee, Renske Lok, Elise McGlashan, and Raymond P. Najjar, for the ENLIGHT Consortium

ENLIGHT: A consensus checklist for reporting laboratory-based studies on the non-visual effects of light in humans

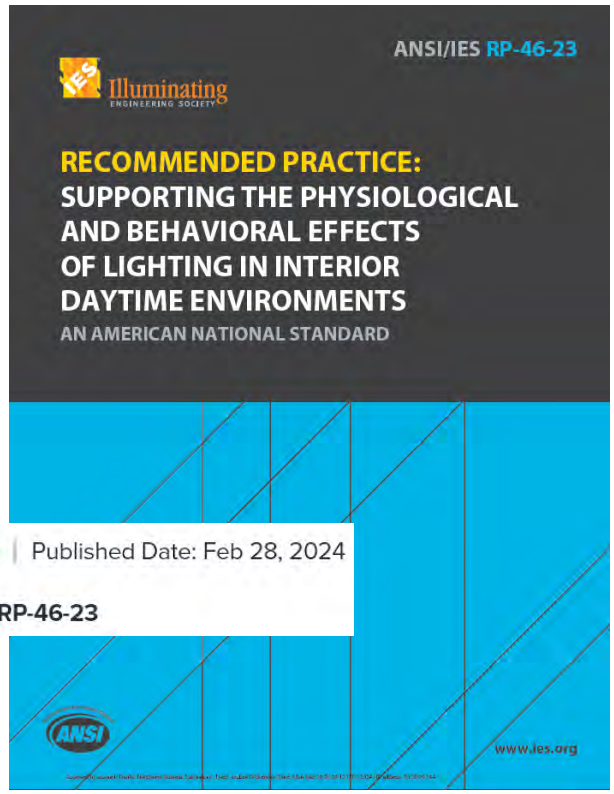
Manuel Spitschan,[a,b,c,d,*,m] Laura Kervezee,[e,*,m] Renske Lok,[f,***,m] Elise McGlashan,[g,h,****,m] and Raymond P. Najjar,[i,j,k,l,*****,m] for the ENLIGHT Consortium[n]

Item	Description
A. Study characteristics	
A.1. Protocol-level characteristics	
Description of experimental setting[a]	Describe the experimental setting (e.g., room geometry).
Timeline of experiment (including timing and duration of light)[a]	Provide an overview of the timing of key study events, including timing and duration of light exposure
Pre-laboratory sleep-wake/rest-activity behaviour	Describe the pre-laboratory sleep-wake or rest-activity behaviour (e.g., any measurement of participants' sleep-wake or rest-activity behaviour prior to entering the laboratory).
Pre-laboratory light exposure	Describe the pre-laboratory light exposure, including whether participants were given any instructions related to light exposure.
Immediate prior light exposure (in laboratory)	Describe the in-laboratory light conditions immediately prior to the experimental light exposure.
A.2. Measurement-level characteristics	
Measurement plane (e.g., horizontal or vertical)[a]	Describe the plane in which light measurement(s) were performed.
Measurement viewpoint and location[a]	Describe the location and direction at which the light sensor was placed during light measurements.
Type, make and manufacturer of the measurement instrument[a]	Describe the instrument being used to take each light measurement, including the manufacturer, type, make and model of the device.
Calibration status of the instrument	Describe the calibration status of the light sensor that was used to take each light measurement.
A.3. Participant-level characteristics	
Ocular health and functioning[a]	Provide any details on health and functioning of the participants' eyes.
Pupil size and/or dilation	Describe any pupil size measurements and/or whether pupils were pharmacologically dilated during the experimental protocol.
Relative time (e.g., to circadian phase or sleep)	Describe the time of the experimental light exposure relative to the participants' sleep or circadian timing.
B. Light characteristics	
B.1. Light sources	
Light source type(s)[a]	Tick all relevant boxes to indicate the type(s) of background and experimental light sources used in the study.
Type, make and manufacturer of the light source[a]	Describe the type, make, and manufacturer of the light source(s) used in the study.
Use of wearable filtering apparatus (e.g., blue-blocking glasses)	Describe any wearable device(s) that modifies the absolute flux level or relative spectral distribution, or both, of light passing through it.
B.2. Light level characteristics	
Illuminance (lux) and/or luminance (cd/m^2)[a,b]	Provide the illuminance and/or luminance of the experimental light condition(s) used in the study.
Spectral irradiance and/or radiance distribution[b]	Provide the spectral irradiance and/or radiance distribution of the experimental light condition(s) used in the study.
α-opic irradiance and/or radiance (including melanopic)[b]	Provide the α-opic irradiance and/or radiance of the experimental light condition(s) used in the study.
α-opic equivalent daylight illuminance and/or luminance (EDI/EDL, including melanopic)[b]	Provide the α-opic equivalent daylight illuminance and/or luminance of the experimental light condition(s) used in the study.
B.3. Colour characteristics	
Peak wavelength and bandwidth	Provide the peak wavelength and bandwidth of the experimental light condition(s). Note that these metrics are most relevant for monochromatic or narrowband light sources.
Colour appearance quantities (any)	Provide colour appearance quantities of the experimental light condition(s), such as any metric describing position in a chromaticity diagram or color space, or correlated colour temperature, CCT (Tc).
Colour rendering metrics (any)	Provide any colour rendering metrics, such as the Colour Fidelity Index, Rf.
B.4. Temporal and spatial characteristics	
Location of stimulus and viewing distance[a]	Describe the location of the light stimulus relative to the participant, and/or the relative distance between the light stimulus and the participant.
Temporal pattern (including flash frequency and waveform)	Describe the temporal pattern of the light sequence (e.g., the flash frequency or inter-stimulus interval) and the waveform (e.g., square, sinusoidal).
Relative or absolute size of the stimulus	Describe the size of the light stimulus, either absolute or relative (in relation to the visual field).

[a]Item reached consensus for being essential to report in any study regardless of experimental context. [b]Luminance and radiance metrics (as opposed to illuminance and irradiance) are mainly relevant for emissive surfaces.

Table 2: **Items in final ENLIGHT checklist.**

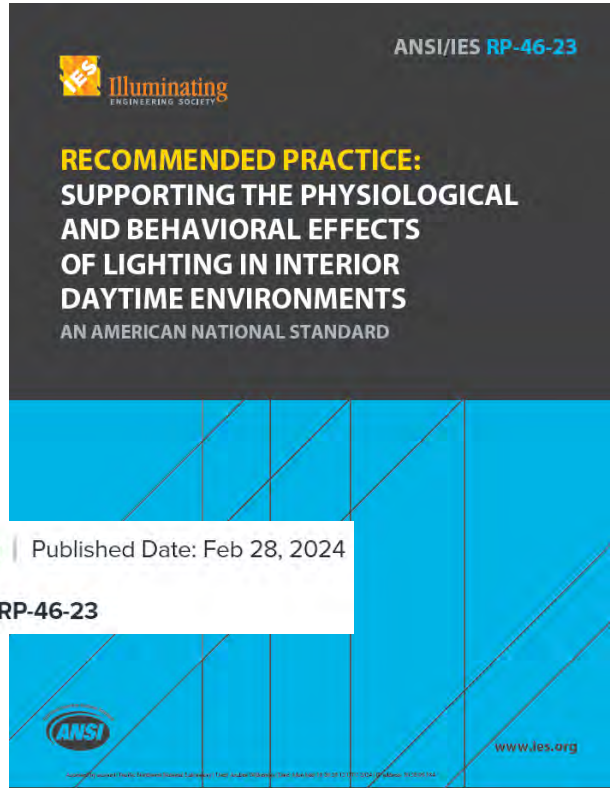
Reality:
New recommendations, ongoing research



- Implementation companion to IES TM-18-18
- Applies to the design of lighting for interior spaces that are used 7 am to 7 pm
- For populations going about their normal day, where alertness is desired
- There is mixed evidence that daytime light exposures directly affect alertness.

The **immediate effects of light exposure during daytime hours on other physiological indicators remain under debate**. Exposure to white light at night immediately suppresses the release of the hormone melatonin and increases alertness, effects that underpin the identification of the ipRGCs and of the action spectrum for melanopsin, the active photoreceptor molecule. **This has led many to think that exposure to white light by day must also have similar immediate alerting effects.**

Reality:
New recommendations, ongoing research



Standard Active | Published Date: Feb 28, 2024

IES ANSI/IES RP-46-23

Table 5-1. Lighting Design Considerations to Provide Inclusive Environments

Recommendation	Design and Lighting Strategy	Population Benefited
Provide Lighting to support communication	• Provide wide corridors with vertical illumination to support facial recognition and social interaction. • In public gathering spaces, provide seating facing each other; avoid patterned wall surfaces, sharp lighting contrasts, and backlighting.	• Visually and cognitively impaired individuals, who often face social isolation when unable to easily recognize faces. • Hearing impaired and deaf individuals who rely on reading expressions and/or lips to assist in understanding the spoken word.
Control glare	• In daylit spaces, provide overhead daylight apertures (e.g., skylight, clerestory), view fenestration, and electric lighting to balance daylight contribution and/or supplement illumination as needed. • Avoid lighting and materials that create direct glare, reflected glare, shadow, or shine that can be difficult to process.	• Many neurologically diverse individuals are hyper-photosensitive.
Provide wayfinding cues	• Provide visual and audible cues to aid navigation. • Provide visual and audible cues about change of status, e.g., open doors, a view panel beside a door, or a visual alert triggered by approach. • Provide visual and audible cues about change of heights or location of exits.	• Visually and hearing impaired individuals.
Define light zones to match activity	• Create and define spaces and cues to identify types of activities—e.g., social activity, modes of work—utilizing "sensory stimulus zoning" to designate high stimulus and low stimulus areas. • Provide transitions so that an individual can "recalibrate" to manage the sensory load appropriately.	• Neurologically diverse individuals who are hyper- or hypo-stimulus sensitive.

Speck Demo – Data Review

What’s Next?

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Thank you

Please reach out with your comments or questions!

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LEDucation
Trade Show and Conference

This concludes The American Institute of Architects Continuing Education Systems Course

LEDucation.org